

**Table 2.1 pH values of fermented and raw samples**

	<b>PM1</b>	<b>PM2</b>	<b>PM3</b>	<b>Sor</b>
RAW	6.84±0.02 <sup>c</sup>	6.78±0.03 <sup>c</sup>	6.83±0.02 <sup>d</sup>	6.75±0.01 <sup>d</sup>
145	4.39±0.00 <sup>b</sup>	4.35±0.04 <sup>b</sup>	4.84±0.01 <sup>c</sup>	5.09±0.01 <sup>c</sup>
511	3.85±0.01 <sup>a</sup>	3.76±0.01 <sup>a</sup>	3.87±0.01 <sup>b</sup>	4.11±0.01 <sup>a</sup>
W14	3.75±0.01 <sup>a</sup>	3.73±0.01 <sup>a</sup>	3.76±0.01 <sup>a</sup>	4.31±0.04 <sup>b</sup>

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.

**Table 2.2 Organic acids and sugar contents**

	<b>Acetic acid</b>	<b>Citric acid</b>	<b>Lactic acid</b>	<b>Glucose</b>	<b>Maltose</b>	<b>Fructose</b>
145 PM1	15.4±0.01 <sup>c</sup>	45.9±1.52 <sup>c</sup>	133.2±2.52 <sup>b</sup>	1.53±0.13 <sup>c</sup>	0.09±0.12 <sup>a</sup>	0.19±0.01 <sup>b</sup>
511 PM1	11.4±0.04 <sup>b</sup>	21.8±2.56 <sup>b</sup>	306.7±7.67 <sup>c</sup>	1.40±0.05 <sup>bc</sup>	0.00 <sup>a</sup>	0.22±0.00 <sup>c</sup>
W14 PM1	11.5±0.10 <sup>b</sup>	7.78±1.05 <sup>a</sup>	388.6±11.5 <sup>d</sup>	0.72±0.04 <sup>a</sup>	0.00 <sup>a</sup>	0.15±0.00 <sup>a</sup>
Raw PM1	0.00 <sup>a</sup>	52.9±0.00 <sup>d</sup>	0.00 <sup>a</sup>	1.24±0.00 <sup>b</sup>	0.00 <sup>a</sup>	0.33±0.14 <sup>d</sup>
145 PM2	16.1±0.71 <sup>c</sup>	8.13±0.10 <sup>a</sup>	113.0±6.00 <sup>b</sup>	0.92±0.01 <sup>b</sup>	0.00 <sup>a</sup>	0.27±0.00 <sup>c</sup>
511 PM2	14.2±0.27 <sup>bc</sup>	13.5±1.13 <sup>b</sup>	284.0±5.08 <sup>c</sup>	1.00±0.07 <sup>b</sup>	0.00 <sup>a</sup>	0.15±0.01 <sup>b</sup>
W14 PM2	13.5±1.19 <sup>b</sup>	6.32±0.71 <sup>a</sup>	283.9±4.92 <sup>c</sup>	0.56±0.01 <sup>a</sup>	0.00 <sup>a</sup>	0.10±0.00 <sup>a</sup>
Raw PM2	0.00 <sup>a</sup>	46.8±0.00 <sup>c</sup>	0.00 <sup>a</sup>	0.65±0.02 <sup>a</sup>	0.00 <sup>a</sup>	0.24±0.00 <sup>d</sup>
145 PM3	10.9±0.47 <sup>b</sup>	45.0±1.11 <sup>c</sup>	55.0±4.04 <sup>b</sup>	0.69±0.00 <sup>b</sup>	0.00 <sup>a</sup>	0.37±0.01 <sup>c</sup>
511 PM3	14.0±0.18 <sup>c</sup>	12.4±0.37 <sup>b</sup>	253.0±4.10 <sup>c</sup>	1.20±0.04 <sup>d</sup>	0.00 <sup>a</sup>	0.27±0.01 <sup>b</sup>
W14 PM3	11.2±0.41 <sup>b</sup>	9.54±0.16 <sup>a</sup>	291.8±2.22 <sup>d</sup>	0.45±0.01 <sup>a</sup>	0.00 <sup>a</sup>	0.13±0.00 <sup>a</sup>
Raw PM3	0.00 <sup>a</sup>	54.9±0.00 <sup>d</sup>	0.00 <sup>a</sup>	1.03±0.03 <sup>c</sup>	0.00 <sup>a</sup>	0.40±0.00 <sup>d</sup>
145 Sor	15.3±0.08 <sup>d</sup>	11.0±1.50 <sup>a</sup>	55.6±1.55 <sup>b</sup>	0.17±0.02 <sup>b</sup>	0.00 <sup>a</sup>	2.00±0.35 <sup>c</sup>
511 Sor	10.9±0.23 <sup>b</sup>	48.3±0.89 <sup>b</sup>	150.6±2.86 <sup>d</sup>	0.13±0.01 <sup>b</sup>	0.17±0.00 <sup>b</sup>	0.11±0.00 <sup>b</sup>
W14 Sor	13.7±0.30 <sup>c</sup>	12.3±0.79 <sup>a</sup>	114.0±0.32 <sup>c</sup>	0.05±0.02 <sup>a</sup>	0.00 <sup>a</sup>	0.03±0.00 <sup>a</sup>
Raw Sor	0.00 <sup>a</sup>	113.7±0.00 <sup>c</sup>	0.00 <sup>a</sup>	1.34±0.01 <sup>c</sup>	0.00 <sup>a</sup>	0.42±0.00 <sup>d</sup>

