

## TABLE OF CONTENTS

	<b>Page</b>
<b>ACKNOWLEDGEMENT</b>	iii
<b>ABSTRACT (IN ENGLISH)</b>	iv
<b>ABSTRACT (IN THAI)</b>	vi
<b>TABLE OF CONTENTS</b>	viii
<b>LIST OF TABLES</b>	xiii
<b>LIST OF FIGURES</b>	xvi
<b>ABBREVIATIONS</b>	xxi
<b>CHAPTER 1 INTRODUCTION</b>	1
<b>1.1 Background information</b>	1
<b>1.2 Research Objectives</b>	3
<b>CHAPTER 2 LITERATURE REVIEW</b>	4
<b>2.1 Nutritional value of ostrich meat and its products</b>	4
<b>2.2 Processing of Meat Yor</b>	7
<b>2.3 Gum or hydrocolloid in meat products</b>	8
<b>2.4 Effects of high pressure on hydrocolloids</b>	11
<b>2.5 Influences of high pressure on meat texture</b>	14
<b>2.6 Effects of high pressure on meat products</b>	16
<b>2.7 Chemical changes induced by high-pressure treatment</b>	19
<b>2.8 Effects of high pressure on microorganisms</b>	22
<b>2.9 Viscoelastic properties of food</b>	23
<b>CHAPTER 3 MATERIALS AND METHODS</b>	26
<b>3.1 Materials</b>	26
<b>3.2 Chemicals</b>	26

<b>3.3 Instruments</b>	27
<b>3.4 Research designs and methods</b>	28
3.4.1 Determination of physicochemical properties of ostrich-meat trimmings, carboxymethylcellulose (CMC), locust bean gum (LBG), xanthan gum (XAN) and tapioca starch	28
3.4.1.1 The chemical quality of raw materials	28
3.4.1.2 Differential scanning calorimetry (DSC)	28
3.4.1.3 Avian influenza test	29
3.4.2 Investigation of the effects of pressure, temperature and holding time on physicochemical properties of ostrich-meat yor	29
3.4.2.1 Preparation of ostrich-meat yor	29
3.4.2.2 Viscoelastic characterisation and modeling	30
3.4.2.2.1 <i>Stress relaxation testing</i>	32
3.4.2.2.2 <i>Creep testing</i>	32
3.4.2.2.3 <i>Dynamic viscoelastic oscillatory measurement</i>	32
3.4.2.3 Textural measurements	32
3.4.2.3.1 <i>Puncture testing</i>	32
3.4.2.3.2 <i>Compression testing</i>	33
3.4.2.3.3 <i>Shear force</i>	33
3.4.2.4 Texture Profile Analysis (TPA)	33
3.4.2.5 Water holding capacity	34
3.4.2.5.1 <i>Released water</i>	34
3.4.2.5.2 <i>Expressible water</i>	34
3.4.2.6 Microstructure determination	35
3.4.2.7 Differential Scanning Calorimetry (DSC)	35
3.4.2.8 Electrophoretic analysis	36
3.4.2.9 Statistical analysis	36
3.4.3 Investigation of the effects of carboxymethylcellulose (CMC), locust bean gum (LBG) and xanthan gum (XAN) on the physicochemical properties of pressurised ostrich-meat yor	37
3.4.3.1 Preparation of ostrich-meat yor	37
3.4.3.2 Viscoelastic characterisation and modeling	38

