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NOVEL PROCESSING SYSTEM FOR RATION MEAT ITEMS—PHASE II & III

by
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Clermont-Ferrand, France

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14. ABSTRACT

This technical report documents a Science and Technology initiative for a novel meat processing technology to produce shelf stable, high quality, and nutritious meat snacks for ration. The US Army Natick Soldier, Research, Development and Engineering Center (NSRDEC), now the Combat Capabilities Development Command Soldier Center (CCDC SC), conducted series of experiments, titled " Novel Processing System for Ration Meat Items", to explore a French-developed technology for the potential US industrial adaptation. The funding for the study came from the Foreign Comparative Testing (FTC) program sponsored by the Office of Secretary of Defense from FY 10-FY12, and from several Combat Feeding Ration Improvement related projects from FY12-FY16. The work was done in three phases—feasibility, trial run, and purchase of the system for the US meat industry. This report shows the result of Phase II & III

15. SUBJECT TERMS

HAM	ROLLERS	NUTRIENTS	LAMINATION	TEMPERATURE
BEEF	SAMPLES	BEEF JERKY	MEAT DRYING	PASTEURIZATION
PORK	TURKEYS	CONVEYORS	MINCED MEAT	PHYSIOCHEMICAL
JERKY	TEXTURE	DRIED MEAT	SHELF STABLE	SENSORY ANALYSIS
DRYING	STORAGE	EXTRUDERS	DEHYDRATION	VACUUM PACKAGING
FLAVOR	QUALITY	LAMINATED	MEAT EXTRUDER	TEMPERATURE KINETICS
RECIPES	SHELF LIFE	THIN LAYERS	OSMOTIC DRYING	

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PREFACE

This technical report documents a Science and Technology (S&T) initiative for a novel meat processing technology to produce shelf stable, high quality, and nutritious meat snacks for ration. The US Army Combat Capabilities Development Command (CCDC) Soldier Center, formerly known as the US Army Natick Soldier, Research, Development, and Engineering Center (NSRDEC), conducted series of experiments, titled " Novel Processing System for Ration Meat Items", to explore a French-developed technology for the potential US industrial adaptation. The funding for the study came from the Foreign Comparative Testing (FTC) program sponsored by the Office of Secretary of Defense from May 2010-Apr 2012, and from several Combat Feeding Ration Improvement related projects from Apr 2012-Apr 2016. This S&T initiative has proceeded in three phases: feasibility, trial run, and purchase of the system for the US meat industry. This report shows the result of Phase II – trial runs, and Phase III – manufacture, delivery, install, and commission of an OsmoFood® pilot line in a U.S. meat processing company.

The names and contact information of the NSRDEC personnel who contributed to this study are as follows:

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NOVEL PROCESSING SYSTEM FOR RATION MEAT ITEMS: PHASES II & III

1.0 INTRODUCTION

This report documents contract work performed from October 2010 to December 2012 and research work performed from January 2013 to October 2016 by the US Army Combat Capabilities Development Command (CCDC) Soldier Center, formerly known as the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC), to explore a novel meat processing method developed by Association Pour Le Développement De L'Institut La Viande (ADIV), Clermont Ferrand, France.

Currently, military rations containing meat items are either processed and produced via traditional retort sterilization (e.g., Meal, Ready-to-Eat (MRE) entrées) or via a series of curing and drying methods (e.g., jerky snack). Retort processing uses excessive heat for a long period of time (i.e., 90 minutes) to render foods sterile, but it also destroys quality and nutrients in the process. Retorted meats are often mushy, dry, and tasteless, which can result in lower consumption by the warfighter. The curing and drying methods currently employed to produce jerky are complex and costly due to a requirement of a delicate balance of safety, quality, and storageability. Also, jerky products are often too hard and salty to consume, especially after long storage at elevated temperatures.

A novel technology, using the OsmoFood® system developed by ADIV (ADIV Patent, 2004), is a simple one-step process that uses inexpensive ground meat to produce shelf stable meat items with a desirable texture and targeted water activity to ensure safety and maintain shelf life. The system never uses extremely high temperature like a retort process; hence, the quality and nutrients are well preserved. Furthermore, the system can be used to incorporate supplemental nutrients (e.g., curcumin, green tea extract) and quality enhancers (e.g., canola protein for meat succulence) to produce a meat roll-up that can be consumed as a savory snack or used as a filling for a shelf stable sandwich. Application of such a system to develop numerous new ration items that were previously impossible is now possible due to its technical simplicity and compatibility with various hurdle technologies, such as water activity, pH, and natural preservatives.

ADIV has developed and owns the technical expertise that is required to dehydrate minced meat laminated in thin layer using the OsmoFood® osmotic dehydration technology.
Thus, the US Army commissioned ADIV to perform osmotic dehydrating tests of various food products. The collaboration included three phases:

Phase 1: Laboratory feasibility study on ADIV premises in Clermont Ferrand, France. The main purpose of this phase was to review and demonstrate all the possibilities of the OsmoFood® technology. The technological limitations of the recipes tested, with regard to their further scaling up at the industrial production stage, were also determined for meat (i.e., beef, pork, and chicken), fish (i.e., haddock), and fruit and vegetables products.

Phase 2: Pilot plant dehydration test at ADIV pilot plant in Clermont Ferrand, France. The purpose of this phase was to test the recipes selected at the end of Phase 1 on ADIV industrial pilot line.

Phase 3: Purchase of a pilot industrial line by the US Army. The purpose of this phase was to install, commission, and startup the line under ADIV control and supervision at a U.S. food company.

The Phase I report described principle of osmosis (Borg, 2003; Kosinski and Morlok, 2008; Kramer and Myers, 2012 a&b) and a schematic pilot line OsmoFood® system (ADIV Patent A235-b-9749 FR, 2004).

At the end of the first phase trials, the US Army selected five recipes in order to check and validate the feasibility of their drying on ADIV's semi-continuous OsmoFood® pilot line. The meat used for each recipe was minced, salted, laminated in a thin layer between two sheets of paper, and then plunged into an acidified osmotic solution (pH ≈ 2.75) before being pasteurized for 2 min in brine heated at approximately 72 °C. The dried meat was then vacuum packed in bags of approximately 400 g. Finally, in order to optimize the microbiological stability of the products at ambient temperature, some of the samples were subjected to additional high-pressure treatment.

The selected recipes, as well as the different unit operations imposed on the products, are presented in this report.

2.0 MATERIALS, METHODS, AND RESULTS:

2.1 Selected recipes

In total, five recipes were tested as follows:

Three based on beef meat

- Original beef jerky
- Beef jerky with chipotle flavor
- Beef jerky with Mexican flavor

One based on pork meat

- Pork with dry cured ham

One based on turkey meat

- Turkey jerky

Table 1 details the different recipes used.

