

A Preliminary Technology Assessment Analysis for the use of High Pressure Treatment on Halloumi Cheese

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Abstract—This paper presents preliminary results of a technology assessment analysis for the use of high pressure treatment (HPT) on Halloumi cheese. In particular, it presents the importance of this traditional Cyprus cheese to the island's economy, explains its production process, and gives a brief introduction to HPT and its application on cheese. More importantly, it offers preliminary results of HPT of Halloumi samples and a preliminary economic feasibility study on the financial implications of the introduction of such technology.

Keywords—Economic feasibility analysis, high pressure treatment, Halloumi cheese, technology assessment

I. INTRODUCTION

CYPRUS is a small southeastern European island-country that covers an area of just 9,248 km² [1]. To estimate the size of its domestic food sector one must consider both its population and number of tourists it accommodates annually, roughly 800K and 2.2 mil., respectively.

Despite Cyprus' size, its traditional cheese, called Halloumi [2], has become known worldwide in recent years. This is demonstrated by the level of exports it has managed. According to Cyprus' Statistical Service, Ministry of Trade and Industry, Halloumi exports in 2010 were of the order of €47 mil., a rise of 15% compared to those of 2009 [3], accounting for 4.1% of its overall exports. Domestic consumption is an estimated 8Kg per person per yr.

Due to Cyprus' geographical position and weather, prolonging the product's expiry date and ensuring a more adequate microbial inactivation are key elements in maintaining its domestic success and achieving further increases in exports. Thus, based on the framework of a technology assessment, this paper investigates both the impact of High Pressure Treatment (HPT) on the product's organoleptic properties as well as the financial feasibility for the use of such a technology.

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II. THE HALLOUMI CHEESE

The success of Halloumi can be sought in its semi-soft texture, which hardens with age. This texture enables it to have a high melting point and hence to be fried or grilled. It is made from a mixture of goat and sheep milks, but it could also contain cow milk [4]. It is set with rennet and is unusual in that no acid or acid-producing bacterium is used in its preparation [4].

Its manufacture is nowadays regulated by Governmental and Standardisation bodies. The procedure contains the following steps [5]:

- 1 Preparation of fresh pasteurized milk (Goat, sheep, cow milk or a mixture)
- 2 Coagulation with rennet at 33±1 °C for 40–60 min
- 3 Curd cutting to 1 cm³ grains
- 4 Coagulum left to rest & precipitate for 10 min
- 5 Pressure of 550 Pa applied on curd for 1hr
- 6 Cut into blocks of 10 cm x 15 cm x 3 cm
- 7 Blocks placed in hot whey (94 – 96 °C)
- 8 Crucial step, set by law: Blocks cooked for minimum 30 min at a temperature of at least 90° C; Halloumi attains 'chicken breast' characteristic of developing cheddar cheese
- 9 Blocks drained and cooled
- 10 Blocks dry salted (3% w/w) and sprinkled with crushed dry mint leaves, *Mentha viridis*
- 11 Blocks folded crossways (in half), piled into convenient container, and leave to chill overnight
- 12 Salted prime poured into container covering blocks (Fresh Halloumi) for approximately 3hrs
- 13 Stored in 11% NaCl whey containers for local distribution or shrink wrapped for exports.

Various factors can affect the quality of the finished Halloumi, but the time/temperature profile within the cheese during the cooking stage is crucial. For example, half cooked curds give an irregular greenish color in the centre of the block.

The high temperatures employed when the curd is cooked, eliminates most of the microorganisms that could initiate proteolytic and/or lipolytic action; Nevertheless, Halloumi is by no means free of bacteria. Colony forming units (cfu) of greater than 10³ per g have been reported for fresh Halloumi [6]. After storage at 20°C for only 4 days, the number of microorganisms in the center of a typical block increased to greater than 10⁶ cfu/g. During cold storage, it took around 6 wks for the same number to be reached. Spore formers like *Bacillus* contribute to these microfloras, but thermophilic

species in the milk and contaminants from the salt or mint leaves elevate the numbers, as well. Yeasts are often isolated from Halloumi, particularly on the surface of the individual blocks, and the presence of post-pasteurization contaminants raises the question of safety. For e.g., *Listeria monocytogenes* could survive in the brine used to transport feta cheese and, although the numbers were probably low, the result did highlight the need for high standards of hygiene operating during cheese packaging [7].

