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RE-EVALUATION OF OHMIC HEATING TECHNOLOGY FOR RATION ENTRÉE QUALITY IMPROVEMENT

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14. ABSTRACT

The US Army Natick Soldier, Research, Development, and Engineering Center (NSRDEC), now the US Army Combat Capabilities Development Command Soldier Center (CCDC SC) conducted a series of experiments, titled "Advanced Thermal Processing of UGR H&S Group Sized Entrees", to explore novel thermal technologies to enhance quality of traditionally retorted ration entrees. This technical report documents a Science and Technology initiative for an advanced thermal processing technology, ohmic heating, to produce shelf stable, high quality, and nutritious ration entrees. The funding for the study came from the Combat Feeding Research and Engineering Board (CFREB) from FY13-FY17.

15. SUBJECT TERMS

RECIPES	SHELF LIFE	FOOD STORAGE	MILITARY RATIONS	THERMAL PROCESSING
RETORT	NUTRIENTS	GROUP RATIONS	ASEPTIC PROCESSING	SENSORY EVALUATION
RATIONS	SHELF STABLE	OHMIC HEATING		
ENTREES	TEMPERATURE	UNITIZED GROUP RATIONS		
STORAGE	STERILIZATION	UGR(UNITIZED GROUP RATIONS)		

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PREFACE

The US Army Combat Capabilites Development Command (CCDC) Soldier Center, formerly known as the Natick Soldier, Research, Development, and Engineering Center (NSRDEC) conducted series of experiments, titled "Advanced Thermal Processing of UGR H&S Group Sized Entrees" to explore novel thermal technologies to enhance quality of traditionally retorted ration entrees. This technical report documents a Science and Technology initiative for an advanced thermal processing technology, ohmic heating, to produce shelf stable, high quality, and nutritious ration entrees. The funding for the study came from the Combat Feeding Research and Engineering Board (CFREB) from FY13-FY17.

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RE-EVALUATION OF OHMIC HEATING TECHNOLOGY FOR RATION ENTRÉE QUALITY IMPROVEMENT

1.0 INTRODUCTION

1.1 Background

The general goal of heat processes like pasteurization or sterilization is to protect the food against microbiological changes (high temperature exposition is needed) without endangering quality of the food products too much. High temperature heating with very short temperature exposition is therefore demanded. These conditions can be achieved using an Ultra High Temperature (UHT) sterilization method (Chavan et al., 2011). One of the UHT methods is direct ohmic heating (and similar microwave heating or inductive heating). Ohmic heating is an advanced thermal processing method wherein the food material, which serves as an electrical resistor, is heated by passing electricity through it (Figure 1).

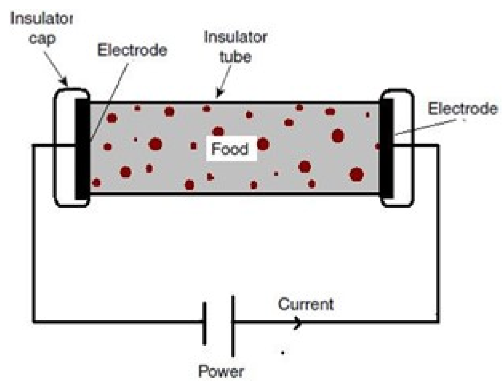


Figure 1 Traditional ohmic heating

Electrical energy is dissipated into heat, which results in rapid and uniform heating (Duguay et al., 2017). Ohmic heating volumetrically heats the entire mass of the food material at once; thus, the resulting product is of far greater quality than its retorted counterpart. The food material maintains its sterility and aseptically fill into pre-sterilized containers (e.g. pouches, bags, cans, or drums).

Ohmic heating can be used for rapidly heating liquid foods containing large particulates, such as soups, stews, fruit slices in syrups and sauces, and heat sensitive liquids. It is possible to process large particulate foods (up to 1 inch) that would be difficult to process using conventional heat exchangers. The technology is useful for the treatment of proteinaceous foods, which tend to denature and coagulate when thermally processed. For example, liquid egg can be processed in a fraction of a second without coagulating the protein, and juices can be treated to inactivate enzymes without affecting the flavor. Other potential applications of ohmic heating include blanching, thawing, on-line detection of starch gelatinization, fermentation, peeling, dehydration, and extraction. Ohmic heater cleaning requirements are comparatively less than those of traditional heat exchangers due to reduced product fouling on the food contact surface. Advantages over conventional indirect heating methods are speed and uniformity of heating, and also easy control of the heating process (Jones, 1897; Stirling, 1987; Skudder and Biss, 1987;

Parrott, 1992; Zhang and Fryer, 1993; Zoltai and Swearingen, 1996; Kim et al., 1996 a&b; Zareifard et al., 2003; Icier and Ilicali, 2005; Varghese et al., 2014). Research of this technology covers a wide range of applications including thermal processing of solid foods, liquid foods, solid-liquid food mixtures, meats, and vegetables.

Natick Combat Feeding Directorate (CFD) has been exploring the ohmic sterilization technology and its commercialization since the 1990s. Starting from joining the Ohmic Heating Consortium with Land-O-Lakes Co. in 1990, and a contract in 1992 with APV Bakers Co. in England to produce six prototype ohmic heated entrees—through a Foreign Technology Comparison Program (i.e., D650 program): Carbonarra Sauce, Winter Soup, Mushrooms in Tomato Sauce, California Beijing Beef, Cappelletti, and Ratatouille (Yang et al., 1994). Although the products received satisfactory ratings, they could have been improved by using formulations specifically developed for the systems. The study demonstrated that reduced-temperature sterilization processes will produce an acceptable product that is an alternative to thermal sterilization. More studies on ohmic heating efficiency were performed in the years that followed (Kim et al., 1996 a&b; Yang et al., 1997; Yang, 1999).

A yearly survey of upgraded ohmic heating systems has been conducted, and currently the Ohmic Heating System at Emmepiemme s.r.l,, Piacenza, Italia is one of the most advanced, patented systems in existence that could deliver the test samples with desirable characteristics (Pain et al., 2013).

1.2 Objective

CFD had a Joint Statement of Need (JSN) project to explore advanced thermal processes to improve the quality of Unitized Group Ration Heat & Serve™ (UGR-H&S™) entrees. Group rations are the mainstay of small units at expeditionary base camps where resupply efforts may be highly unreliable. Warfighters located in Forward Operating Bases (FOB), Combat Outposts (COP) and Patrol Bases (PB) desire shelf stable rations with 'fresh-like' quality, including fruits and vegetables, when they do not have access to Unitized Group Ration – A™ (i.e., ration prepared from fresh or frozen ingredients; UGR-A™) or freshly prepared foods. Current UGR-H&S™ group sized entrees, and individual sized entrees like the Meal, Ready-to-Eat™ (MRE™) are processed via traditional retort thermal sterilization which has a known detrimental effect on the quality of entrees due to a long thermal exposure. The challenge of increasing consumption and acceptability of MRE and UGR-H&S entrees will be met by leveraging ongoing breakthroughs in the area ohmic heating sterilization process.

Rations generated from this effort will support the Army's need to enable sustainment by independence and self-sufficiency through improved consumption and reduction of food and packaging waste. This effort provides a mechanism to develop high quality, individual and group size entrée items with an extended shelf life, may optimize nutrient delivery at time of consumption, and will expand ration component variety and menu options. Under-consumption of rations could have long term effects that could negatively impact the warfighter both physically and mentally in areas of contingency. A warfighter who is under-nourished, whether it is due to menu monotony or ration dissatisfaction, further magnifies the physical burden of carrying needed gear in areas of conflict. Performance can be negatively affected and may result in injury, death, or other long term effects. As such, ohmic heating technology has the following benefits:

Affordability and Capability of Defense Operations:

- Reduce Costs: Extending shelf life and reducing processing costs, logistics costs, footprint, and field waste of field rations and packaging.
- Improve Capability: Improving Warfighter morale, performance, and capability.

New Capabilities to Counter Emerging Technologies and Meet Needs Across Domains:

- Reduce Soldier Load: Aseptic packaging allows easy customization of entrée sizes to meet a variety of ration platforms.
- Force Application: Serving individual, small squad, and groups of all Services and Special Forces.
- Increase Human Systems Performance: Improving ration consumption and providing sufficient energy, nutrients, and varieties of ration entrees.

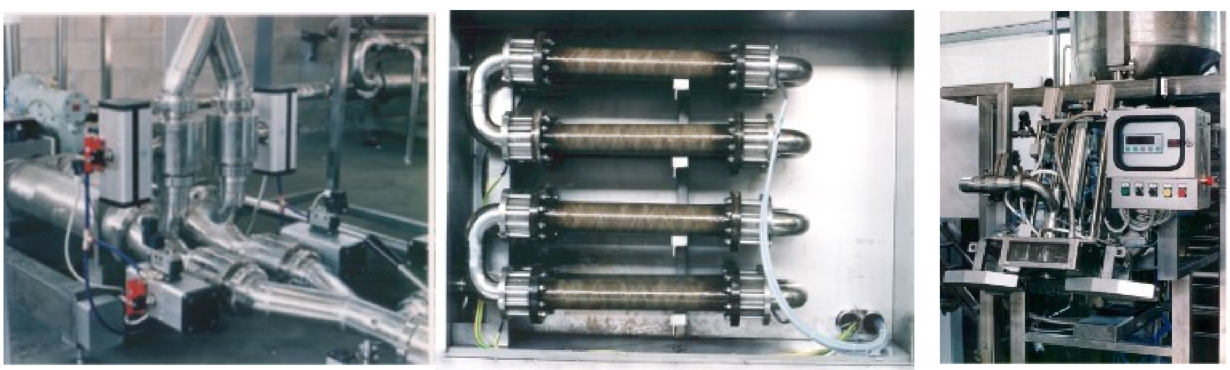
The objective of this contract is to produce and compare quality and shelf stability of four entrée items using standard retort and the Emmepiemme Ohmic heater.

2.0 MATERIAL, METHODS, AND RESULTS

2.1 Contractor: Emmepiemme s.r.l., Piacenza, Italia

Stancl and Zitny (2008) reported that the efficiency of older generations of ohmic heaters was limited by the effect of electrode material and the significant effect of the current density. The fastest drop of power was recorded with electrodes made of stainless steel material, especially by using high values of the current density. Samaranayake and Sastry (2005) and Samaranayake et al. (2005) also pointed out undesirable electrochemical phenomena at electrode-solution interfaces during ohmic heating that could be avoided or effectively inhibited by choosing an appropriate electrode material.

The newly designed ohmic heater, the Emmipiemmi Model, addressed and improved on these potential shortfalls. The Emmepiemme piston pump, ohmic heater, and aseptic filler (Figure 2) are the main elements that provide reliable and versatile continuous heating and packaging (US Patent 20130315574 A1; Pain et al., 2013). It offers a number of innovative patented designs: the voltage supply, assured by "switching" modules with unitary power up to 60 Kw; the possibility to change the voltage to fit the different product conductivities; the applicator, consisting of a series of insulted pipes and annular electrodes; the product passage section, completely fouling-free and with uniform diameter up to 100 mm; and more.



Piston pump Ohmic heater: power applicator Aseptic filler

Figure 2. Typical Emmepiemme piston pump, ohmic heater, and aseptic filler

The Emmepiemme volumetric pump is one of the critical pieces of equipment to feed the ohmic heating system with a high percentage of solid pieces, as well as in case low throughputs are required in the presence of solids. It's specially designed to ensure the utmost regular plant operation, it can move fluid-solid mixture containing up to 90% of solids, and it minimizes product damage.

Ohmic heating enables short processing times, eliminates contact with hot surfaces, and homogenous heating that ensure particularly high quality finished products, as well as the possibility to process products which cannot be treated with conventional thermal processes. Particular applications of the ohmic system are: processing of large particulate products, e.g. whole, sliced, and diced fruits and vegetables; chopped meat recipes (with typical heating times around 45 s); processing of soups and purees; pasteurization of dairy products (with heating time around 10-15 s); and processing of liquid products such as juices (heating time is below 1 s).

The aseptic filler is equipped with 2 inch spout filling heads, which allow the filling of four consecutive bags directly positioned on pallets by means of a horizontal displacement of the head.

A pilot scale testing unit of ohmic heating is shown in Figure 3.

Figure 3. Pilot Scale Emmpiemme Ohmic Heating system

2.2 Processing and Testing Facilities: SSICA, Parma, Italy

The Experimental Station for the Food Preserving Industry (aka SSICA) is an applied and experimental research institute founded as a Public Body in 1922. It is now a special Agency of the Chamber of Commerce of Parma with the purpose of improving the quality and safety standards of products along the entire food supply chain. The Agency has various departments specific to the different product sectors, as well as departments and laboratories in charge of more general activities; it has equipment and know-how aimed at experimenting with new products, new processing and preservation procedures, analyzing possible economic and social impact. It aims to promote the technical and technological progress of the Italian food-preserving industry for the sectors of fruits, vegetables, meat, and fish products through its activities of research, consultancy, training, and dissemination of information. SSICA is one of the most important applied research bodies in the preserved food sector in Europe and in the world, and it takes part in national and international research projects.

2.3 Thermal Process Equipment at SSICA

A pilot scale retort that produced the traditional canned products is shown in Figure 4.

Figure 4. Levati batch retort

A Levati batch retort (Levati Food Tech s.r.l, Traversetolo, Italy) is capable of conducting sterilization in different conditions and for different materials of packaging:

- Hot water rain or steam injection
- Rotary or static retort
- Sterilization (or pasteurization) for metal cans, glass containers, paperboard cartons or flexible pouches, and plastic containers

For this project, a static condition with hot water rain in the retort was used, because of the necessity to put into the cans the probes for the measuring of temperatures and for the correct calculation of sterility value Fo.

For ohmic Fo, the reference bacterium was Clostridium Botulinum and it was assumed Fo =1 for 1 min at 121.1 °C. The holding time in the pilot plant was 1.2 min at 100 kg/h (the holding volume was 2 L).

Fo was calculated using the following formula:

$$\text{Log } F = \text{Log } F_o - (T - 121.1)/Z \quad (1)$$

where:

F= 15 (to take into account a flow index of 0.6 - 0.7)

Z=10

T= treatment temperature

From this formula, it is possible to calculate T that was 132 °C. The set point of the ohmic was fixed at 135 °C.

Fo values for retort cans were obtained by installing a probe in four cans for every trial, and calculated using a standard thermal processing method (Heyliger, 2012).

