APPENDIX A

The profiles of stress relaxation and creep-recovery curves

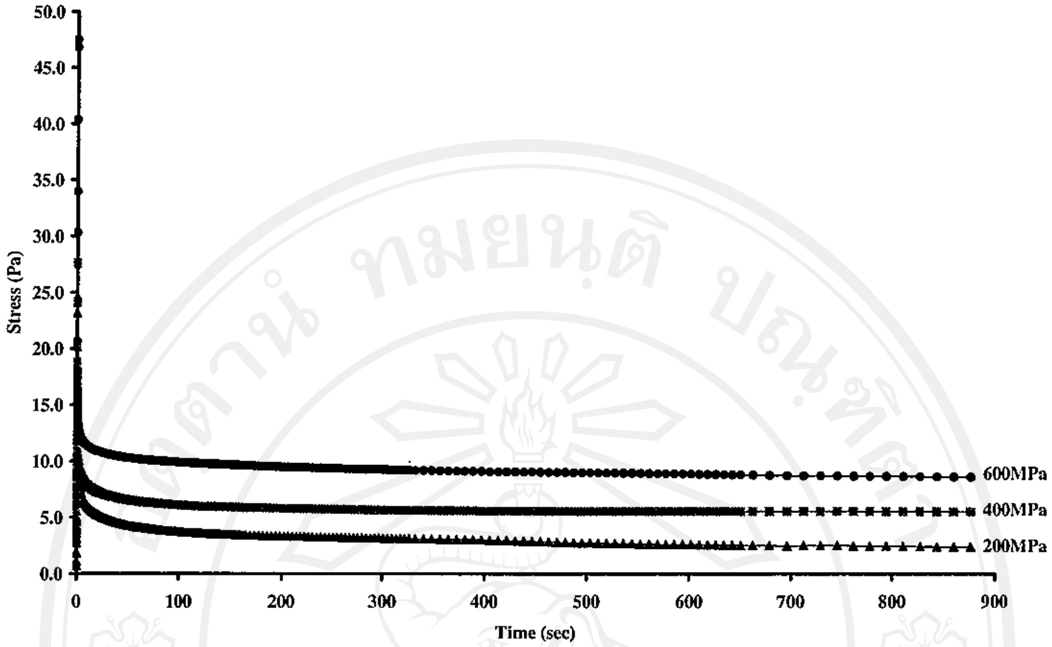

Figure A-1 Stress relaxation curves of ostrich-meat yor pressurised at 200, 400, and 600 MPa at 40 °C (holding time of 40 min).

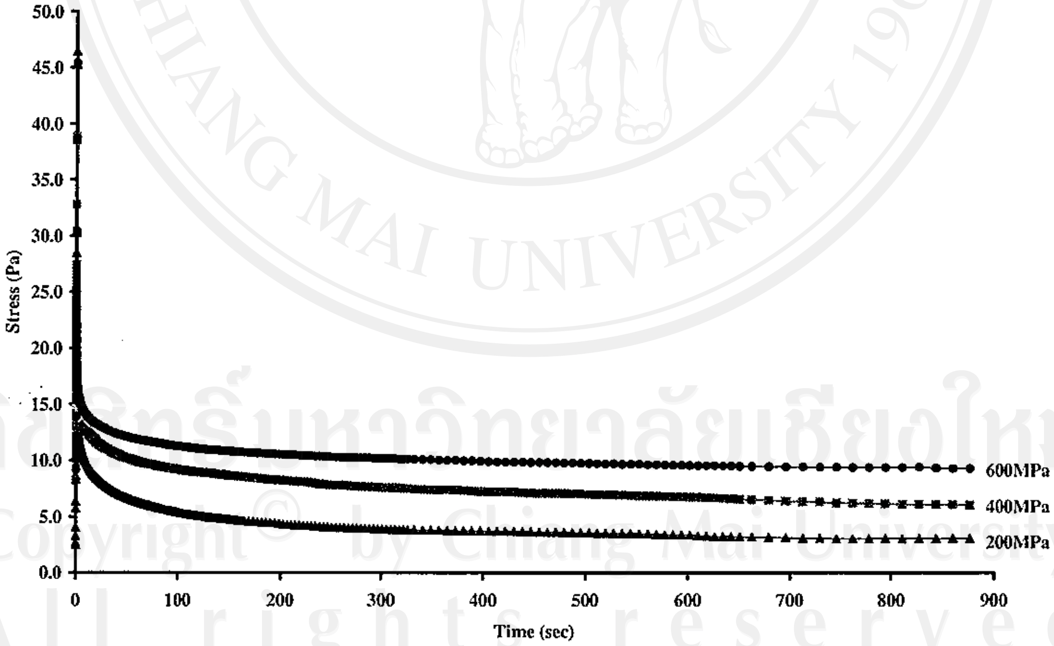

Figure A-2 Stress relaxation curves of ostrich-meat yor pressurised at 200, 400, and 600 MPa at 50 °C (holding time of 40 min).

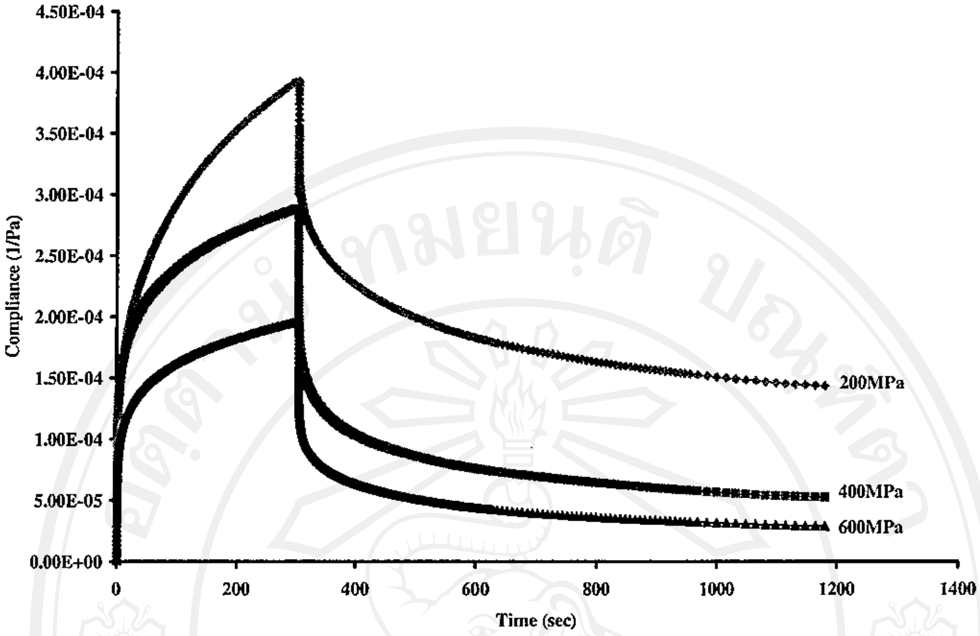

Figure A-3 Typical creep curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 40 °C with holding time of 40 min.

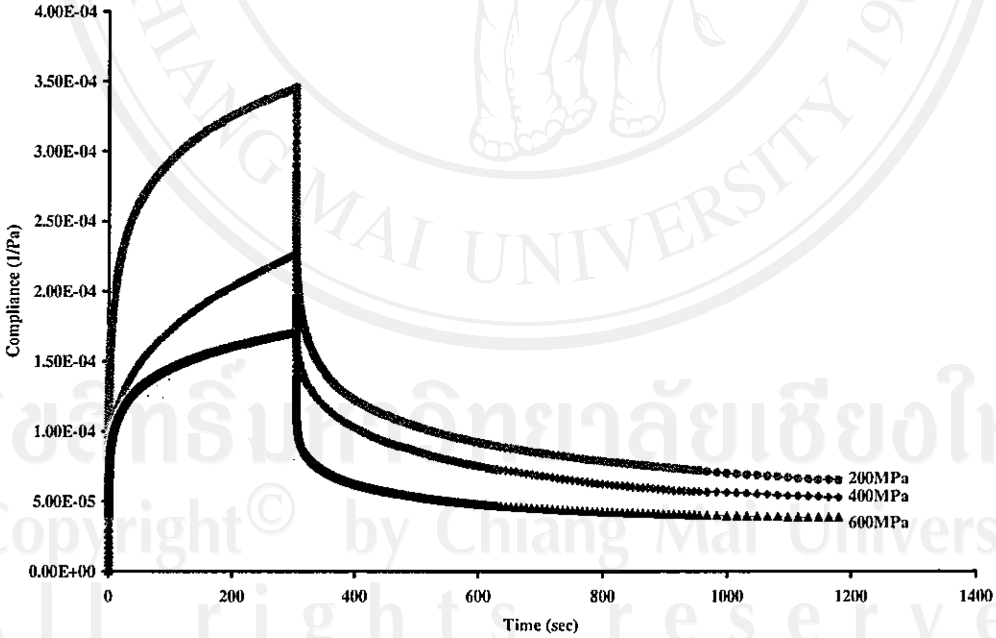

Figure A-4 Typical creep curves of ostrich-meat yor pressurised at 200, 400 and 600 MPa at 50 °C with holding time of 40 min.