3.4.3.2.1	<i>Stress relaxation testing</i>	38
3.4.3.2.2	<i>Creep testing</i>	38
3.4.3.2.3	<i>Dynamic viscoelastic oscillatory measurement</i>	38
3.4.3.3	Textural measurements	40
3.4.3.3.1	<i>Puncture testing</i>	40
3.4.3.3.2	<i>Compression testing</i>	40
3.4.3.3.3	<i>Shear force</i>	40
3.4.3.4	Texture Profile Analysis (TPA) and sensory evaluation	40
3.4.3.4.1	<i>Texture Profile Analysis (TPA)</i>	40
3.4.3.4.2	<i>Sensory evaluation</i>	40
3.4.3.5	Water holding capacity	40
3.4.3.6	Microstructure determination	41
3.4.3.7	Differential Scanning Calorimetry (DSC)	41
3.4.3.8	Electrophoretic analysis	41
3.4.3.9	Microbiology determination	41
3.4.3.10	Statistical analysis	42
3.4.4	Determination of the effect of the concentration of xanthan gum on viscoelastic characteristics and microstructure of pressurised ostrich-meat yor	42
3.4.4.1	Preparation of ostrich-meat yor	42
3.4.4.2	Viscoelastic measurement and modeling	42
3.4.4.2.1	<i>Dynamic viscoelastic oscillatory measurement</i>	43
3.4.4.2.2	<i>Creep testing</i>	43
3.4.4.3	Microstructure determination	43
3.4.4.4	Statistical analysis	43
<b>CHAPTER 4</b>	<b>RESULTS AND DISSCUSSIONS</b>	<b>44</b>
<b>4.1</b>	<b>Determination of physicochemical properties of ostrich-meat trimmings, carboxymethylcellulose (CMC), locust bean gum (LBG), xanthan gum (XAN) and tapioca starch</b>	<b>44</b>
4.4.1	The chemical quality of raw materials	44
4.4.2	Differential Scanning Calorimetry (DSC)	45

<b>4.2 Investigation of the effects of pressure, temperature and holding time on physicochemical properties of ostrich-meat yor</b>	47
4.2.1 Viscoelastic characterisation and modeling	47
4.2.1.1 <i>Stress relaxation testing</i>	47
4.2.1.2 <i>Creep testing</i>	54
4.2.1.3 <i>Dynamic viscoelastic oscillatory measurement</i>	61
4.2.2 Textural measurements	64
4.2.2.1 <i>Puncture, compression and shear force measurements</i>	64
4.2.3 Texture Profile Analysis (TPA)	66
4.2.4 Water holding capacity	69
4.2.4.1 <i>Released water plus expressible water</i>	69
4.2.5 Microstructure determination	70
4.2.6 Differential Scanning Calorimetry (DSC)	74
4.2.7 Electrophoretic analysis	77
<b>4.3 Investigation of the effects of carboxymethylcellulose (CMC), locust bean gum (LBG) and xanthan gum (XAN) on the physicochemical properties of pressurised ostrich-meat yor</b>	81
4.3.1 Viscoelastic characterisation and modeling	81
4.3.1.1 <i>Stress relaxation testing</i>	81
4.3.1.2 <i>Creep testing</i>	85
4.3.1.3 <i>Dynamic viscoelastic oscillatory measurement</i>	89
4.3.2 Textural measurements	93
4.3.2.1 <i>Puncture, compression and shear force measurements</i>	93
4.3.3 Texture Profile Analysis (TPA) and sensory evaluation	94
4.3.3.1 <i>Texture Profile Analysis (TPA)</i>	94
4.3.3.2 <i>Sensory evaluation</i>	95
4.3.3.3 <i>Correlation of sensory against instrumental attributes</i>	96
4.3.4 Water holding capacity	98
4.3.5 Microstructure determination	100
4.3.6 Differential Scanning Calorimetry (DSC)	105
4.3.7 Electrophoretic analysis	106
4.3.8 Microbiology determination	107

<b>4.4 Determination of the effect of the concentration of xanthan gum on viscoelastic characteristics and microstructure of pressurised ostrich-meat yor</b>	110
4.4.1 Viscoelastic measurement and modeling	110
4.4.1.1 <i>Dynamic viscoelastic oscillatory measurement</i>	110
4.4.1.2 <i>Creep testing</i>	113
4.4.2 Microstructure determination	116
<b>CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS</b>	120
5.1 Conclusions	120
5.2 Recommendation for further investigation	121
<b>REFERENCES</b>	122
<b>APPENDIX</b>	139
Appendix A: The profiles of stress relaxation and creep-recovery curves	139
Appendix B: The influences of interaction among of pressure, temperature and holding time on the properties of ostrich-meat yor	142
Appendix C: The regression analysis of effects of hydrocolloids on the properties of ostrich-meat yor	149
Appendix D: Questionnaire for Sensory Evaluation	154
<b>CURRICULUM VITAE</b>	156

