ULTRATENDER

NON-INVASIVE HIGH POWER ULTRASOUND (HPU) PROCESSING METHOD FOR MEAT TENDERIZATION

FINAL PUBLISHABLE SUMMARY

Grant Agreement number: *603429*

Project acronym: *ULTRATENDER*

Project title: *Non-invasive high power ultrasounds (HPU) processing method for meat tenderization*

Funding Scheme: FP7-SME-2011-BSG- Research for the Benefit of SMEs

Date of latest version of Annex I against which the assessment will be made: 2013-06-24

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1. Executive Summary

The ULTRATENDER project aims providing meat producers with a method for beef meat tenderization by high power ultrasounds. Meat tenderness has long being recognized as the most important attribute of meat, greatly influencing consumer acceptability. After meat slaughtering, shortening of the muscle protein fibers causes the meat to become tough ("rigor mortis"). For meat to become enough tender to be sold to the final consumer, it has to be under chilling storage for a period, between 7-90 days, resulting in high meat processing costs, along with high energy consumption. A variety of chemical, physical and mechanical methods are currently available for tenderizing meat, although they have not fulfilled meat processors requirements in terms of production costs and modification of the meat or organoleptic properties.
The most promising technique for meat tenderization is High Power Ultrasound. It significantly reduces the aging period, being a low-cost non-invasive technique, avoiding changes in the organoleptic properties of meat. However, commercially application of HPU for tenderization is not available since current studies have not taken into consideration the natural variation on muscle size, animal type, meat cuts and geometry. ULTRATENDER project developed an optimized process for beef meat tenderization by high power ultrasounds, covering a wide range of meat cuts with different tenderness grades, geometries and sizes.
The main results obtained are:

- Easy method for initial meat quality grading (before tenderization) based on tenderness that will help the selection of the appropriate HPU tenderization process for each meat sample.
- Tenderness prediction software tool to support the selection of the best tenderization protocol for each meat cut and the final assessment of meat quality based on the most important quality affecting factor: "tenderness".
- Low-cost meat tenderization process using high power ultrasounds. The process covers the main meat cuts considering size, geometry and initial structural meat features (fat content, amount of collagen, tenderness...). HPUs industrial prototype was developed.

Our optimized tenderization process lead to a time reduction up to 80% of the whole tenderization process for a wide range of meat cuts and animal types. This will lead to 60% production costs reduction increasing profit margins of fresh meat products by 4.5€/Kg. Moreover, ULTRATENDER the new technology will be in line with the European legislation of Safety and Quality of meat and meat products (Regulation (EC) N° 1760/2000). Finally, one of the main results of ULTRATENDER project is to reduce energy consumption associated with the tenderization process of meat up to 80% for the whole tenderization process. Three different phases have been identified for exploitation of the project:

- Market Launch within participant SME countries (Italy, Spain and Portugal)
- Market expansion in Europe (rest of EU countries)
- International Expansion to non-European countries (USA, Brazil, Argentina and Australia)

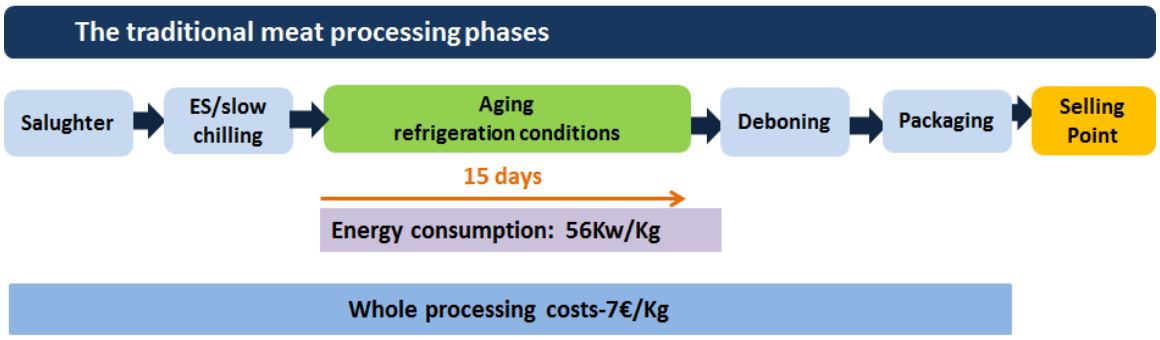
2. Summary description of project context and objectives

"THE NEED UNDERLYING ULTRATENDER PROJECT"

Meat tenderness (toughness or resistance to cut) has long been recognized as the most important attribute of meat, greatly influencing consumer acceptability. In fact, consumers are willing to pay up to four times higher prices when buying sirloin, the most tender beef meat. Therefore, it is not surprising that ***the major priorities in the meat industry are to improve beef tenderness and to have access to a method for objectively classify meat quality grades according to tenderness,*** rather than to other more conventional properties such as the "EUROPE grid" grading based on marbling (fat content).

What is meat tenderness and how is meat tenderized?

Tenderness is an attribute of meat that is based on ease of chewing. The main responsible for meat tenderness are two muscle components: muscle fibre and the connective tissue (collagen). After slaughter, a natural process called "rigor mortis" shortens muscle protein fibres, causing the meat to become tough. 48 hours after the completion of rigor mortis, biochemical changes take place in beef that result in the meat becoming progressively tenderer (softer), allowing its consumption by the consumers. This naturally occurring process is called tenderization or aging. The most traditional and extended method among beef producers to allow natural tenderization to occur consists on holding the meat just above freezing for a period that ranges 15-90 days (*traditional aging*).