The ohmic plant is showed in the pictures below (Figures 5-7) and made by different sections:

- Loading tank
- Pump
- EMMEPIEMME Ohmic heating section: it is made by four stages divided into two different sections, with a holding pipe between the sessions. There is a probe for the measuring of temperature in the inlet and outlet of both sections
- Holding section for the official sterilization: 2 L of pipes where Fo is guaranteed
- Cooling section: indirect exchangers with cold water
- Aseptic filler machine for pouches (0.5 to 3 kg)

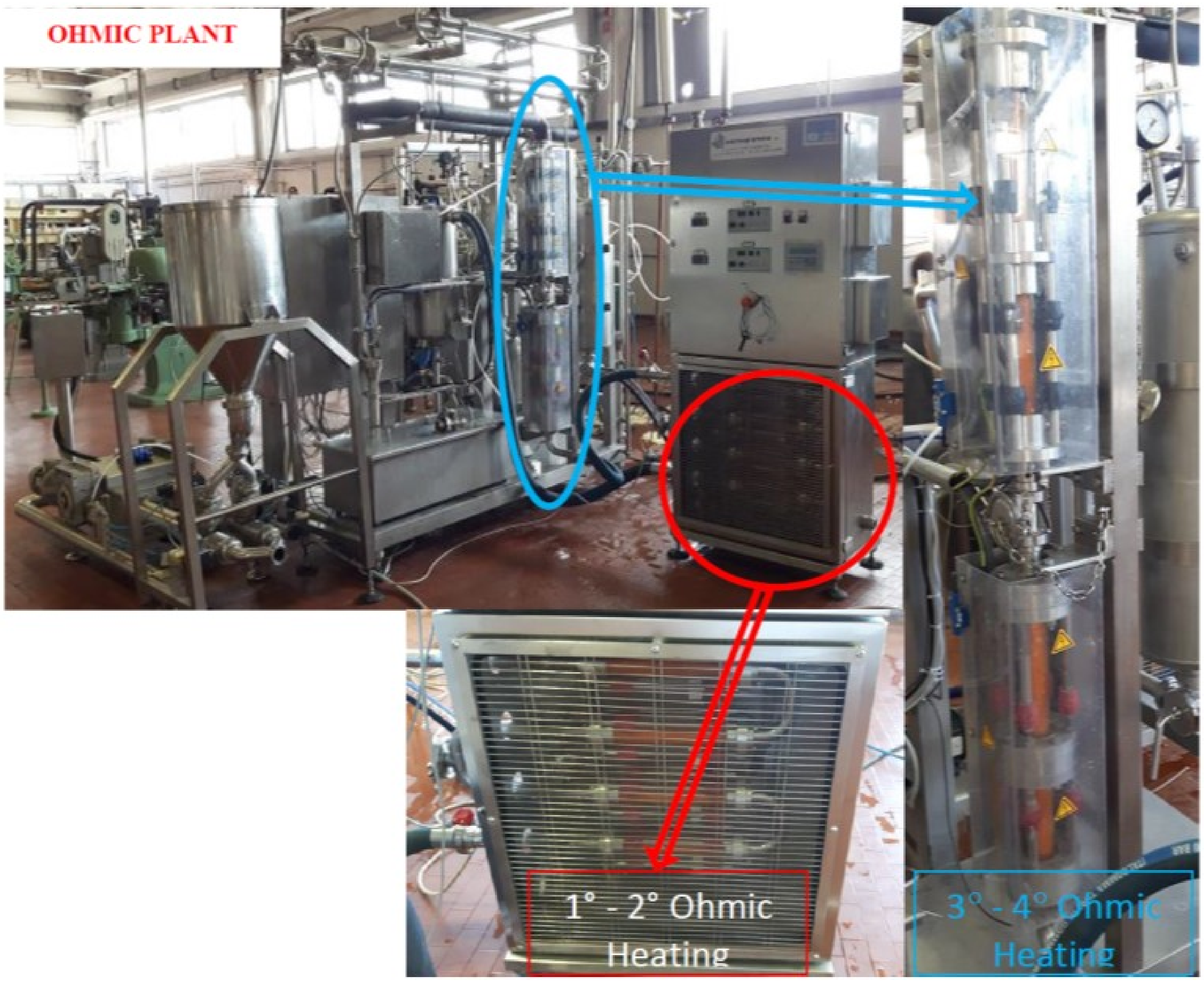


Figure 5. Ohmic heater shows sessions with pre-heating (1-2°) and final heating (3-4°)

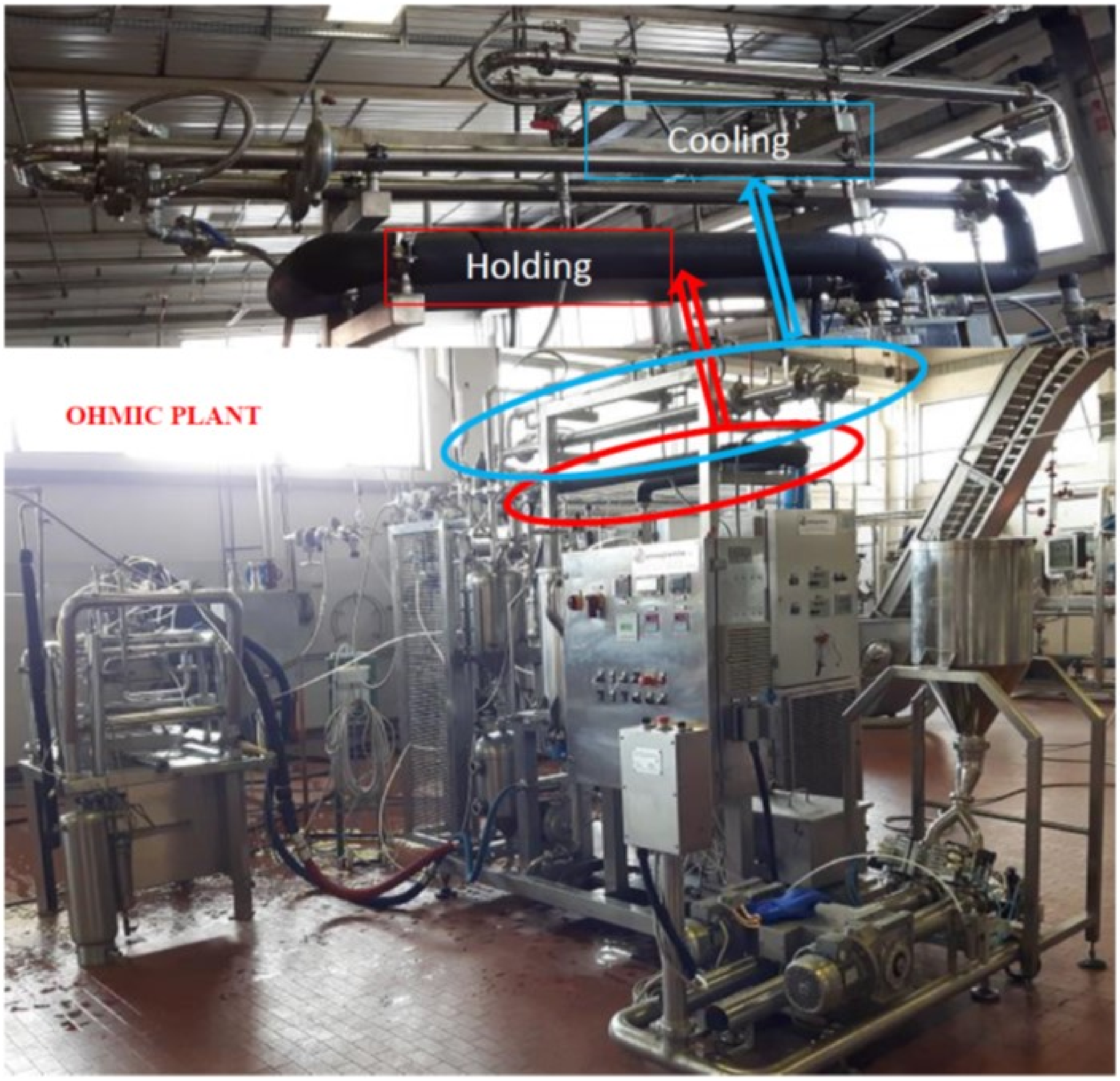


Figure 6. Ohmic heater shows sessions with holding and cooling pipes

Figure 7. Aseptic filler machine for pouches

Finished products are shown in Figure 8.

Figure 8. Retorted can and ohmic processed pouch of finished products

2.4 Experiments and Initial Product Evaluation

The four prototype products were: Buffalo Chicken, Plain Pasta, Chicken Potpie Filling, and Macaroni and Cheese, and the original recipes were provided by Natick (i.e., Buffalo Chicken, Plain Pasta, and Chicken Potpie Filling) and Kraft Heinz Co. (i.e., Macaroni and Cheese; Chicago, IL). For all products, parts of the processed recipe (e.g. Table 1) was modified from the original one in order to guarantee the correct processing into the ohmic system: it's just a precaution due to the dimension of pipes and machineries into this pilot plant model, because on a well-dimensioned industrial plant there will be no issues in processing the recipe with the right percentage of pieces and sauce. The same processed recipe was used in retort and ohmic system.

2.4.1 Buffalo Chicken

The recipe of Buffalo Chicken is shown in Table 1.

Table 1. Recipe of Buffalo Chicken

Buffalo Chicken recipe	Original Recipe 1 batch		Processed Recipe 1 batch	
	%	Kg	%	Kg
1/2" Thick, Grilled Chix Strip #CC0135	64,5	76,00	40,6	35,00
Frank's Red Hot (Buffalo Sandwich Sauce):	35,5	42,00	59,4	51,19
TOTAL	100,0	118,00	100,0	86,19

Frank's Red Hot (Buffalo Sandwich Sauce)	%	Kg
Harissa	32,0	17,00
Distilled Vinegar	49,0	26,00
Clear Gel Starch	7,0	1,85
Salt	1,4	0,70
Xantham Gum	0,3	0,17
Guar Gum	0,3	0,17
Butter	5,5	2,90
Soy Seed Oil	4,5	2,40
TOTAL	100,0	51,19

Frozen chicken pieces previously thawed at 4 °C were partially minced in order to have the proper dimension into the pipes (Figure 9a).

The sauce was prepared into a jacketed and stirred vessel (Figure 9b). The gums and the starch were previously mixed with vinegar into a NILMA emulsifier (Figure 9c): this action was taken because the direct adding of starch into the vessel produced lumps as shown in Figure 9d. The sauce was prepared at 50 °C in order to preserve the structure of gums and starch. The mixing was heated up to 70 °C for 5 min and the chicken pieces were added into the vessel in a percentage of 41%.

(a)

(b)

(c)

(d)

Figure 9. Buffalo Chicken recipe preparation: (a) chicken piece preparation; (b) steam jacketed and stirred vessel; (c) NILMA emulsifier; (d) starch lumps in the sauce

At the end of preparation the product looks as in Figure 10. The pH of the product before sterilization is 4.0.

Figure 10. Buffalo Chicken recipe mix ready to process

The mix was treated to a sterility value of Fo = 6 by using the retort and ohmic heating system.

The Fo = 6 was evaluated by considering the contribution of the only holding section for both processes. Two batches of product were processed in ohmic while the third one was processed in retort.

The ohmic treatment was conducted in the following conditions:

- Flow rate: 100 L/h
- Holding pipe diameter: 40 mm
- Holding length: 2 m
- Temperature at holding outlet: 128 °C

Ohmic processing data of Buffalo Chicken (referred to the stationery phase) are listed in Table 2.

Table 2. Ohmic processing data of Buffalo Chicken

Time (h:min)	Temp inlet (°C) 1st ohmic applicator	Temp inlet (°C) 3rd ohmic applicator	Δ Temp (°C) 1st ohmic station	Temp outlet (°C) 4th ohmic applicator	Δ Temp (°C) 2nd ohmic station	Temp outlet (°C) Holding section
12:50	57.9	93	35.1	130	37	128
13:09	61.1	95	33.9	129	34	129
13.14	62	95.3	33.3	129	33.7	130
13:25	63.3	97.2	33.9	129	31.8	129
13:35	65	97.7	32.7	130	32.3	128
13:43	62.1	96.4	34.3	129	32.6	128
13:52	55.8	94.4	38.6	130	35.6	129
14:04	54.2	91.2	37	130	38.8	130

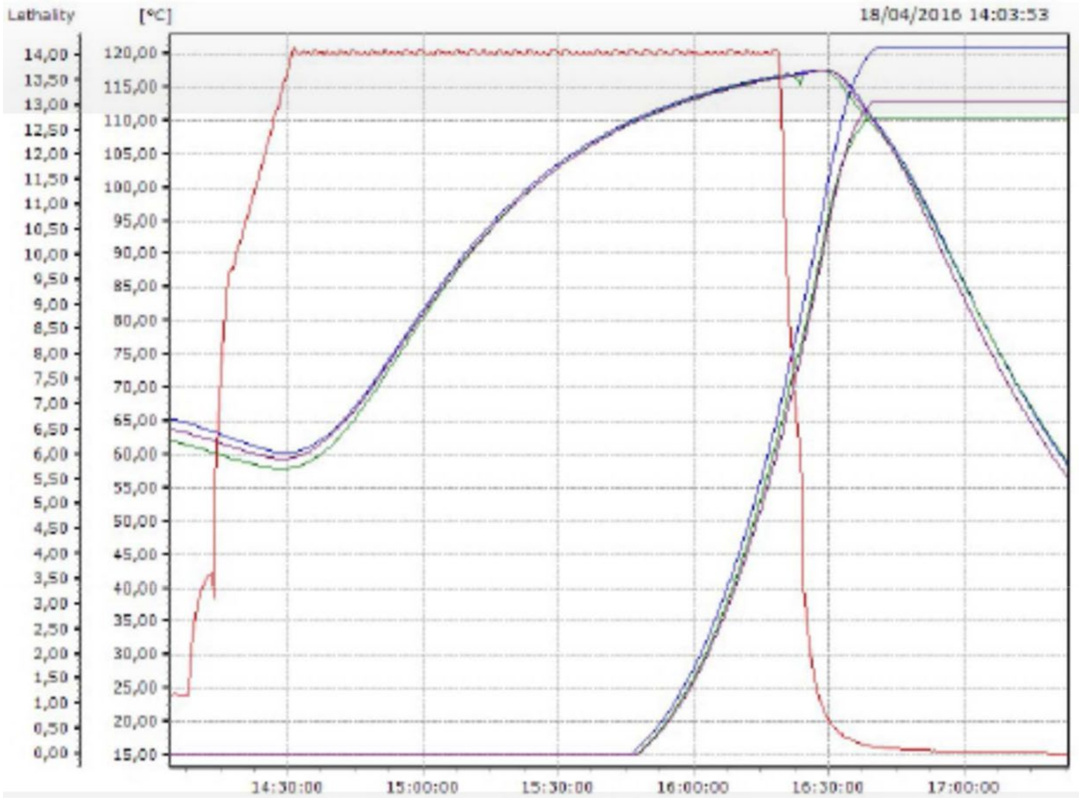
Processing data were collected at the control panels (Figure 11).

(a)

(b)

Figure 11. Control panel: (a) 1st ohmic station [1st and 2nd applicators]; (b) 2nd ohmic station [3rd and 4th applicators]

The retort process of Buffalo Chicken is shown in Figure 12.



Nome	Min	Max	17:23:40
Retort	15,24	120,82	15,29
Posizione 2	57,81	117,58	57,81
Posizione 2 (F0) Le	0,00	14,14	14,14
Posizione 3	57,85	117,46	58,25
Posizione 3 (F0) Le	0,00	12,73	12,73
Posizione 4	56,01	117,47	56,01
Posizione 4 (F0) Le	0,00	13,07	13,07

Figure 12. Retort processing data of Buffalo Chicken

Results:

The ohmic system was really stable during the processing and the ΔT of the single station was more or less 35 °C. The product is very conductive; during the ohmic process, the 1st and 2nd applicators were in TAP 0 and 1 respectively, while the 3rd and the 4th were in TAP 1. Every applicator managed a product from TAP 0 (very conductive) to TAP 7 (least conductive) depending on the electric conductivity of the product. The pH of the product before sterilization was 4.0.

The initial products (pre-sterilization vs. after process) are shown in Figure 13.

Retort **Ohmic**

Retort vs. Ohmic

Figure 13. Visual comparison of ohmic vs. retort Buffalo Chicken

The product obtained from the ohmic treatment was more homogeneous than retort one, and the sauce was more consistent (i.e., less liquidities). The chicken treated in retort was darker, with signs of burns due to the static retort process. The ohmic treated product has a more balanced flavor and the acidic note of vinegar is less persistent than the retort product.

2.4.2 Plain Pasta

The recipe of Plain Pasta is shown in Table 3.

Table 3. Recipe of Plain Pasta

Plain Pasta recipe	Original Recipe 1 batch		Processed Recipe 1 batch	
	%	Kg	%	Kg
Recheis Enriched Elbows 10% Egg White After boiling (2 x dry weight)	59,87	71,16	35,11	25,00
Suspension	38,28	45,50	63,90	45,5
Extra Sunflower oil	1,85	2,20	0,98	0,70
TOTAL	100,0	118,86	100,0	71,20

SUSPENSION	%	Kg
Water (Filtered)	91,2	41,49
Unsalted Butter	5	2,27
Clear Gel Starch	3,2	1,45
Xanthan Gum (200 mesh)	0,3	0,136
Guar Gum	0,3	0,136
TOTAL	100,0	45,48

Pasta was pre-cooked for 10 min in boiling water. At the end of this phase the weight of pasta was more or less double the weight of dry pasta (Figure 14). After cooking, pasta was drained and put it in cold water to reduce continuous cooking of pasta. The cooled pasta was then mixed with 1.5 kg of oil.

Dry pasta

Cooked and drained pasta

Figure 14. Dry pasta and cooked pasta

In the meantime, the suspension (butter sauce) was prepared in the jacketed and stirred vessel. The gums and the starch were previously mixed with water into a NILMA emulsifier. The suspension was prepared at 50 °C by adding the pre-mix of starch and gums to the water; butter was added and the temperature was increased to 80 °C.

In each batch, 25 kg of pre-cooked pasta were used (Figure 15).

Figure 15. Pre-sterilized pasta in butter sauce

The pH of the product before sterilization was 6.0. The batch was treated to a sterility value of Fo = 10 by using a retort and ohmic heating system. The Fo = 10 was evaluated by considering the contribution of the only holding section for both processes.