APPENDIX B

The influences of interaction among of pressure, temperature and holding time on the properties of ostrich-meat yor

Table B-1 Interactions of pressure, temperature and holding time on viscoelastic parameters of model fitted into stress relaxation curve of ostrich-meat yors.

Pressure	Temperature		Stress relaxation parameters				
(MPa)	(°C)		σ_e (Pa)	A_1 (Pa)	λ_1 (Pa)	A_2 (Pa)	λ_2 (Pa)
200	40		2.24 ± 0.57^{ns}	29.23 ± 3.62^{a}	3.21 ± 0.15^{ns}	5.22 ± 2.18^{a}	123.97 ± 16.22^{ns}
200	50		3.67 ± 0.79^{ns}	32.19 ± 4.15^{b}	3.21 ± 0.15^{ns}	4.75 ± 1.84^{a}	119.31 ± 18.46^{ns}
400	40		5.87 ± 0.65^{ns}	22.44 ± 3.34^{d}	3.27 ± 0.16^{ns}	3.02 ± 0.78^{b}	132.01 ± 11.66^{ns}
400	50		6.94 ± 0.59^{ns}	24.33 ± 3.24^{cd}	3.32 ± 0.15^{ns}	5.41 ± 1.16^{a}	137.64 ± 7.88^{ns}
600	40		9.03 ± 0.71^{ns}	32.65 ± 3.51^{a}	3.36 ± 0.10^{ns}	3.35 ± 1.29^{b}	152.32 ± 14.47^{ns}
600	50		10.00 ± 0.90^{ns}	25.08 ± 6.74^{c}	3.41 ± 0.12^{ns}	4.82 ± 1.21^{a}	156.01 ± 5.21^{ns}
200		40	2.64 ± 1.02^{ns}	31.08 ± 5.31^{ab}	3.14 ± 0.15^{ns}	6.73 ± 1.11^{a}	111.62 ± 10.09^{c}
200		60	3.28 ± 0.90^{ns}	30.34 ± 2.60^{b}	3.27 ± 0.12^{ns}	3.23 ± 0.49^{d}	131.65 ± 17.06^{b}
400		40	6.15 ± 0.86^{ns}	22.30 ± 3.58^{c}	3.29 ± 0.17^{ns}	3.87 ± 1.61^{cd}	133.33 ± 10.34^{b}
400		60	6.66 ± 0.73^{ns}	24.47 ± 2.86^{c}	3.31 ± 0.14^{ns}	4.56 ± 1.50^{bc}	136.32 ± 10.19^{b}
600		40	9.22 ± 0.76^{ns}	33.19 ± 3.78^{a}	3.37 ± 0.12^{ns}	3.16 ± 1.34^{d}	153.53 ± 14.62^{a}
600		60	9.81 ± 1.03^{ns}	24.54 ± 5.81^{c}	3.40 ± 0.11^{ns}	5.02 ± 0.79^{b}	154.80 ± 5.44^{a}
	40	40	5.43 ± 2.98^{ns}	$27.21 \pm 7.08^{\underline{b}}$	3.24 ± 0.17^{ns}	3.93 ± 2.44^{ns}	132.09 ± 20.26^{ns}
	40	60	6.00 ± 2.87^{ns}	$29.00 \pm 3.20^{\underline{ab}}$	3.32 ± 0.12^{ns}	3.80 ± 0.76^{ns}	140.11 ± 15.84^{ns}
	50	40	6.58 ± 2.73^{ns}	$30.50 \pm 5.21^{\underline{a}}$	3.29 ± 0.18^{ns}	5.24 ± 1.36^{ns}	133.57 ± 22.07^{ns}
	50	60	7.16 ± 2.80^{ns}	$23.90 \pm 4.84^{\underline{c}}$	3.33 ± 0.14^{ns}	4.74 ± 1.47^{ns}	141.73 ± 15.31^{ns}

All values are the mean ± sd of five samples.

Means followed by the different letters within the same column are significantly different, $P \leq 0.05$ (analysed using Duncan's multiple range test).

ns, no significance different ($P > 0.05$) for any treatment.

Table B-2 Interactions of pressure, temperature and holding time on viscoelastic parameters for four-element Burgers model of creep curve of ostrich-meat yors.

Pressure	**Temperature**	**Time**	**Creep compliance parameters**					
(MPa)	**(°C)**	**(sec)**	**J_0 (1/Pa) ($x10^{-5}$)**	**G_0 (Pa) ($x10^3$)**	**J_1(1/Pa) ($x10^{-5}$)**	**G_1(Pa) ($x10^3$)**	**λ_{ret} (sec)**	**η_0(Pa.s) ($x10^6$)**
200	40		18.56 ± 5.31^{a}	5.78 ± 1.56^{d}	13.51 ± 0.78^{a}	7.43 ± 0.41^{e}	53.31 ± 1.09^{a}	2.99 ± 0.52^{ns}
200	50		16.10 ± 1.97^{b}	6.23 ± 0.80^{d}	10.79 ± 0.71^{b}	9.30 ± 0.63^{d}	50.61 ± 1.10^{b}	4.63 ± 0.76^{ns}
400	40		13.65 ± 1.04^{c}	7.37 ± 0.60^{c}	7.67 ± 1.43^{c}	13.48 ± 2.64^{c}	49.26 ± 0.60^{c}	6.69 ± 1.54^{ns}
400	50		10.30 ± 0.88^{d}	9.77 ± 0.86^{b}	6.04 ± 0.64^{d}	16.84 ± 1.86^{b}	48.98 ± 1.28^{c}	6.93 ± 2.59^{ns}
600	40		9.80 ± 0.53^{de}	10.23 ± 0.58^{b}	5.07 ± 0.46^{e}	19.89 ± 2.06^{a}	48.98 ± 1.79^{c}	8.56 ± 1.37^{ns}
600	50		8.92 ± 0.90^{e}	11.31 ± 1.12^{a}	4.80 ± 0.52^{e}	21.03 ± 2.15^{a}	46.66 ± 0.99^{d}	9.59 ± 1.39^{ns}
200		40	20.58 ± 3.42^{a}	4.98 ± 0.79^{f}	12.11 ± 1.58^{a}	8.37 ± 1.04^{e}	51.60 ± 2.02^{ns}	4.50 ± 0.99^{c}
200		60	14.29 ± 0.91^{b}	7.02± 0.42^{e}	12.06 ± 1.64^{a}	8.44 ± 1.19^{e}	52.16 ± 1.52^{ns}	3.27 ± 0.74^{b}
400		40	12.72 ± 1.82^{c}	8.01 ± 1.15^{d}	7.61 ± 1.46^{b}	13.61 ± 2.74^{d}	49.11 ± 1.34^{ns}	4.94 ± 0.60^{b}
400		60	11.23 ± 1.88^{d}	9.13 ± 1.51^{c}	6.10 ± 0.73^{c}	16.61 ± 1.97^{c}	49.14 ± 0.48^{ns}	8.68 ± 0.98^{a}
600		40	9.75 ± 0.55^{e}	10.28 ± 0.60^{b}	5.14 ± 0.38^{d}	19.57 ± 1.40^{b}	47.84 ± 1.83^{ns}	9.01 ± 1.81^{a}
600		60	8.97 ± 0.94^{e}	11.26 ± 1.16^{a}	4.73 ± 0.54^{d}	21.36 ± 2.42^{a}	47.80 ± 1.96^{ns}	9.13 ± 1.05^{a}
	40	40	15.56 ± 5.97$^{\underline{a}}$	7.28 ± 2.49$^{\underline{c}}$	8.88 ± 3.48^{ns}	13.01 ± 5.02$^{\underline{c}}$	50.39 ± 2.35^{ns}	5.60 ± 1.71^{ns}
	40	60	12.25 ± 2.07$^{\underline{b}}$	8.41 ± 1.55$^{\underline{b}}$	8.31 ± 3.92^{ns}	14.56 ± 5.94$^{\underline{b}}$	50.45 ± 2.37^{ns}	6.74 ± 3.20^{ns}
	50	40	12.81 ± 3.73$^{\underline{b}}$	8.39 ± 2.15$^{\underline{b}}$	7.47 ± 2.71^{ns}	15.00 ± 4.88$^{\underline{b}}$	48.56 ± 1.92^{ns}	6.77 ± 2.85^{ns}
	50	60	10.74 ± 2.83$^{\underline{c}}$	9.87 ± 2.30$^{\underline{a}}$	6.95 ± 2.74^{ns}	16.38 ± 5.57$^{\underline{a}}$	48.94 ± 2.09^{ns}	7.32 ± 2.54^{ns}

All values are the mean ± sd of five samples.

Means followed by the different letters within the same column are significantly different, $P \leq 0.05$ (analysed using Duncan's multiple range test).

ns, no significance different ($P > 0.05$) for any treatment.

Table B-3 Interactions of pressure, temperature and holding time on dynamic viscoelastic parameters of various ostrich-meat yors assessed by oscillatory measurement.