The diagram above shows schematically the whole process from animal slaughter to the selling point and as it could be seen, meat tenderization or aging is by far the longest and more energy consuming stage. This aging process highly influences meat processing cost, reducing profit margins for fresh meat products.

Why is meat tenderization so important and what does it imply for meat producers?

Tenderness is the most relevant quality attribute of beef meat for consumers. The most tender beef meats are those with the higher acceptability by consumers. This means that the tenderer the meat is the higher price the consumers are willing to pay. However, apart from being tenderness important from a consumer acceptability perspective, it is important to make clear that a tenderization process is always needed before any beef meat can be placed in the market. The rigor mortis occurred after slaughter is a natural process that cannot be avoided and that makes beef meat tough to the point that it becomes not edible. Non-tenderized beef meat do not meet the quality requirements for its consumption, so the tenderization stage is totally unavoidable in the meat processing chain. This is why, the traditional meat tenderization process described above is used by all meat processors as the only way to make beef meat edible for the consumers. The long processing times, the high energy consumption and the impact on profit

margins that meat tenderization implies are therefore problems that affect all types of beef meats. Nevertheless, the most dramatic effects are produced for old and dairy cattle and for those tougher meat cuts, the so called *middle meat cuts*. For these types of beef meat, the tenderization periods are the longer ones (even reaching 3 months) for making some cuts tender enough for consumption, making the process completely unprofitable for some meat producers. This is why majority of these tougher meats are sold in the market as minced of processed meat, losing market value.

In this scenario, it is clear why the meat industry is strongly interested in having access to a more efficient solution for meat tenderization, which can help meat producers to increase profit margins in fresh meat products and revalorize those tougher beef meats. Trying to provide a solution to this problem, the research and industrial communities have worked hard in the development of more efficient methods for meat tenderization as alternatives to traditional aging. In this context a variety of chemical, physical and mechanical methods have been developed so far for tenderizing meat, although they have not fulfilled meat processors requirements in terms of production costs (hydrostatic pressure) and modification of the meat or organoleptic properties (enzyme marinating or microperforation). The most promising technique for meat tenderization is the use of High Power Ultrasound. It significantly reduces the aging period, being a low-cost non-invasive technique, avoiding changes in the organoleptic properties of treated meat.

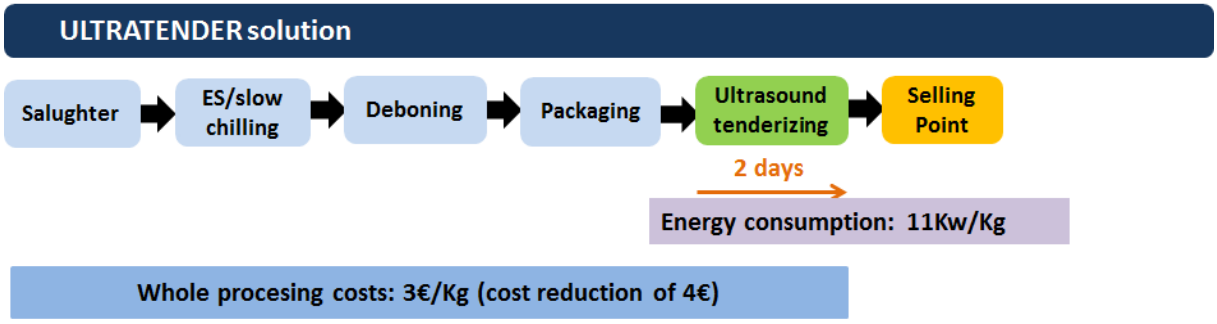
However, commercially application of HPU as tenderization method is not available since current studies have not taken into consideration the natural variation on muscle size, animal type, meat cuts and geometry. Moreover, current Ultrasound Equipment Providers need to adapt ultrasound intensity, frequency, wave propagation direction and wave transmission media, in order to offer their devices for meat tenderness applications.

Is there any way for consumers to know the tenderness grade of meat at the time of purchasing?

Considering the importance that consumers give to tenderness at the time of purchasing and consuming meat, it seems obvious that there should be a way to classify meat according to tenderness. However, despite the huge interest towards an objective mean for meat classification based on tenderness, to date there is no single and agreed upon criteria for meat producers to classify meat quality according to its tenderness. The major barrier preventing this method to be available for meat producers is the complexity of tenderness as a meat attribute. Tenderness is not depending on a single and easy measurable parameter, but on a combination of factors such as fat content, content of collagen and connective tissue, direction of the muscle fibres, etc. The combination of all these factors results in more or less tender meat, being thus almost impossible to determine meat tenderness through a simple analytical method that can be performed in a meat processing plant. In fact, instead of based on tenderness, the most extended beef meat quality grading relies on the “EUROPE grid”, a grading system based on marbling (fat content) instead of tenderness. This extended quality grading method is not totally useful because many times fat content cannot be directly correlated with meat tenderness. Since tenderness has proved to be the most important quality affecting factor, the industry has focused its demands on the development of a meat tenderness measurement to classify meat quality grades.

"THE ULTRATENDER SOLUTION AND THE PROJECT OBJECTIVES"

The ULTRATENDER project aims providing meat producers with a method for beef meat tenderization by high power ultrasounds. The following diagram shows schematically the solution proposed in the ULTRATENDER project, for comparison with the traditional tenderization process (diagram above).