The ohmic treatment was conducted in the following conditions:

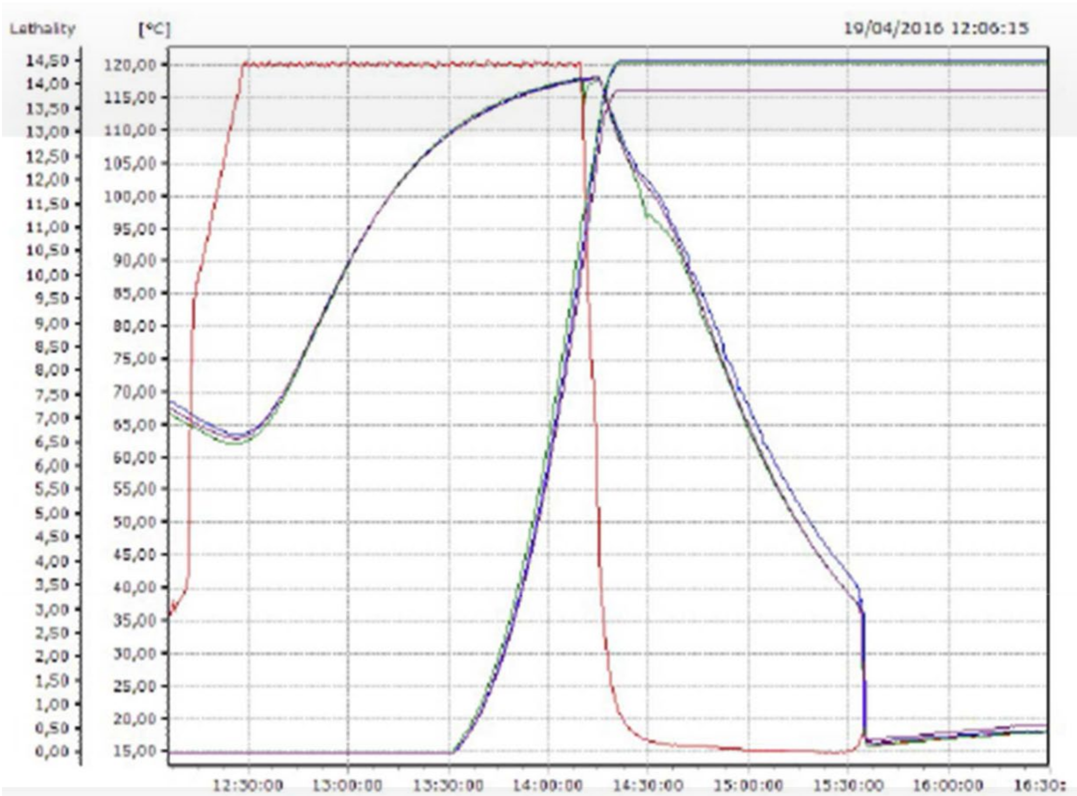
- Flow rate: 100 L/h
- Holding pipe diameter: 40 mm
- Holding length: 1.7 m
- Temperature at holding outlet: 131 °C

Ohmic processing data of Plain Pasta (referred to the stationery phase) are listed in Table 4.

Table 4. Ohmic processing data of Plain Pasta

Time (h:min)	Temp inlet (ºC) 1st ohmic applicator	Temp inlet (ºC) 3rd ohmic applicator	Δ Temp (ºC) 1st ohmic station	Temp outlet (ºC) 4th ohmic applicator	Δ Temp (ºC) 2nd ohmic station	Temp outlet (ºC) Holding section
14:15	58.1	96.3	38.2	134	37.7	133
14:17	58.2	96.9	38.7	135	38.1	135
14:23	58.6	98.9	40.3	136	37.1	134
14:32	57.0	98.2	41.2	135	36.8	133
14.39	54.5	96.6	42.1	136	39.4	134
14:47	54.1	98.7	44.6	135	36.3	134
14.57	53.1	95.2	42.1	134	38.8	135
15:17	52.3	95.5	43.2	134	38.5	135
15:25	56.0	93.8	37.8	135	41.2	133

The retort process of Pasta in Butter Sauce is shown in Figure 16.



Nome	Min	Max	16:30:12
Retort	14,87	120,68	17,96
Posizione 2	16,32	118,22	18,21
Posizione 2 (F0) Le	0,00	14,50	14,50
Posizione 3	15,82	118,11	17,97
Posizione 3 (F0) Le	0,00	14,47	14,47
Posizione 4	16,57	118,16	19,13
Posizione 4 (F0) Le	0,00	13,86	13,86

Figure 16. Retort processing data of Plain Pasta

Results:

The Plain Pasta was less conductive than the Buffalo Chicken recipe. During the ohmic process the 1st and 2nd applicators were in TAP 5 and 6 respectively, while the 3rd and the 4th are in TAP 4. The process data were not as stable as the process data for buffalo chicken. There were some fluctuations in terms of temperatures which were probably due to the presence of little quantity of air in the pasta. The shape of pasta and the viscosity of suspension are responsible for the entrainment of air into the product.

The initial products were compared in Figure 17.

Pre-sterilization **Retort** **Ohmic**

Pre-sterilization **Retort** **Ohmic**

Figure 17. Visual comparison of ohmic vs. retort Plain Pasta

The ohmic treated pasta was less over-cooked and clearer than the retort pasta. In terms of texture, the difference was significant. For both the retort and ohmic processes, the shape and texture of pasta were quite mashed when compared with the pre-treatment shape (Figure 17). Ohmic treated pasta was bigger than the retorted pasta. It was due to the ohmic process condition that the pasta stayed longer in cold water before the discharging into the vessel, which caused more hydration of the pasta. The pasta treated in retort is darker, with signs of burns due to the static retort process.

After the experience with this recipe, some modifications to the subsequent Macaroni and Cheese process were proposed:

- Reducing the pre-cooking time of pasta from 10 to 6 min: pasta continues to cook after draining and during the mixing with suspension
- After pre-cooking, cooling the pasta in cold water just for 2 min and draining immediately after in order to avoid excess rehydration

2.4.3 Chicken Potpie Filling

The recipe for Chicken Potpie Filling is shown in Table 5.

Table 5. Recipe of Chicken Potpie Filling

Chicken Pot Pie recipe	**Original Recipe 1 batch**		**Processed Recipe 1 batch**	
	%	Kg	%	Kg
Whole muscle chicken breast meat strips 1	28,88	33,70	17,78	18,0
Soup, cream of celery, canned 2	27,25	31,80	31,40	31,8
Potatoes, diced 1/2 inch, 80 percent cooked	16,10	18,80	18,57	18,8
Cream, heavy	11,60	13,60	13,43	13,6
Carrots, dice 3/8 inch, frozen	5,37	6,30	6,22	6,3
Green beans, cut, frozen	5,37	6,30	6,22	6,3
Peas, green, frozen	5,37	6,30	6,22	6,3
Pepper, Black, Ground	0,04	0,10	0,10	0,1
Thyme, Leaf, Dried, Ground	0,02	0,06	0,06	0,06
TOTAL	100,0	117,00	100,0	101,26

Frozen chicken pieces previously thawed at 4 °C were partially minced in order to have the proper dimension into the pipes, like in the Buffalo Chicken recipe. All the ingredients (Figure 18) were mixed into the vessel and heated up to 80 °C.

Figure 18. Ingredients of Chicken Potpie Filling

The pH of this recipe before sterilization was 6.04. The mix was treated to a sterility value of Fo = 10 by using a retort and the ohmic heating system. The Fo = 10 was evaluated by considering the contribution of the only holding section for both processes.

The ohmic treatment was conducted in the following conditions:

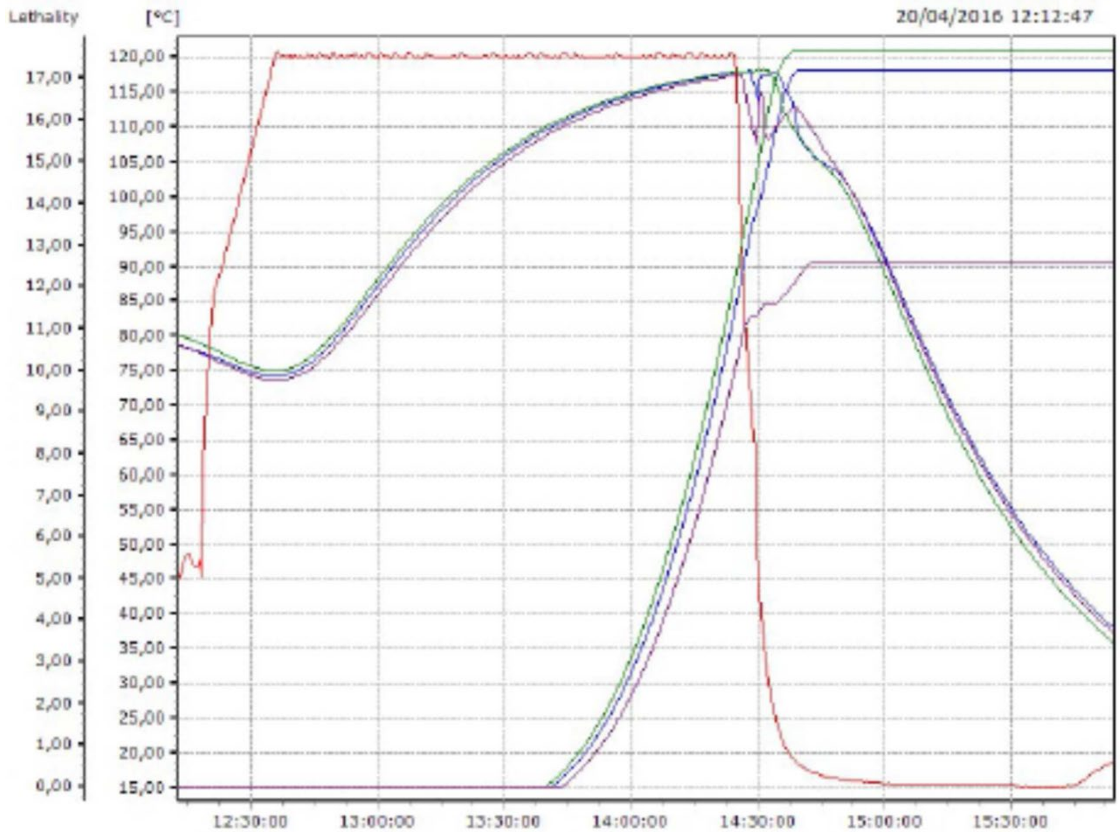
- Flow rate: 100 L/h
- Holding pipe diameter: 40 mm
- Holding length: 1.7 m
- Temperature at holding outlet: 131 °C

Ohmic processing data of Chicken Potpie Filling (referred to as the stationery phase) are listed in Table 6.

Table 6. Ohmic processing data for Chicken Potpie Filling

Time (h:min)	Temp inlet (ºC) 1st ohmic applicator	Temp inlet (ºC) 3rd ohmic applicator	Δ Temp (ºC) 1st ohmic station	Temp outlet (ºC) 4th ohmic applicator	Δ Temp (ºC) 2nd ohmic station	Temp outlet (ºC) Holding section
12:51	65.2	100.2	35.0	134	33.8	132
13:00	61.9	108.5	46.6	133	24.5	132
13:06	64.4	111.0	46.6	133	22	128
13:22	64.0	112.2	48.2	132	19.8	131
13:42	62.2	111.0	48.8	136	25	132
13:51	66.8	112.0	45.2	136	24	132
14:02	65.0	112.5	47.5	135	22.5	132
14:25	64.2	113.4	49.2	131	17.6	129

The retort process of Chicken Potpie Filling is shown in Figure 19.



Nome	Min	Max	15:54:49
Retort	15,15	120,88	18,85
Posizione 2	37,67	118,11	37,67
Posizione 2 (F0) Le	0,00	17,18	17,18
Posizione 3	35,58	118,30	35,58
Posizione 3 (F0) Le	0,00	17,64	17,64
Posizione 4	36,92	117,57	36,92
Posizione 4 (F0) Le	0,00	12,55	12,55

Figure 19. Retort processing data of Chicken Potpie Filling

Results:

For this test, the ohmic heater went sometimes under the minimum temperature of 131 °C, and some fluctuations in terms of temperature were recorded. These conditions were probably due to the mixing of the product, which was not so homogeneous, and the process amount in a pilot scale ohmic heater (i.e., less likely to happen in a production scale system). This product needed a higher back-pressure into the ohmic heater in order to avoid boiling phenomena. This adjustment is needed due to an increasing of the ΔT into the 1st ohmic station, which produced a decreasing ΔT guaranteed by the 2nd one. This is a clear demonstration that the back-pressure is not just dependent on the settings of sterilization temperature, but is also a matter of the rheological properties of the product. The product is really conductive: during the ohmic process the 1st and 2nd applicators were in TAP 2 and 1 respectively, while the 3rd and the 4th were in TAP 1. In terms of matching between finished products (retort vs. ohmic) the comparisons are shown in Figure 20.

Figure 20. Visual comparison of ohmic vs. retort Chicken Potpie Filling

The ohmic treated product is less cooked and clearer than the retort one. In terms of taste, the ohmic treated product is fresher than the retort one. The product treated in retort is darker, with signs of burns due to the static retort process. The pictures in Figure 20 are quite obvious; in particular, the detail of the pieces showed the differences in terms of color for all kinds of particles present in the recipe. The chicken treated in retort is softer than the chicken treated in ohmic, but the ohmic process guaranteed to give the meat a consistency which seems nearer to fresh.

2.4.4 Macaroni and Cheese

The only difference with the original recipe regarded the percentage of starch. It reduced from 2.65% to 1.22% because of a lack in raw material (Table 7). Starting from pre-cooking pasta, based on the experience in the plain pasta processing, the pasta was boiled for 6 min (instead of 10 min). After cooking, the pasta was drained and immediately put in cold water for 2 min in order to reduce continuous cooking of pasta (Figure 21).

Table 7. Recipe of Macaroni and Cheese

Maccaroni & Cheese recipe	**Original Recipe 1 batch**		**Processed Recipe 1 batch**	
	%	Kg	%	Kg
Recheis Enriched Elbows 10% Egg White After blanching (2 x dry weight)	31,02	36,20	30,69	36,20
Sauce	68,98	80,50	69,31	81,75
TOTAL	100,0	116,7	100,0	117,95

SAUCE	%	Kg
Water	69,60	56,90
Cheddar Cheese short hold	18,84	15,40
Sunflower	7,95	6,50
Amido	1,22	1,00
Sodium Casinate	0,98	0,80
Disodium Phosphate	0,80	0,65
Salt	0,37	0,30
Xanthan gum	0,24	0,20
TOTAL	100,0	45,48

Figure 21. Pasta preparation for Macaroni and Cheese

The sauce was prepared in a jacketed and stirred vessel (Figure 22) until reaching 85 °C, and then the cheddar cheese was added. In this case, the gum and the starch were previously mixed with water into a NILMA emulsifier; the same action was performed for sodium casinate and disodium phosphate. These actions were taken in order to avoid lumps forming.

When the sauce was ready, pasta was added just 5 min before reaching the retort and the ohmic system at 80 °C. The pH of the product before sterilization was 6.0.

Figure 22. Pre-sterilized Macaroni and Cheese

The mix was treated to a sterility value of Fo = 10 by using the retort and ohmic heating system. The Fo = 10 was evaluated by considering the contribution of the only holding section for both technologies.