## LIST OF TABLES

<b>Table</b>	<b>Page</b>
2.1 Mineral composition of ostrich meat in comparison to beef and chicken.	5
3.1 Formulations of ostrich-meat yor with different levels of gums.	37
4.1 Proximate compositions of ostrich-meat trimmings, CMC, LBG, XAN and tapioca starch.	44
4.2 Viscoelastic parameters of model fitted into stress relaxation curve of ostrich-meat yors.	54
4.3 Viscoelastic parameters for four-element Burgers model of creep curve of ostrich-meat yors.	60
4.4 Dynamic viscoelastic parameters of various ostrich-meat yors assessed by oscillatory measurement.	63
4.5 Textural parameters of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 or 50 °C for holding times both of 40 and 60 min.	65
4.6 TPA parameters of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 or 50 °C for holding time both of 40 and 60 min.	67
4.7 Correlation coefficient (r) among TPA parameters of pressure treated ostrich-meat yor.	68
4.8 Released plus expressible water of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 or 50 °C for holding time both of 40 and 60 min.	69
4.9 Transition temperature and enthalpies of endothermic peaks of myofibrillar proteins ( $T_{max1}$ , $T_{max2}$ , $\Delta H_1$ , $\Delta H_2$ ) of pressurised samples at 200, 400 and 600 MPa at temperature of both 40 and 50 °C with holding times of 40 and 60 min.	76
4.10 Stress relaxation parameters of pressurised ostrich-meat yors with different levels of gum concentration	83
4.11 Creep parameters of pressurised ostrich-meat yor with different levels and types of gum addition.	89

4.12	Viscoelastic oscillatory parameters measured at 1 Hz for pressurised ostrich-meat yors with different levels of gum addition.	90
4.13	Textural parameters of pressurised ostrich-meat yor with different levels of gum addition (puncture, compression and shear force measurements).	93
4.14	TPA parameters of pressurised ostrich-meat yor with different levels of gum addition.	94
4.15	Sensory attributes of pressurised ostrich-meat yor with different levels of gum addition.	95
4.16	Correlation coefficients between textural analysis and sensory evaluation of pressurised ostrich-meat yor.	97
4.17	Amount of released plus expressible water of pressurised ostrich-meat yor with different levels of gum addition.	98
4.18	Mean of cross-sectioned area size of fat droplets distributed in pressurised ostrich yor with various levels of gum addition.	100
4.19	Microbiological quality of pressurised ostrich-meat yor 600 MPa at 50 °C for 40 min including native samples with various levels of gum addition.	108
4.20	Dynamic oscillatory parameters of ostrich-meat yor with different levels of gum addition at 1 Hz and a constant stress 5 Pa.	112
4.21	Creep parameters of ostrich sausages with four levels of added xanthan gum.	116
4.22	Mean of cross-sectioned area size of fat droplets distributed in ostrich sausages with four levels of added xanthan gum.	117
B-1	Interactions of pressure, temperature and holding time on viscoelastic parameters of model fitted into stress relaxation curve of ostrich-meat yors.	143
B-2	Interactions of pressure, temperature and holding time on viscoelastic parameters for four-element Burgers model of creep curve of ostrich-meat yors.	144
B-3	Interactions of pressure, temperature and holding time on dynamic viscoelastic parameters of various ostrich-meat yors assessed by oscillatory measurement.	145
B-4	Interactions of pressure, temperature and holding time on textural parameters of ostrich-meat yors.	146