Our optimized tenderization process will lead to a time reduction up to 80% of the whole tenderization process for a wide range of meat cuts and animal types. This will lead to 60% production costs reduction increasing profit margins of fresh meat products by 4.5€/Kg.

The development of ULTRATENDER integrated solution required the successful consecution of the following objectives:

1. To develop a standardized method for industrial meat quality grading based on "tenderness", which is the major quality affecting parameter according to consumer´s perception.

- To establish a qualitative correlation between meat parameters measurable by complex analytical techniques (texture, collagen content, colour, drip loss, cook loss, fat content) and meat tenderness for the most common primal meat cuts from different animals.
- To establish a quantitative statistical correlation between these meat quality parameters, tenderness and meat properties that can be defined by a common industrial selection method (age, sex, breed, meat primal cut, size and geometry).

2. To develop a prediction software tool for the selection of the best HPU protocol and the prediction of the final tenderness achieved for each meat cut.

- To create a software tool for final tenderness prediction using HPUs with at least 80% of reliability.
- To develop a software tool for selection of the most appropriate protocol for meat tenderization by means of HPUs.

3. To develop a method for meat tenderization using HPUs effective for industrial primal beef cuts.

- To optimize the HPU protocol to be used for an effective tenderization of each of the most common primal cuts.
- To create an industrial design for the adaptation of ultrasound equipment for meat tenderization at industrial scale.

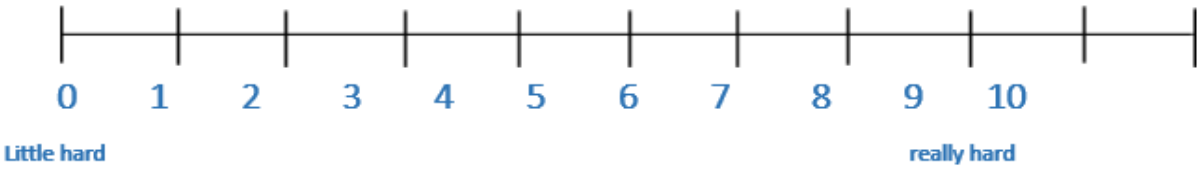
3. Description of main S & T results/foregrounds

"THE WORK PERFORMED AND THE RESULTS ACHIEVED"

The major objectives assessed against milestones during the project have been successfully achieved by the project partners and now there is available a method for meat tenderization using HPUs effective for industrial primal beef cuts. Moreover, a standardized method for industrial meat quality grading based on "tenderness" was developed and a prediction software tool for the selection of the HPU best protocol and the prediction of the final tenderness achieved for each meat cut is available.

First, a guideline for easy grading of the initial quality (before being tenderized) of the most common beef meats in the European Market was performed, it allows to classify meat samples based on their initial tenderness degree before being tenderized. Meat quality is an expression which is used for describing the overall meat characteristics, including physical, chemical, morphological, microbiological, sensory, nutritive and culinary properties. The appearance of meat, its texture, juiciness, tenderness, smell and taste are some of the most important characteristics of meat from the consumers' perspective and they influence their buying decision. The tenderness of beef is the attribute most demanded by consumers and its improvement is the primary reason for post-mortem aging. Meat aging is a process involving post-mortem proteolysis of myofibrillar proteins in muscles. Tenderization begins shortly after slaughter and increases after the rigor mortis phase. To improve the consistency of meat quality with respect to tenderness, beef should be aged. It has been shown that during the aging process certain changes take place in portions of the structure of collagen and muscle fibers. Currently, it is thought that enzymatic-caused changes in the structure of muscle fibers are largely responsible for the increase in tenderness. The most widely used instrumental test for meat tenderness evaluation is Warner-Bratzler shear force (WBSF) test. However, numerous factors can affect the results of Warner-Bratzler shear force measurements. The one with perhaps the largest potential impact is the orientation of the cores relative to the muscle fibers. Sensory analysis is generally considered as the reference method to evaluate eating quality. For these reasons also sensory evaluation has been reported in several studies to predict tenderness. Sensory properties of meat which are agreeable to the senses make contributions to meat palatability. Important sensory characteristics are texture (hardness), juiciness and chewiness. Sensory evaluation of texture is made by means of attributes, which can be established, well a priori by the sensory analyst, well a posteriori, after consensus has been reached between the assessors.

Two model have been performed, one based on instrumental measures (WBSF) and the other on sensorial (hardness). To perform the two models, firstly there were analyzed correlations between the selected parameter (WBSF or hardness score) and different parameters to select the main factors contributing to meat tenderization, secondly there were fitted both regression models to predict beef meat tenderness finally it was developed the guidelines for easy grading of beef meat quality available for beef producers. To achieve this goal, a scale that takes values from 0 to 10 is used.