Pressure	Temperature	Time	Oscillatory parameters at 1 Hz		
(MPa)	(°C)	(sec)	G′ (kPa)	G″ (kPa)	Tan δ
200	40		10.37 ± 0.98^{a}	2.38 ± 0.13^{ns}	0.23 ± 0.01^{ab}
200	50		12.63 ± 0.63^{b}	2.89 ± 0.12^{ns}	0.23 ± 0.01^{abc}
400	40		13.71 ± 0.35^{d}	3.19 ± 0.07^{ns}	0.23 ± 0.00^{a}
400	50		16.53 ± 0.44^{c}	3.73 ± 0.11^{ns}	0.23 ± 0.00^{bc}
600	40		19.93 ± 0.89^{f}	4.18 ± 0.23^{ns}	0.21 ± 0.01^{d}
600	50		21.65 ± 1.01^{e}	4.84 ± 0.15^{ns}	0.22 ± 0.01^{c}
200		40	10.84 ± 1.49^{e}	2.57 ± 0.31^{ns}	0.24 ± 0.01^{a}
200		60	12.16 ± 1.00^{d}	2.70 ± 0.26^{ns}	0.22 ± 0.01^{cd}
400		40	15.01 ± 1.48^{c}	3.47 ± 0.35^{ns}	0.23 ± 0.00^{b}
400		60	15.24 ± 1.59^{c}	3.46 ± 0.24^{ns}	0.23 ± 0.01^{bc}
600		40	20.37 ± 1.09^{b}	4.46 ± 0.38^{ns}	0.22 ± 0.01^{de}
600		60	21.21 ± 1.37^{a}	4.56 ± 0.41^{ns}	0.21 ± 0.01^{e}
	40	40	14.31 ± 4.43^{ns}	3.20 ± 0.80^{ns}	0.23 ± 0.01^{ns}
	40	60	15.03 ± 3.86^{ns}	3.31 ± 0.75^{ns}	0.22 ± 0.01^{ns}
	50	40	16.50 ± 3.75^{ns}	3.80 ± 0.82^{ns}	0.23 ± 0.00^{ns}
	50	60	17.37 ± 3.98^{ns}	3.84 ± 0.85^{ns}	0.22 ± 0.01^{ns}

All values are the mean ± sd of five samples.

Means followed by the different letters within the same column are significantly different, *P*≤0.05 (analysed using Duncan's multiple range test).

ns, no significance different (*P*>0.05) for any treatment.

Table B-4 Interactions of pressure, temperature and holding time on textural parameters of ostrich-meat yors.

Pressure (MPa)	**Temperature (°C)**	**Time (sec)**	**Gel strength from puncture test (N.mm)**	**Hardness from compression test (N)**	**Shear strength from shear test (N/mm)**	**Shear energy from shear test (N/mm.sec)**
200	40		8.92 ± 1.19$^{\mathrm{f}}$	21.44 ± 3.31$^{\mathrm{ns}}$	0.13 ± 0.01$^{\mathrm{e}}$	0.43 ± 0.12$^{\mathrm{f}}$
200	50		10.95 ± 1.11$^{\mathrm{e}}$	28.14 ± 1.62$^{\mathrm{ns}}$	0.27 ± 0.00$^{\mathrm{d}}$	0.72 ± 0.01$^{\mathrm{e}}$
400	40		15.31 ± 2.24$^{\mathrm{d}}$	43.75 ± 2.38$^{\mathrm{ns}}$	0.37 ± 0.00$^{\mathrm{c}}$	0.92 ± 0.11$^{\mathrm{d}}$
400	50		17.93 ± 0.95$^{\mathrm{c}}$	50.27 ± 5.77$^{\mathrm{ns}}$	0.43 ± 0.00$^{\mathrm{b}}$	1.04 ± 0.01$^{\mathrm{c}}$
600	40		21.04 ± 1.02$^{\mathrm{b}}$	63.80 ± 3.82$^{\mathrm{ns}}$	0.49 ± 0.00$^{\mathrm{a}}$	1.35 ± 0.00$^{\mathrm{b}}$
600	50		24.83 ± 3.49$^{\mathrm{a}}$	70.88 ± 2.80$^{\mathrm{ns}}$	0.50 ± 0.00$^{\mathrm{a}}$	1.47 ± 0.12$^{\mathrm{a}}$
200		40	9.34 ± 1.58^{f}	23.42 ± 5.50$^{\mathrm{ns}}$	0.16 ± 0.01^{e}	0.51 ± 0.20$^{\mathrm{ns}}$
200		60	10.54 ± 1.29^{e}	26.16 ± 2.02$^{\mathrm{ns}}$	0.23 ± 0.01^{d}	0.65 ± 0.11$^{\mathrm{ns}}$
400		40	15.51 ± 2.38^{d}	44.04 ± 2.16$^{\mathrm{ns}}$	0.37 ± 0.00^{c}	0.92 ± 0.11$^{\mathrm{ns}}$
400		60	17.74 ± 1.13^{c}	49.98 ± 6.19$^{\mathrm{ns}}$	0.42 ± 0.00^{b}	1.04 ± 0.01$^{\mathrm{ns}}$
600		40	20.98 ± 0.98^{b}	65.06 ± 5.04$^{\mathrm{ns}}$	0.49 ± 0.00^{a}	1.35 ± 0.00$^{\mathrm{ns}}$
600		60	24.88 ± 3.43^{a}	69.62 ± 3.66$^{\mathrm{ns}}$	0.50 ± 0.00^{a}	1.46 ± 0.13$^{\mathrm{ns}}$
	40	40	13.86 ± 5.29$^{\mathrm{ns}}$	40.85 ± 18.22$^{\underline{\mathrm{c}}}$	0.30 ± 0.17$^{\underline{\mathrm{d}}}$	0.82 ± 0.43$^{\underline{\mathrm{d}}}$
	40	60	16.32 ± 5.10$^{\mathrm{ns}}$	45.15 ± 17.88$^{\underline{\mathrm{b}}}$	0.36 ± 0.14$^{\underline{\mathrm{c}}}$	0.98 ± 0.35$^{\underline{\mathrm{c}}}$
	50	40	16.69 ± 4.70$^{\mathrm{ns}}$	47.50 ± 17.39$^{\underline{\mathrm{b}}}$	0.38 ± 0.11$^{\underline{\mathrm{b}}}$	1.03 ± 0.29$^{\underline{\mathrm{b}}}$
	50	60	19.12 ± 7.26$^{\mathrm{ns}}$	52.03 ± 19.17$^{\underline{\mathrm{a}}}$	0.41 ± 0.01$^{\underline{\mathrm{a}}}$	1.12 ± 0.35$^{\underline{\mathrm{a}}}$

All values are the mean ± sd of five samples.

Means followed by the different letters within the same column are significantly different, $P \leq 0.05$ (analysed using Duncan's multiple range test).

ns, no significance different ($P > 0.05$) for any treatment.

Table B-5 Interactions of pressure, temperature and holding time on TPA parameters of ostrich-meat yors.

Pressure (MPa)	Temperature (°C)	Time (sec)	Hardness (N)	Springiness	Cohesiveness	Gumminess	Chewiness
200	40		10.39 ± 1.79^{f}	0.58 ± 0.01^{d}	0.62 ± 0.00^{e}	6.42 ± 1.10^{f}	3.78 ± 0.93^{f}
200	50		14.93 ± 1.83^{e}	0.71 ± 0.00^{c}	0.67 ± 0.00^{d}	9.96 ± 1.10^{e}	7.07 ± 0.87^{e}
400	40		23.48 ± 5.63^{d}	0.73 ± 0.00^{c}	0.71 ± 0.00^{c}	16.62 ± 3.90^{d}	12.18 ± 3.01^{d}
400	50		32.27 ± 4.23^{c}	0.77 ± 0.00^{b}	0.71 ± 0.00^{c}	22.96 ± 3.14^{c}	17.74 ± 2.73^{c}
600	40		47.10 ± 2.20^{b}	0.78 ± 0.00^{ab}	0.74 ± 0.00^{b}	34.85 ± 1.63^{b}	27.19 ± 1.68^{b}
600	50		53.18 ± 6.07^{a}	0.80 ± 0.00^{a}	0.79 ± 0.00^{a}	42.36 ± 5.86^{a}	34.02 ± 4.98^{a}
200		40	12.25 ± 2.85^{e}	0.61 ± 0.00^{d}	0.63 ± 0.00^{ns}	7.75 ± 1.99^{e}	4.90 ± 1.88^{e}
200		60	13.08 ± 3.09^{e}	0.68 ± 0.01^{c}	0.66 ± 0.00^{ns}	8.63 ± 2.22^{e}	5.95 ± 1.86^{e}
400		40	23.71 ± 5.82^{d}	0.75 ± 0.00^{b}	0.71 ± 0.00^{ns}	16.82 ± 4.16^{d}	12.64 ± 3.61^{d}
400		60	32.04 ± 4.48^{c}	0.76 ± 0.00^{b}	0.71 ± 0.00^{ns}	22.76 ± 3.24^{c}	17.28 ± 2.96^{c}
600		40	48.26 ± 3.49^{b}	0.79 ± 0.00^{a}	0.75 ± 0.00^{ns}	36.31 ± 3.97^{b}	28.68 ± 3.90^{b}
600		60	52.02 ± 6.49^{a}	0.79 ± 0.00^{a}	0.78 ± 0.00^{ns}	40.90 ± 6.39^{a}	32.53 ± 5.49^{a}
	40	40	25.27 ± 16.66^{ns}	0.68 ± 0.11^{ns}	0.68 ± 0.00^{ns}	17.79 ± 12.46^{ns}	13.11 ± 10.29^{ns}
	40	60	28.71 ± 15.36^{ns}	0.72 ± 0.01^{ns}	0.70 ± 0.01^{ns}	20.81 ± 12.19^{ns}	15.66 ± 9.99^{ns}
	50	40	30.87 ± 14.97^{ns}	0.75 ± 0.00^{ns}	0.71 ± 0.01^{ns}	22.80 ± 12.62^{ns}	17.71 ± 10.65^{ns}
	50	60	36.05 ± 17.97^{ns}	0.77 ± 0.00^{ns}	0.73 ± 0.01^{ns}	27.38 ± 15.44^{ns}	21.51 ± 12.78^{ns}

All values are the mean ± sd of five samples.