Table 1. OsmoMeat jerky recipes

	Original beef jerky	Beef jerky with chipotle flavor	Beef jerky with Mexican flavor	Pork with dry cured ham	Turkey jerky
Salt (g/kg)			7	5	7
Nitrite salt (g/kg)			20	10	20
Ascorbic acid (g/kg)	1	1	1	1	1
Sodium lactate (60%) (g/kg)	25	25	25	25	25
Garlic (g/kg)			0.5		
Black pepper (g/kg)			1.5		
White pepper (g/kg)				1.5	1.5
Water (g/kg)			20	20	
Mexican spice mix (g/kg)			25		
Jerky brine (g/kg)*	100	100			
Sugar (g/kg)	20	20			
Original beef jerky spice mix (g/kg)	15				
Chipotle (g/kg)		15			
Dry cured ham (g/kg)				250	
Teriyaki sauce (g/kg)					5
Worcestershire sauce (g/kg)					5
Soy sauce (g/kg)					5
Cayenne pepper (g/kg)					2.5
Liquid smoke (g/kg)					1
Honey (g/kg)					15
Brown sugar (g/kg)					30

*Jerky brine: Nitrite salt = 20 %; Pastrami = 5 %; Water = 75 %

2.2 Preparation of the raw materials

The meat needed to carry out the trials was minced beforehand using a MANURHIN® grinder with a 3 mm plate, salted and spiced in a STALE® meat mixer (volume=100 l), vacuum packed (MULTIVAC® double-lid vacuum packer), then tempered at 4 °C for an approximate duration of 20 h. This rest period favored the nitrozation of the final dried product and produced a stable red color.

Three different types of meat were used for the five recipes (beef, pork, and turkey). For each recipe, a minimum of 60 kg of raw materials was used. The different muscles used are presented in Table 2.

Table 2. Materials used for the five recipes

Recipes	Meat muscle
Original beef jerky	40% Beef brisket 60% Beef neck
Beef jerky with chipotle flavor	
Beef jerky with Mexican flavor	
Pork with dry cured ham	Pork shoulder (rindless, deboned, fat free)
Turkey jerky	Turkey leg

2.3 Description of the OsmoFood® pilot line

2.3.1 Presentation of the main elements

The pilot line on which the trials were carried out was comprised of the following main elements:

- Stuffer – Its function is to transmit the meat at a constant rate into the meat extruder.
- Meat Extruder – Its function is to preform a strip of meat and to deposit it onto the Extruding Laminator/Entrance Conveyor. The meat extruder has a 15-kg meat capacity. For this reason, each recipe used a minimum of 45 kg of fresh meat into the Osmo Chambers for osmotic drying.
- Extruding Laminator/Entrance Conveyor – Its function is to convey the strip of preformed meat between two sheets of paper and to laminate it at a thickness of 3 mm. The conveyor then guides the strip of laminated meat towards the Osmo Chambers. The conveyer is shown in Figure 1.

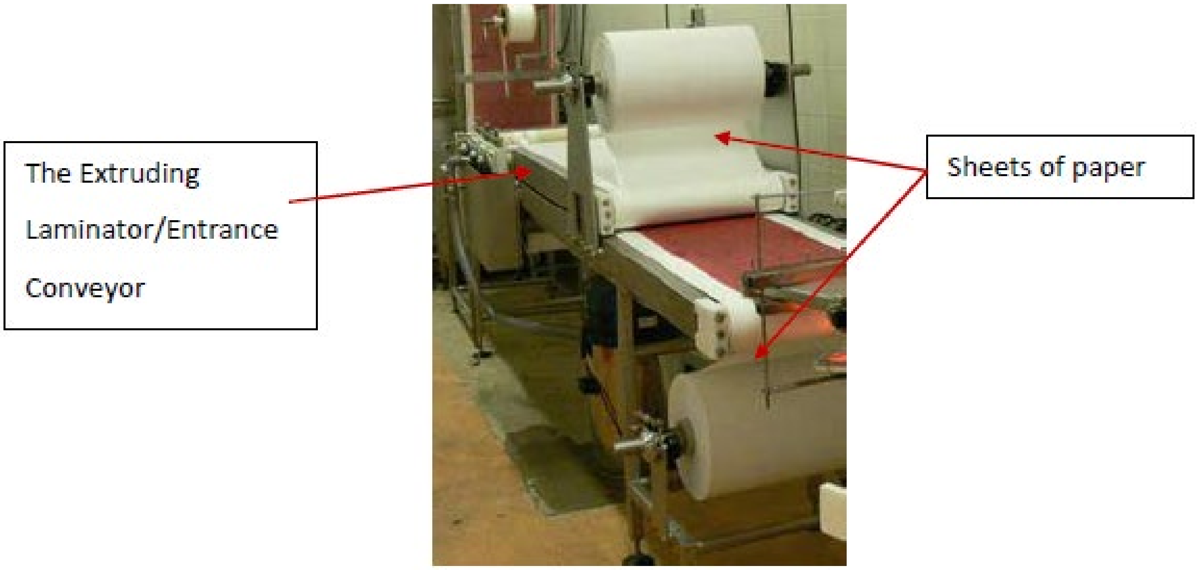
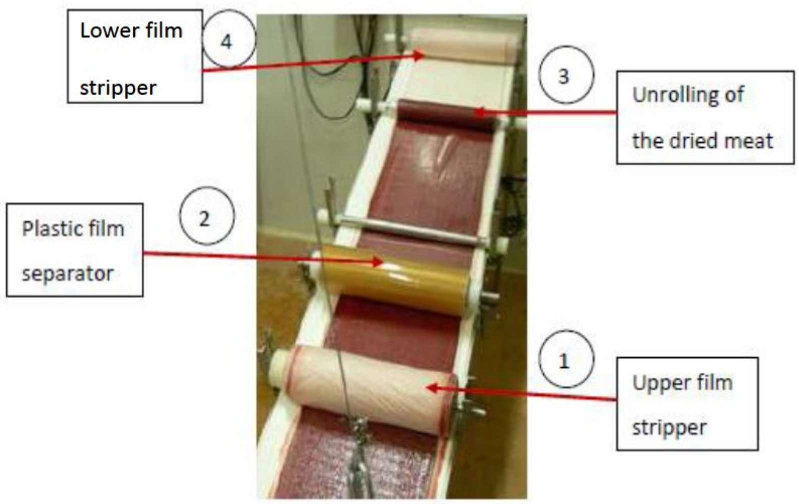


Figure 1: Conveyer of the OsmoFood® system

- Osmo Chamber-- Its function is to convey the strip of meat towards the osmotic solution. When the meat enters into contact with the solution, and coupled with the effect of the osmotic pressure, it dehydrates. The chamber is comprised of a series of upper and lower rollers (Figure 2) that guide the strip of meat. For mechanical design reasons, the upper rollers are placed above the osmotic solution. During its passage in the chamber, the strip of meat is therefore forced to momentarily exit the brine. As the OsmoFood® pilot line is equipped with just one osmosis tank, drying is carried out continuously. After the meat is introduced into the chamber, the strip of meat stops its run for 20 min and is then run for 30 s so that the non-immerged meat is put into contact with the osmotic solution. This operation is renewed cyclically for the whole duration needed to obtain the desired drying yield. The meat is dried to obtain a 60% yield (i.e., a water loss of 40% of the initial weight). The time necessary to obtain this yield is approximately 4 h.

Figure 2: Rollers to guide the conveyer into the Osmo tank

- Flash Pasteurization Tank – The function of this chamber is to store a small quantity of osmotic solution heated at 72 °C in order to continuously pasteurize the strip of meat for a period of 2 min. The mechanical design of this tank is identical to that of the Osmo chamber (except that it is not as long). The osmotic solution contained in this chamber is heated and maintained at 72 °C using a heat exchanger circulation. The energy necessary to heat the solution is provided by pressurized saturated steam.
- Exit Conveyor – The function of this conveyor is to draw the dried strip of meat, to strip its paper, and to roll it around itself. A separator sheet is placed between each layer of meat in order to facilitate the future unrolling of the meat. An image of the exit conveyer is shown in Figure 3.



Note: Steps 1,2,3,4 indicate the order in which the operations are carried out.