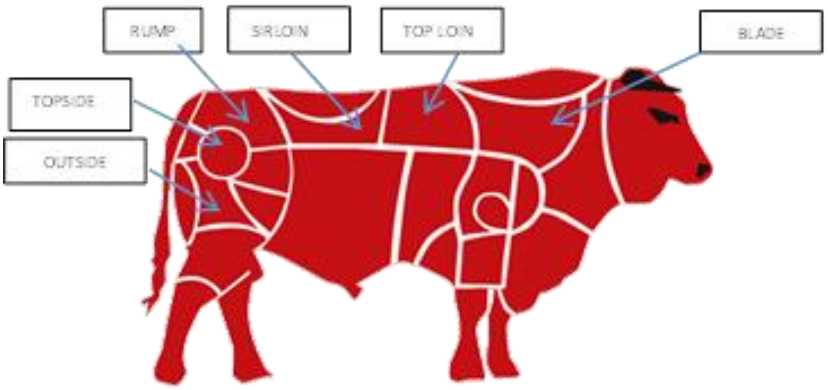


To use these models it should be known a series of data about beef meat and its origin:

- Gender
- Age of the animal
- Day after slaughter
- Type of cut

Once this information is known, there must be assigned numerical values depending on selected variables as described below:

- GENDER:
  - 1- Female
  - 2- Male
- AGE OF THE ANIMAL
  - The number of years
- DAY AFTER SLAUGHTER
  - the number of days that have elapsed since the slaughter
- TYPE OF CUT:
  - 1-Blade
  - 2-Toploin
  - 3-Sirloin
  - 4-Rump
  - 5-topside
  - 6-outside

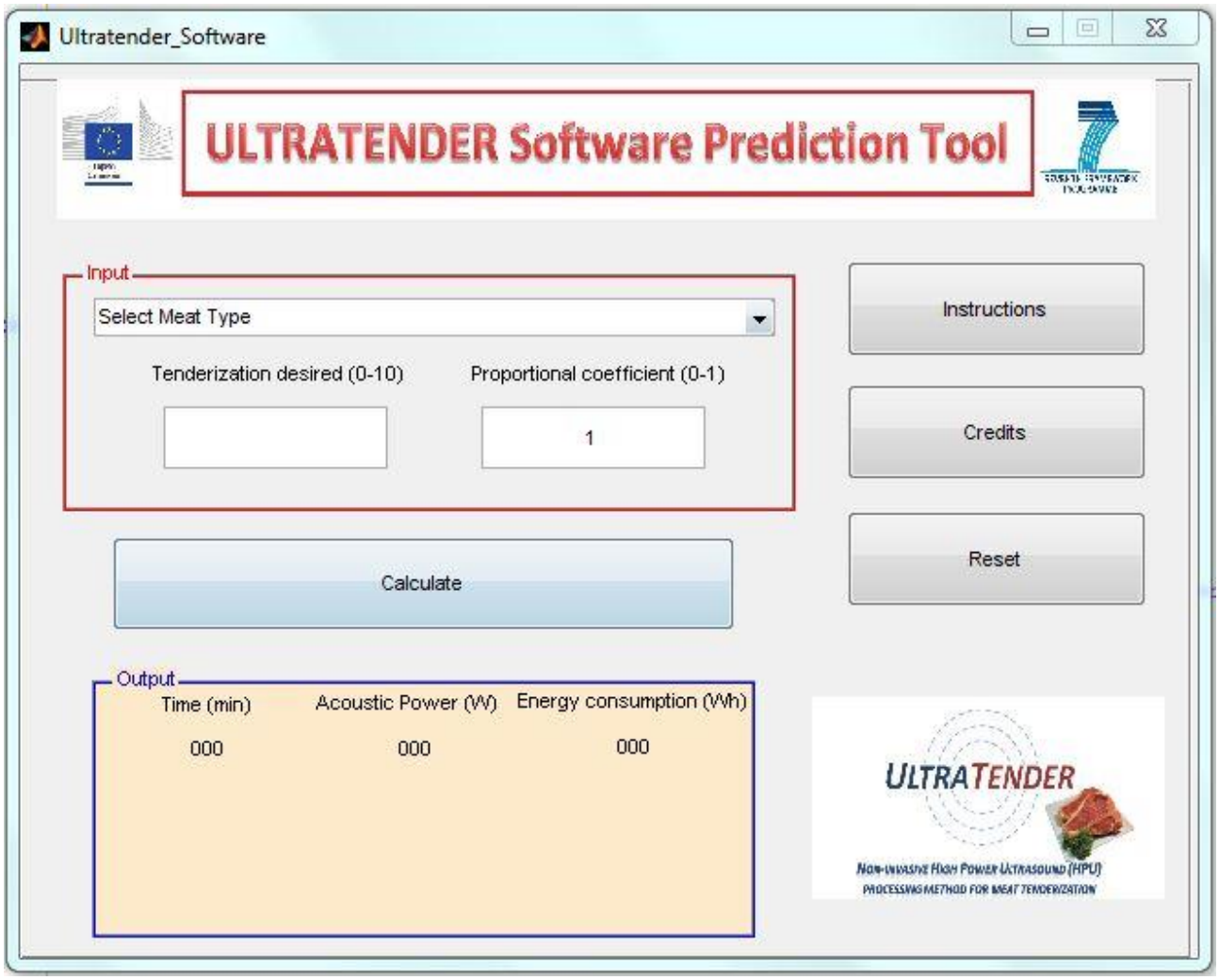


Once values have been assigned, it is possible to calculate the meat hardness/tenderness by defined mathematical multiple regression formulation.