The ohmic treatment was conducted in the following conditions:

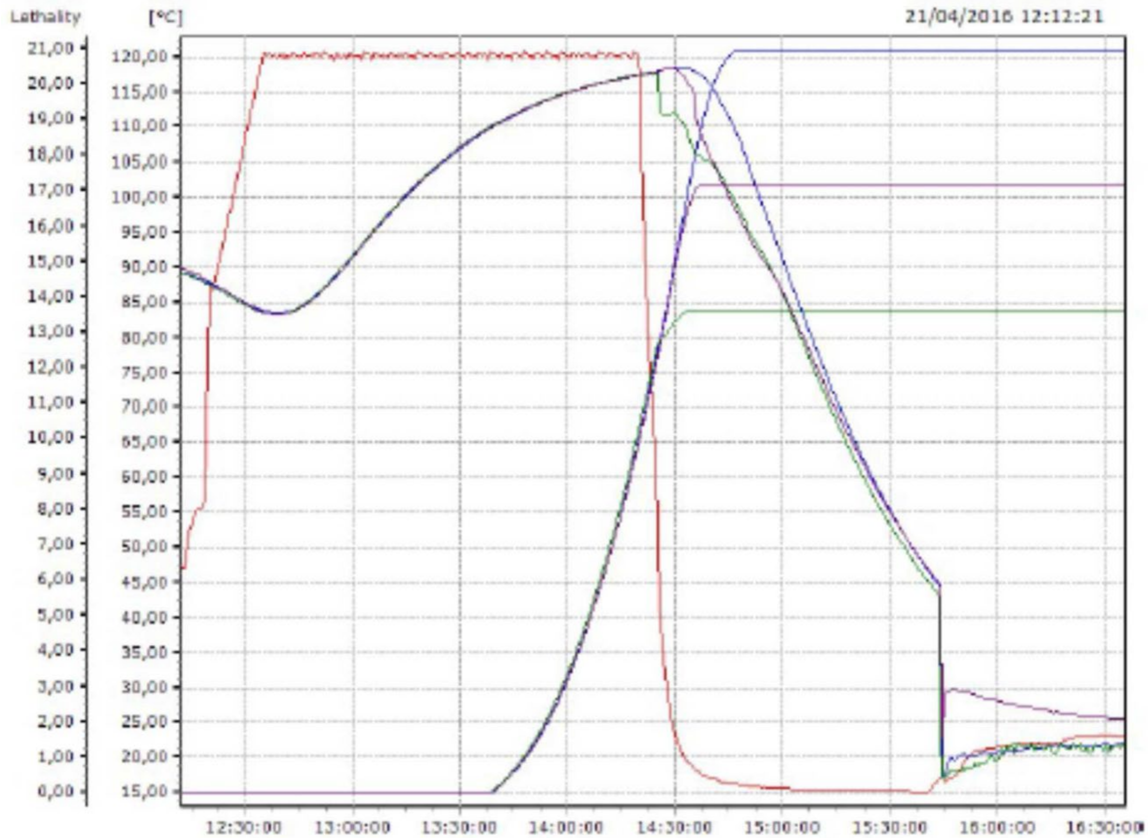
- Flow rate: 100 L/h
- Holding pipe diameter: 40 mm
- Holding length: 1.7 m
- Temperature at holding outlet: 131 °C

Ohmic processing data for Macaroni and Cheese (referred to as the stationery phase) are listed in Table 8.

Table 8. Ohmic processing data of Macaroni and Cheese

Time (h:min)	Temp inlet (ºC) 1st ohmic applicator	Temp inlet (ºC) 3rd ohmic applicator	Δ Temp (ºC) 1st ohmic station	Temp outlet (ºC) 4th ohmic applicator	Δ Temp (ºC) 2nd ohmic station	Temp outlet (ºC) Holding section
13:01	67.0	109.0	42.0	130	21.0	128
13:05	66.7	110.3	43.6	133	22.7	129
13:12	65.8	108.4	42.6	135	26.6	134
13:17	66.5	106.8	40.3	135	28.2	132
13:30	65.0	107.5	42.5	136	28.5	135
13:39	63.3	107.9	44.6	135	27.1	133
13:54	61.5	105.6	44.1	135	29.4	133
14:09	58.7	103.8	45.1	135	31.2	134
14:37	55.2	103.0	47.8	136	33.0	135
14:51	53.8	100.7	46.9	136	35.3	135

The retort process of Macaroni and Cheese is shown in the Figure 23.



Nome	Min	Max	16:35:56
Retort	15,05	120,76	23,15
Posizione 2	17,33	118,41	22,05
Posizione 2 (F0) Le	0,00	20,91	20,91
Posizione 3	16,98	117,76	21,33
Posizione 3 (F0) Le	0,00	13,57	13,57
Posizione 4	18,92	118,30	25,37
Posizione 4 (F0) Le	0,00	17,13	17,13

Figure 23. Retort processing data for Macaroni and Cheese

Results:

The product was really conductive: during the ohmic process the 1st and 2nd applicators were in TAP 2 and 1 respectively, while the 3rd and the 4th were in TAP 1. The ohmic system was quite stable during the test: there were some fluctuations in terms of the start-up, but they were solved by an adjustment of the back-pressure.

Appearance between finished products (retort vs. ohmic) is shown in Figure 24.

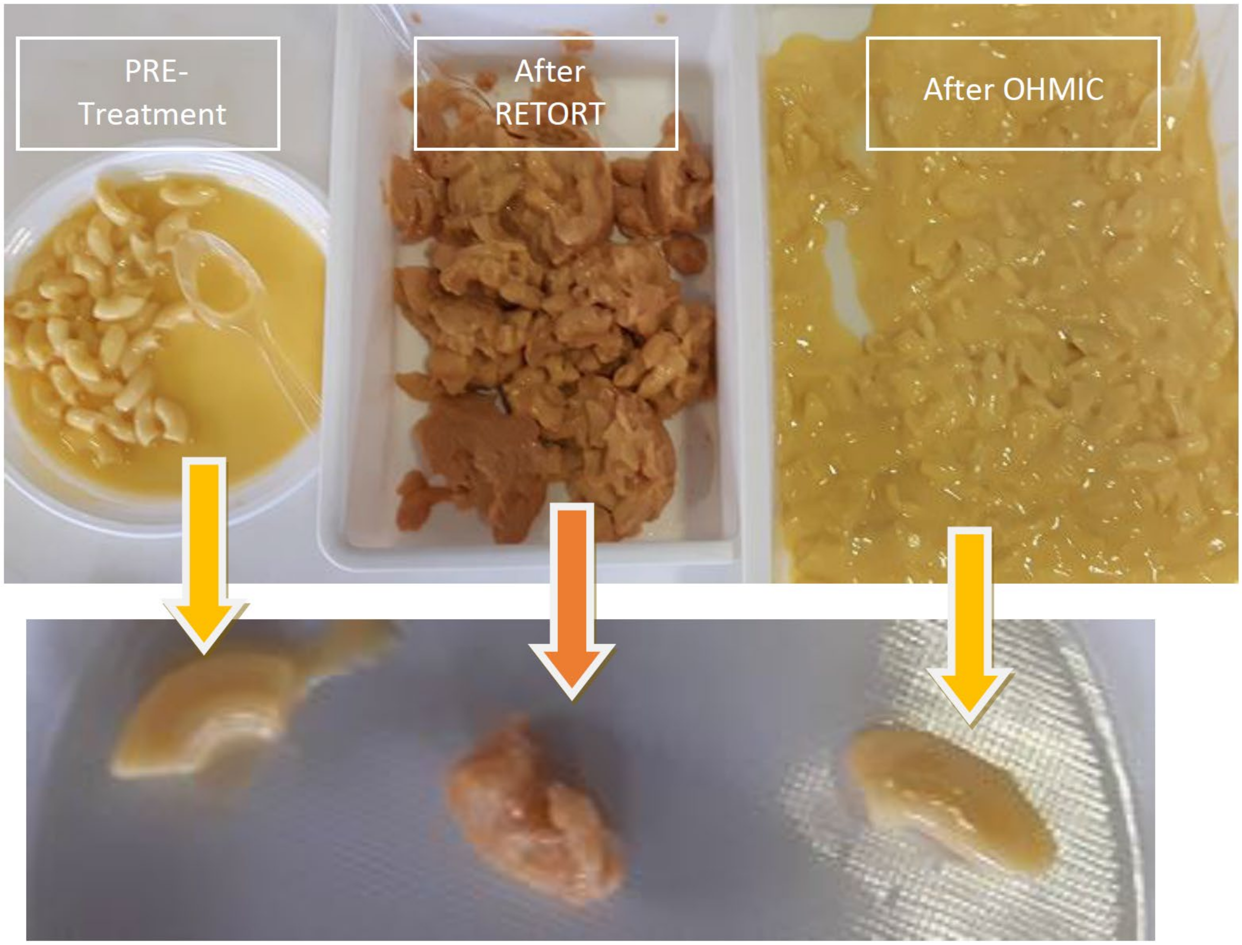


Figure 24. Visual comparison of ohmic vs. retort Macaroni and Cheese

The ohmic treated product is less cooked and clearer than the retort one. Also, in terms of taste, there is a sensible difference. For both retort and ohmic treated pasta, the shape of pasta is quite mashed if compared with the pre-treatment shape. In this test the dimension of pasta after sterilizing is not much bigger than the shape before processing: this is due to the changes in the pre-cooking phase with respect to what was done during the plain pasta test.

2.4.5 Conclusions of Initial Ohmic vs. Retort Processing

All the recipes were processed without issues, and ohmic technology showed great potential to retain the fresh quality (vs. retort). The ohmic system is quite simple to manage and process conditions are stable and uniform.

2.5 Microbial Validation, Storage Stability, and Sensory Evaluation

2.5.1 Microbial validation

The sterility of samples was assessed by incubating them at two different times and temperatures (at 30 °C and 55 °C) in order to verify the absence of mesophilic and thermophilic microorganisms. Five samples per reference were analyzed, and the results are shown in Table 9.

Table 9. Microbial validation results

Sample ID*	Process Method	Incubation Temp 30 °C	Incubation Temp 55 °C	Sample ID	Process Method	Incubation Temp 30 °C	Incubation Temp 55 °C
BC1	Retort	Sterile	Sterile	CPP1	Retort	Sterile	Sterile
BC2	Retort	Sterile	Sterile	CPP2	Retort	Sterile	Sterile
BC3	Retort	Sterile	Sterile	CPP3	Retort	Sterile	Sterile
BC4	Retort	Sterile	Sterile	CPP4	Retort	Sterile	Sterile
BC5	Retort	Sterile	Sterile	CPP5	Retort	Sterile	Sterile
OBC1	Ohmic	Sterile	Sterile	OCPP1	Ohmic	Thermophilic Aerobic Bact	Sterile
OBC2	Ohmic	Sterile	Sterile	OCPP2	Ohmic	Sterile	Sterile
OBC3	Ohmic	Sterile	Sterile	OCPP3	Ohmic	Sterile	Sterile
OBC4	Ohmic	Sterile	Sterile	OCPP4	Ohmic	Sterile	Sterile
OBC5	Ohmic	Sterile	Sterile	OCPP5	Ohmic	Sterile	Sterile
PP1	Retort	Sterile	Sterile	MC1	Retort	Sterile	Sterile
PP2	Retort	Sterile	Sterile	MC2	Retort	Sterile	Sterile
PP3	Retort	Sterile	Sterile	MC3	Retort	Sterile	Sterile
PP4	Retort	Sterile	Sterile	MC4	Retort	Sterile	Sterile
PP5	Retort	Sterile	Sterile	MC5	Retort	Sterile	Sterile
OPP1	Ohmic	Sterile	Sterile	OMC1	Ohmic	Sterile	Sterile
OPP2	Ohmic	Sterile	Sterile	OMC2	Ohmic	Sterile	Sterile
OPP3	Ohmic	Sterile	Sterile	OMC3	Ohmic	Sterile	Sterile
OPP4	Ohmic	Sterile	Sterile	OMC4	Ohmic	Sterile	Sterile
OPP5	Ohmic	Sterile	Sterile	OMC5	Ohmic	Sterile	Sterile

*: BC: Buffalo Chicken, Retort; OBC: Buffalo Chicken, Ohmic
PP: Plain Pasta, Retort; OPP: Plain Pasta, Ohmic
CPP: Chicken Potpie Filling, Retort; OCPP: Chicken Potpie Filling, Ohmic
MC: Macaroni & Cheese, Retort; OMC: Macaroni & Cheese, Ohmic

As shown in the table, all samples incubated at 30 °C were sterile, whereas only one sample of those treated by ohmic (ref: OCPP) was altered by aerobic thermophilic microorganisms.

2.5.2 Comparison of the sensory quality of the ohmic vs. retort samples during storage

Experiment Design:

An aliquot of the samples was transferred into a thermostatic oven at 37 °C. After the testing period regarding the post-production stability required for microbiological evaluation had elapsed, affective sensory tests were conducted according to the procedures and the tests suggested by NSRDEC, namely the LAM scale (Labeled Magnitude Affective) test on the following attributes: "Appearance", "Odor", "Flavor", "Texture", "Overall Acceptance", and according to the subsequent time-intervals:

- t = 0 (initial observation time); a week from production, the sensory evaluation took place on products processed with the ohmic and retort processes, and stored at 0 °C;
- t = 2 and 4 weeks of storage at 50 °C. Rating the four products processed with Ohmic and retort.
- t = 2, 4, and 6 months of storage at 37 °C. Rating the four products processed with Ohmic and retort.

The testing was performed in the sensory evaluation laboratory at the Department of Consumer Science at SSICA, using a computerized scoring system (software version 2.50 Fizz by Biosystèmes) and equipped according to the UNI ISO 8589 guidelines. For this scope, a panel composed of 10 trained sensory evaluators was asked to give evaluation on the above mentioned attributes, on the LAM-scale with the following scale:

- dislike absolutely (= 0)
- dislike extremely (= 10)
- dislike very much (= 20)
- dislike moderately (= 30)
- dislike slightly (= 40)
- neither like nor dislike (indifferent) (= 50)
- like slightly (= 60)
- like moderately (= 70)
- like very much (= 80)
- like extremely (= 90)
- like absolutely (= 100)

The sensory tests were conducted to determine any quality deterioration for each product group, and to establish comparison over time for the sensory quality of the samples produced with the two thermal processes under examination. In order to determine whether there was a statistically significant difference among the values of the various attributes studied for the two sample groups, a one-way analysis of variance (ANOVA) with a test of the least significant difference (LSD) was performed. It is worth recalling that for this type of sensory tests, it often happens in the initial phases that the maximum score on the scale may not always be reached (contrary to what one may expect). In fact, the goal to monitor over time is the trend (decreasing or increasing) of the individual parameters, which will indicate a significant variation of the overall acceptance/liking. For all product categories, the overall liking scores obtained during the storage of observation are shown in Figures 24-31. For an immediate understanding of the statistically significant differences detected between the two types of containers/technologies, a Quantitative Descriptive Analysis (QDA) sensory profile method related to time sampling observations of products stored at various temperatures was used.

The attributes that are statistically significant are marked with asterisk.

Results:

Buffalo Chicken:

1. **Storage at 50 °C for 4 weeks (Figures 25-27) –** The ohmic-treated products had significantly better flavor than those retorted right after processing (between 15% and 21%; p = 0.0297), and at 2 weeks of storage (p = 0.0107). The difference of attributes of these two products tended to disappear at the end of 4 weeks at 50 °C.