Figure 3: Exit conveyer sequence

2.3.2 Synoptic of the OsmoFood® pilot line

Figure 4 shows a synoptic of the OsmoFood® pilot line.

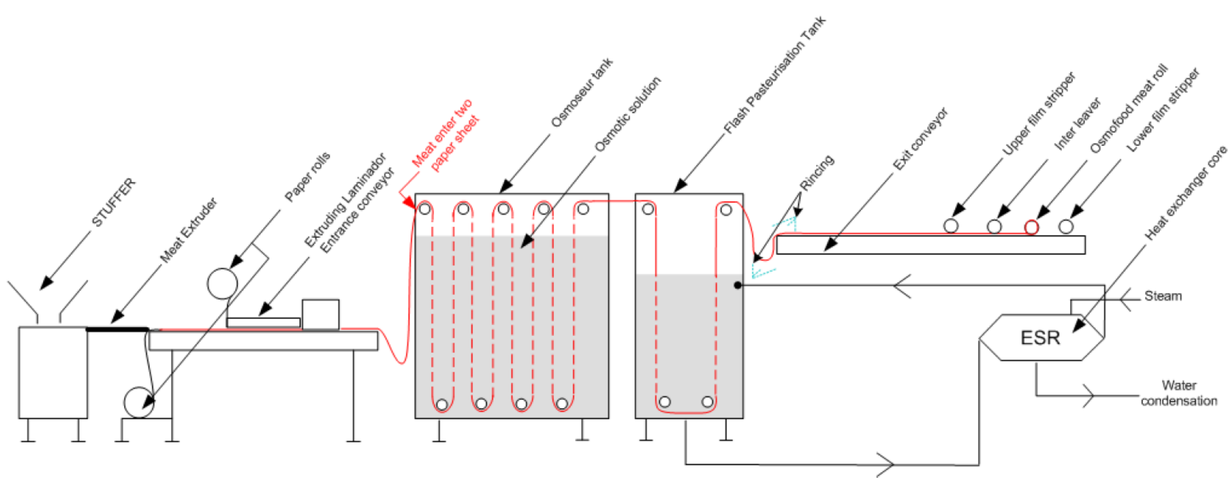


Figure 4. Synoptic of the OsmoFood® pilot line

2.3.3 Meat drying operation on the OSMOFOOD® pilot line

The main steps of the osmotic dehydration are summarized below:

1. Mincing of the meat to 3 mm
2. Mixing of spices
3. 20-h rest period
4. Extrusion of the minced meat
5. 3 mm lamination between two sheets of paper
6. Drying in an osmatic acid bath
7. Pasteurization
8. Rinsing
9. Stripping of the paper
10. Rolling of the dried meat
11. Cutting of the dried meat
12. Vacuum packing

After the packing, some of the samples were high-pressure treated in order to assess the impact of this technology on shelf stability of the finished product.

2.4 High-pressure treatment

The pasteurized and vacuum packed samples were divided into four batches, and three of these had an additional high-pressure treatment. In order to visualize and quantify the impact of this technology on the microbial flora and on the color of the products, three high-pressure processes were applied, as follows:

- 500MPa; dwell time 6 min
- 600MPa; dwell time 6 min
- 650MPa; dwell time 6 min

High-pressure processes were carried out in Spain at Monells in the premises of IRTA (Institute of Research in Food Technologies), on the NC Hyperbaric's Wave 120/650 model (for up to 650 MPa for 60 s) and a Thiot Ultra-high pressure 2L/900 (for 650 MPa for 6 min) (Figure 5).

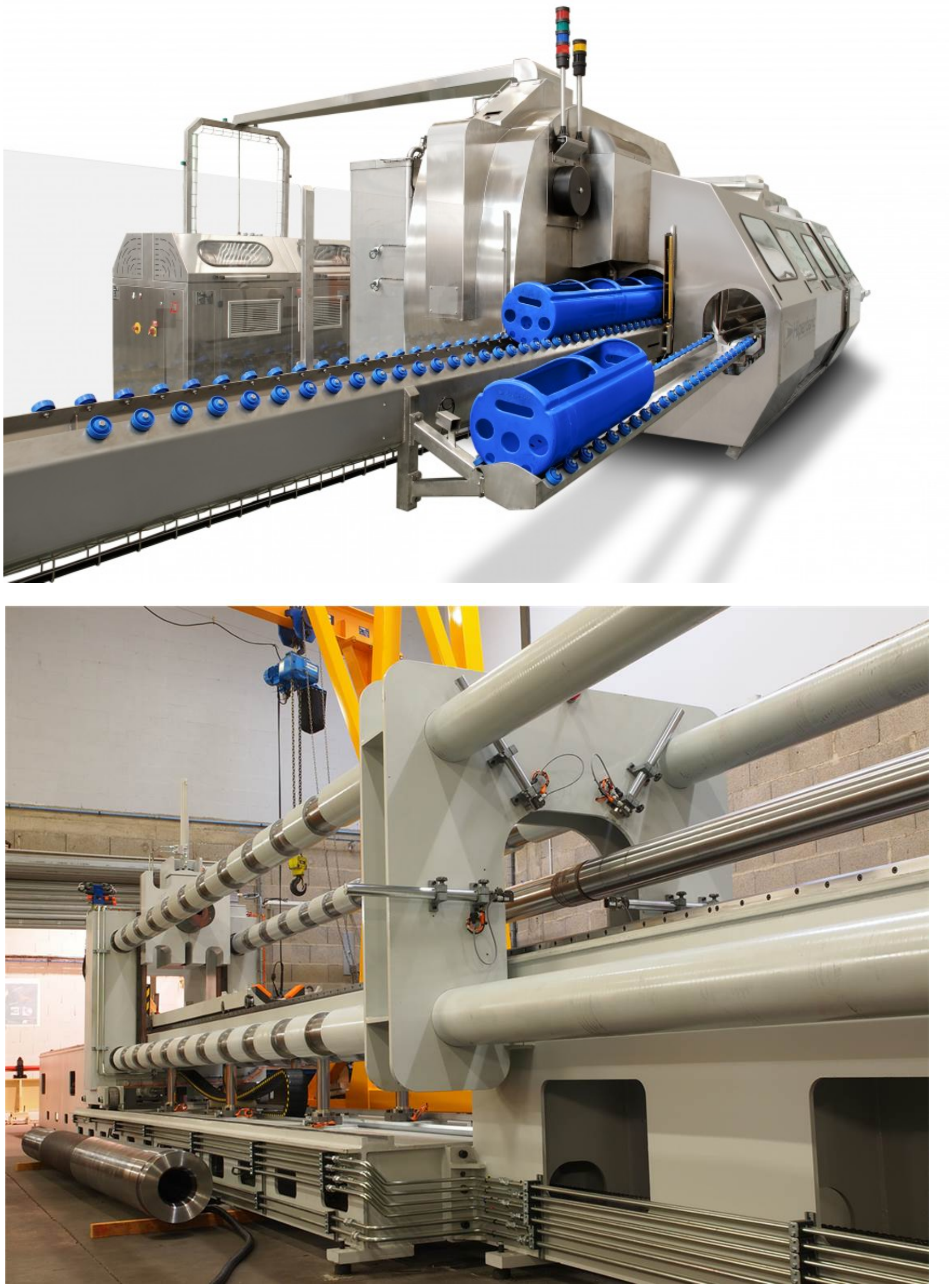


Figure 5: Horizontal High Pressure processor (Top: NC Hyperbaric; bottom: Thiot)

3.0 RESULTS

The results of the drying trials on the OsmoFood® pilot line are presented in this section with respect to the product's characteristics, its duration and drying yields, and its physicochemical properties.