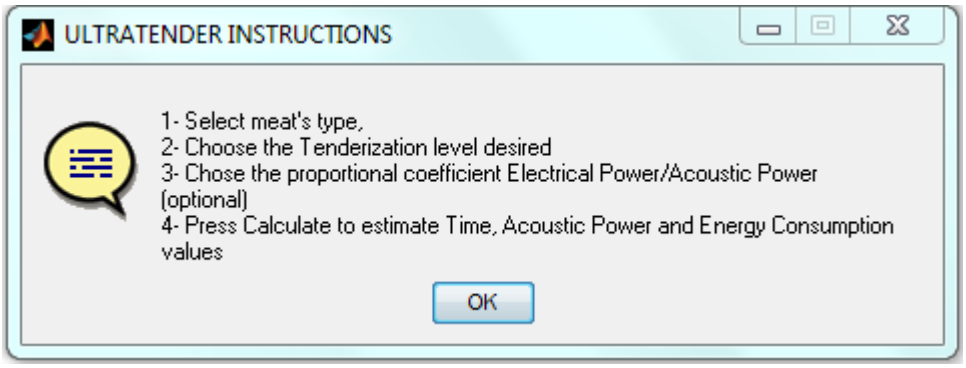
After the completion of a full characterization of the selected meat samples, a software prediction tool was developed in MATLAB programming language. The tenderness prediction software uses a simple user interface and will have a dual functionality:

-To help to define the most suitable tenderization protocol for each meat sample: selection of time, intensity of the HPU process as a function of different initial meat parameters (age of the animal, breed, sex, size and meat cutting area).

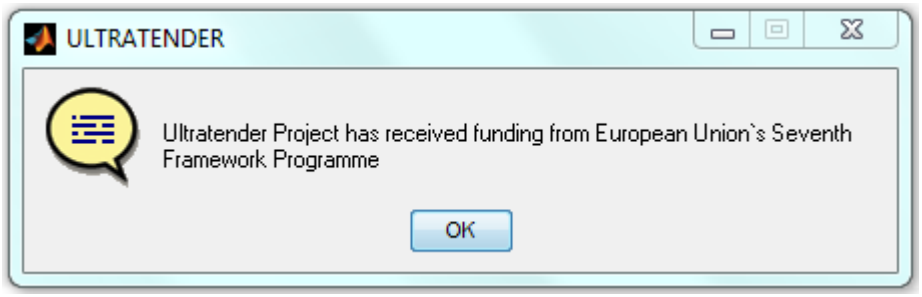
-To predict and quantify these values for a final tenderness achieved (in a 0-10 numerical scale) after the HPU treatment for each meat cut.



It is extremely user-friendly tool: there are three main sections, the inputs block, the outputs block and the last section dedicated to instruction, credits and reset button. The inputs section allows the user to select the meat type, the Tenderization level desired and the proportional coefficient between electrical and acoustic power. Once selected the input values, the user pushes the button "calculate" and immediately the software shows the estimated values for the time of treatment (min), acoustic power (W) and Energy consumption. An "Instructions" button shows a list of instructions, consisting of four simple steps.



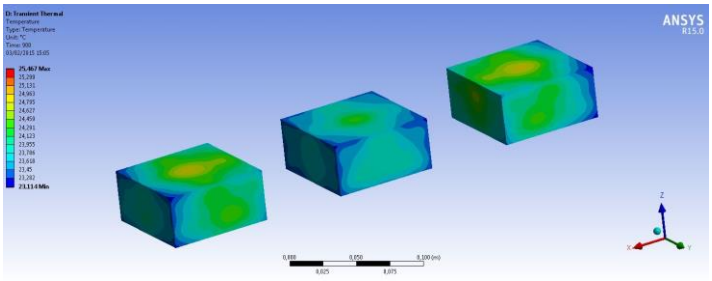
A credits box gives further information about the project.

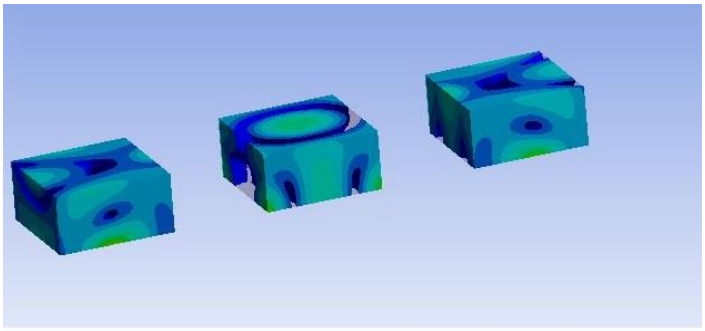


This will be an effective industrial method for meat quality grading based on tenderness as the most important quality determinant. Moreover the software tool is fully opened to further implementations.