III. HPT TECHNOLOGY

Nowadays, consumers are certainly better informed and thus more sensitive to high standards of hygiene in the manufacture of food products, including Halloumi. Hence, there is an increased need for alternative methods of food production to eliminate pathogen microorganisms. Except for micro-biologically safe foods, there is growing consumer demand for high quality, minimally processed, and additive-free foods of, if possible, longer shelf-life that is also influencing the development of industries that process food [8], [9].

One non-thermal technique that has particular potential to achieve microbial inactivation and consumer-desired qualities is high hydrostatic pressure (HP), in which food is subjected to elevated pressures of up to approximately 600 MPa [10]. Relatively recent progress in the design of HP processing systems, influenced in part by this consumer demand, have ensured the world-wide acknowledgement for this technology's potential in food processing [9].

Heat treatment inactivates microorganisms, but also causes a loss in nutrients and flavors. In contrast, HPT at room temperature of foods may extend their microbiological shelf-life, maintaining natural freshness and causing negligible impairment of their quality characteristics such as nutritional value, taste, color, flavor or vitamin content. This is a consequence of the fact that only non-covalent bonds within biological matter are perturbed by HPT. Thus, small molecules such as amino acids, vitamins and flavor compounds remain unaffected by HP, while the structure of large molecules such as proteins, enzymes, polysaccharides and nucleic acids may be altered.

Research that began over a century ago, studied the pressure sensitivity of microorganisms in milk, fruits, vegetables, and other foods and beverages, and demonstrated that HPT could control microbial growth in and extend the refrigerated shelf life of foods.

IV. HPT TECHNOLOGY AND CHEESE

In recent years, there has been much research on the use and effect of HPT on several types of cheese. The combined aim has been to accelerate its expensive and complex ripening process, check for improved functional characteristics and textural changes, reduce microorganisms and increase its refrigerated shelf-life due to high bacterial and enzymatic inactivation [11].

For e.g., some types of cheese were studied in [9]:

Goat milk cheese, where the cheese milk was inoculated with *E. coli*. The resultant cheese was treated using combinations of pressure (400–500 MPa), temperature (2, 10 or 25 °C) and time (5–15 min) and subsequently stored at 2–4 °C. No survival of *E. coli* was detected 1 day after pressurization, except for in samples treated at 400–450 MPa and 25 °C for 5 min, while *E. coli* in the control cheese remained at 108 CFU/g cheese.

Swiss cheese slurries were treated at 340 or 544 MPa for 10 or 30 min. The microbial population (coliforms, yeasts and moulds, starter bacteria, NSLAB and staphylococci) was notably reduced during subsequent storage at 30 °C for up to 5 days.

Gouda, Camembert and Kurpiowski (Swiss-type) cheeses, at different stages of ripening. Yeasts and moulds were completely inactivated at 200 MPa in Gouda and Kurpiowski cheeses and at 400 MPa in 10 day old Camembert. This study demonstrated that the type of cheese and its degree of maturity affect the degree of microbial inactivation following HPT. This is perhaps a result of the species and quantity of starter cultures used and the cheese's acidity and composition.

Gouda, Edamski and Podlaski, three different ripened hard cheese varieties. HPT reduced the numbers of the pathogen *L. monocytogenes* that survived.

Cheese slurry and Cheddar cheese. HPT inactivated more of the pathogenic and spoilage microorganisms *Staphylococcus aureus*, *E. coli*, and *Penicillium roqueforti* spores reducing their numbers.

Some more types of cheese were studied in [12]: Fresh goat milk cheese, goat milk cheese, Swiss cheese slurries, Queso Fresco cheese, raw milk La Serena cheese, cow milk model and fresh cheeses, and Turkish white cheese. It was found that HPT may cause inactivation or reduction of pathogenic and spoilage microorganisms in these types as well as extend the shelf life of fresh cheese.