3.1 Characteristics of the products during the osmotic drying process

The five recipes made it possible to use different types of meat: beef, pork, and turkey. Their differences in terms of physicochemical characteristics had a significant impact during the osmotic drying operation. In order to appreciate the industrial transfer of the tested recipes, the observations noted during the trials were used for each operation of the process.

3.1.1 Lamination

For this operation, the meat extruder and the Extruding Laminator/Entrance Conveyor were used.

3.1.1.1 Impact of the meat extruder on the quality of the lamination

The characteristics of the different types of meat when they exited the meat extruder are described in Table 3.

Table 3. Observation of the meat mixtures when they exit the meat extruder.

Recipes	Remarks	Corrective Actions
Original beef jerky	A few grains of meat blocked the meat extruder and therefore the strip of meat was not uniform. The generated holes were filled manually.	The meat should be mixed in a more intensive manner in order to obtain an extraction that has sufficient proteins. An additional laminator roller should be placed at the exit of the meat extruder.
Beef jerky with chipotle flavor	Perfect extrusion	
Beef jerky with Mexican flavor	Perfect extrusion	
Pork with dry cured ham	Perfect extrusion	
Turkey jerky	Pieces of connective tissues, resulting from insufficient de- nerving during the boning of the upper legs, blocked the meat extruder. The strip of meat was not homogeneous. Due to the multitude of recorded defects, not all the holes were able to be filled manually	An additional laminator roller should be placed at the exit of the meat extruder.

3.1.1.2 Lamination between two sheets of paper

The characteristics of the different types of meat in the Extruding Laminator/Entrance Conveyor are described in Table 4.

Table 4 Observation of the meat during lamination

Recipes	**Remarks**	**Corrective actions**
• Original beef jerky • Beef jerky with Chipotle flavor • Beef jerky with Mexican flavor • Pork with dry cured ham • Turkey jerky	During all the trials, air sometimes remained imprisoned between the meat and the paper, which caused, after drying, a difference of color in the finished product. The meat that was in contact with the air was characterized by a darker color.	Place an additional roller laminator between the meat extruder and the Extruding Laminator/Entrance Conveyor.

3.1.1.3 Conclusion regarding lamination

Depending on the different recipes tested, some small defects appeared during lamination. The main defects were linked – on the one hand, to the meat extruder being blocked by residual connective tissues, and on the other hand, to the presence of air between the paper and the meat. These two defects can be limited or reduced by the implementation of a roller laminator between the meat extruder and the entrance conveyor.

Figure 6 presents the roller laminator, which could be used to correct these two small defects.

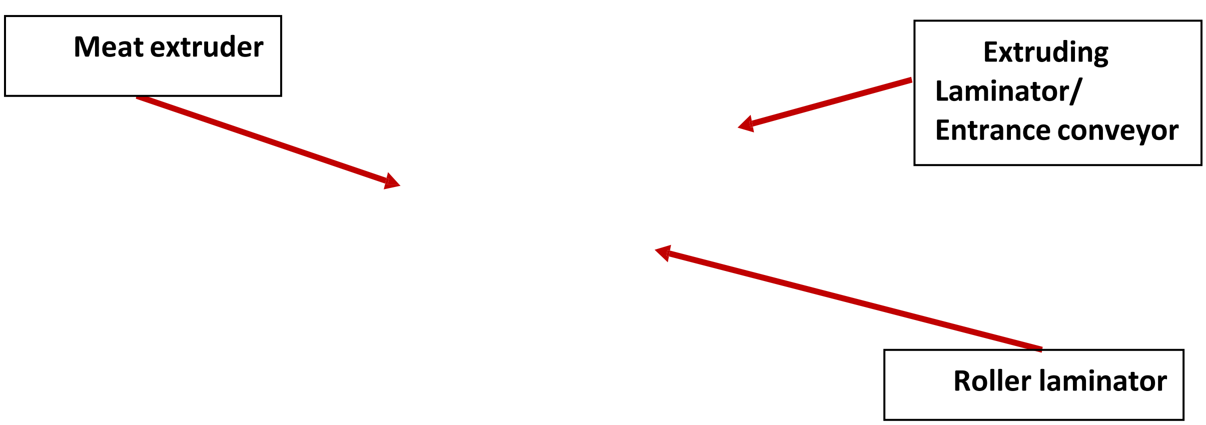


Figure 6. Roller laminator

3.1.2 Drying

The different recipes did not present any conveying difficulties in the chamber. The drying time for each trial is presented Table 5.

Table 5. Drying time of the five recipes

Recipes	Drying Time
Original beef jerky	4h 00m
Beef jerky with chipotle flavor	4h 10m
Beef jerky with Mexican flavor	4h 05m
Pork with dry cured ham	3h 55m
Turkey jerky	3h 50m

3.1.3 Pasteurization

The osmotic solution (pH 5.67) of the Flash Pasteurization Tank was heated by a heat exchanger core. The power energy needed to maintain the temperature was provided by the saturated vapor at a reduced pressure of 3 bars. The adjustment settings were set at 72 ± 1 °C.

The temperature kinetics, before and during pasteurization, as well as the pasteurization times, are illustrated in Figures 7-10.

3.1.3.1 Temperature kinetics measured in the tank during pasteurization

3.1.3.1.1 Original beef Jerky

The adjustment settings were fixed at 72 ± 1 °C. The evolutions of the temperatures at the entrance, during the re-opening of the pasteurization tank as well as their mean average, are presented in Figure 7.

Figure 7 shows that the pasteurization temperature decreased as soon as the dried meat entered the solution. The mean temperature stabilized at 68.45 °C. In order to maintain it at 72 °C, the temperature setting was increased to 75 °C for the following trials.

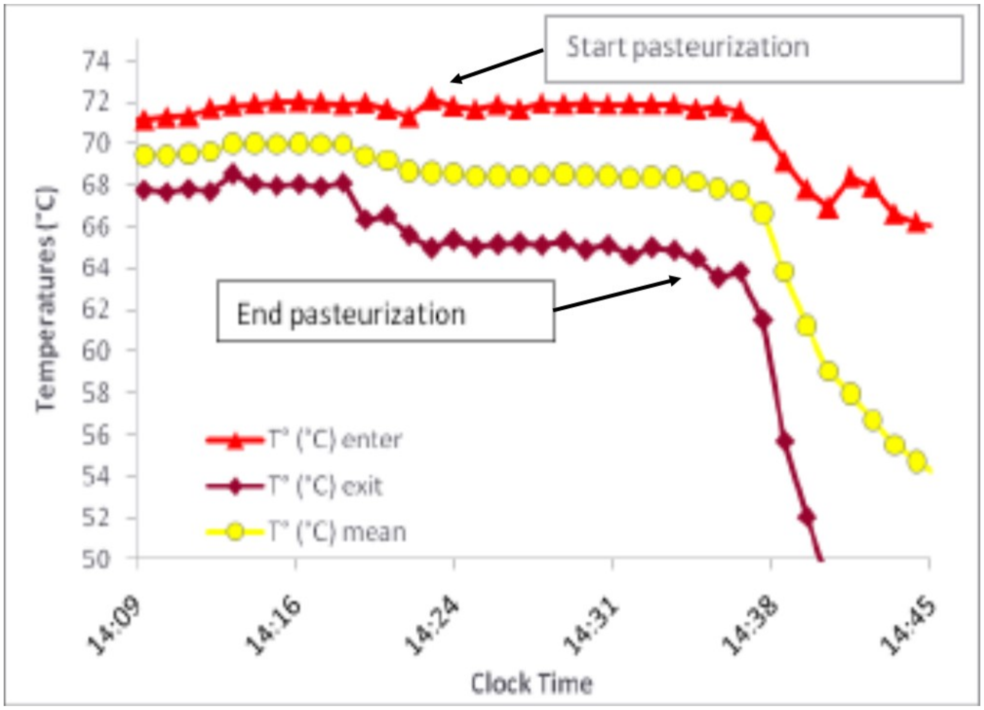


Figure 7. Temperature of the brine during pasteurization of the Original beef jerky

3.1.3.1.2 Beef jerky with chipotle flavor

The pasteurization setting was fixed at 75 °C. The recordings of the temperatures at the entrance, during the re-opening of the pasteurization tank as well as their mean average, are presented in Figure 8.