Means followed by the different letters within the same column are significantly different, $P \leq 0.05$ (analysed using Duncan's multiple range test).

ns, no significance different ($P > 0.05$) for any treatment.

Table B-6 Interactions of pressure, temperature and holding time on the amount of released plus expressible water of ostrich-meat yors.

Pressure (MPa)	Temperature (°C)	Time (sec)	% (Released+Expressible)
200	40		26.10 ± 4.24^{ns}
200	50		21.98 ± 1.75^{ns}
400	40		18.48 ± 2.08^{ns}
400	50		17.25 ± 1.66^{ns}
600	40		15.37 ± 4.03^{ns}
600	50		13.17 ± 0.79^{ns}
200		40	25.45 ± 3.85^{ns}
200		60	22.63 ± 3.41^{ns}
400		40	18.11 ± 2.05^{ns}
400		60	17.63 ± 1.91^{ns}
600		40	14.96 ± 3.24^{ns}
600		60	13.58 ± 2.86^{ns}
	40	40	20.93 ± 6.10^{ns}
	40	60	19.04 ± 5.54^{ns}
	50	40	18.09 ± 4.50^{ns}
	50	60	16.85 ± 3.48^{ns}

All values are the mean ± sd of five samples.

Means followed by the different letters within the same column are significantly different, $P \leq 0.05$ (analysed using Duncan's multiple range test).

ns, no significance different ($P > 0.05$) for any treatment.

APPENDIX C

The regression analysis of effects of hydrocolloids on the properties of ostrich-meat yor

Table C-1 Regression coefficients and analysis of variances of the regression models for stress relaxation parameters of pressurised ostrich-meat yors.

Model	**Stress relaxation parameters**				
	σ_e (Pa)	**A_1 (Pa)**	**λ_1 (Pa)**	**A_2 (Pa)**	**$\lambda_{2\ (Pa)}$**
Linear					
CMC	13.386***	44.982***	6.100***	13.128***	156.478***
LBG	25.938***	86.910***	6.400***	24.714***	192.078***
XAN	6.401***	40.146***	6.000***	7.950***	156.478***
Quardratic					
CMC x LBG	-24.072***	44.982***	-0.560	3.188	12.099
CMC x XAN	-24.244***	-16.216	-9.400***	-15.407**	-83.858***
LBG x XAN	18.259***	7.664	6.100	-35.897***	73.187***
Special cubic					
CMC x LBG x XAN	157.054***	456.953***	33.790***	191.177***	537.085***
R^2	0.995	0.989	0.996	0.989	0.998

***, **, * = Significant at $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, respectively.

Table C-2 Regression coefficients and analysis of variances of the regression models for creep parameters of pressurised ostrich-meat yors.

Model	**Creep compliance parameters**					
	J_0 (1/Pa) ($x10^{-5}$)	**G_0 (Pa) ($x10^{4}$)**	**J_1(1/Pa) ($x10^{-5}$)**	**G_1(Pa) ($x10^{3}$)**	**λ_{ret} (sec)**	**η_0 (Pa.s) ($x10^{6}$)**
Linear						
CMC	6.946***	1.444***	5.398***	1.855***	50.625***	8.698***
LBG	4.211***	2.396***	2.692***	3.730***	46.505***	17.144***
XAN	10.000***	1.001***	5.696***	1.764***	52.648***	8.851***
Quardratic						
CMC x LBG	10.100***	-2.735***	2.612*	-2.645***	8.141	-13.373***
CMC x XAN	47.290***	-2.917***	33.730***	-4.370***	5.967	-20.579***
LBG x XAN	-10.380***	2.208***	-4.744***	2.359***	-9.685	12.570***
Special cubic						
CMC x LBG x XAN	-215.200***	30.152***	-113.100***	18.696***	-37.713	66.943**
R^2	0.998	0.991	0.996	0.994	0.999	0.991

***, **, * = Significant at $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, respectively.

Table C-3 Regression coefficients and analysis of variances of the regression models for viscoelastic oscillatory parameters of pressurised ostrich-meat yors.

Model	Oscillatory parameters at 1 Hz		
	G' (kPa)	**G" (kPa)**	**Tan δ**
Linear			
CMC	19.834***	4.553***	0.230***
LBG	48.528***	10.784***	0.222***
XAN	17.280***	4.046***	0.234***
Quardratic			
CMC x LBG	-25.876***	-4.506***	0.041***
CMC x XAN	-5.228	1.788*	0.174***
LBG x XAN	-0.110	0.569	0.230
Special cubic			
CMC x LBG x XAN	212.280***	36.422***	-0.568***
R^2	0.999	0.998	1.000

***, **, * = Significant at $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, respectively.

Table C-4 Regression coefficients and analysis of variances of the regression models for textural parameters of pressurised ostrich-meat yors.

Model	Gel strength from puncture test (N.mm)	Hardness from compression test (N)	Shear strength from shear test (N/mm)	Shear energy from shear test (N/mm.sec)
Linear				
CMC	14.021***	52.616***	0.347***	1.053***
LBG	39.273***	132.490***	0.704***	1.835***
XAN	11.106***	30.446***	0.287***	0.920***
Quardratic				
CMC x LBG	-18.371***	-76.537***	-0.043	-0.047
CMC x XAN	-18.823***	-102.102***	-0.841***	-2.279***
LBG x XAN	46.392***	84.621***	0.370***	1.514***
Special cubic				
CMC x LBG x XAN	464.861***	1120.850***	4.042***	11.038***
R^2	0.998	0.999	0.998	0.999

***, **, * = Significant at $P \leq 0.001$, $P \leq 0.01$, $P \leq 0.05$, respectively.

Table C-5 Regression coefficients and analysis of variances of the regression models for TPA parameters of pressurised ostrich-meat yors.

Model	**TPA parameters**				
	Hardness (N)	**Springiness**	**Cohesiveness**	**Gumminess**	**Chewiness**
Linear					
CMC	27.862***	0.657***	0.433***	12.135***	7.851***
LBG	50.122***	0.737***	0.677***	33.903***	24.989***
XAN	14.041***	0.651***	0.371***	5.178***	3.279***
Quardratic					
CMC x LBG	-27.344***	0.162***	-0.392***	-33.262***	-23.19***
CMC x XAN	-41.048***	-0.078*	-0.199*	-19.541***	-12.429***
LBG x XAN	69.081***	0.162***	0.388***	44.379***	33.751***
Special cubic					
CMC x LBG x XAN	513.458***	0.766**	4.285***	365.818***	283.722***
R^2	0.999	1.000	0.995	0.997	0.999

***, **, * = Significant at *P*≤0.001, *P*≤0.01, *P*≤0.05, respectively.

Table C-6 Regression coefficients and analysis of variances of the regression models for sensory attributes of pressurised ostrich-meat yors.

Model	**Sensory attribution**				
	Colour	**Flavour**	**Juiciness**	**Cohesiveness**	**Acceptability**
Linear					
CMC	5.140***	4.620***	3.240***	2.320***	2.780***
LBG	6.260***	6.180***	6.380***	6.420***	6.500***
XAN	5.540***	4.580***	3.120***	1.700***	2.160***
Quardratic					
CMC x LBG	2.880**	4.400***	6.120***	6.040***	6.960***
CMC x XAN	0.240	1.280	6.000***	7.960***	6.840***
LBG x XAN	2.560*	3.040*	5.000***	8.720***	7.320***
Special cubic					
CMC x LBG x XAN	-3.583	-0.139	-11.926	2.243	-0.700
R^2	0.937	0.909	0.892	0.911	0.914

***, **, * = Significant at *P*≤0.001, *P*≤0.01, *P*≤0.05, respectively.

Table 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.

Model	%(Release+Expressible)
Linear	
CMC	14.123***
LBG	9.651***
XAN	18.496***
Quardratic	
CMC x LBG	3.766
CMC x XAN	13.883*
LBG x XAN	-7.325
Special cubic	
CMC x LBG x XAN	-65.131
R^2	0.986

***, **, * = Significant at *P*≤0.001, *P*≤0.01, *P*≤0.05, respectively.

Table C-8 Regression coefficients and analysis of variances of the regression models for mean size of fat droplets contributed in pressurised ostrich-meat yors.