Acceleration of ripening for some cheese types and improved functional characteristics of Mozzarella cheese using selected pressure conditions have also been reported.

Moreover, some changes in physical and biochemical characteristics of HP treated cheese have been observed. For e.g., the viscoelastic properties of Gouda cheese treated at 225 and 400 MPa were studied in [13]. Following HPT at 400 MPa, Gouda was found to be less rigid, less solid-like, and more viscoelastic. In [14], per an expert taste panel, Gouda cheese treated at pressures in the range 0–500 MPa for a combined 4 hrs was found to be more elastic and have superior organoleptic properties than untreated cheese. However, when sensory studies of the hard cheeses Gouda, Edamski and Podlaski treated at 200–500 MPa for 15 min were carried out by a trained panel, it was reported that HP did not have any influence on the appearance, smell or taste of the cheeses, while a positive effect on the color of Gouda cheese was noted. Besides, when HP without freezing was applied to Mozzarella, a cheese primarily used as pizza topping, there was a desirable substantial plasticization of the cheese.

In conclusion, the use of HPT appears to have advantages in both cheese manufacture and ripening, the level of which depends on the cheese variety. Additional research is required to define the optimal operating conditions required under HPT and to achieve the correct balance of positive effects of HPT of cheesemilk and cheese.

V. PRELIMINARY HPT OF HALLOUMI

A preliminary HPT of Halloumi cheese samples, demonstrated that the new technology is promising as the anaerobic, aerobic bacteria and yeasts were better inactivated than in the traditionally heat treated samples. Moreover, HPT led to increasing water binding capacity, softer texture, and lower color deviation in comparison to the regularly treated samples.

More specifically, 24 Halloumi samples were treated at a specialized German food technology center at 400, 500 and 600 MPa for 3 and 5 min, and subsequently the level of microbial inactivation was evaluated. Aerobic total count, anaerobic total count, yeasts/molds, *Clostridium perfringens* and *Listeria monocytogenes* were tested. At 600 MPa, aerobic and anaerobic bacteria, yeasts and molds were inactivated. Furthermore, the impact on product properties (bite strength, moisture, pH value, and color measurement) of HPT at 600 MPa for 5 min was evaluated for 8 Halloumi samples. For comparison reasons, a second setting was chosen with 500 MPa for 5 min. HPT at 600 MPa led to anaerobic total count below detection limit, and aerobic total count downwards to around 200 CFU/g, also below detection limit. In relation to untreated references, HP treated samples show lower differences in color. The changes of pH values of HP treated Halloumi cheese, were imperceptible in comparison to those treated with the traditional heat method.

More research is required to extract some safer results on the effect that HPT has on Halloumi. Such research should be focused on the examination of: a) The impact of HPT on product properties and microbial inactivation using samples from various producers and of different fresh pasteurized milk mixtures and b) the inactivation of some common relevant pathogens, such as *E. coli* and *Salmonella*.

VI. AN ECONOMIC FEASIBILITY STUDY

The Economic feasibility study was based on calculating the cost/Kg when utilizing HPT technology on Halloumi. This parameter indicates the additional cost burden that a company must bear if it adopts HPT as an add-on process step in its production line. It also offers an easy means of a direct comparison to the thermal treating method.

Equipment models of the company NC Hyperbaric [15], in particular, the Wave 6000/55, Wave 6000/135, Wave 6000/300, Wave 420, and Wave 600/300 Tandem models were examined. The economic model was set up in MS Excel and the processing cost/Kg was calculated as the average during the 5-yr period of the investment. A number of input parameters were taken into account:

The technology investment was represented by the €550K to €2.5 mil. purchasing cost for each piece of equipment model, as given by the manufacturer. To finance this investment an extreme scenario of a capital structure of 100% borrowed funds at a 5% interest rate was considered.