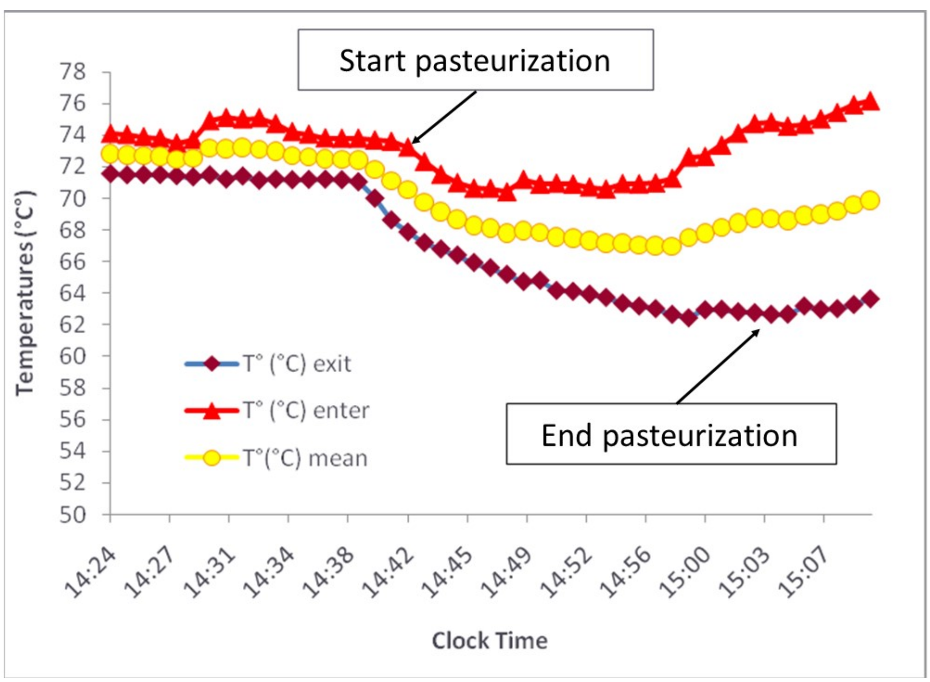


Figure 8. Temperature of the brine during pasteurization of the beef jerky with Chipotle flavor

As with the Original beef jerky, the mean temperature of the pasteurization tank remained at 68.78 °C after the strip of meat was introduced. In order to limit this fall, the temperature setting was increased to 78 °C during the last 10 min of the pasteurization process.

3.1.3.1.3 Beef jerky with Mexican flavor

In order to limit the fall of the mean temperature of the tank, the adjustment setting of the latter was increased to 78 °C.

The kinetic temperature during the thermal treatment of the Mexican beef jerky is presented in Figure 9.

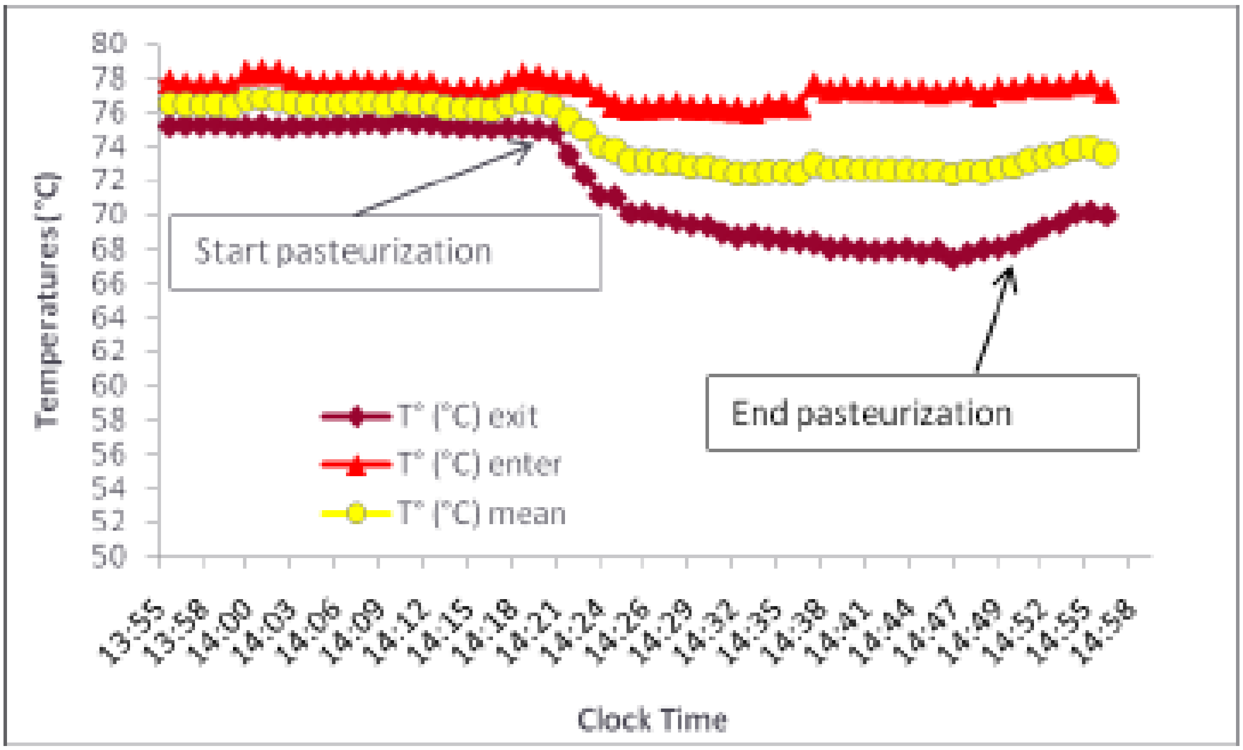


Figure 9. Temperature of the brine during pasteurization of the beef jerky with Mexican flavor

The 78 °C temperature setting made it possible to maintain a mean temperature of 73.18 °C during the thermal treatment.

3.1.3.1.4 Pork with dry cured ham

There was a problem with the temperature measuring device during the recording of the data. Therefore, the data are not available.

3.1.3.1.5 Turkey jerky

The pasteurization temperature setting was set at 80 °C. The kinetic temperature during the thermal treatment of the Turkey jerky is presented in Figure 10.