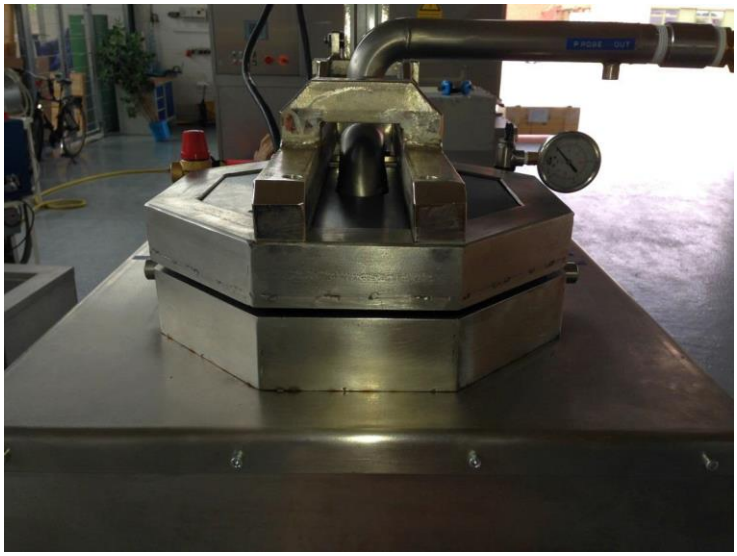
Finally, the results of the ULTRATENDER project show that a suitable high power ultrasound treatment can be used to increase the tenderness of beef meat cuts. However, the validation of the high power ultrasound treatment of beef meat with respect to its effect on tenderness demonstrated that such a tenderization is not possible for all cuts of all animals (female/male and age). Significant quality improvements are obtained especially for the outside cut from steer and the sirloin from heifer. These positive changes are detectable both by instrumental analytics (shear force) and by sensory tests. The effect of HPU treatment was evaluated by detection of pH-values, L*, a*, b* colour measurement, cook loss and Warner Bratzler shear force analysis. HPU treatment had no impact on the quality parameters pH-value, colour, cook loss and microbial status. No significant differences were observed in compositional parameters between HPU treated samples and control samples. No loss or detrimental change of the meat quality was observed. The product texture was evaluated with the Warner-Bratzler shear force test. There was a significant effect of HPU treatment with the maximum power on peak shear force ($p<0.05$) for heifer blade, sirloin and outside. After HPU treatment the peak shear force was significantly reduced. Also a significant effect of HPU treatment on peak shear force for steer outside cut was observed. The shear force was reduced. HPU treatment also showed a tendency to reduce the peak shear force of ox rump cuts after longer treatment times. The ULTRATENDER results also show that a further increase in energy input and treatment intensity may be required to enhance the treatment effect. In this context, the mathematical model developed helped to define the most suitable HPU and geometrical parameters for the meat tenderization process.

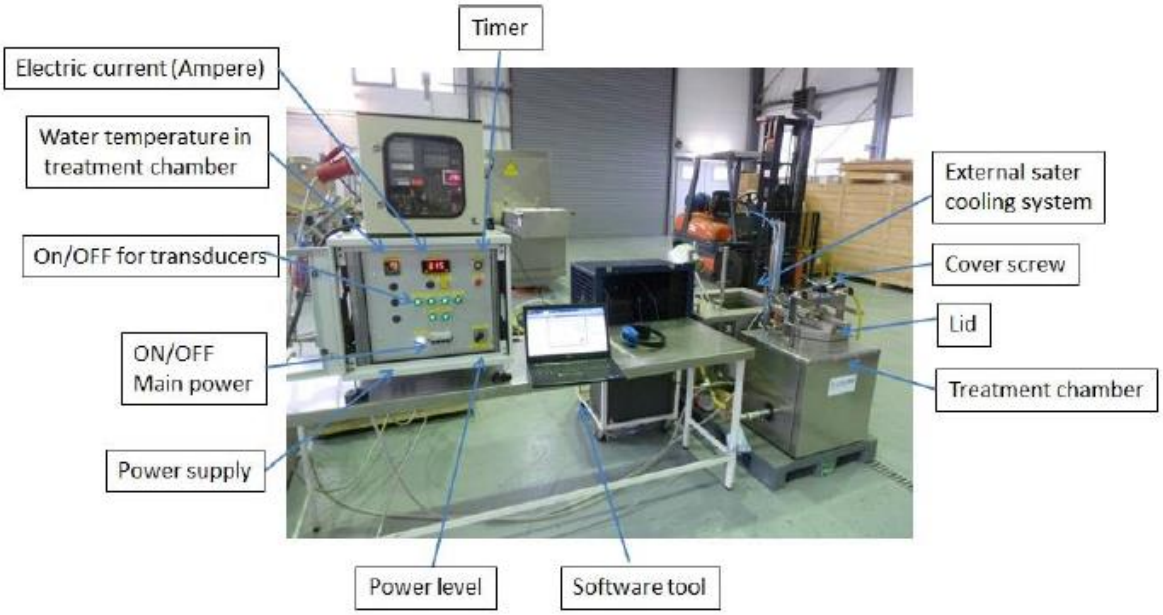
Multiple FEM simulations allowed to design the experimental set-up and investigate the main parameters involved. Acoustic simulations` results allowed to define the geometrical parameters and the correct positioning of the meat samples in the US bath. In addition, thermal simulations' results allowed to prevent an excessive temperature increase in the meat.





Based on that, an industrially applicable prototype to test the high power ultrasound treatment and evaluate the effects on beef meat quality is now available as one result of the ULTRATENDER project.





The treatment tank of the prototype can only be used in connection with the power generator. The generator transmits the power to the transducers in the side walls of the treatment tank. The meat pieces to be treated are placed in the holding basket. The basket is connected to the lid through a fixed guide rail. Raising and lowering of the basket can be realized by the up and down button of the lid. At the end of the treatment time the product basket is transported upward together with the basket. After reaching the end position by the lid, the basket is disconnected from the lid and the product can be withdrawn from the basket.

