Influence of HPP conditions on selected lamb quality attributes and their stability during chilled storage

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Abstract— **The aim of this research was to determine the effects of combined pressure and temperature treatments on ovine quality after processing and during storage. Lamb *M. pectoralis profundus* samples were pressurised at 200, 400 and 600 MPa at temperatures 20°C, 40°C and 60°C. Both pressure and temperature regimes applied had significant effects ($p<0.001$) on texture, pH, colour and lipid oxidation. Pressurisation at 200 MPa had a lower ($p<0.001$) impact on colour and pH parameters compared to higher pressurisation levels. High pressure processing (HPP) at higher temperatures (60°C) resulted in lower warner bratzler shear force (WBSF) values compared to processing at 20 and 40°C. Thiobarbituric acid reactive substances (TBARS) values during storage showed an increase of TBARS values with time of storage in all samples studied. Samples pressurised at 400 & 600 MPa at 60°C resulted in the highest TBARS values at each time analysed.**

Keywords— **High pressure processing, minimal processing, lamb**

I. INTRODUCTION

There has been a growing demand among consumers for ready to eat meat products, which are microbiologically safe and possess superior sensory attributes and nutritional quality, with an accompanying shelf-life extension [1]. This has stimulated renewed interest in technologies that provide an alternative to conventional heat processing. One such technology is high pressure processing (HPP) which improves the microbiological quality of food, by inactivating microorganisms with minimal changes to taste and nutrient content [2]. The combined use of pressure and temperature offers promising possibilities for imparting specific textural characteristics to products. The objective of the study was to examine the impact of pressure-heat processing on ovine quality parameters after processing and over an extended shelf life.

II. MATERIALS AND METHODS

A. Meat sampling and high pressure treatment

Lamb *pectoralis profundus* muscles were obtained at 2 days post mortem from a local meat plant. Muscles were cut into steaks 2.5cm in thickness, vacuum packed and pressures of 200, 400 and 600 MPa were applied at 20, 40 and 60°C for 20 min using a 1L Stansted high pressure unit (Stansted Fluid Power Ltd., Stansted, UK). Non treated (NT) samples were kept as a control. Five replicates of each treatment were obtained.

B.Cook loss and *Warner Bratzler Shear Force (WBSF)*

Steaks were cooked in a water bath at 72°C, until an internal temperature of 70°C was achieved. Weight was recorded before and after cooking. Cook loss was expressed as the percentage of the weight difference. WBSF was carried also out [3].

C. pH measurement

pH values were measured using a glass probe (Orion pH meter 250A, Orion Research Inc.) by direct insertion into the meat. An average of three measurements were made for each sample.

D. Colour measurement

Internal colour of samples was analysed using the CIE L*a*b* system with a dual beam xenon flash

spectrophotometer (Ultra Scan XE, Hunter lab). An average of three measurements were taken for each sample.

E. Microbiological analysis

Total Viable Counts (TVC's) were enumerated by plating on PCA agar (Merck, Darmstadt, Germany) and incubated at 30°C for 72 h. Lactic Acid Bacteria (LAB) were enumerated by plating on MRS agar (Oxoid, Basingstoke, Hampshire, England) and incubated at 37°C for 24 h; *Enterobacteriaceae* were enumerated by plating on Violet Red Bile Glucose agar (Merck) and incubated at 30°C for 24 h. The presence of *Listeria*, *Salmonella* and *Campylobacter* was determined according to ISO 11290-1:1996, ISO 6579:2002 and ISO 10272-1:2006 respectively.

F. Measurement of lipid oxidation

TBARS values were measured as an index of lipid oxidation [5]. The TBARS number was expressed as mg of malondialdehyde (MDA) per kilogram of sample.

G. Fatty acid

Total lipids were extracted using the method of Folch, Lees & Stanley [6]. Fatty acid methyl esters (FAME) were prepared according to the method of Slover & Lanza [7].