Model	Mean size (μm^2)
Linear	
CMC	591.785***
LBG	694.210***
XAN	485.117***
Quardratic	
CMC x LBG	-463.356**
CMC x XAN	-1215.214***
LBG x XAN	2.944***
Special cubic	
CMC x LBG x XAN	-1514.544***
R^2	0.984

***, **, * = Significant at *P*≤0.001, *P*≤0.01, *P*≤0.05, respectively.

APPENDIX D

Questionnaire for Sensory Evaluation

Questionnaire for Sensory Evaluation of Pressurised Ostrich-meat Yor

Name.. Date... No..........

Instruction: Please taste these samples, to mark like/dislike score of each attribute from your feeling and rinse your mouth with plain water after finishing each trial. The score rate as follow:

1 = dislike extremely
2 = dislike very much
3 = dislike moderately
4 = dislike slightly
5 = Neither like nor dislike
6 = like slightl
7 = like moderately
8 = like very much
9 = like extremely

Attributes

Acceptability	Assessment all four attributes of product
Colour	Overall colour of product
Flavour	Overall flavour of product
Juiciness	Juciness of product; dry or juicy
Chewiness	Texture of product; very hard or very soft

Score

	....	....	....	....	....	....	....	....
Acceptability	....	....	....	....	....	....	....	....
Colour	....	....	....	....	....	....	....	....
Flavour	....	....	....	....	....	....	....	....
Juiciness	....	....	....	....	....	....	....	....
Chewiness	....	....	....	....	....	....	....	....

Comment : ....

....

....

Thank you for your cooperation

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Effects of hydrocolloid addition and high pressure processing on the rheological properties and microstructure of a commercial ostrich meat product "Yor" (Thai sausage)

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Abstract

"Yor" is a traditional sausage like product widely consumed in Thailand. Its textures are usually set by steaming, in this experiment ultra-high pressure was used to modify the product. Three types of hydrocolloid; carboxymethylcellulose (CMC), locust bean gum (LBG) and xanthan gum, were added to minced ostrich meat batter at concentration of 0–1% and subjected to high pressure 500 MPa, 50 °C, 40 min. The treated samples were analysed for storage (G') and loss (G'') moduli by dynamic oscillatory testing as well as creep compliance for control stress measurement. Their microstructures using confocal microscopy were also examined. Hydrocolloid addition caused a significant ($P < 0.05$) decrease in both the G' and G'' moduli. However the loss tangent of all samples remained unchanged. Addition of hydrocolloids led to decreases in the gel network formation but appears to function as surfactant materials during the initial mixing stage as shown by the microstructure. Confocal microscopy suggested that the size of the fat droplets decreased with gum addition. The fat droplets were smallest on the addition of xanthan gum and increased in the order CMC, LBG and no added gum, respectively. Creep parameters of ostrich yors with four levels of xanthan gum addition (0.50%, 0.75%, 1.00% and 1.25%) showed an ncrease in the instantaneous compliance (J_0), the retarded compliance (J_1) and retardation time (λ_1) but a decrease in the viscosity η_0) with increasing levels of addition. The results also suggested that the larger deformations used during creep testing might be more helpful in assessing the mechanical properties of the product than the small deformations used in oscillatory rheology.

Keywords: Ostrich sausages; Yor; Hydrocolloids; Rheology; Confocal microscopy; High pressure

. Introduction

Fresh or processed ostrich meat is gaining in importance n recent years and is promoted as a healthy "red meat" because of its exceptional nutritional properties and its low fat, cholesterol and salt levels. Ostrich meat, in general, is similar in protein, amino acid and mineral contents to other red meat sources (Cooper & Horbañczuk, 2002; Girolami et al., 2003).

Several ostrich meat products (Italian fermented sausages, "Vienna" ham and pressurised ostrich meats) are already found in European markets. Traditional sausages, known to Thai people as "Yor", are the most popular meat product in Thailand. It is made by grinding and blending the meat with ice cubes, vegetable oil, curing and flavoring agents (sodium chloride, phosphate, garlic, pepper, sugar, starch and monosodium glutamate). The finished product has a paste-like texture in the raw state but, gradually changes into a more rigid structure during cooking (Barbut, Gordon, & Smith, 1996; Thai Industrial Standards Institute, 1996).

Macromolecular hydrocolloids or gums are considered to influence many of the functional properties of processed meat products. They are commonly used in comminuted meat products as emulsifiers, water and fat binders and

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"texture modifying" ingredients. In addition, polysaccharide gums have been reported to affect the thermal transition temperatures of meat proteins (DeFreitas, Sebranek, Olson, & Carr, 1997; Fonkwe, Narsimhan, & Cha, 2003; Pietrasik, 2003). The addition of prehydrated or thermally activated hydrocolloid materials may structurally interfere with the cross-linking required for the protein gel network formation. This may give rise to "weaker" gel structures (Pérez-Mateos, Hurtado, Montero, & Fernández-Martín, 2001).

Yor contains a range of hydrocolloids added to improve texture and appearance. In this study three of the major systems used have been examined to assess their effects on the ostrich meat product. While it is appreciated that the gums themselves are unlikely to produce a "network" of carboxymethylcellulose (CMC), locust bean gum (LBG) or xanthan gum at the concentrations added (approximate 1% (w/w)) even after pressure treatment considerable organoleptic changes have been observed (Steyer et al., 1999).

High pressure processing of meat has been a relatively new and challenging area of research because of its potential in extending shelf-life (Fonberg-Broczek et al., 2005). Moreover, pressure treatment brings about changes in the constituent molecules of meat, and may affect the functional properties of proteins such as solubility, emulsification, surface tension, hydration and gelation properties (de Lamballerie-Anton, Taylor, & Culioli, 2002). High pressure can improve the texture of meat by increasing elasticity, water holding and binding properties, soften the structure as well as giving it an improved glossy appearance (Apichartsrangkoon, Ledward, Bell, & Brennan, 1998). To date little information has been published with regards to the effects of high pressure on ostrich meat systems.

In the present study basic quasi-static methods; creep and dynamic testing were used to assess the viscoelastic behaviour of ostrich meat emulsions during or after cooking. Several authors have studied the viscoelastic behaviour of food gels using these measurements. Apichartsrangkoon, Bell, Ledward, and Schofield (1999); Apichartsrangkoon and Ledward (2002); Apichartsrangkoon (2003) investigated the dynamic viscoelastic behaviour of high pressure treated wheat gluten, gluten-soy mixtures and soy protein gels and found that all responded as weak viscoelastic gels with a loss tangent (loss modulus G''/storage modulus G') of less than 1 indicating solid-like behaviour of the gel systems. Cross-link formation in these gels increased with increasing severity of the treatment. In addition, Jiménez-Avalos, Ramos-Ramírez, and Salazar-Montoya (2005) studied the dynamic oscillatory behaviour and the creep test of mixtures of gum arabic (GA) and maize starch (MS) gels and found that for the oscillatory test at low frequencies G' was slightly lower than G'' but, at higher frequencies the storage modulus predominated. In the creep test MS gels displayed full creep and recovery curves which is an indication of viscoelastic-solid behaviour whereas the mixture showed only a creep curve without recovery indicating viscoelastic-fluid behaviour. Some creep parameter can be used to describe the rheological characteristic. For instance in the measurement of a mixture of agar and κ-carrageenan gels with increasing κ-carrageenan, gel rigidity was reduced with a marked increase of instantaneous compliance (J_0) and long retardation times (Norziah, Foo, & Karim, 2006).

Therefore, the aims of this study were to investigate the effects of the addition of hydrocolloids and high pressure processing on the rheological behaviour, by the application of oscillatory and transient testing, as well as the microstructure, by confocal microscopy of ostrich yor.

2. Materials and methods

2.1. Ostrich yor preparation

Minced ostrich meat was purchased from Alternatived Meats Ltd., Shropshire, UK with a proximate composition of 76.46% moisture, 20.78% protein, 1.90% fat, 0.89% ash and pH 6.40 (AOAC, 2000). The ostrich yors were manufactured according to a commercial yor formulation. The comminuted ostrich meat was chopped with 2% (w/w) sodium chloride and 5% (w/w) sodium tripolyphosphate. Flavoring agents (garlic and pepper) were omitted in this experiment. Then linseed oil 5% (w/w), ice 5% (w/w) and gums in dry powder form were added to the meat batter. Four sausage formulations were developed using three types of gums at 1% (w/w), carboxymethylcellulose (CMC) (Nippon Paper Chemicals co., Ltd., Japan), locust bean gum (LBG) (System Bio-Industries Maroc SA, Marocco) and xanthan gum (CP Kelco US, Inc., USA) and a control containing no added gum. The yor produced from these formulations were assessed by oscillatory testing for storage (G') and loss (G'') moduli. Formulations using four levels of xanthan gum, 0.50%, 0.75%, 1.00% and 1.25% (w/w) were assessed by transient testing for creep compliance.