4. Potential impact and main dissemination activities and exploitation results.

The main area of application of the technology developed within ULTRATENDER project is the meat industry, especially the beef production and processing sector, since beef requires the longest and highest energy consuming tenderization processes. Compared with the existing solutions used by the beef industry, the new and innovative tenderization process using HPUs will lead to 80% time and energy consumption reduction associated to the process for meat tenderization. This will help to increase profit margins by 4.78€ per Kg of fresh beef meat, having a positive impact on the competitiveness of European beef industry sector. Compared with the potential State Of Art solutions, the ultrasound tenderization method is safety (non-invasive) and does not impact the final meat organoleptic proprieties. Additional, the low price of the ultrasound equipment (between 15,000€ and 20,000€) will be a key advantage in order to ensure a market acceptability and consequently an easy wide spread adoption of the technology by the meat industry. The novelty of the solution proposed relies on that the ULTRATENDER solution will allow for the first time the use of the High Power Ultrasounds (HPUs) in meat tenderization at industrial level. The concept of using HPUs in meat tenderization is not new, but to date it has been only described and demonstrated by scientists at a lab scale. The ULTRATENDER project will help bringing this novel concept to a real industrial application. To achieve this objective, the project has been planned in a way that will fill the gap that currently exists between the concept and the implementation of this technology by the industry: we carried out a throughout statistical study that covered a wide range of meat cuts with different tenderness grades, geometries and sizes. The outcome of this extensive statistical study was used to feed a software tool capable to determine the appropriate HPU treatment protocol to be applied to each meat cut depending on several initial parameters (sex, age, type of cut, geometry, etc.). This software tool is also capable to predict the final tenderness grade of a meat cut undergoing the HPU process, thus serving as a tool for meat quality grading based in tenderness. In this way, the ULTRATENDER solution provides the meat industry not only with a more effective and less energy consuming method for meat tenderization, but also with an objective and reliable method for meat quality grading based on tenderness.

"MAIN DISSEMINATION ACTIVITIES"

The dissemination activities undertaken have been addressed to get the highest possible impact for the results achieved in the project, guaranteeing the maximum dissemination of scientific results, coordinating the IPR protection strategy for the consortium and designing and developing the exploitation strategy. It also gathers all training activities devoted to ensure an effective knowledge transfer from the RTD performers for training of the SMEs partners. These activities are key for the ULTRATENDER consortium partners in order to maximize the potential success of ULTRATENDER in the market and have been planned carefully and consciously since the very beginning of the project. The dissemination activities included continuous communication with relevant stakeholders, maintaining the project website, press release, social network dissemination, presentations, conferences, etc.

In that sense, the project web site is available at: www.ultratender.eu

Several actions were also followed in order to get the maximum distribution of ULTRATENDER results among the other companies involved in the meat and ultrasound industries in different geographical areas. These activities were targeted to prepare the path for success during the different Exploitation phases.

Other dissemination activities involved:

- The creation of ULTRATENDER project Linked-in group
- The creation of ULTRATENDER project Facebook group.
- The creation of ULTRATENDER project Twitter account.

Finally, but not less important the technology and its benefits was disseminated among the SMEs Customers through commercial meetings, including physical visit to the experimental and industrial lines during part the manufacturing trials. Potential customer could see by themselves the technical advantages of the developed technology.

"THE MARKET OPPORTUNITY FOR THE SME PARTNERS"

The meat and meat products market is a huge market and it's growing worldwide. Given the market trends it is clear that the vast majority of the sales of meat will come through supermarkets and that the market share of pre-packed meat and meat products will continue to rise. The total market size for the ultrasound equipment is estimated based on the number of meat production and processing enterprises in Europe which is 44,000. Considering that the EU normally produces between 6.5 and 7 million tonnes of beef per year, each single enterprise will have to process an average of 430 Kg of beef meat each day. This will be increasing year by year due to the annual growth rate of the Meat production and processing market with an average growth of 1.7% until to 2020.

ULTRATENDER solution is broken down in two differentiated but associated components commercialised by RILAVO and LINCIS respectively:

A) **A *novel tenderization method Using High Power Ultrasounds (HPUs***) in the power range between 1-4 Kw, as it has proved to be the most promising technique in terms of time and cost reduction. Ultrasounds are currently used by the food industry for processing (mainly cutting and extraction) and preservation. In ULTRATENDER, we developed an extensive validation of the HPU technology for meat tenderization covering the widest range of common meat cuts to ensure the maximum applicability of the technology at industrial scale. ULTRATENDER developed an industrial design of HPU system adapted to meat tenderization that will be easily installed in meat processing plants, providing RILAVO of a new industrial application of their equipment.

- **Low investment cost:** selling price of ultrasound equipment between 15,000 and 20,000€.
- **Low operating cost:** HPU equipment easy to adapt to meat processing plants (around 1 m^3).
- **Consumer acceptance:** HPUs is a non-invasive technique

B) **A *software prediction tool*** that allows pre-selecting meat cuts in terms of the most appropriate ultrasound tenderization protocol, ensuring the best quality grade of the final meat product. To develop this software we will carried out a complete set of experiments of the use of HPUs to tenderize the widest range of meat cuts, in order to ensure prediction reliability up to 80%. This tenderness prediction software uses a simple user interface and has a dual functionality:

- **Low investment cost:** selling price of software tool between 3,000 and 5,000€.
- **Low operating cost:** only one software tool required per meat processor.

- To help to define the most suitable tenderization protocol for each meat sample: selection of time, frequency and intensity of the HPU process as a function of different initial meat parameters (age of the animal, breed, sex, size, geometry and meat cutting area).
- To predict and quantify (in a 1-10 numerical scale) the final tenderness achieved after the HPU treatment for each meat cut. This will be an effective industrial method for meat quality grading based on tenderness as the most important quality determinant.