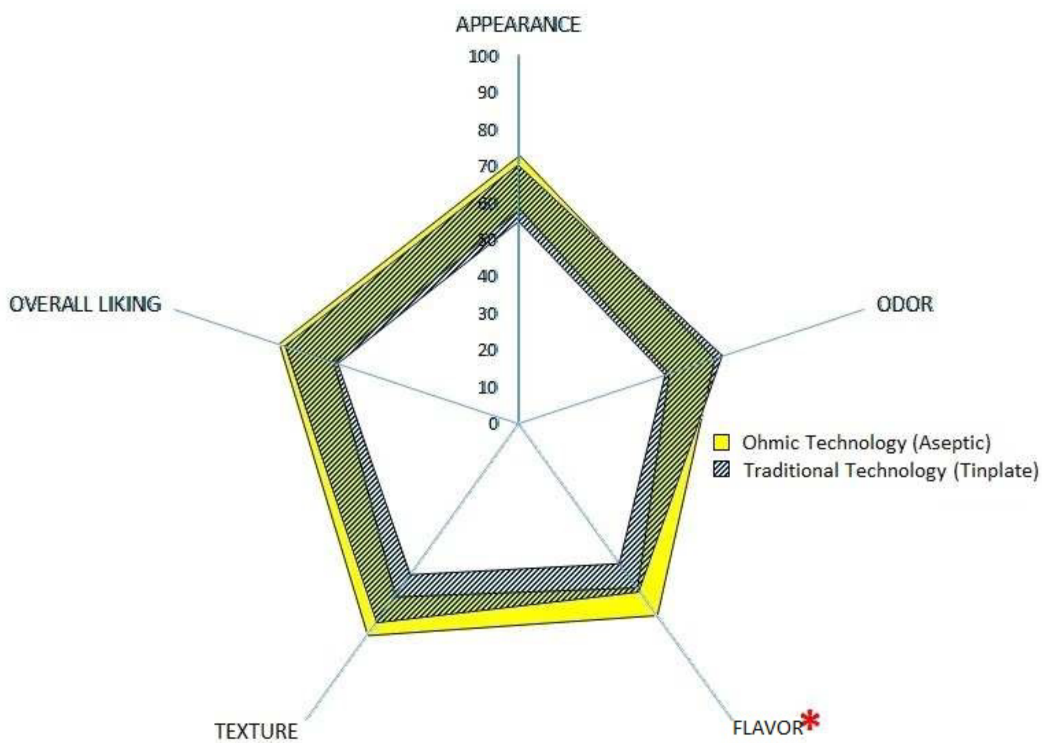


Figure 25. Buffalo Chicken – Comparison between the two technologies at t0 time

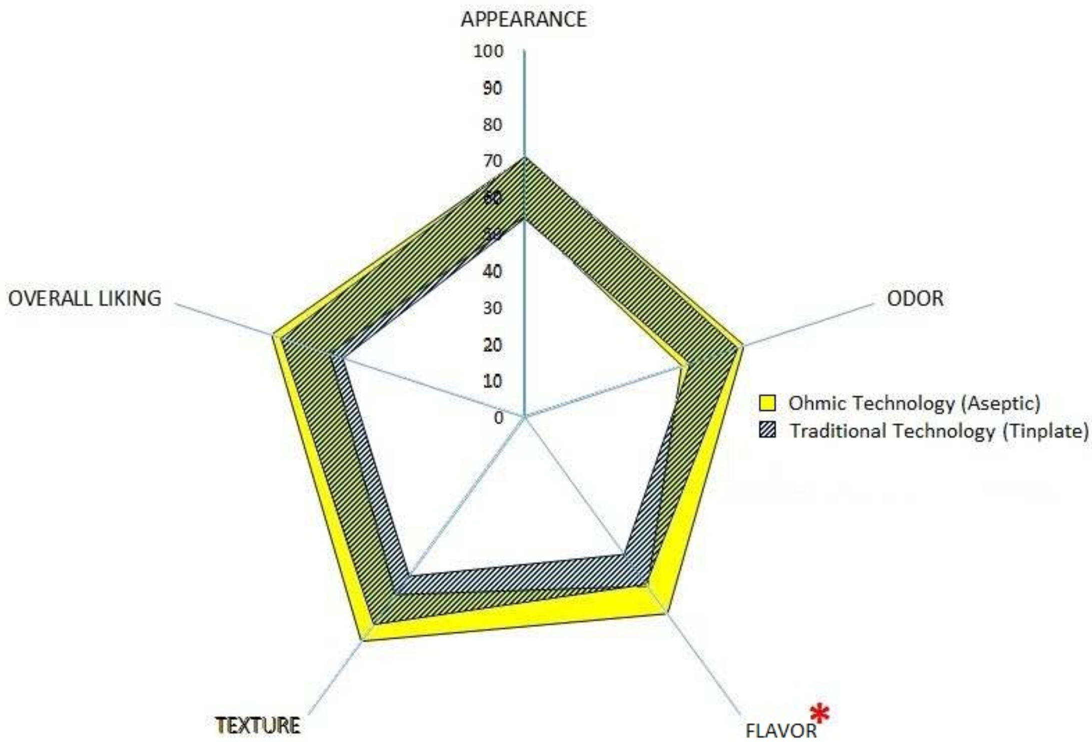


Figure 26. Buffalo Chicken – Comparison between the two technologies after 2 weeks of storage at 50 °C

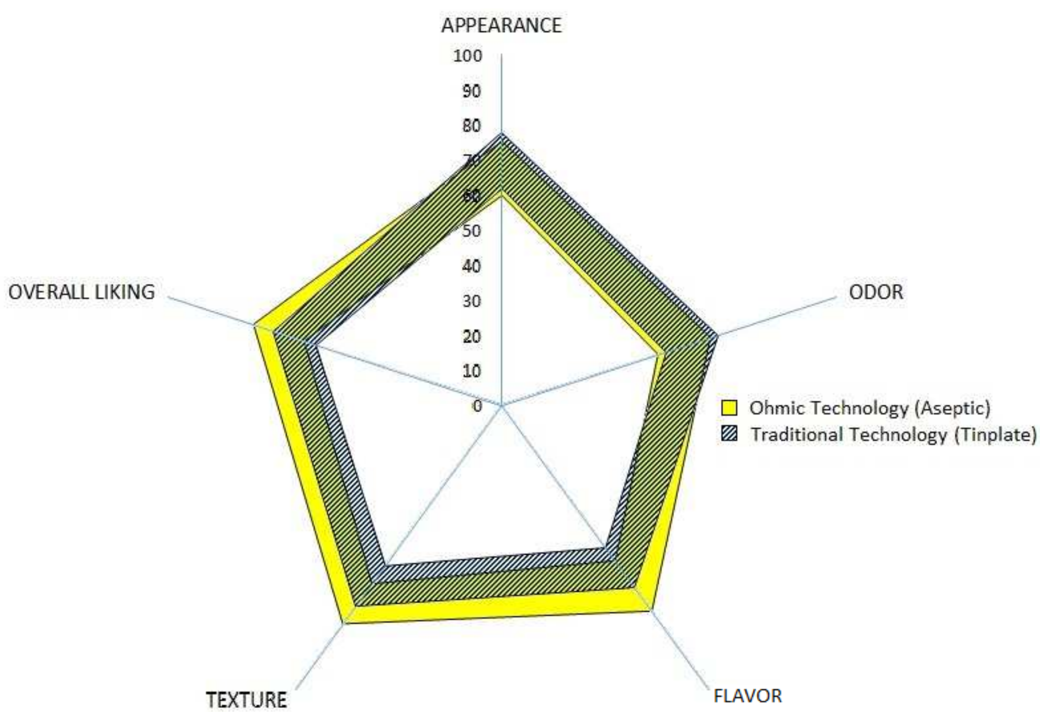


Figure 27. Buffalo Chicken – Comparison between the two technologies after 4 weeks of storage at 50 °C

2. Storage at 37 °C for 6 months (Figures 28-30) – After 2 and 4 months, the products stabilized by ohmic process have statistically better flavor (with a percentage difference between the mean values ranging from 17% to 36%) and overall acceptance (17% to 27%) compared to the retort counterparts ($p<0.05$). After 6 months, ohmic treated product showed a significantly ($p= 0.0007$) better texture than the retorted counterparts (percentage difference between the average values of 22%). For both products, the liking scores that had remained constant during the first 4 months of storage began to drop significantly after 6 months.

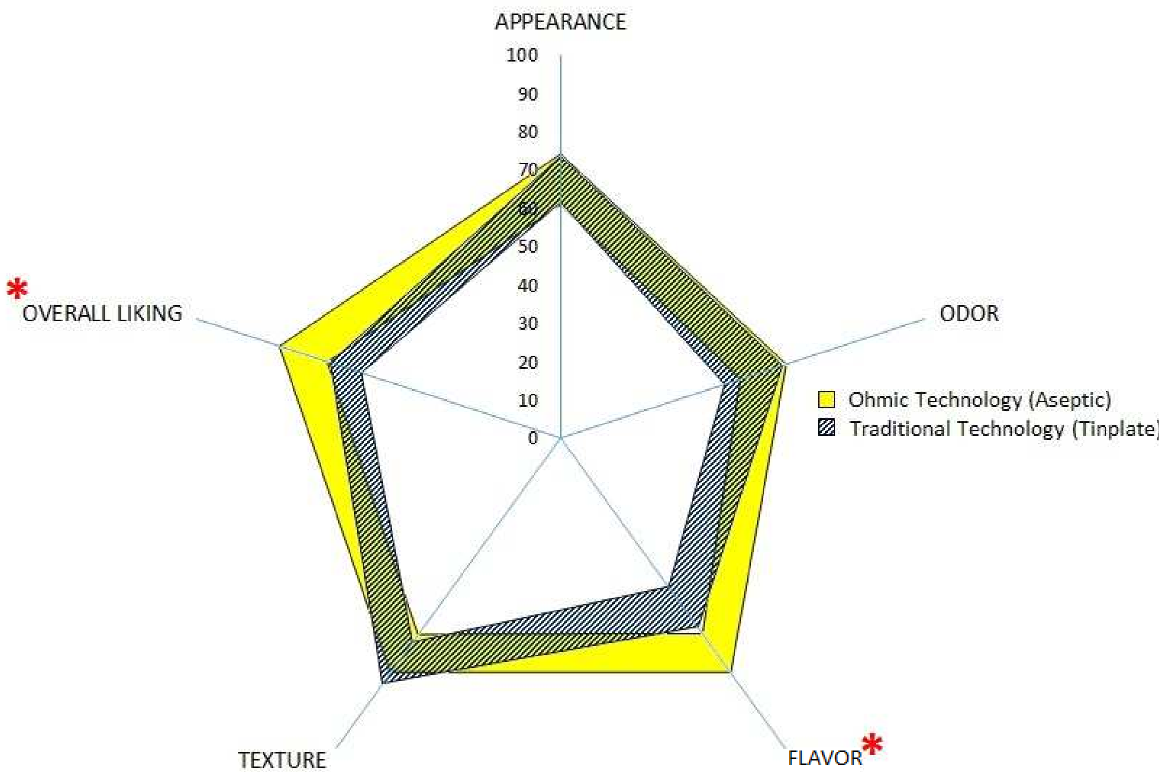


Figure 28. Buffalo Chicken – Comparison between the two technologies after 2 months of storage at 37 °C

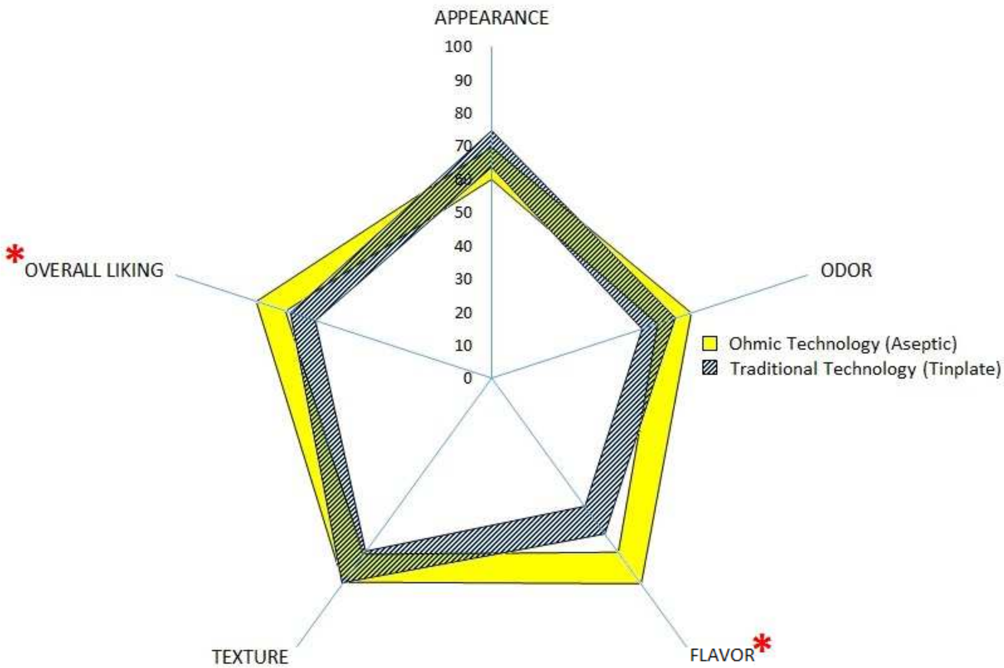


Figure 29. Buffalo Chicken – Comparison between the two technologies after 4 months of storage at 37 °C

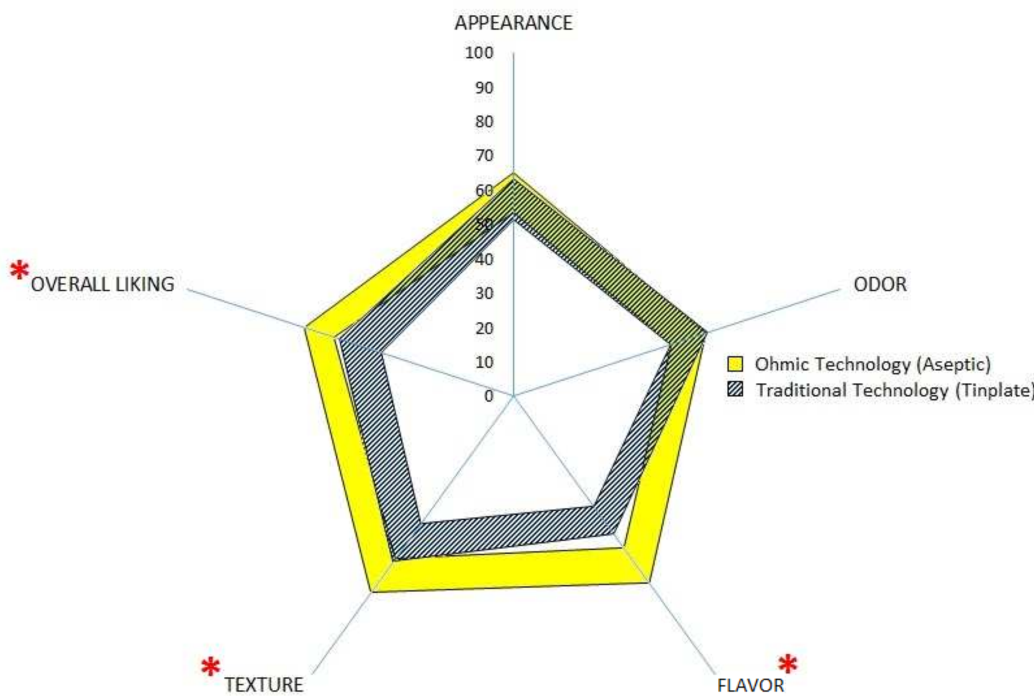


Figure 30. Buffalo Chicken – Comparison between the two technologies after 6 months of storage at 37 °C

Plain Pasta:

1. Storage at 50 °C for 4 weeks (Figures 31-33) – At 2 weeks of storage at 50 °C, the samples processed with the ohmic process had significantly better appearance ($p = 0.0184$, with a percentage difference between the mean values of 21%) than the retorted ones. At 4 weeks, ohmic processed products scored better appearance ($p = 0.0001$, with a percentage differences in average values of 44%) and overall acceptance ($p = 0.0008$; with a percentage difference between the mean values of 31%). From the second week of storage at 50 °C, the retorted products underwent browning phenomena and had influenced the panelist reception of appearance and overall acceptance.