B-5	Interactions of pressure, temperature and holding time on TPA parameters of ostrich-meat yors.	147
B-6	Interactions of pressure, temperature and holding time on the amount of released plus expressible water of ostrich-meat yors.	148
C-1	Regression coefficients and analysis of variances of the regression models for stress relaxation parameters of pressurised ostrich-meat yors.	150
C-2	Regression coefficients and analysis of variances of the regression models for creep parameters of pressurised ostrich-meat yors.	150
C-3	Regression coefficients and analysis of variances of the regression models for viscoelastic oscillatory parameters of pressurised ostrich-meat yors.	151
C-4	Regression coefficients and analysis of variances of the regression models for textural parameters of pressurised ostrich-meat yors.	151
C-5	Regression coefficients and analysis of variances of the regression models for TPA parameters of pressurised ostrich-meat yors.	152
C-6	Regression coefficients and analysis of variances of the regression models for sensory attributes of pressurised ostrich-meat yors.	152
C-7	Regression coefficients and analysis of variances of the regression models for the amount of released plus expressible water of pressurised ostrich-meat yors.	153
C-8	Regression coefficients and analysis of variances of the regression models for mean size of fat droplets contributed in pressurised ostrich-meat yors.	153



## LIST OF FIGURES

Figure	Page
3.1 Typical oscillatory stress sweep (1-1,500 Pa) at frequency 1 Hz of high-pressure-treated ostrich-meat yor with ■ 200 MPa, 40 °C, and 40 min and, ▲ 600 MPa, 50 °C, and 60 min.	31
3.2 Typical stress amplitude sweep (1-1,500 Pa) at frequency 1 Hz of high-pressure-treated ostrich-meat yor with ▲, Δ 200 MPa, 40 °C, and 40 min and ■, □ 600 MPa, 50 °C, and 60 min. The closed symbols = G' and opened symbols = G''.	31
3.3 Oscillatory stress sweep (1-1,000 Pa) at frequency 1 Hz of pressurised ostrich-meat yor with ● added 0.5% (w/w) CMC with 0.5% (w/w) xanthan gum (Treatment 5) and ▲ added 1.0% (w/w) LBG (Treatment 2)	39
3.4 Stress amplitude sweep (1-1,000 Pa) at frequency 1 Hz of pressurised ostrich-meat yor, storage modulus (G'; closed symbols) and loss modulus (G''; opened symbols), ▲, Δ added 1.0% (w/w) LBG (Treatment 2), ▲, Δ added 0.5% (w/w) CMC with 0.5% (w/w) xanthan gum (Treatment 5).	39
3.5 Stress amplitude sweep (0.5-500 Pa) at frequency 1 Hz of pressurised meat yors, storage modulus (G'; closed symbols) and loss modulus (G''; opened symbols), ▲, Δ no added xanthan gum, ■, □ added xanthan gum 1% (w/w).	43
4.1 Typical differential scanning calorimetry curves at a heating rate of 5 °C/min for ostrich-meat trimmings.	46
4.2 Typical differential scanning calorimetry curves at a heating rate of 5 °C/min for CMC.	46
4.3 Typical differential scanning calorimetry curves at a heating rate of 5 °C/min for LBG.	47

4.4	Typical differential scanning calorimetry curves at a heating rate of 5 °C/min for XAN.	47
4.5	Typical differential scanning calorimetry curves at a heating rate of 5 °C/min for tapioca starch.	48
4.6	Typical stress relaxation curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 °C (holding time of 60 min).	49
4.7	Typical stress relaxation curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 50 °C (holding time of 60 min).	49
4.8	Typical stress relaxation curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 °C (holding time of 60 min).	50
4.9	Typical stress relaxation curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 50 °C (holding time of 60 min).	51
4.10	Typical stress relaxation curve of pressurised ostrich-meat yor with two “Maxwell” units and a free spring.	52
4.11	Typical creep curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 °C with holding time of 60 min.	56
4.12	Typical creep curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 50 °C with holding time of 60 min.	56
4.13	Typical creep-recovery curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 °C (holding time of 60 min).	57
4.14	Typical creep-recovery curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 50 °C (holding time of 60 min).	58
4.15	Typical storage (G') and loss (G'') moduli as a function for frequency of pressure treated ostrich-meat yor at 200 and 600 MPa at 40 and 50 °C for 40 and 60 min (All treatments as indicated in Table 4.4).	62
4.16	Typical force-by-time plot to determine TPA parameters. Peak force $\odot$ is hardness; springiness = Length 2/Length 1; cohesiveness = Area 2/Area 1; gumminess = hardness x cohesiveness; chewiness = hardness x cohesiveness x springiness.	66
4.17	SEM micrograph of surface areas of pressurised ostrich-meat yor 200 MPa at 200X magnification.	71