Through the new ULTRATENDER technology the SME consortium partners will benefit from:

ALONSO (meat producer from Spain):

- Increasing sales of good quality meat by 20% through the possibility of obtaining quality meat from old cattle and middle meat cuts.
- Reducing meat processing costs by 60% (for the whole processing stage) through a shorter meat tenderization period (time reduction up to 80%).

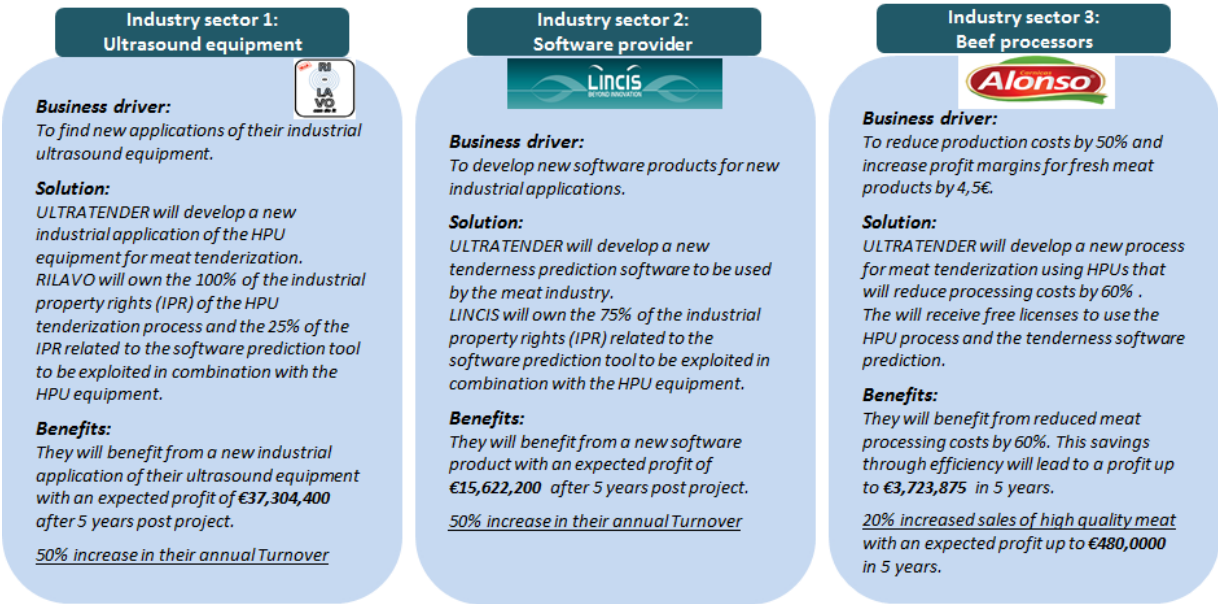
RILAVO (ultrasound equipment manufacturer from Italy):

- New Market application of their ultrasound equipment.

LINCIS (specialised software provider from Portugal):

- New software product for a new industrial application.

The figure below summarizes the components of the solution that each SME partner will exploit and the benefits they expect achieving from their commercial exploitation.



After the end of the project in 2016, the exploitation of the IPR generated during the project period will commence. We considered two parallel actions, firstly to start commercializing the ULTRATENDER process based on commercial available US equipment and start to industrialize the prototype for an improved equipment able to provide an all-in-one optimized solution for meat tenderization. We developed a prototype in order to optimize the process, although no prototype was strictly needed, because ULTRATENDER just developed a process that uses commercial ultrasound equipment, and for this reason we estimate time to market is just 6 months after the project completion. During these 6 months RILAVO as the ultrasound equipment manufacturer of the consortium, will adapt its technology for meat processing plants and beef producer will integrate and validate the process and the tenderness prediction tool in real industrial conditions. After these 6 months, the exploitation strategy will start.

We have identified 3 phases of the exploitation strategy:

Phase 1:	**Implementation in Europe**		**Duration:**	**6 months after project end-2017**
Market Sectors		**Countries**	**Partners Involved**	**Outside Support Needed**
Main Market:	Meat industry	Participant SME countries (Italy, Spain and Portugal) and commercial partners countries	All SME consortium partners	National meat associations to disseminate the project results among their members

Phase 2:	**Market expansion in Europe**		**Duration:**	**2017-**
Market Sectors		**Countries**	**Partners Involved**	**Outside Support Needed**
Main Market:	Meat industry	Rest of Europe	All SME consortium partners and their commercial partners	European meat associations and other manufacturing SMEs in countries where participant SMEs don´t have access.

Phase 3:	**International expansion to non-EU countries**		**Duration:**	**2017-**
Market Sectors		**Countries**	**Partners Involved**	**Outside Support Needed**
Main Market:	Meat industry	Europe and non-European countries: USA, Australia, Brazil, Argentina	All SME consortium partners and their commercial partners	Commercial partners and international distributors

5. Address of project public website and relevant contact details

5.1. Consortium Members

Beneficiary name	Beneficiary short name	Beneficiary type	Country
Tecnologías Avanzadas Inspiralia S.L.	INSP	RTD	Spain
Industrias Cárnicas Alonso S.L	ALONSO	SME	Spain
LINCIS, Soluções Integradas para Sistemas de Informação, Lda	LINCIS	SME	Portugal
RILAVO Srl	RILAVO	SME	Italy
Centro Tecnológico de la Industria Cárnica de la Rioja	CTIC-CITA	RTD	Spain
Deutsches Institut für Lebensmitteltechnik e.V	DIL	RTD	Germany

5.2. Project Contact

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