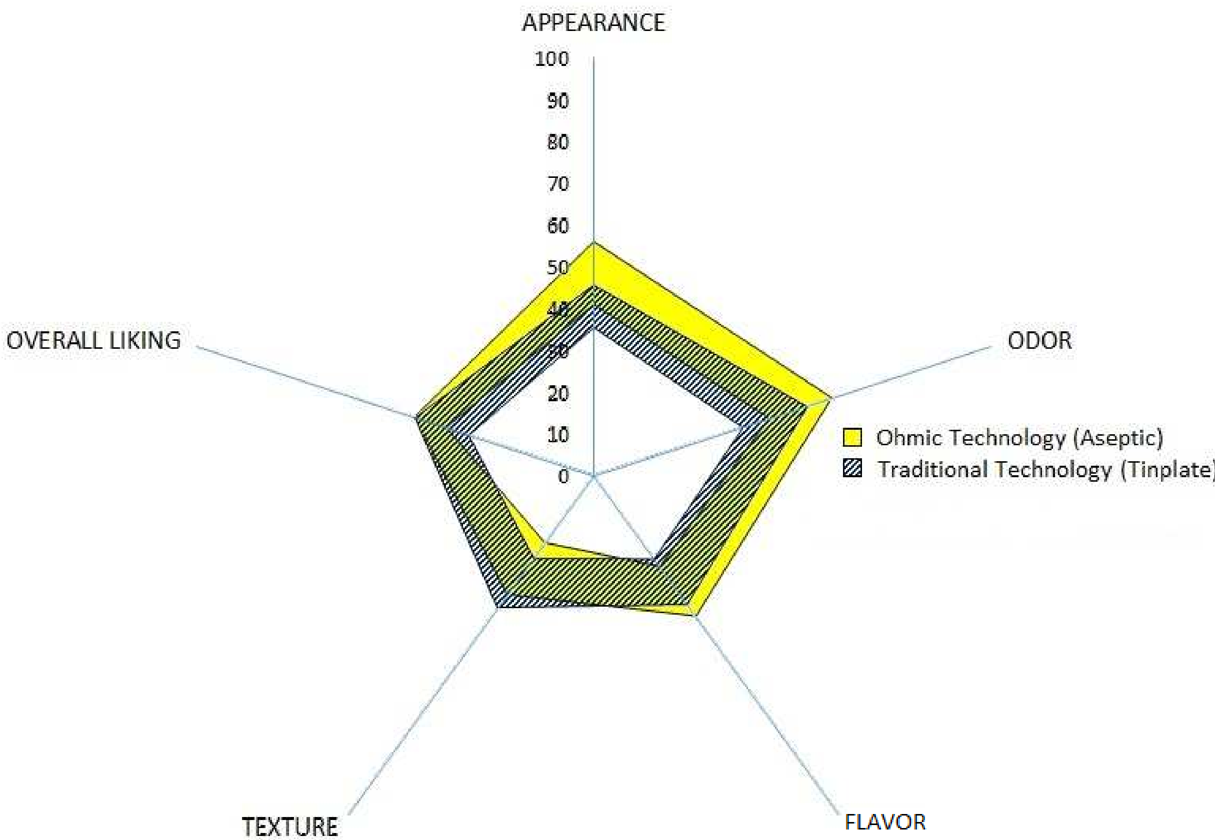


Figure 31. Plain Pasta – Comparison between the two technologies at t0 time

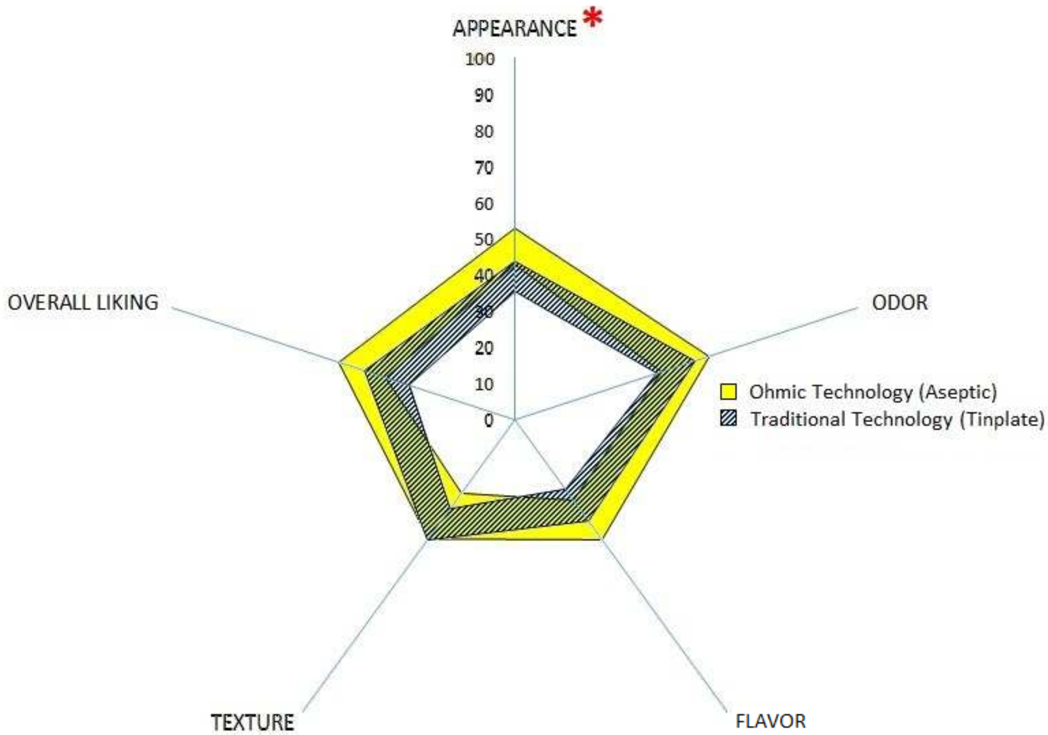


Figure 32. Plain Pasta – Comparison between the two technologies after 2 weeks of storage at 50 °C

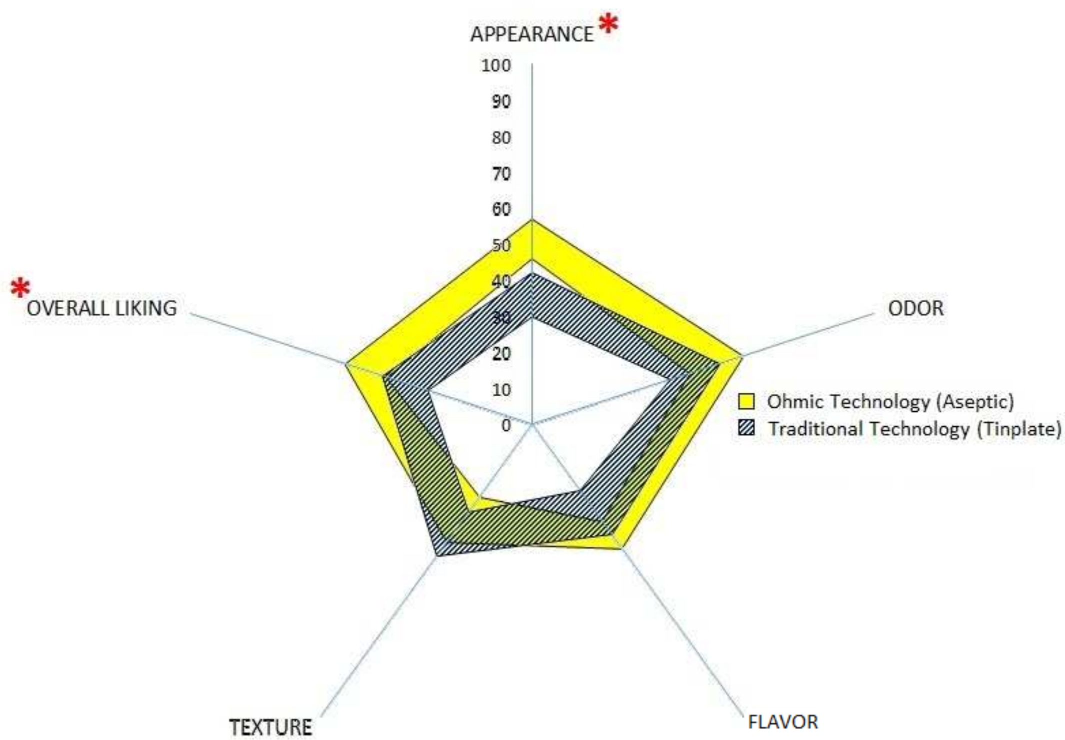


Figure 33. Plain Pasta – Comparison between the two technologies after 4 weeks of storage at 50 °C

2. Storage at 37 °C for 6 months (Figures 34-36) – At start time, the two products showed statistically non-significant difference ($p \geq 0.05$) for all the attributes under consideration. On the contrary, the observations conducted at 2 and 4 months of storage onwards showed significant differences ($p < 0.05$) for all attributes. In particular, the retorted products were given lower liking scores than the ohmic ones, i.e., for the "appearance" attribute (the percentage difference between the mean values comprised between 31% and 33%), "odor" (with a difference of 19-30%), "flavor" (35-43%) and "overall acceptance" (18-20%). The retorted products have shown evidence of oxidation/browning phenomenon which have inevitably influenced the evaluation of the "appearance" attribute; off-odors/flavors were also detected, having a negative impact on the "odor" assessment and "overall acceptance". The retorted products have obtained higher liking scores compared to those ohmic treated products for the "texture" attribute, with a percentage difference between the mean values comprised between 23% and 42%. At 6 months of storage, significant differences ($p < 0.05$) between the two products were still observed. In particular, the retorted products have obtained lower liking scores compared to those processed with ohmic, for the "appearance" attribute ($p = 0.0022$, with a 20% reduction of the average score) and "odor" ($p = 0.0039$, with a 25% reduction of the average score), whereas once again, they have obtained statistically higher scores for "texture" ($p = 0.0018$, with a percentage difference of the average score of 40%). No statistically significant differences were recorded ($p \geq 0.05$), in reference to the "flavor" and "overall acceptance" attributes since a decrease [level of significance ($p < 0.05$)] of liking scores was observed for the two attributes on products processed with ohmic heating.

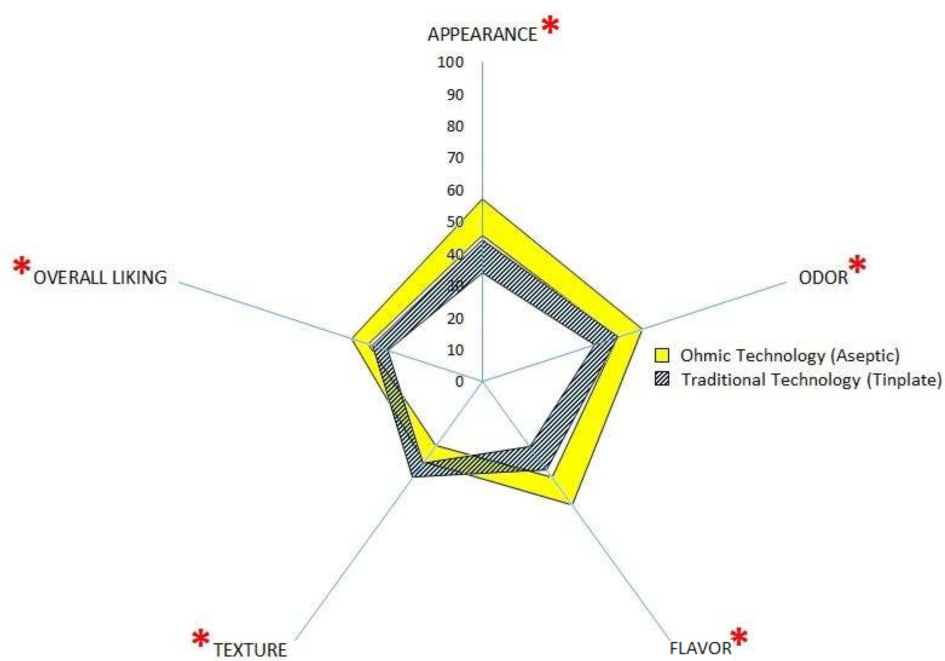


Figure 34. Plain Pasta – Comparison between the two technologies after 2 months of storage at 37 °C

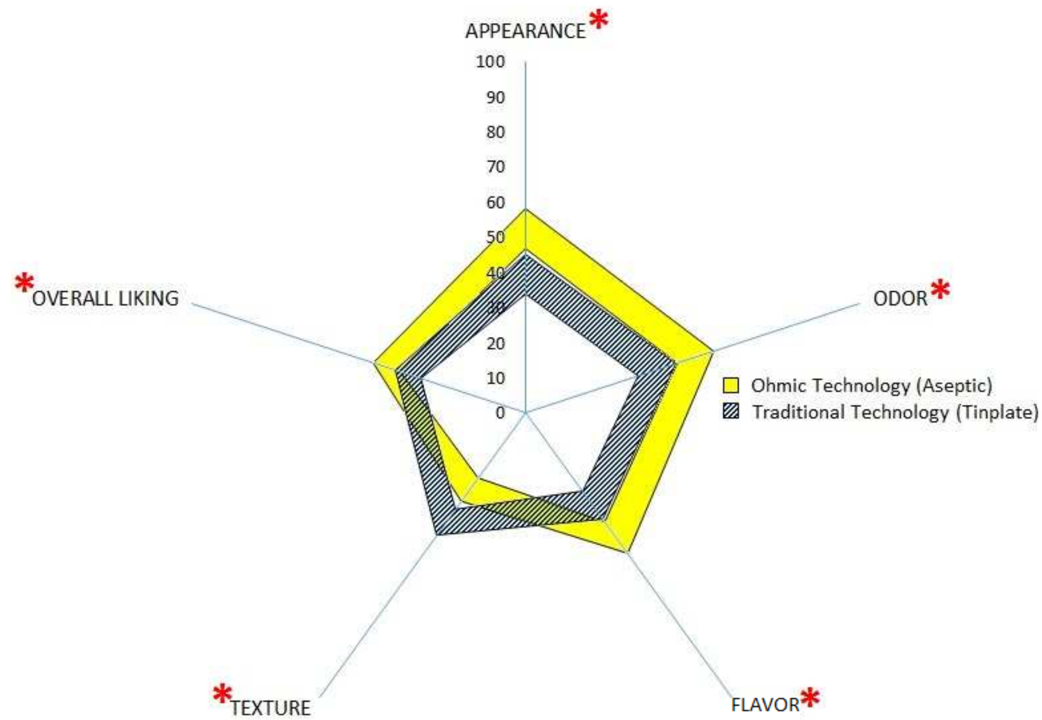


Figure 35. Plain Pasta – Comparison between the two technologies after 4 months of storage at 37 °C

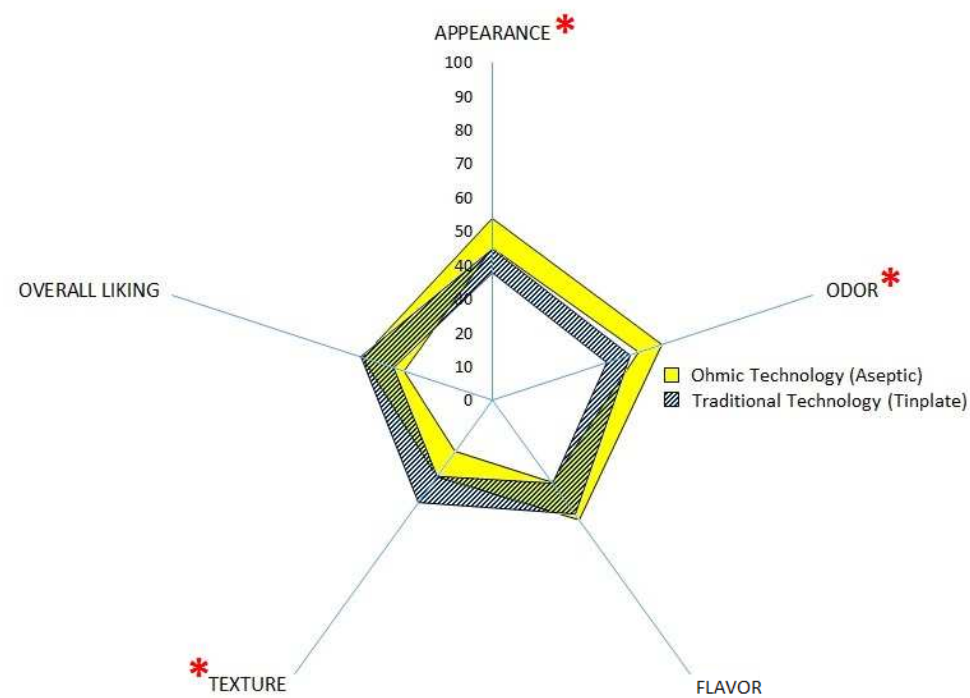


Figure 36. Plain Pasta – Comparison between the two technologies after 6 months of storage at 37 °C

Chicken Potpie Filling:

1. Storage at 50 °C for 4 weeks (Figures 37-39) – Immediately after processing, significant statistical differences were found between the products processed with the two methods (the ones processed by ohmic technology earned higher liking scores) for the "flavor" attribute ($p = 0.0097$, with a percentage difference between the mean values of 17%), for the "texture" attribute ($p = 0.0024$, with a percentage difference of 20%) and for the "overall acceptance" ($p = 0.0077$ with a difference of 15%). At 2 weeks of storage at 50 °C, the ohmic treated products were found to be significantly more acceptable for the attributes: "odor" ($p = 0.0211$), "flavor" ($p = 0.0024$), "texture" ($p = 0.0045$), "overall acceptance" ($p = 0.0325$) with a percentage difference between the mean values of 17%, 18%, 21% and 14%, respectively. Even after 4 weeks of storage at 50 °C, the ohmic treated products continued to receive significantly higher ratings ($p < 0.05$) for all the liking attributes: "appearance" ($p = 0.0318$), "odor" ($p = 0.0128$), "flavor" ($p = 0.0121$), "texture" ($p = 0.0366$), and "overall acceptance" ($p = 0.0040$), with a percentage difference between the mean values of 14%, 14%, 14%, 12% and 15%, respectively. For the retorted products, appearance was found to undergo a gradual deterioration (as previously underlined for the Plain Pasta, showing the effects of a more pronounced browning) and the onset of foreign odors.