H. Shelf life study

Vacuum packed samples were stored at 4°C for 30 days. Monitoring of TBARS, colour, fatty acids and microbiology was carried out during the shelf life.

I. Statistical analysis:

Data were analysed using the GLM procedure from the SAS statistical package (SAS 9.1 version). Two different models were applied. The first model included treatment (NT and HP treatments) as a fixed effect (*model 1*). The second model only considered pressurised samples, included pressure, temperature, pressure x temperature interaction as fixed effects (*model 2*). Non-significant interactions between temperature and pressure were excluded from the second model. Differences were assessed using the Tukey test.

III. RESULTS AND DISCUSSION

A. Quality measurements after HPP

No differences ($p>0.05$) in WBSF values were observed between NT and pressurised lamb samples with the exception of samples treated with 200 MPa at 60°C (data not shown) Pressurisation of samples at 200 MPa at 20 and 40°C and had no significant effect on a*, b* and TBARS values, while pressurising at the higher pressure and temperature levels resulted in an increase ($p<0.001$) in pH, L*, b* and TBARS values and a decrease in a* values (Table 1).

Table 1: Quality measurements of non-treated, pressurised lamb *M. pectoralis profundus*

Treatment	pH	L*	a*	b*	TBARS
Non-treated	5.7^{c}	34.9^{f}	7.4^{a}	10.0^{e}	0.181^{e}
20°C, 200MPa	5.7^{c}	40.2^{ef}	6.2^{abc}	9.6^{e}	0.363^{e}
20°C, 400MPa	5.9^{ab}	52.8^{bc}	6.4^{abc}	14.0^{bc}	0.589^{d}
20°C, 600MPa	5.9^{a}	54.7^{ab}	5.5^{abc}	14.5^{ab}	1.272^{c}
40°C, 200MPa	5.8^{bc}	41.5^{de}	6.8^{abc}	11.4^{de}	0.723^{d}
40°C, 400MPa	5.9^{a}	58.8^{ab}	3.9^{c}	15.3^{ab}	1.596^{b}
40°C, 600MPa	5.9^{a}	58.6^{ab}	4.9^{abc}	15.7^{ab}	1.727^{b}
60°C, 200MPa	5.9^{a}	46.9^{cd}	6.9^{ab}	13.3^{cd}	1.102^{c}
60°C, 400MPa	6.0^{a}	59.7^{a}	3.8^{c}	15.7^{ab}	2.006^{b}
60°C, 600MPa	6.0^{a}	58.3^{ab}	4.3^{bc}	16.4^{a}	2.137^{a}
SE	0.03	1.35	0.63	0.47	0.04
p	<0.001	<0.001	<0.001	<0.001	<0.001

Results are mean values of five replicates. SE: standard error. Different letters within a column indicate differences among values.

No interaction between pressure and temperature was observed for WBSF, pH, L* a* and b* values. Thus pressure and temperature had an independent effect on these parameters *(model 2).* Samples treated at the highest pressure level of 600 MPa had higher ($p<0.001$) WBSF, pH, L* and b* values when compared to samples treated at 200 MPa, independent of the pressurisation temperature (*model 2*).

Samples pressurised at the highest temperature (60°C) resulted in lower ($p<0.001$) WBSF values

when compared to samples treated at 20 and 40°C, independently of the level of pressure applied. Samples pressurised at 60°C also showed an increase in pH, L* and b* values (Table 2).