Each formulation was subsequently packed into synthetic sausage casing (Food EQ Ltd., Thailand, 29 mm diameter) prior to pressure treatment. Samples were pressurised at 600 MPa and 50 °C for 40 min (found from previous experiments to cause complete denaturation of the meat proteins as assessed by differential scanning calorimetry) using a 'Food lab' high pressure rig (Stansted Fluid Power, Essex, UK). After treatment, samples were kept at 4 °C for further analysis.

2.2. Rheological measurements

Samples were assessed rheologically by both small deformation oscillatory rheology and creep compliance (Stress Tech Rheometer, Rheological Instruments AB, Lund, Sweden). Dynamic oscillatory assessments were taken using parallel plates geometry (20 mm diameter with a gap of 2 mm) as a function of the frequency (0.01–10 Hz). Edges of samples were covered by silicone oil to prevent drying. The stress used (5 Pa) was found to be within the linear viscoelastic region of all of the samples measured at 1 Hz (Fig. 1). Both creep and recovery of the samples was determined (Initial load 50 Pa for 300 s, unloaded recovery 600 s). Using Maxwell and Kelvin–Voight models for curve fitting, a four-element Burgers model was found (Steffe, 1996). Initial compliance (J_0), retarded compliance (J_1), retardation time (λ_1) and asymptotic viscosity (η_0) were determined according to this model. All rheological measurements are the mean values determined from assessment of six samples from six individual pressure treatments ($n = 6$).

2.3. Confocal scanning laser microscopy (CSLM)

Ostrich sausage samples (1–2 mm thick) were stained with a mixture of Fluorescein Isothiocyanate (FITC, 0.02% w/v in water/ethanol) and Nile Red (0.02% w/v in ethanol) for protein and fat, respectively. A Leica scanning laser microscopy (Leica Microsystems Heidelberg, Germany) equipped with a helium/neon laser was used for the fluorescence excitation (500–530 nm for FITC and 505–586 nm for Nile Red). Data from representative areas for each sample were taken using a 10X magnification objective.

2.4. Image analysis

For image processing and analysis, the ImageJ software was used. The digital image files (* · TIF) were converted to 8-bit greyscale and the particle size distribution was analysed.

2.5. Statistical analysis

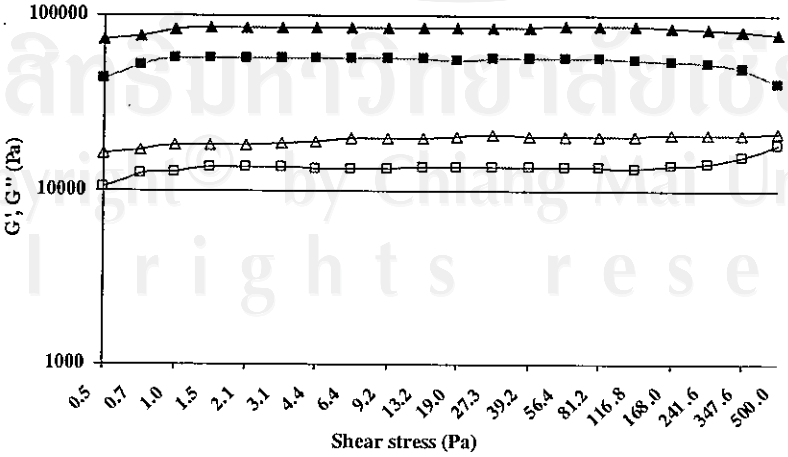
Results for all treatments were analysed by an analysis of variance using a completely randomized design and he general linear model procedure of the SPSS 10.0.1 software (SPSS inc., Chicago, USA) with batch as a random factor. Significant univariate differences at $\alpha = 0.05$ were assessd by Duncan's test.

3. Results and discussion

Dynamic rheological measurement for storage modulus (G'), loss modulus (G'') and loss tangent ($\tan\delta$) are among parameters that characterise the ostrich yor system generated by high pressure treatments in which G' and G'' are measures of the energy stored and dissipated in the material whereas $\tan\delta$ is G'' divided by G' (Jiménez-Avalos et al., 2005). The basic formulation when exposed to high pressure (600 MPa, 40 min, 50 °C) shows essentially weak viscoelastic behaviour with G' being greater than G'' over all of the measured frequency range (Fig. 2). The "weak" nature of the system is reflected in the slight frequency dependency of the moduli and the relatively low loss tangent (0.24 at 1 Hz) (Ferry, 1980).

Apichartsrangkoon et al. (1999); Apichartsrangkoon (2002); Apichartsrangkoon and Ledward (2002); Apichartsrangkoon (2003) pressurised and heated gluten and soy protein and found that G' and G'' increased with severity of treatment and displayed little frequency dependence which was an indication of a stronger gel structure with a more solid-like characteristic, suggesting that the strong gel had a higher cross-link density than the weaker gel structure.

Moreover, all samples containing mixtures of polysaccharide and meat showed a significant ($P < 0.05$) decrease in both the storage and loss moduli when compared with the untreated sample. Therefore, adding hydrocolloids led to a decrease in the network interactions. This implies that added hydrocolloid gives rise to less elastic-like behaviour compared to the control sample. However the loss tangent of all samples remained essentially unchanged. The profile remaining that of a weak viscoelastic gel (Fig. 2). Doerscher, Briggs, and Lonergan (2003) suggested that the



ig. 1. Stress amplitude sweep at frequency 1 Hz of high-pressure-treated ostrich meat yor, storage modulus (G'; closed symbols) and loss modulus ″; opened symbols), (▲, △) no added polysaccharide, (■, □) 1.0% added xanthan gum ($n = 6$).

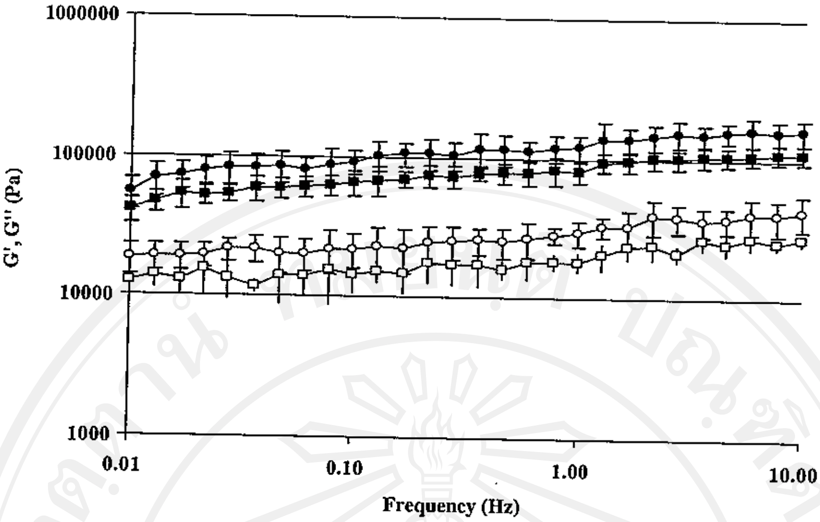


Fig. 2. Storage (*G′*; closed symbols) and Loss (*G″*; opened symbols) moduli as a function of frequency of pressure treated ostrich meat yor with (●, ○) no added polysaccharide and (■, □) 1.0% added xanthan gum ($n = 6$).

non-meat ingredients incorporated had no effect on the gelling properties of meat proteins. Regenstein (1989) noted that non-meat ingredients may function in one or more ways: supplementing the muscle proteins by forming a protein matrix in the aqueous phase and directly participating in the myofibrillar matrix, improving water retention and/or complementing the activity of the aqueous phase muscle proteins by acting as surface active material at the oil/water interface.

Confocal microscopy suggested that the pressure treated samples consist of a general protein matrix (continuous area, stained green[1]) with fat material (light round areas, stained red), fairly evenly distributed in droplets throughout the structure (Fig. 3a). Using standard image analysis techniques, these droplets can be seen to decrease in mean size depending on the polysaccharide added (Fig. 3 and Table 1). The most marked reduction occurring with xanthan (Fig. 3d, see also Table 1), however the main protein matrix seems essentially the same in all of the samples and it may be this which is responsible for the similar "weak" viscoelastic behaviour observed by small strain oscillatory rheology (Ferry, 1980).

Locust bean gum (LBG) is essentially 1–4 linked linear polymers and may be regarded as a neutral polymer. Hence, LBG being both non-ionic and with only "single sugar" side groups was observed to produce only a limited reduction in fat droplet size (Pettitt, 1969). Both carboxymethylcellulose (CMC) and xanthan are anionic in nature ($-COO^-$), which likely interact with meat proteins by cross-linking their negatively charged carboxyl groups with the positively charged side chains of amino acids in the meat protein (Morin, Temelli, & McMullen, 2004; Ramírez, Barrera, Morales, & Vázquez, 2002). While CMC is linear polymers, xanthan differs in having a highly branched structure (Nussinovitch, 1997). It is likely that both the branched and the charged nature of the xanthan is responsible for its enhanced surface activity in the product leading to the smaller fat droplets observed (Fig. 3). While the polysaccharides do not seem to produce a coherent network contributing to the physical structure, they do seem to have a role as "surfactants" acting on fat droplet size.