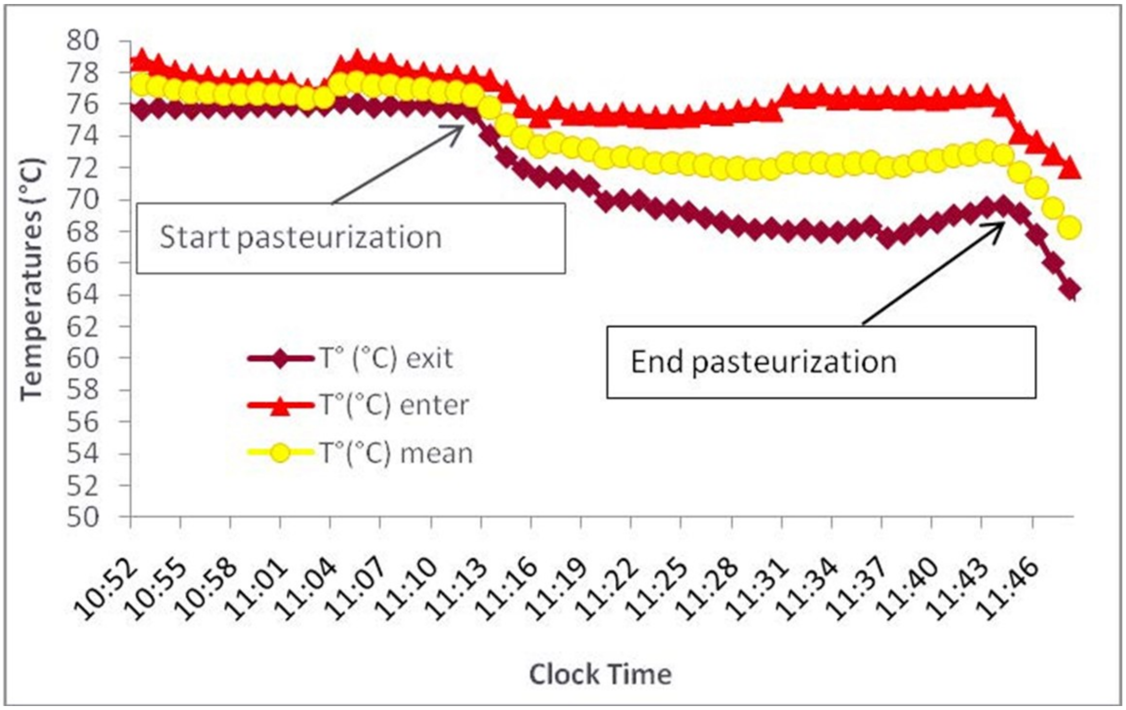


Figure 10. Temperature of the brine during pasteurization of the turkey jerky

The 80 °C temperature setting made it possible to maintain a mean pasteurization temperature of 72.68 °C.

3.1.3.2 Pasteurization time

The pasteurization times for all the trials are presented in Table 6.

Table 6. Pasteurization time of the different samples

Recipes	Speed of the strip of meat (m/min)	Treatment length (m)	Pasteurization time
Original beef jerky	1.37	2.60	1 min 54 s
Beef jerky with chipotle flavor	1.65	2.60	1 min 35 s
Beef jerky with Mexican flavor	1.15	2.60	2 min 15 s
Pork with dry cured ham	1.20	2.60	2 min 10 s
Turkey jerky	1.25	2.60	2 min 04 s

The pasteurization times differed from one sample to the other. These fluctuations were linked to the speed of the exit conveyors. The conveyor is driven by an electric motor with limited power, and depending on the mechanical constraints encountered by the motor, the speeds can be different. The use of an adapted electric motor will therefore be vital for an accurate adjustment of the pasteurization time in the future.

3.1.3.3 Conclusions regarding the pasteurization of the products

In order to maintain a mean pasteurization temperature at 72 °C, the adjustment setting of the heat exchanger core must be set to a minimum of 78 °C.

The differences in the pasteurization times reflect the poor dimensioning of the exit conveyor motor on the ADIV pilot line. In order to eliminate this adjustment defect, the motor's capacity should be increased when building a semi-industrial pilot line.

3.1.4 Stripping of the paper

For all the trials, there were no problems stripping the paper.

3.1.5 Vacuum packaging

All the samples were cut into blocks of approximately 400 g and then vacuum packed in Krehalon® bags (reference number ML40K, PET/PA/EVOH/PE). Their controlled permeability with regard to oxygen minimized the risks of graying the finished products.

3.1.6 Conclusions regarding the characteristics of the products during the drying process

In order to optimize the running of the OsmoFood® pilot line, the following changes should be made in view of installing a pilot line on an industrial site:

- The implementation of a roller laminator between the meat extruder and the extruding laminator/entrance conveyer seems to be the best solution in order to limit all the defects that were observed during the lamination process (e.g., blockage of the meat extruder, presence of air between the paper and meat, etc.).
- Adjusting the heating setting of the osmotic solution to 78 °C seems necessary to guarantee a pasteurization temperature of 72 °C.
- The installation of a motor with sufficient electric power, on the exit conveyor, is vital to obtaining identical pasteurization times across product lines.

3.2 Physicochemical characteristics of the dried products

3.2.1 Dehydration Rate

Table 7 summarizes the dehydration yields after osmotic treatment.

Table 7. Dehydration yields for the five recipes

Recipes	Original beef jerky	Beef jerky with chipotle flavor	Beef jerky with Mexican flavor	Pork with dry cured ham	Turkey jerky
Yield (%)	58.6	62.8	60.1	64.2	62.9

These yields are calculated as follows:

Yield (%) = [Fresh weight (g)/ Dry weight (g)] x 100 (1)

The result provides the final weight of the product after dehydration. The quantity of water lost is calculated as follows:

Water extract (%) = 100 – yield (%) (2)

3.2.2 Physicochemical analysis

3.2.2.1 Results

Table 8 shows physicochemical analysis performed on the five recipes.

Table 8. Physicochemical analysis of the five samples

	Original beef jerky	Beef jerky with chipotle	Beef jerky with Mexican flavor	Pork with dry cured ham	Turkey jerky
Dry matter (%)	57.85	57.35	57.80	52.40	50.20
Humidity (%)	42.15	42.65	42.20	47.60	49.80
pH	5.37	5.35	5,42	5.68	5.54
Aw	0.923	0.928	0.918	0.937	0.929
Free lipids (%)	15.70	17.40	16.50	13.90	6.80
Humidity of the de-lipided product (HPD) (%)	50.40	51.2	50.50	55.3	53.40
Free lipids/HPD 77 (%)	8.00	9.00	8.40	7.70	3.50
Residual nitrites (mg/kg)	2.00	0.00	3.00	2.00	1.00

3.2.2.2 Data Analysis

Dry matter:

The mixture of spices used for the beef-based recipes led to an increase in the dry matter of the finished products. They were on average 57.60%, while those of the pork-based and turkey-based recipes were 52.40% and 50.20%, respectively. The difference in dry matter content between the latter two is due to the addition of dry ham in the pork-based recipe and to the lower fat control of the turkey raw material.

pH:

The beef-based recipes had an average pH of 5.38, while those of the pork and turkey based recipes were 5.68 and 5.54, respectively. This variation is linked to the initial pH of the raw materials.

Aw:

The Aw of the beef and turkey-based trials were relatively similar.
The Aw of the pork-based recipe is relatively high. In this recipe, only 15 g/kg of sodium chloride (NaCl) was added. The quantity of NaCl provided by the dry ham was certainly not sufficient to equal the salt concentration of the other recipes, which were 27 g/kg for the turkey and 20 g/kg for the beef-based recipes, respectively.

Free lipids/HPD 77 (%):

This chemical analysis characterized the lipid content of the raw materials.
The turkey-based recipe was therefore made up of very lean meat, which only contains 3.50% of free lipids. The pork-based recipe was less fatty than that of the beef recipe, with mean averages of 7.70% and 8.50%, respectively.