Table 2: Effect of pressurisation conditions (temperature and pressure levels) on lamb *M. pectoralis profundus.*

Treatment	WBSF	pH	L*	a*	b*
Temperature					
20°C	37.0^{a}	5.8^{b}	49.2^{b}	6.0	12.7^{b}
40°C	35.3^{a}	5.8^{b}	53.0^{a}	5.2	14.1^{a}
60°C	30.6^{b}	6.0^{a}	55.0^{a}	5.0	14.8^{a}
SE	1.12	0.02	0.77	0.37	0.27
p	<0.001	<0.001	<0.001	NS	<0.001
Pressure					
200MPa	31.3^{b}	5.8^{b}	42.8^{b}	6.6^{a}	11.1^{b}
400MPa	33.0^{b}	5.9^{a}	57.1^{a}	4.7^{b}	15.0^{a}
600MPa	38.6^{a}	6.0^{a}	57.2^{a}	4.9^{b}	15.6^{a}
SE	1.12	0.02	0.77	0.37	0.27
p	<0.001	<0.001	<0.001	<0.001	<0.001

Results are mean values of fifteen replicates. SE: standard error. Different letters within a column indicate differences among values.

The P/S ratios of pressurised samples were significantly higher when compared to NT samples, with the exception of the milder treatments (20°C at 200 and 400 MPa) (Table 3). The proportional change in fatty acid composition may be explained by the breakdown of SFAs during HPP.

Table 3: Fatty acid classes of non treated and pressurised lamb *M. pectoralis profundus.*

Treatment	SFA	MUFA	PUFA	P/S
Non-treated	54.1^{a}	34.9	11.0^{d}	0.21^{e}
20 °C, 200 MPa	50.9^{a}	38.4	10.6^{d}	0.21^{e}
20 °C, 400 MPa	49.8^{a}	40.0	10.2^{e}	0.21^{e}
20 °C, 600 MPa	42.9^{c}	43.5	13.6^{cd}	0.32^{d}
40 °C, 200 MPa	45.8^{bc}	36.8	17.4^{bc}	0.38^{cd}
40 °C, 400 MPa	45.7^{bc}	39.4	15.9^{c}	0.35^{cd}
40 °C, 600 MPa	39.5^{c}	40.5	20.0^{ab}	0.51^{ab}
60 °C, 200 MPa	39.5^{c}	39.5	21.1^{a}	0.54^{a}
60 °C, 400 MPa	41.8^{c}	40.3	17.9^{abc}	0.43^{bc}
60 °C, 600 MPa	45.3^{bc}	36.5	18.2^{abc}	0.40^{c}
SE	1.37	1.54	0.52	0.47
p	<0.001	NS	<0.001	<0.01

Results are mean values of five replicates. SE: standard error. Different letters within a column indicate differences among values.

Principal component analysis (PCA) was conducted to visualise and understand the relationships of the studied variables and to assess the different effects of the HP treatments applied on meat quality. The analysis shows that the first two components explained 82.77% of the total variation (Fig. 1). In relation to the F1 axis, samples pressurised at 200 MPa 20°C/40°C are located on the left of the plot along with the non-treated sample. In contrast samples treated at the higher pressure and temperature levels are located on the right hand side of the figure i.e. to the right of F1 zero point. pH, L*,a*,b* and TBARS are strongly correlated to the F1 axis while WBSF is correlated to the F2 axis (Fig 2), showing the influence of higher pressure/temperature on these attributes. The correlation loading plot (Fig. 2) illustrates quality parameters studied in the work. In this plot TBARS, pH, L* and b* are clustered together on the right hand side of the plot with a* being negatively correlated to L*. The location of the NT and mild HPP samples (200, 20°C and 40°C) in the sample score plot may be explained by their high a* values. In contrast the location of samples treated at the higher pressure and temperature levels may be explained by their high L*, TBARS and pH values. When the sample locations were analysed in relation to the F2 axis, NT and samples treated with 600 MPa at 40 and 20°C are located in the upper half of the plot while samples at 200 MPa at 60°C are located in the lower half of the plot. This indicates that samples treated at 600 MPa at 20 and 40 °C were tougher than samples treated with 600 MPa at 60°C, which suggests that HPP at 60°C has a tenderising effect on meat.