The number of cycles/hr ranged from 7 to 9 depending on the equipment model and based on a 3 min holding time at 600 MPa, including the loading process. The vessel capacity was from 55L to 600L and the filling ratio was assumed equal to that of ready meals, as given by the manufacturer. The average Kg throughput/hr for each particular filling ratio was given by the manufacturer and aforementioned parameters were used to calculate the processed Kg/yr.

Two scenarios were considered: a) 8 hr shifts for Cyprus' norm of 220 working days/yr and b) 20 hr shifts corresponding to the 300 working days/yr given by the manufacturer. The hourly rate per labourer was based on Cyprus' average worker wage set to €1K/mo. The number of laborers required to operate each model was based on manufacturer's specifications, each model's electricity consumption and maintenance cost per cycle.

The depreciation period and method were based on Cyprus' Inland Revenue regulations; a 5-yr straight line depreciation model was used. 10% corporate tax and 3% inflation rate were assumed. Finally, overhead expenses were set at 5% of the purchasing cost.

Table I presents the input parameters and a summary of the findings under the two scenarios. All costs were calculated based on the data of table I for year 1 of operation. Subsequent years of the 5-yr plan were increased based on the inflation rate.

A few of the useful conclusions that are drawn from this preliminary economic analysis are listed below:

- Machine Utilisation plays an important role in the final processing cost/Kg. As per Table I, in most cases the cost reduces almost to half when machine utilisation changes from that of the 1st to that of the 2nd scenario.
- At the same levels of machine utilisation, the average processing cost/Kg gradually reduces as the machine capacity increases. Thus, a careful analysis of the processing needs of a prospective buyer needs to precede any HPT purchase.
- The analysis was conducted for relatively low filling ratios and number of hourly cycles. Prospective buyers along with respective equipment suppliers must investigate other ways to increase these parameters. This may decrease dramatically the processing cost/Kg.
- The shape and size of the Halloumi packs are such that high throughput/hr is achieved. This fact further reduces the processing cost/Kg.

VII. SENSITIVITY ANALYSIS

Figs. 1 and 2 illustrate how the average processing cost/Kg changes when the input parameters are varied. Fig. 1 illustrates 8 different input parameters for the case of the bvWave 55 equipment model and the "8 hrs, 220 days/yr"

scenario. The parameters that have a negative effect on the average processing cost/Kg when increased are, in order of impact: Maintenance (M), Cost Electricity price (CE), Hourly Rate (HrR), Interest rate (t) and Inflation (I), to a much lesser degree. Similarly, Fig. 2 illustrates the case of the Wave 300 Tandem equipment model. In this case, the order of negative effect parameters is: CE, M, t , HrR and I, to a much lesser degree. Hence, a company that plans to use HPT technology has to consider the impact that each parameter's variation may have on the processing cost. At the same time, though, careful planning is crucial since each equipment model dictates a different behavior for each parameter hence affecting the processing cost differently.

VIII. CONCLUSIONS

This paper conducts a preliminary technology assessment for the use of HPT technology on Halloumi. Preliminary testing for such HPT has demonstrated promising results as the anaerobic, aerobic bacteria and yeasts are better inactivated compared to the traditional heat treatment. It was

also found that HPT can lead to increasing water binding capacity, softer texture, and lower color deviation compared to regularly treated samples.

But, further tests analyzing more Halloumi samples are required to study the a) Potential impact of HPT on product properties and microbial inactivation and b) Inactivation of some common pathogens, such as E.-coli and Salmonella.

As far as the potential economic merits of this technology, a preliminary economic analysis was conducted by calculating the associated expected cost/Kg. As anticipated, this is a technology and capital intensive technique and as such significant investment is required. Subsequently, economies-of-scale do apply and as a result, the cost/Kg processed reduces significantly as the processing volume increases.

Besides, it appears that at constant processing time the average processing cost/Kg gradually reduces as the machine capacity increases. Thus, prior to any investment in this technology, prospective buyers should conduct a thorough analysis of their food processing needs. To secure financial viability of any prospective investment, they should study several parameters concurrently and assess their impact by selectively varying some of them.