Humidity (%):

Final moisture of the de-lipided product ranged from 50.4 to 55.3 %, and were correlated with water activity.

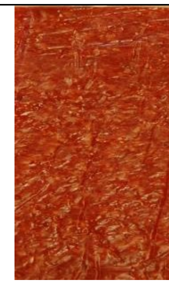
Residual nitrites (mg/kg):

The residual nitrite concentrations were very low for all the trials, even non-existent for the beef jerky with chipotle flavor. These results demonstrate that nitrite absorption was perfect.

3.2.3 Sensory Analysis

The different observations carried out during the sample tasting session for the different samples are presented in Table 10.

Table 9. Sensory analysis of samples

Recipes	Specification	Remarks	Photos
Original beef jerky	Taste	Not strong	
	Texture	Non-rubbery, firm but not a tough texture	
	Color	Good color	
Beef jerky with chipotle flavor	Taste	Good flavor	
	Texture	Non-rubbery, firm but not a tough texture	
	Color	Redder than the original beef jerky	
Beef jerky with Mexican flavor	Taste	Very strong	
	Texture	More chewy than the two previous samples	
	Color	Normal	
Pork with dry cured ham	Taste	Very tender, could not smell the garlic	
	Texture	Good texture	
	Color	Red pink	
Turkey Jerky	Taste	Sweet taste	
	Texture	chewy	
	Color	Normal	

In order to smell the aroma of garlic in the pork with dry cured ham, its dosage must be increased by roughly 1 g/kg for future recipes. For the turkey jerky, the slightly excessive sweet ranking was due to the honey in the recipe.

3.3 High-pressure treatment

The high-pressure treatments at 500 MPa (6 min) and 600 MPa (6 min) were carried out without any visual incidences (color) for the five samples (see Appendix A).

Problems were encountered with the treatment at 650 MPa. This latter treatment was carried out with a pressurization time of roughly 60 s (Appendix B). A technical incident, provoked by the rupture of a reinforced pipe at the level of the pressure transmitter, led to the cycle being stopped during the treatment. This incident concerned the original beef jerky, Mexican beef jerky, and pork with dry cured ham samples.

A small portion of the pork with dry cured ham and turkey jerky samples were treated with 2-L pilot equipment (THIOT 2L/900). A portion of each sample was cut into three identical parts and then repackaged in transparent polypropylene packets (150x200 PA/PE). Figure 11 presents the new packaging.

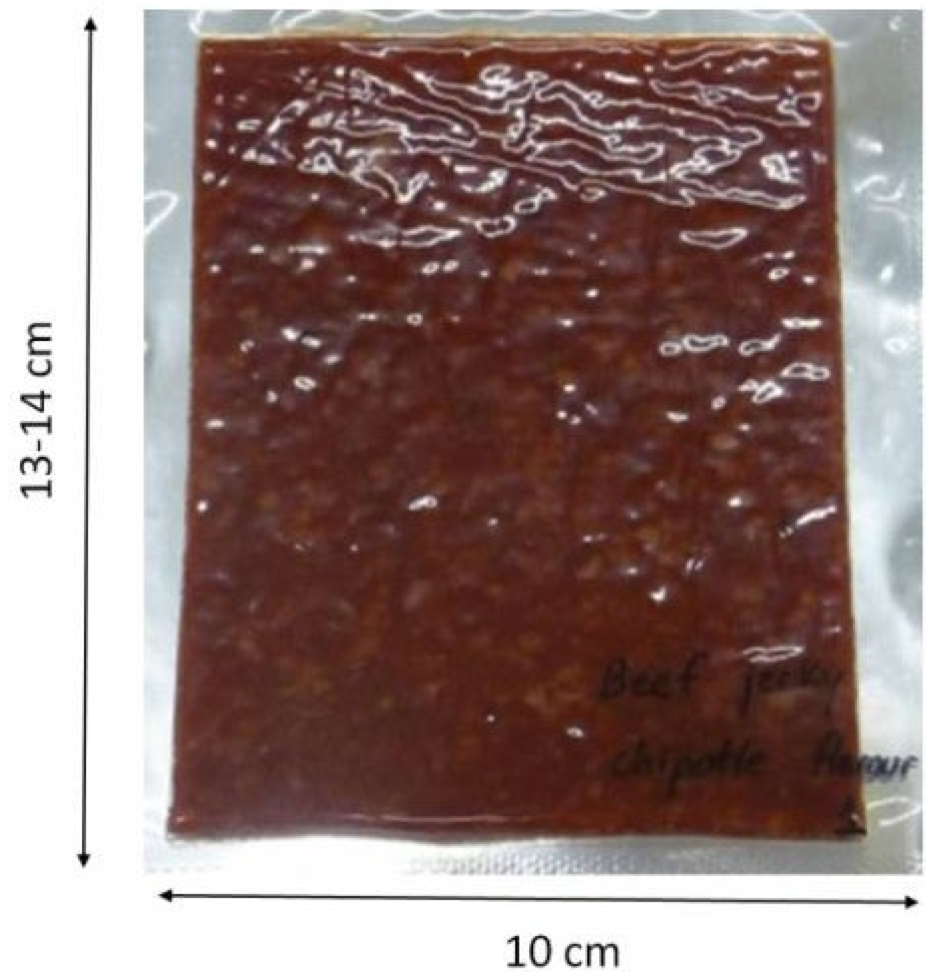


Figure 11. Jerky sample packaged in polypropylene pouch

The samples were then packed individually in a metallic liner (165x240 MET/T+MET/T) before being pressurized in the pilot equipment (Figure 12).

Figure 12: Pouched jerky samples with metallic liners.

The different settings used for the high-pressure treatment of the samples are shown in Table 11.

Table 10. Process of the different high-pressure treatments.

	Max. Press.	Dwell time	Pressure speed increase	Water temperature	Equipment	Samples
Test 1	500 MPa	360 s	235 MPa/min	10-12 ºC	Wave 120/650	Original beef Jerky, Chipotle beef Jerky, Mexican beef Jerky, Pork with dry cured ham, Turkey Jerky,
Test 2	600 MPa	360 s	250 MPa/min	10-12 ºC	Wave 120/650	Original beef Jerky, Chipotle beef Jerky, Mexican beef Jerky, Pork with dry cured ham, Turkey Jerky,
Test 3	650 MPa	60 s	250 MPa/min	10-12 ºC	Wave 120/650	Original beef Jerky, Chipotle beef Jerky, Mexican beef Jerky
Test 3a*	650 MPa	360 s	216 MPa/min	10ºC	Thiot 2L/900	Pork with dry cured ham, Turkey Jerky.

4.0 CONCLUSIONS OF PHASE II

The trials carried out on the pilot line enabled the study team to assess the feasibility of drying the different recipes implemented on the OsmoFood® pilot line as installed on the ADIV platform at Clermont-Ferrand.

Globally, the different products behaved satisfactorily during the process's different unit operations. Nevertheless, in order to optimize the work of the OsmoFood® pilot line, some changes have to be made in view of installing a pilot line on a U.S.-based industrial site.

The implementation of a roller laminator between the meat extruder and the extruding laminator/entrance conveyer is necessary to limit all the defects, which were observed during lamination (i.e., blocking of the meat extruder, presence of air between the paper and the meat).

The installation of a sufficiently powerful electric motor on the exit conveyor is vital in order to obtain identical pasteurization times no matter which product is being treated.