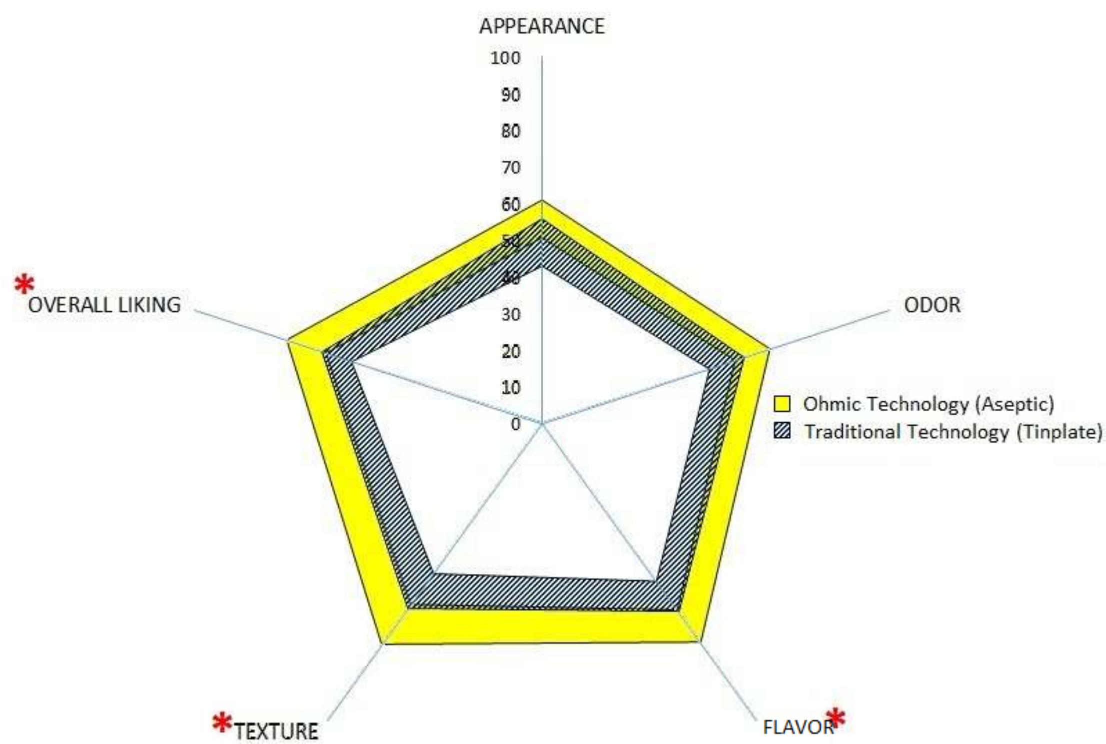


Figure 37. Chicken Potpie Filling – Comparison between the two technologies at t0 time

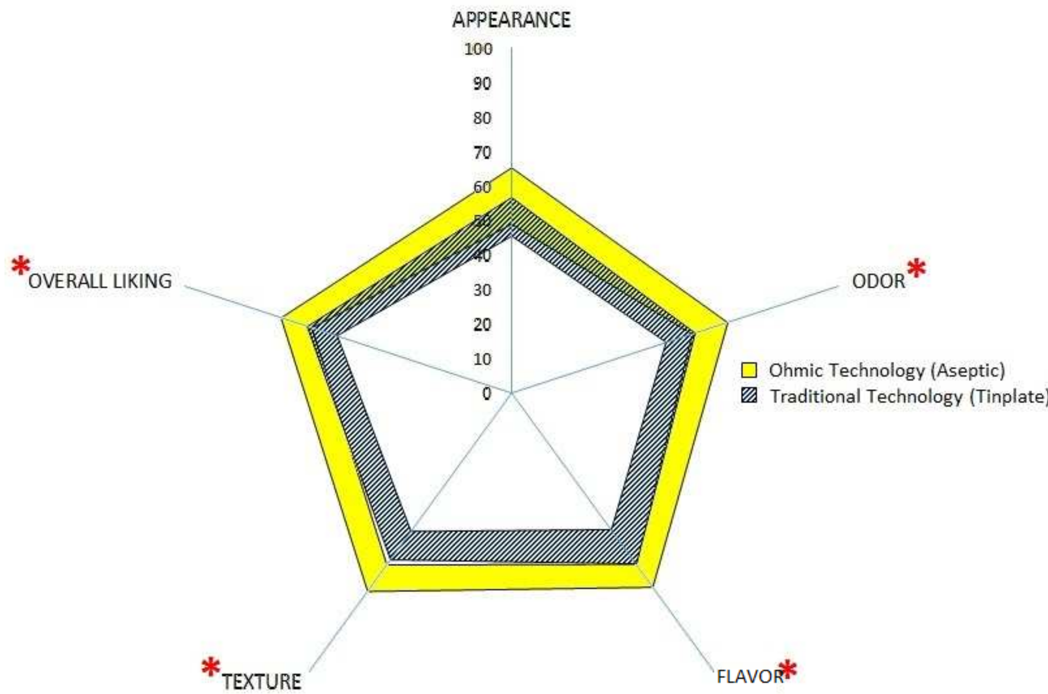


Figure 38. Chicken Potpie Filling – Comparison between the two technologies after 2 weeks of storage at 50 °C

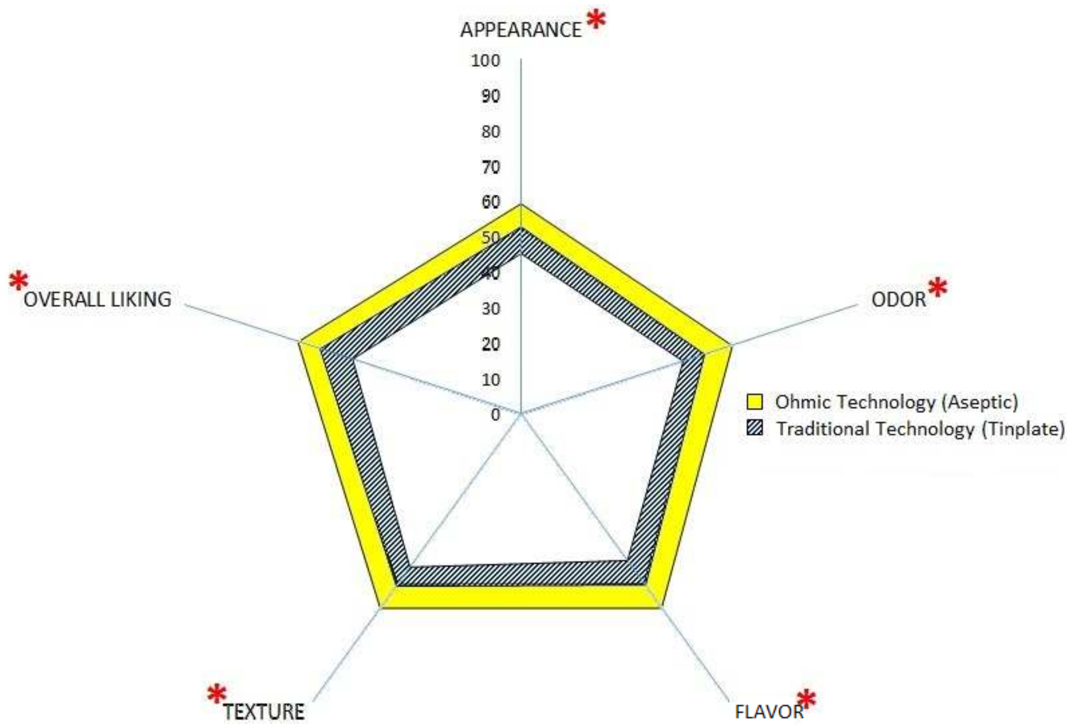


Figure 39. Chicken Potpie Filling – Comparison between the two technologies after 4 weeks of storage at 50 °C

2. Storage at 37 °C for 6 months (Figures 40-42) – The ohmic treated products were rated as significantly ($p < 0.05$) more acceptable for all attributes: "appearance" (the percentage difference between the mean values comprised between 15% and 21%), "odor" (difference between 13% and 30%), "flavor" (8%-21%), "texture" (8%-14%) and "overall acceptance" (11%-16%). It should be noted also that the liking scores for the "texture" decreased significantly ($p < 0.05$) after 6 months of storage. The chicken meat started to prove less integral and too soft regardless of the type of process. The probable cause of this phenomenon can be linked to the heterogeneous and complex formulation of the product. Over time, in fact, the vegetables contained tended to release water that was absorbed by the chicken, contributing to the softening of the flesh.

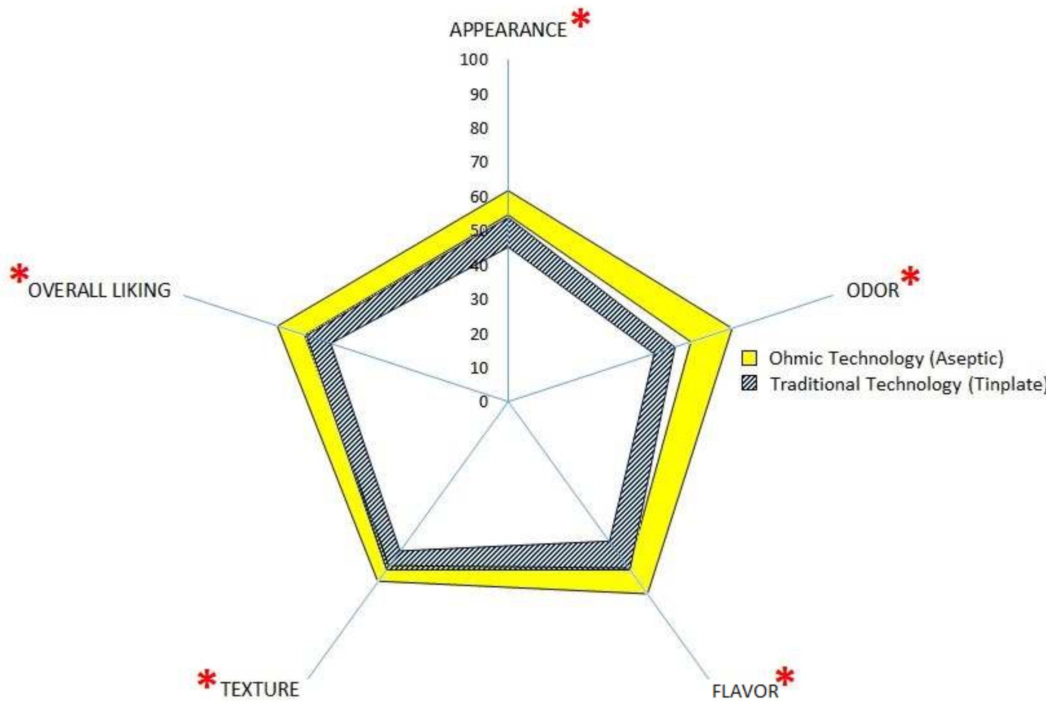
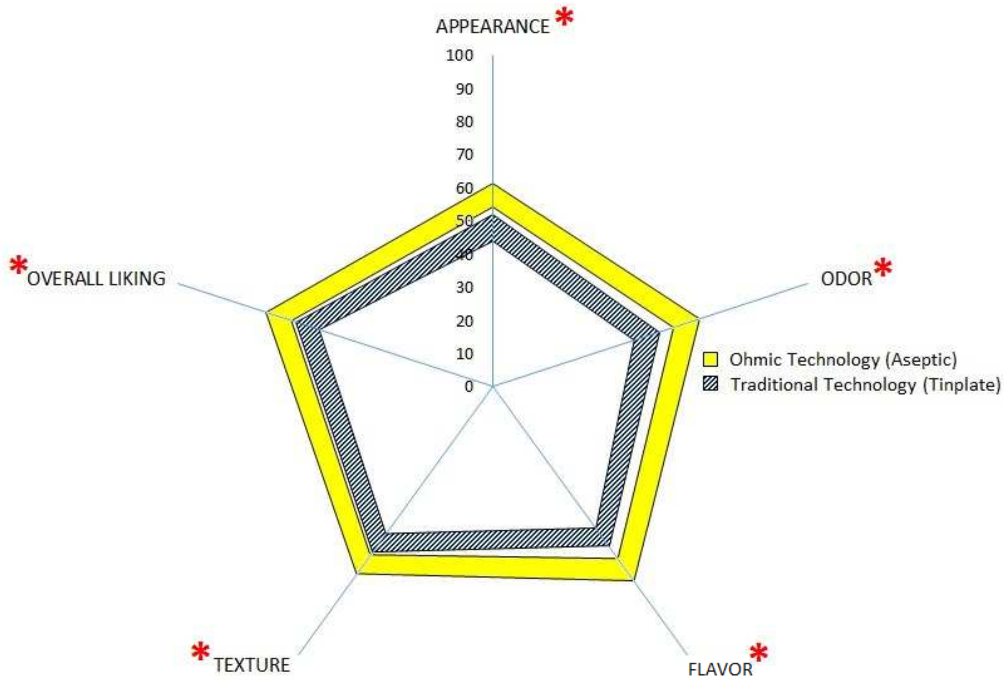


Figure 40. Chicken Potpie Filling – Comparison between the two technologies after 2 months of storage at 37 °C



Figurer 41. Chicken Potpie Filling – Comparison between the two technologies after 4 months of storage at 37 °C

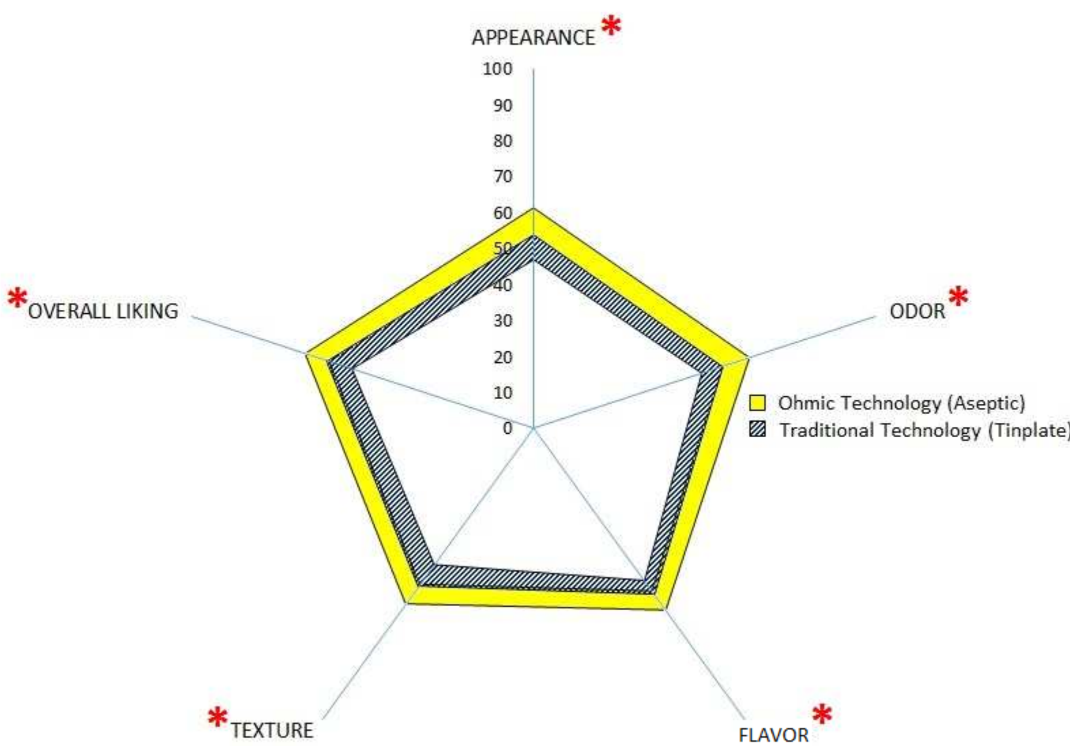


Figure 42. Chicken Potpie Filling – Comparison between the two technologies after 6 months of storage at 37 °C

Macaroni and Cheese:

1. Storage at 50 °C for 4 weeks (Figures 43-45) – In all observation, ohmic treated products showed significantly ($p < 0.05$) better attributes than the retorted counterparts: "appearance" (percentage difference between the mean values of 38% at start time and after 2 months and 28% after 4 months), "odor" (percentage differences, 68%, 66% and 47% respectively), "flavor" (differences of 78%, 55% and 41%), "texture" (differences of 41%, 23% and 12%) and "overall acceptance" (differences of 86%, 52% and 37% respectively). Retorted product showed significant signs of browning during storage, and a gradual development of evident notes (off-odor/off flavor) resembled an overcooked and caramelized condensed milk.