TABLE I
 ECONOMIC ANALYSIS MODEL

Parameters	NC Hypebaric Model range									
	Wave 6000/ 55		Wave 6000/ 135		Wave 6000/ 300		Wave 6000/ 420		Wave 6000/ 600 Tandem	
Invest. Cost (€)	550K		1,100K		1,500K		2,000K		2,500K	
Depreciation model	5-yr, straight line		5-yr, straight line		5- yr, straight line		5- yr, straight line		5- yr, straight line	
Vessel Capacity (L)	55 liters		135 liters		300 liters		420 liters		600 liters	
Cycles / hr	7		9.2		7.8		7.5		8.7	
Filling eff.	45.00%		50.00%		50.00%		60.00%		55.00%	
Avg. Throughput per hr (Kg)	600		1050		1800		2850		3750	
Working days / yr	220	300	220	300	220	300	220	300	220	300
Working hrs / day	8	20	8	20	8	20	8	20	8	20
Processed Kg/ yr	1,056K	3,600K	1,848K	6,300,000	3,168K	10,800K	5,016K	17,100K	6,600K	22,500K
Maintenance cost / cycle (€)	3.28		4.00		4.25		4.50		5.50	
No of Labourers	2		2		3		3		4	
Hourly rate / Labourer (€)	7.4		7.4		7.4		7.4		7.4	
Electricity Cost / KWh (€)	0.1621		0.1621		0.1621		0.1621		0.1621	
Electricity consumption (KW)	110 KW		190 KW		280 KW		370 KW		370 KW	
Borrowed funds (€)	550K		1,100K		1,500K		2,000K		2,500K	
Borrowed funds IR (APR %)	5%		5%		5%		5%		5%	
Inflation (%)	3%		3%		3%		3%		3%	
Processing Cost (€/Kg)	0.249	0.144	0.2549	0.1359	0.1952	0.1002	0.1573	0.0796	0.1474	0.0714