The 500MPa and 600MPa pressurization treatments carried out on a portion of each product were successful. However, the 650MPa treatment was a failure as this pressure led to the degradation of the equipment's reinforced pipe.

The storage tests carried out at NSRDEC will determine the microbiologic and physicochemical stability of the different recipes dried by the OsmoFood® process.

Based on the results of this effort, NSRDEC will most likely purchase an OsmoFood® pilot line and install it in in a U.S.-based industrial site.

5.0 PHASE III. MANUFACTURE, DELIVERY, INSPECTION, AND INSTALLATION OF AN OSMOFOOD® PILOT LINE IN A U. S. MEAT PROCESSING COMPANY

Phase III described the ordering of a pilot scale OsmoFood® unit from ADIV, and the installation of it into one of the U.S. meat processing companies. The report (Rispal, 2012) included seven stages of contract tasks, and the outcome was satisfactory. The OsmoFood® system has been used for research and product development work since 2012.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 20/006 in a series of reports approved for publication.

BIBLIOGRAPHY

ADIV Patent: Minced meat transformation. 2004. Patent #: A235-b-9749 FR. Also USA: A235-B-9749-WO; Brazil: A235-B-9749-BR; Europe: EP 1406501.

Borg, F. 2003. "What is osmosis? Explanation and understanding of a physical phenomenon". arXiv:physics/0305011.

Kosinski, R. J. and C. K. Morlok. 2008. "Challenging misconceptions about osmosis". Association for Biology Laboratory Education. **30**: 63–87.

Kramer, E. and D. Myers. 2012. "Osmosis is not driven by water dilution". Trends in Plant Science. **18** (4): 195–197. doi:10.1016/j.tplants.2012.12.001.

Kramer, E. and D. Myers. 2012. "Five popular misconceptions of osmosis". American Journal of Physics. **80** (694). Bibcode:2012AmJPh..80. 694K. doi:10.1119/1.4722325.

Rispal, O. 2012. Phase III. Osmofood pilot line: Commissioning Osmofood pilot line in FPL plant and staff training. Contract report. US Army Natick Soldier, Research, Development, and Engineering Center (NSRDEC) project " Novel Processing System for Ration Meat Items".

APPENDIX

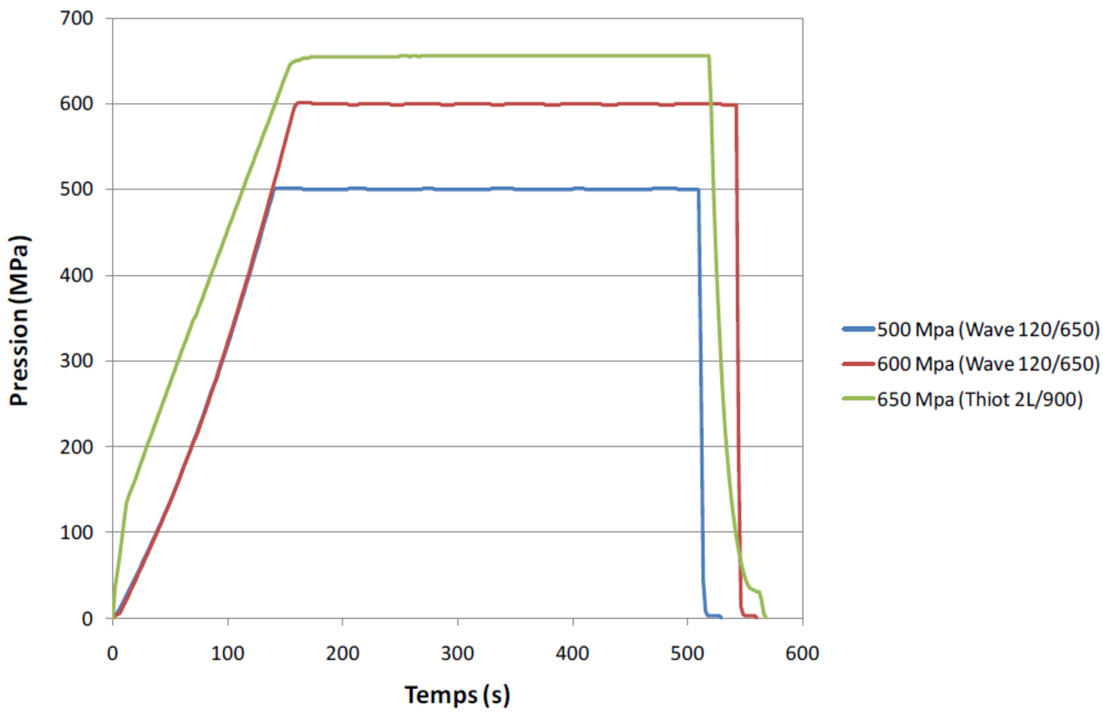


Figure A-1. cycle pressure profiles on the Wave 120/650 and THIOT 2L/900

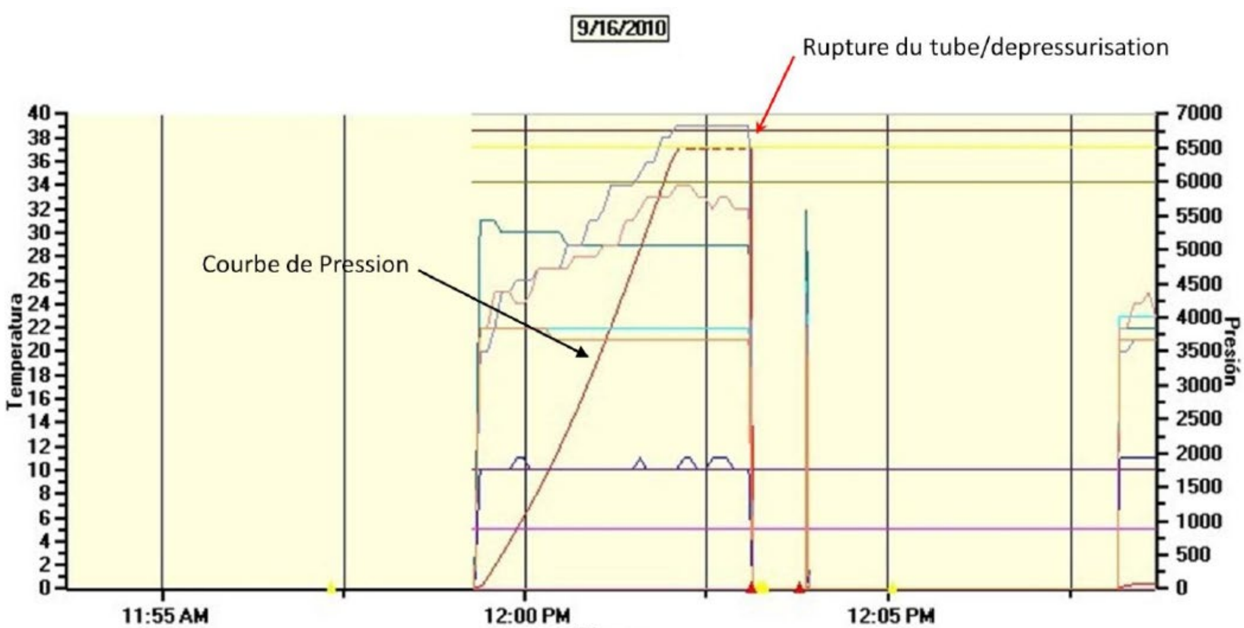


Figure A-2. Treatment at 650 MPa on the (Wave 120/650) control card.