4.18	SEM micrograph of cross-section of pressurised ostrich-meat yor 200 MPa at 400X magnification.	71
4.19	SEM micrograph of surface areas of pressurised ostrich-meat yor 400 MPa at 200X magnification.	72
4.20	SEM micrograph of cross-section of pressurised ostrich-meat yor 400 MPa at 400X magnification.	72
4.21	SEM micrograph of surface areas of pressurised ostrich-meat yor 600 MPa at 200X magnification.	73
4.22	SEM micrograph of cross-section of pressurised ostrich-meat yor 600 MPa at 400X magnification.	73
4.23	Typical DSC thermograms of pressurised ostrich-meat yor at 200, 400 and 600 MPa, 40 °C for 60 min including untreated sample.	75
4.24	Typical DSC thermograms of pressurised ostrich-meat yor at 200, 400 and 600 MPa, 50 °C for 60 min including untreated sample.	75
4.25	SDS-PAGE electrophoregrams of high pressure treated ostrich-meat yor; A untreated sample, B-D pressure treated with 200-600 MPa at 40 °C, E-G pressure treated with 200-600 MPa at 50 °C.	77
4.26	SDS-PAGE electrophoregrams of high pressure treated ostrich-meat yor reduced with 2-mercaptoethanol; A untreated sample, B-D pressure treated with 200-600 MPa at 40 °C, E-G pressure treated with 200-600 MPa at 50 °C.	77
4.27	SDS-PAGE electrophoregrams of high pressure treated samples with silver staining; A untreated sample; B-D pressure treated with 200-600 MPa at 40 °C, E-G pressure treated with 200-600 MPa at 50 °C.	78
4.28	SDS-PAGE electrophoregrams with silver staining of high pressure treated samples reduced with 2-mercaptoethanol for 60 min; A untreated sample, B-D pressure treated with 200-600 MPa at 40 °C, E-G pressure treated with 200-600 MPa at 50 °C.	79
4.29	Typical stress relaxation curves of ostrich-meat yors with added various amount of gums.	82
4.30	Model used for the stress relaxation curves of ostrich-meat yor with added various amount of gums.	83

4.31	Typical creep curves of ostrich-meat yors with various amount of gum addition.	85
4.32	Typical creep-recovery curves of ostrich-meat yors with various amount of gum addition.	86
4.33	Model fitted for creep compliance curves of ostrich-meat yor with various levels of gum addition.	87
4.34	Typical storage ( $G'$ ) and loss ( $G''$ ) moduli as a function of frequency for pressurised ostrich-meat yors with and without added gums.	91
4.35	Typical CSLM image of pressurised sample with no added gum.	101
4.36	Typical CSLM image of pressurised sample with added 1% (w/w) CMC.	101
4.37	Typical CSLM image of pressurised sample with added 1% (w/w) LBG.	101
4.38	Typical CSLM image of pressurised sample with added 1% (w/w) XAN.	102
4.39	Typical CSLM image of pressurised sample with added 0.5% (w/w) CMC and 0.5% (w/w) LBG.	102
4.40	Typical CSLM image of pressurised sample with added 0.5% (w/w) CMC and 0.5% (w/w) XAN.	102
4.41	Typical CSLM image of pressurised sample with added 0.5% (w/w) LBG and 0.5% (w/w) XAN.	103
4.42	Typical CSLM image of pressurised sample with added 0.33% (w/w) CMC, 0.33% (w/w) LBG and 0.33% (w/w) XAN.	103
4.43	Typical DSC thermograms of pressurised ostrich-meat yor with differing amounts of gum addition.	105
4.44	SDS-PAGE electrophoregrams of pressurised samples with added various gums, A = added 1% (w/w) CMC; B = added 1% (w/w) LBG; C = added 1% (w/w) XAN; D = added 0.5% (w/w) CMC and 0.5% (w/w) LBG; E = added 0.5% (w/w) CMC and 0.5% (w/w) XAN; F = added 0.5% (w/w) LBG and 0.5% (w/w) XAN; G = added 0.33% (w/w) CMC, 0.33% (w/w) LBG and 0.33% (w/w) XAN; H = no gum addition.	106
4.45	SDS-PAGE electrophoregrams of pressurised samples with added various gums in the presence of 2-mercaptoethanol; A = added 1% (w/w) CMC; B = added 1% (w/w) LBG; C = added 1% (w/w) XAN; D = added 0.5% (w/w) CMC and 0.5% (w/w)	