Figure 1. PCA scores plot of non-treated and pressurised lamb *M. pectoralis profundus.*

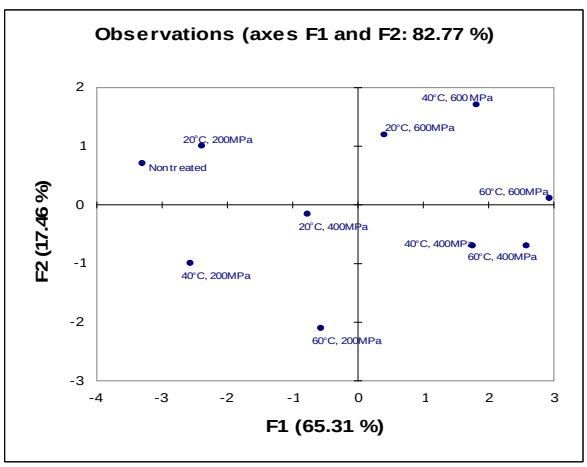
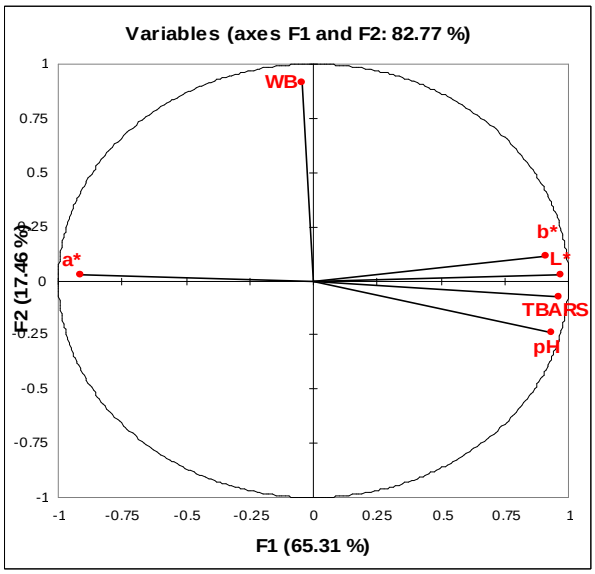


Figure 2. PCA correlation loading plot for quality parameters analysed.



B. Quality measurements during shelf life

Monitoring of beef samples during 30 days of refrigerated storage showed that L* values remained stable for all studied treatments (Fig. 1). L* values of NT samples were lower ($p<0.001$) compared to all other processed samples throughout storage. The a* values of NT lamb and the milder treatments (200 MPa at 20, 40 ,60^{o}C and 400 MPa at 20^{o}C) were maintained higher than samples processed at the higher pressure, temperature levels (data not shown).

TBARS values during storage increased ($p<0.001$) with time of storage, in all samples studied. At each time point analysed, NT samples consistently had the lowest oxidation levels with samples pressurised at 400 & 600 MPa at 60^{o}C, exhibiting the highest TBARS values at all time points analysed (Fig. 2). NT and samples treated with 200 MPa at 20 and 40^{o}C had the lowest ($p<0.001$) TBARS values after 30 days of storage

Fatty acid profiles did not change with time of storage for any of the studied treatments ($p>0.05$) (data not shown).

Lower levels ($p<0.05$) of TVC's for samples pressurised at the higher pressure-temperature combinations (20^{o}C at 400/600 MPa, 40^{o}C at 400/600, 60^{o}C at 200/400/600 MPa) were found when compared to NT and mild HPP samples (20 and 40^{o}C at 200MPa) after 15 days of storage (data not shown).

IV. CONCLUSION

The reported results show that mild pressure treatments (200 MPa) would minimally affect meat quality parameters, while improving meat hygiene. The importance of pressurisation temperature has been shown with higher temperatures resulting in increases in L*, lipid oxidation values and most notably a decrease in WBSF values. P/S ratios were significantly higher in pressurised samples compared to NT samples, with some treatments (200, 400, 600 MPa at 40 and 60^{o}C) having P/S ratios within the recommended levels.

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