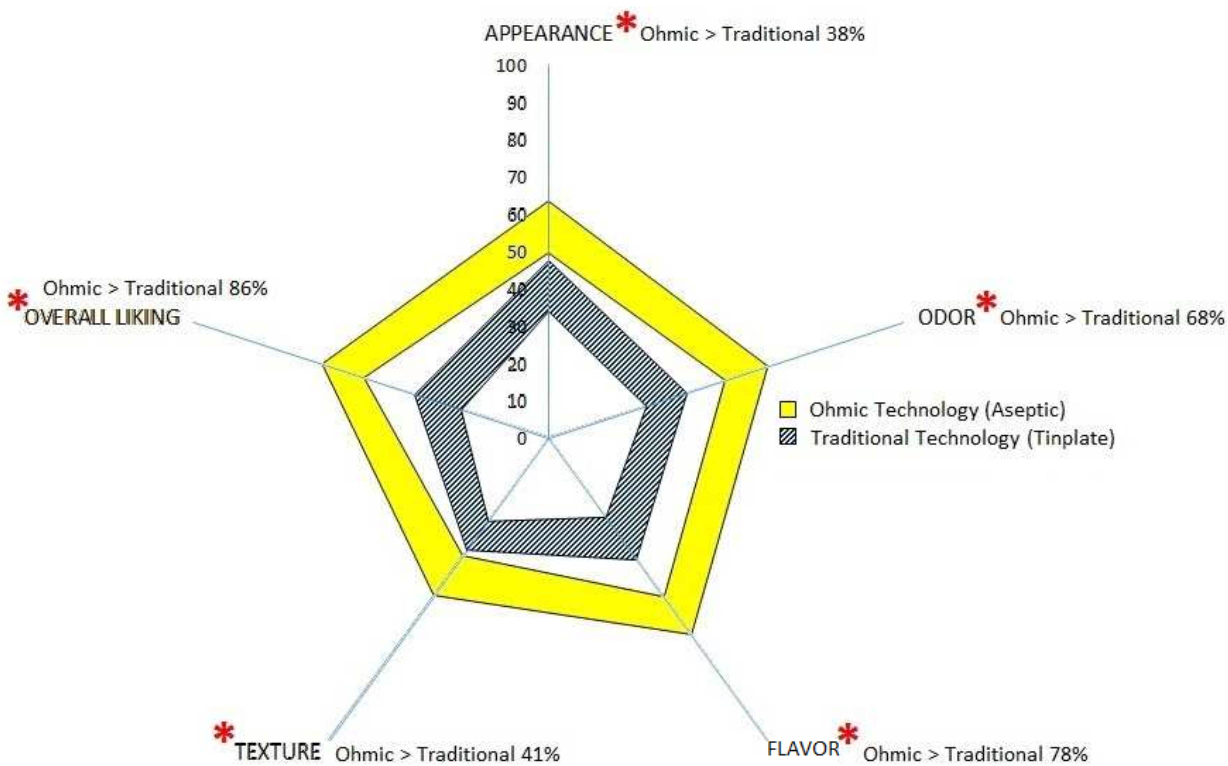


Figure 43. Macaroni and Cheese – Comparison between the two technologies at t0 time

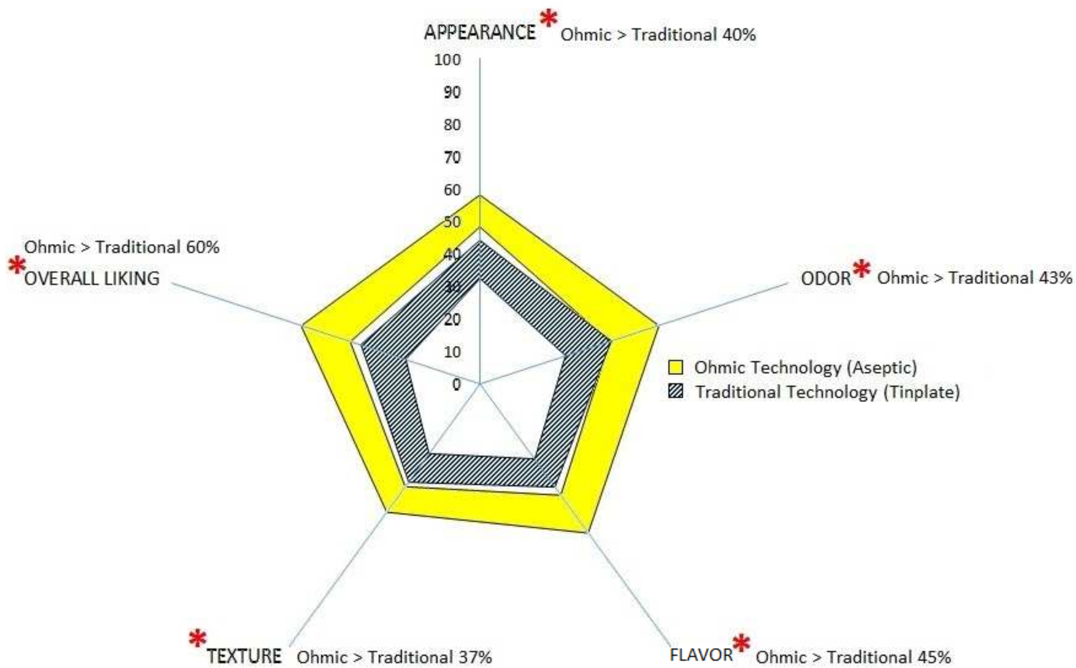


Figure 44. Macaroni and Cheese – Comparison between the two technologies after 2 weeks of storage at 50 °C

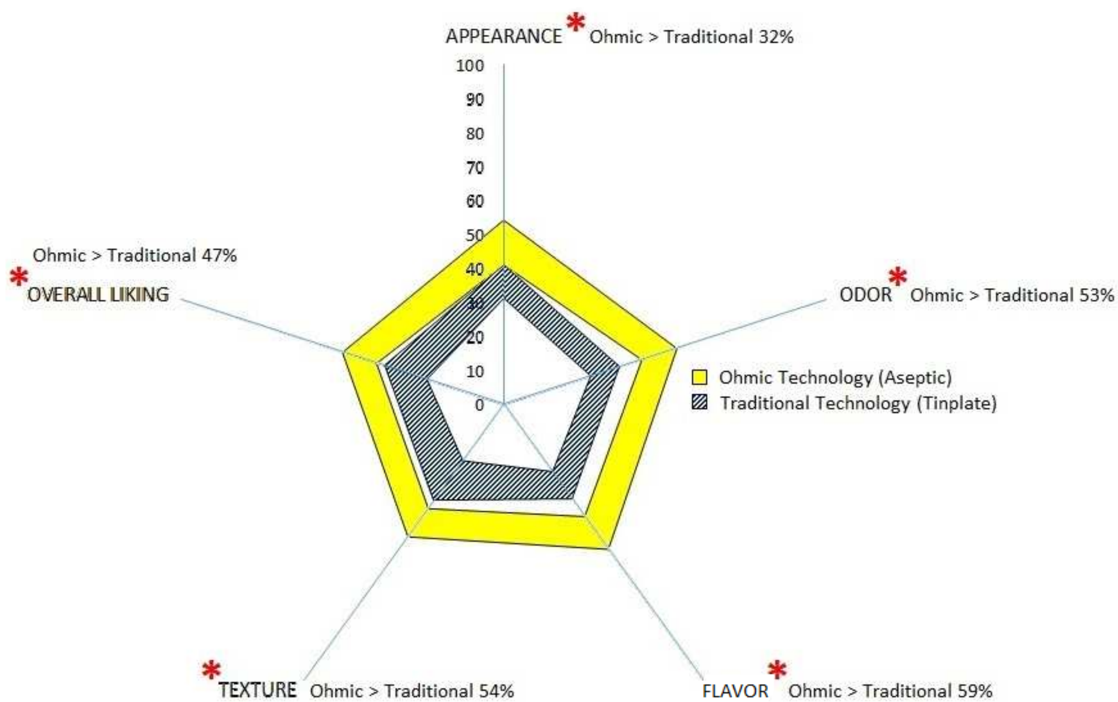


Figure 45. Macaroni and Cheese – Comparison between the two technologies after 4 weeks of storage at 50 °C

2. Storage at 37 °C for 6 months (Figures 46-48) – For the first 4 months of storage, the two products were rated significantly different, with the retorted products being rated as the least liked: regarding the attributes "odor" ($p = 0.0390$ with a percentage difference between the mean values of 20%), for "flavor " ($p = 0.0016$ with a percentage difference between the mean values of 30%) and "texture" ($p = 0.0105$ with a percentage difference between the mean values of 28%). At the end of 6 months, however, the appearance and overall acceptance of the two products were not significantly different ($p \geq 0.05$). The ohmic treated products showed a significant ($p < 0.05$) worsening of the scores after 6 months of storage compared to the previous observations, mainly because of the excessive loss of consistency and the onset of off flavors/extraneous odors. The ratings given to the retorted products were constant over time.

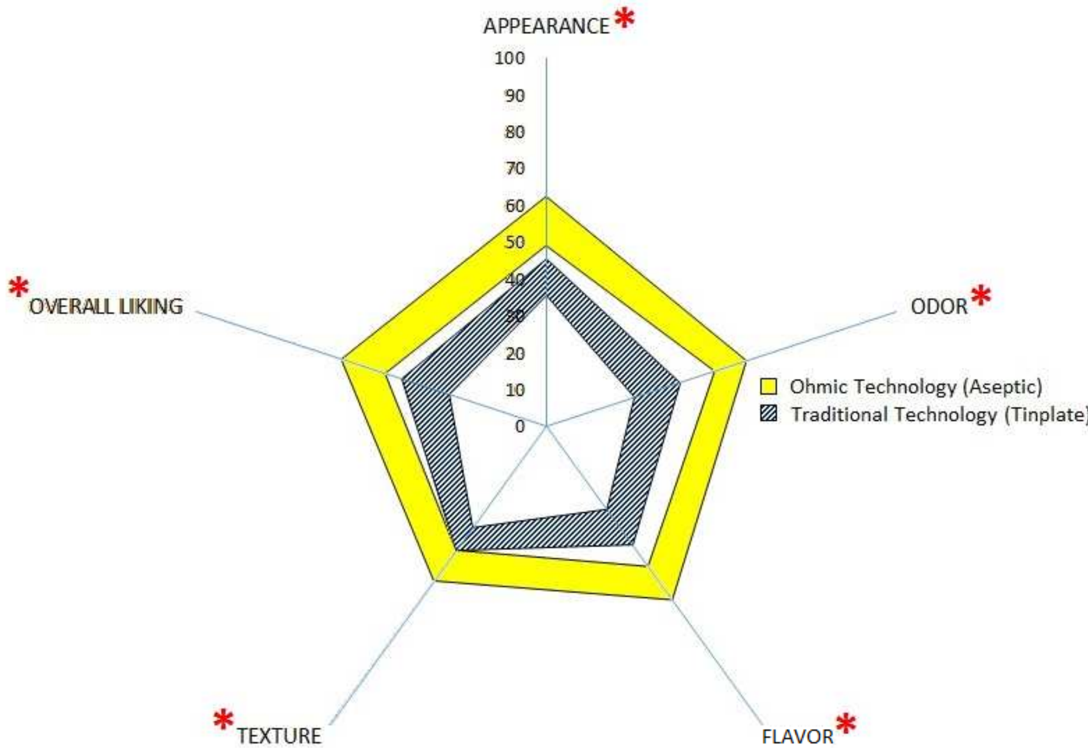


Figure 46. Macaroni and Cheese – Comparison between the two technologies after 2 months of storage at 37 °C

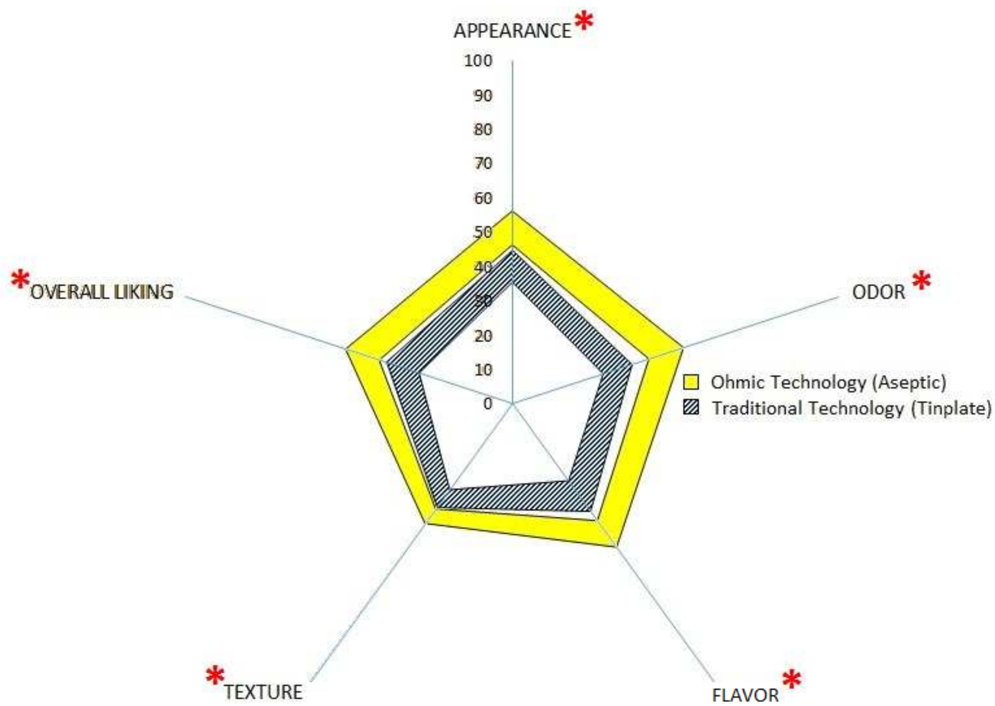


Figure 47. Macaroni and Cheese – Comparison between the two technologies after 4 months of storage at 37 °C

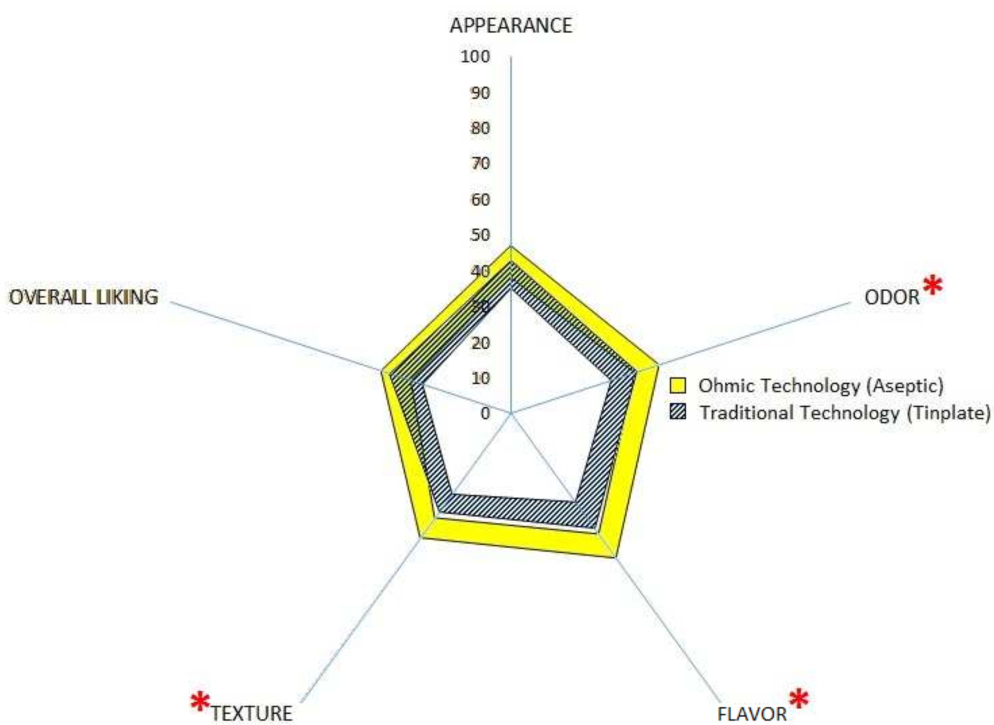


Figure 48. Macaroni and Cheese – Comparison between the two technologies after 6 months of storage at 37 °C

3.0 CONCLUSIONS

The modern ohmic heater is more compact in design, easier to operate, and it provides faster and more uniform heating. Regardless of the homogeneity of the recipe, ohmic treated products showed significantly better quality than the retorted counterparts. The magnitude of sensory quality difference varied with different recipes, but stayed very consistent during prolonged storage.

Ohmic heating technology is suitable to produce particulate-containing ration entrees that need fresh quality and long shelf life. The future plan is to validate nutrient stability of the ohmically treated products (vs. retort treated).

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- 20/007 in a series of reports approved for publication.

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