LBG; E = added 0.5% (w/w) CMC and 0.5% (w/w) XAN;	
F = added 0.5% (w/w) LBG and 0.5% (w/w) XAN; G = added	
0.33% (w/w) CMC, 0.33% (w/w) LBG and 0.33% (w/w) XAN;	
H = no gum addition.	107
4.46 Typical storage ( $G'$ ) and loss ( $G''$ ) moduli as a function of frequency	
of treated and untreated gum ostrich-meat yors at a constant stress 5 Pa.	111
4.47 Typical creep curves of ostrich sausages varied xanthan gum and	
pressurised at 600 MPa, 50 °C with hold time 40 min (n = 6).	114
4.48 Typical creep curve with fitted four-element Burgers model.	115
4.49 Typical CSLM image of pressurised sample with added 0.50% (w/w) XAN.	117
4.50 Typical CSLM image of pressurised sample with added 0.75% (w/w) XAN.	117
4.51 Typical CSLM image of pressurised sample with added 1.00% (w/w) XAN.	118
4.52 Typical CSLM image of pressurised sample with added 1.25% (w/w) XAN.	118
A-1 Stress relaxation curves of ostrich-meat yor pressurised at 200, 400,	
and 600 MPa at 40 °C (holding time of 40 min).	140
A-2 Stress relaxation curves of ostrich-meat yor pressurised at 200, 400,	
and 600 MPa at 50 °C (holding time of 40 min).	140
A-3 Typical creep curves of ostrich-meat yor pressurised at 200, 400	
and 600 MPa at 40 °C with holding time of 40 min.	141
A-4 Typical creep curves of ostrich-meat yor pressurised at 200, 400	
and 600 MPa at 50 °C with holding time of 40 min.	141

## ABBREVIATIONS

ACCEPT	Acceptability
CHEW	Chewiness
CMC	Carboxymethylcellulose
CSLM	Confocal Scanning Laser Microscopy
DSC	Differential Scanning Calorimetry
FITC	Fluorescein Isothiocyanate
GEL_ST	Gel strength
GUM	Gumminess
HM	High methoxyl pectin
JUI	Juiciness
LBG	Locust bean gum
LM	Low methoxyl pectin
LVR	Linear Viscoelastic Regions
MCC	Mmicrocrystalline cellulose
MHC	Myosin Heavy Chain
MLC	Myosin Light Chain
PAGE	Polyacrylamide Gel Electrophoresis
SDS	Sodium Dodecyl Sulfate
SEM	Scanning Electron Microscope
SH_ST	Shear strength
SPR	Springiness
STPP	Sodium tripolyphosphate
TPA	Texture Profile Analysis
TPA_COHE	Cohesiveness from TPA
TPA_HD	TPA hardness
WHC	Water Holding Capacity
XAN	Xanthan gum

°C	Degree Celsius
h	hour
Hz	Hertz
J/g	Joule/gram
kg	kilogram
kDa	kilo Dalton
kPa	kilo Pascal
L/h	Liter/hour
min	minute
mm	millimeter
MPa	Mega Pascal
N	Newton
Pa	Pascal
sd	Standard deviation
sec	second
v/v	volume by volume
w/w	weight by weight
w/v	weight by volume
μm	micrometer

ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่  
 Copyright© by Chiang Mai University  
 All rights reserved