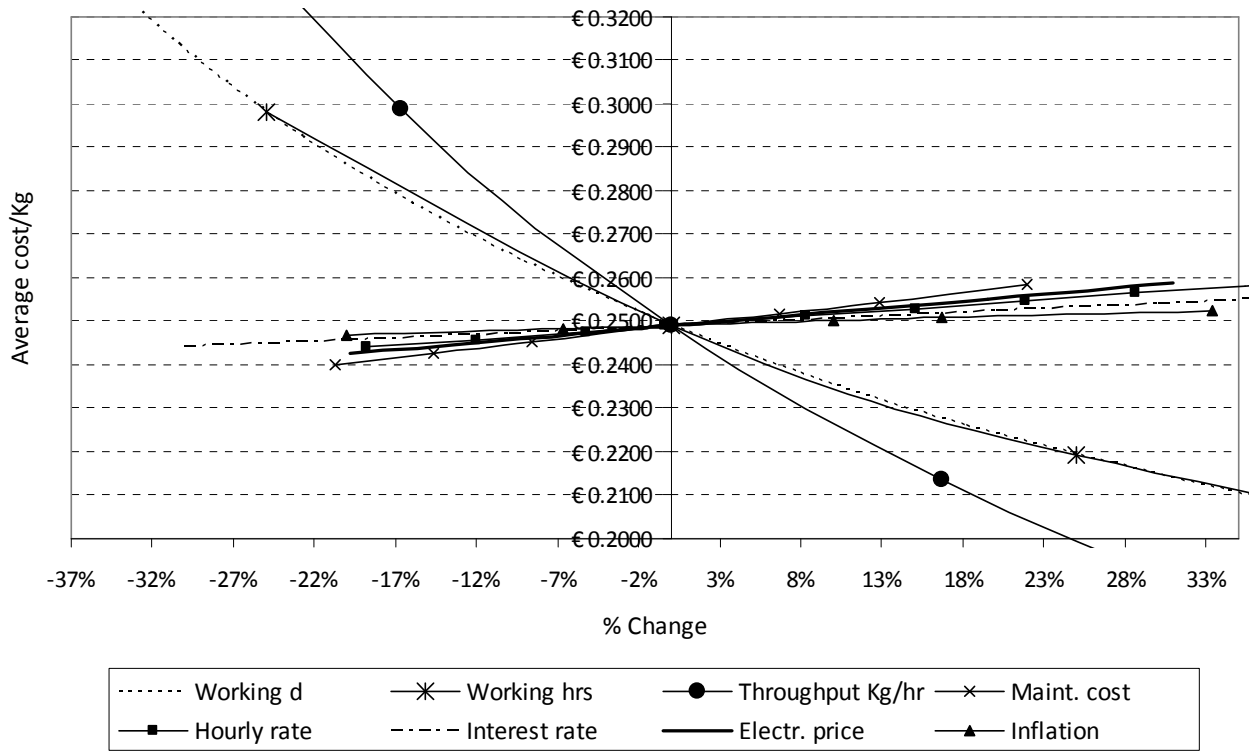


Fig. 1 Sensitivity Analysis for the average Processing cost (Euro/Kg) of the Wave 55, 8h shift, 220 days/ year case

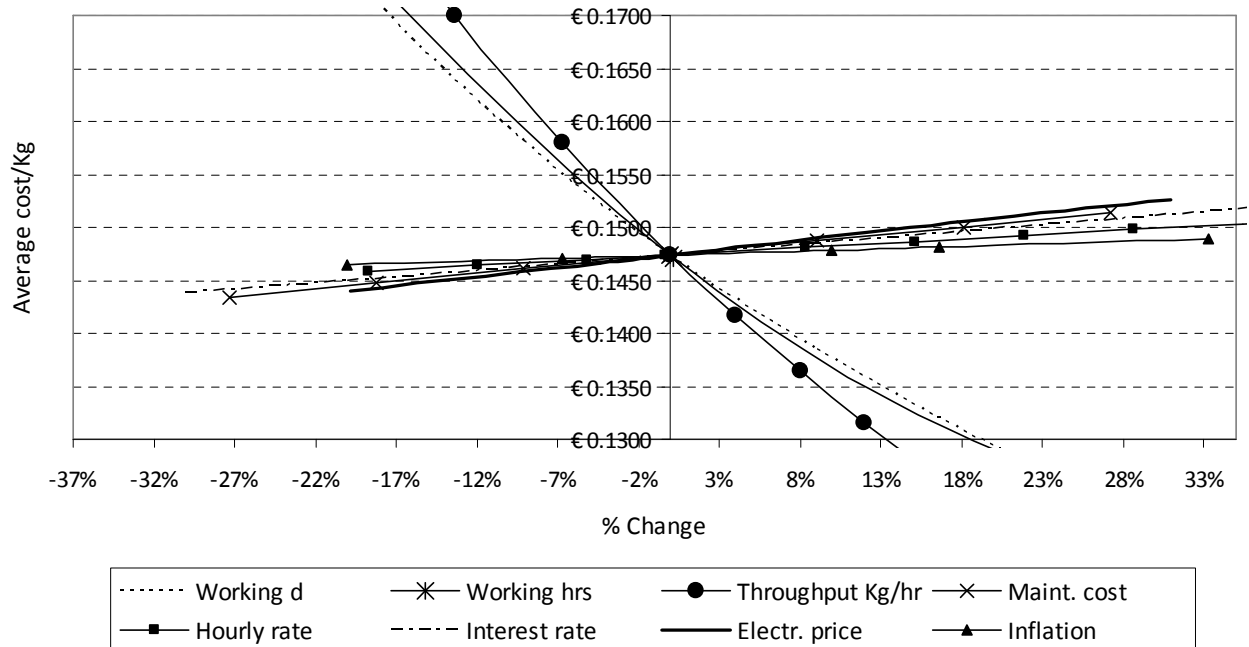


Fig. 2 Sensitivity Analysis For The Average Processing Cost (Euro/Kg) of the Wave 300 Tandem, 8h shift, 220 days/ year case

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