Table 1 also shows the effect of xanthan concentration on the mean fat droplet size in five further samples of pressure treated meat. This suggests a steady decrease in fat droplet size with increasing xanthan concentration and further supports the hypothesis that the polysaccharide material is acting as a surfactant in the original mixing process prior to pressure treatment, rather than contributing to any network formation in the final product. Accordingly, the reduction in fat droplet size by the polysaccharide acting as a surfactant results in a better quality of emulsion in the ostrich yor. Morin et al. (2004) studied the interactions between meat protein and hydrocolloids in a reduced-fat sausage, and found that adding 0.8% β-glucan in the sausage led to a denser matrix with small pores than those made with 0.3% β-glucan or CMC. Samples with 0.8% β-glucan had higher water holding capacity, as a result of a fine, uniform structure with numerous small pores or open spaces which would probably give more absorptive capacity and better retention of water compared to coarse structures with large pores.

The behaviour of a solid gel network under constant stress (50 Pa) can be followed by a creep experiment (Van Camp & Huyghebaert, 1995). Application of an instantaneous shear stress within the elastic limit causes stretching, squeezing, breakage, and reformation of gel

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[1] For interpretation of color in Fig. 3, the reader is referred to the web version of this article.

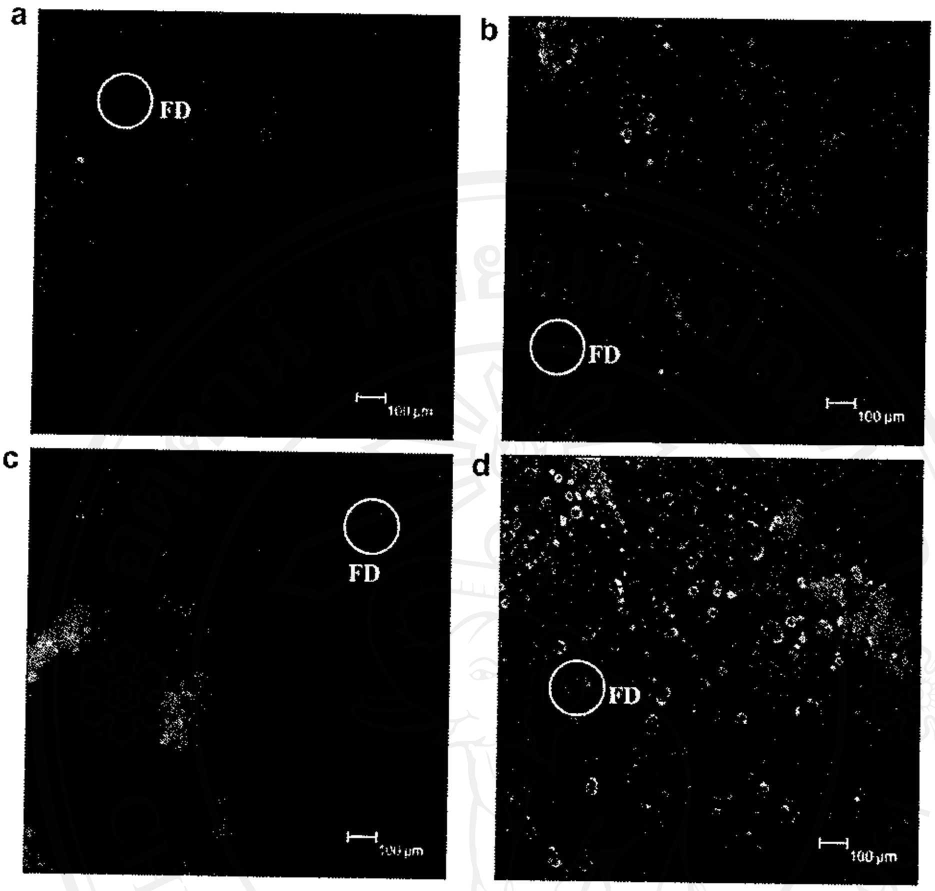

Fig. 3. Confocal scanning laser microscopy images of pressure treated samples with added polysaccharide, light round areas in white circle = fat droplet (FD). (a) No added polysaccharide, (b) Added carboxymethylcellulose (CMC) 1%, (c) Added locust bean gum (LBG) 1%, (d) Added xanthan gum 1%.

Table 1
Mean size of fat droplets distributed in ostrich sausages with three types of gums and four levels of added xanthan gum ($n = 5$)

reatment	Mean size (µm^2)	% Xanthan	Mean size (µm^2)
o added gum	929.50 ± 42.59	0.50	1,114.48 ± 106.25
% CMC	591.79 ± 9.38	0.75	622.93 ± 21.84
% LBG	694.21 ± 29.76	1.00	569.19 ± 13.97
% X anthan	485.12 ± 45.83	1.25	398.13 ± 9.31

etwork bonds, including flow of the viscoelastic materi-ls which generates creep behaviour. The rates of break-ge and reformation of these bonds vary and contribute lifferently to the temporal retarded compliance. Fig. 4 hows the creep-recovery curves of pressurised ostrich ausages with various xanthan concentrations with all lata fitted using four-element Burgers model (Fig. 5). s illustrated in Fig. 5, the creep curves consist of three egions: an instantaneous compliance (represented by the pring unit of the Maxwell element); an intermediate egion of retarded compliance (represented by the Kel-in–Voight element); and the final region of Newtonian ow at long times (represented by the dashpot of the laxwell element) which are all described by the equation teffe, 1996)

$$J(t) = J_0 + J_1[1 - \exp(-t/\lambda_1)] + t/\eta_0 \qquad (1)$$

The initial instantaneous compliance, J_0, which is derived from the curve intercept on the compliance axis of the graph is shown in Table 2. A higher gel rigidity exhibits a lower J_0 and Table 2 shows higher values of the instantaneous compliance, J_0, and the retarded compliance, J_1, with increasing concentration of xanthan, indicating the softer and less rigid nature of the gel system. The corresponding retardation time, λ_1 (η_1/G_1) also displayed an overall increase with increasing xanthan concentration. Generally, the higher the retardation time of the network, the longer it takes to reach full deformation on application of shear stress. This also implies that the retardation times are inversely related to network elasticity. (Ojijo et al., 2004). In addition, newtonian viscosity (η_0), which is derived from the slope (the strain rate) of the curve at large values of time may be attributed to the breakdown of protein network structures (Messens, Van de Walle, Arevalo, Dewettinck, & Huyghebaert, 2000). A decrease in η_0 was observed with an increase in xanthan concentration, indicating a lower resistance to flow. Thus, Table 2 and Fig. 4 both show "decreasing network structure" with increasing xanthan concentration or a less solid-like behaviour in ostrich sau-

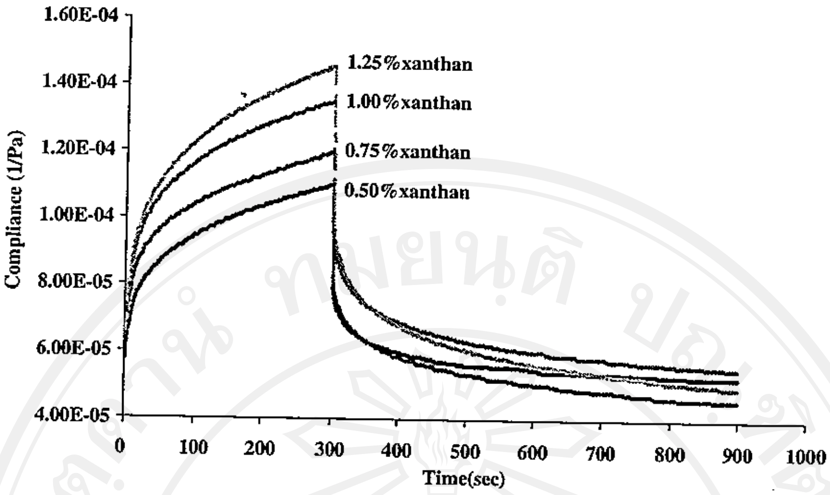

Fig. 4. Creep curves of ostrich sausages varied xanthan gum and pressurised at 600 MPa, 50 °C with hold time 40 min ($n = 6$).

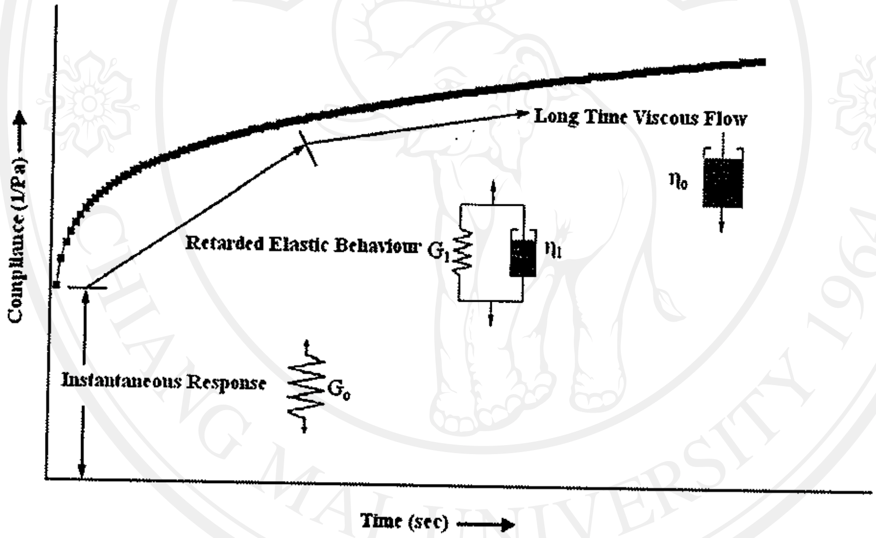

Fig. 5. Typical creep curve with fitted four-element Burgers model.

Table 2
Creep parameters of ostrich sausages with four levels of added xanthan gum ($n = 6$)

% Xanthan	J_0 (1/Pa) ($\times10^{-6}$)	J_1 (1/Pa) ($\times10^{-6}$)	λ_1 (s)	η_0 (Pa s) ($\times10^{6}$)
0.50	57.28 ± 4.74	32.68 ± 5.03	23.42 ± 2.97	15.38 ± 2.71
0.75	62.21 ± 3.84	35.59 ± 6.29	22.42 ± 4.27	14.49 ± 4.47
1.00	64.01 ± 8.80	47.58 ± 4.61	27.67 ± 2.42	13.94 ± 3.65
1.25	65.81 ± 5.04	51.34 ± 5.49	27.56 ± 2.12	10.77 ± 1.63

sages. Both the elasticity and viscosity (η_0) seems to fall with increasing xanthan concentration. Similar results were reported by Bejosano and Corke (1999) who heated maize starch gels incorporating protein concentrate and found that increasing protein concentration produced less elasticity and viscosity or less rigid gel structures as indicated by higher J_0 values in the creep experiment.

The redistribution of fat in the xanthan treated samples produces only limited effects when examined by oscillatory technique whereas creep compliance testing showed major changes.

4. Conclusions

Three types of added polysaccharides i.e. CMC, LBG and xanthan gum do not contribute to network formation in the pressure treated samples however they seem to function as surfactants involved in the distribution of fat during the mixing process which improved the yor quality to some extent.

Dynamic oscillatory measurements, while gives good information on the extent of protein network formation, is unsuitable as a technique to show the textural changes in the product. This is better demonstrated by the deformations present in creep testing.

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References

AOAC (2000). *Official methods of analysis* (2nd ed.). Washington, DC:: Association of Official Analytical Chemists..

Apichartsrangkoon, A. (2002). Dynamic viscoelastic properties of heated gluten/soy protein gels. *Journal of Food Science, 67*, 653–657.

Apichartsrangkoon, A. (2003). Effects of high pressure on rheological properties of soy protein gels. *Food Chemistry, 80*, 55–60.

Apichartsrangkoon, A., Bell, A. E., Ledward, D. A., & Schofield, J. D. (1999). Dynamic viscoelastic behaviour of high-pressure-treated wheat gluten. *Cereal Chemistry, 76*, 777–782.

Apichartsrangkoon, A., & Ledward, D. A. (2002). Dynamic viscoelastic behaviour of high pressure treated gluten–soy mixtures. *Food Chemistry, 77*, 317–323.

Apichartsrangkoon, A., Ledward, D. A., Bell, A. E., & Brennan, J. G. (1998). Physicochemical properties of high pressure treated wheat gluten. *Food Chemistry, 63*, 215–220.

Barbut, S., Gordon, A., & Smith, A. (1996). Effect of cooking temperature on the microstructure of meat batters prepared with salt and phosphate. *Lebensmittel-wissenschaft und-technologie, 29*, 475–480.

Bejosano, F. P., & Corke, H. (1999). Effect of Amaranthus and buckwheat proteins on the rheological properties of maize starch. *Food Chemistry, 65*, 493–501.

Cooper, R. G., & Horbañczuk, J. O. (2002). Anatomical and physiological characteristics of ostrich (*Struthio camelus var. domesticus*) meat determine its nutritional importance for man. *Animal Science Journal, 73*, 167–173.

DeFreitas, Z., Sebranek, J. G., Olson, D. G., & Carr, J. M. (1997). Freeze/thaw stability of cooked pork sausages as affected by salt, phosphate, pH, and carrageenan. *Journal of Food Science, 62*, 551–554.

e Lamballerie-Anton, M., Taylor, R. G., & Culioli, J. (2002). High pressure processing of meat. In J. Kerry, J. Kerry, & D. Ledward (Eds.), *Meat processing: Improving quality*. Cambridge: Woodhead Publishing Ltd. and CRC Press LLC. (chapter 16).

oerscher, D. R., Briggs, J. L., & Lonergan, S. M. (2003). Effects of pork collagen on thermal and viscoelastic properties of purified porcine myofibrillar protein gels. *Meat Science, 66*, 181–188.

Ferry, J. D. (1980). *Viscoelastic properties of polymers* (3rd ed.). New York: John Wiley & Sons.

Fonberg-Broczek, M., Windyga, B., Szczawiński, J., Szczawińska, M., Pietrzak, D., & Prestamo, G. (2005). High pressure processing for food safety. *Acta Biochimica Polonica, 52*, 721–724.

Fonkwe, L. G., Narsimhan, G., & Cha, A. S. (2003). Characterization of gelation time and texture of gelatin and gelatin-polysaccharide mixed gels. *Food Hydrocolloid, 17*, 871–883.

Girolami, A., Marsico, I., D'Andrea, G., Braghieri, A., Napolitano, F., & Cifuni, G. F. (2003). Fatty acid profile, cholesterol content and tenderness of ostrich meat as influenced by age at slaughter and muscle type. *Meat Science, 64*, 309–315.

Jiménez-Avalos, H. A., Ramos-Ramírez, E. G., & Salazar-Montoya, J. A. (2005). Viscoelastic characterization of gum arabic and maize starch mixture using the Maxwell model. *Carbohydrate Polymers, 62*, 11–18.

Messens, W., Van de Walle, D., Arevalo, J., Dewettinck, K., & Huyghebaert, A. (2000). Rheological properties of high-pressure-treated Gouda cheese. *International Dairy Journal, 10*, 359–367.

Morin, L. A., Temelli, F., & McMullen, L. (2004). Interactions between meat proteins and barley (*Hordeum* spp.) β-glucan within a reduced-fat breakfast sausage system. *Meat Science, 68*, 419–430.

Norziah, M. H., Foo, S. L., & Karim, A. Abd. (2006). Rheological studies on mixtures of agar (*Gracilaria changii*) and κ-carrageenan. *Food Hydrocolloids, 20*, 204–217.

Nussinovitch, A. (1997). *Hydrocolloid Applications: Gum Technology in the Food and Other Industry*. Great Britain: T.J Press Chapman & Hall. (chapter 6, 8, 9).

Ojijo, N. K. O., Kesselman, E., Eichler, S., Shuster, V., Neeman, I., Eger, S., et al. (2004). Changes in microstructural, thermal, and rheological properties of olive oil/monoglyceride networks during storage. *Food Research International, 37*, 385–393.

Pérez-Mateos, M., Hurtado, J. L., Montero, P., & Fernández-Martín, F. (2001). Interactions of κ-carrageenan plus other hydrocolloids in fish myosystem gels. *Journal of Food Science, 66*, 838–843.

Pettitt, D. J. (1969). Xanthan. In G. Martin (Ed.), *Gum technology in the food industry* (pp. 127–149). New York: Academic Press.

Pietrasik, A. (2003). Binding and textural properties of beef gels processed with κ-carrageenan, egg albumin and microbial transglutaminase. *Meat Science, 63*, 317–324.

Ramírez, J. A., Barrera, M., Morales, O. G., & Vázquez, M. (2002). Effect of xanthan and locust bean gums on the gelling properties of myofibrillar protein. *Food Hydrocolloid, 16*, 11–16.

Regenstein, J. M. (1989). Are comminuted meat products emulsions or gel matrix?. In J. E. Kinsella & W. G. Soucie (Eds.) *Food proteins* (pp. 178–184). Champaign, IL: American Oil Chemists' Society.

Steffe, J. F. (1996). *Rheological methods in food process engineering* (2nd ed.). Michigan: Freeman.

Steyer, B., Béra, F., Massaux, C., Sindic, M., Blecker, Ch., & Deroanne, C. (1999). Carrageenan gelification under high hydrostatic pressure: preparation and processing of solutions and analysis of gels obtained. In H. Ludwig (Ed.), *Advances in high pressure bioscience and biotechnology* (pp. 353–356). Heidelberg: Springer-Verlag Berlin.

Thai Industrial Standards Institute. (1996). Standard for mu yor sausage. (in Thai). Bangkok: Thai Industrial Standards Institute.

Van Camp, J., & Huyghebaert, A. (1995). A comparative rheological study of heat and high pressure induced whey protein gels. *Food Chemistry, 54*, 357–364.