Values of acetic, citric and lactic acids were expressed in µg/g of dry sample; Values of glucose, maltose, and fructose were expressed in mg/g of dry sample.

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.

**Table 2.3 Results of total phenolic contents**

	<b>PM1</b>	<b>PM2</b>	<b>PM3</b>	<b>Sor</b>
RAW	58.15±1.06 <sup>a</sup>	51.00±0.99 <sup>a</sup>	49.60±0.99 <sup>a</sup>	58.85±2.05 <sup>a</sup>
145	61.00±5.09 <sup>ab</sup>	58.15±3.04 <sup>ab</sup>	58.85±2.05 <sup>b</sup>	58.85±2.05
511	74.60±8.06 <sup>b</sup>	61.00±5.09 <sup>b</sup>	66.00±6.08 <sup>b</sup>	64.60±6.08 <sup>a</sup>
W14	74.60±8.07 <sup>ab</sup>	62.45±3.04 <sup>b</sup>	62.40±0.99 <sup>b</sup>	64.60±6.08 <sup>a</sup>

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 *Lb. brevis*; 511: ASCC511 *Lb. helveticus*; W14: W14 *Lb. casei*.

**Table 2.4 Phenolic acid profile of fermented and raw samples**

<b>Proso millet sample 1 (µg/g dry sample)</b>							
	Gallic acid	Protocatechuic acid	Chlorogenic acid	Vanillic acid	p-Coumaric acid	Ferulic acid	Sinapic acid
145	3.82±0.12 <sup>a</sup>	5.76±1.07 <sup>a</sup>	13.2±0.65 <sup>b</sup>	23.5±2.74 <sup>c</sup>	4.33±0.02 <sup>b</sup>	6.09±0.08 <sup>a</sup>	12.37±3.64 <sup>c</sup>
511	4.79±2.79 <sup>a</sup>	15.7±0.3 <sup>b</sup>	20.0±0.24 <sup>c</sup>	45.6±3.41 <sup>d</sup>	4.94±0.13 <sup>c</sup>	5.77±0.06 <sup>b</sup>	5.76±0.05 <sup>b</sup>
W14	17.7±0.1 <sup>b</sup>	23.9±0.71 <sup>c</sup>	9.55±0.07 <sup>a</sup>	2.68±0.04 <sup>a</sup>	5.55±0.06 <sup>d</sup>	6.44±0.05 <sup>c</sup>	12.67±0.25 <sup>c</sup>
RAW	4.8±0.05 <sup>a</sup>	24.0±0.52 <sup>c</sup>	8.65±0.00 <sup>a</sup>	11.5±4.28 <sup>b</sup>	4.05±0.00 <sup>a</sup>	6.62±0.05 <sup>d</sup>	0.00 <sup>a</sup>
<b>Proso millet sample 2 (µg/g dry sample)</b>							
	Gallic acid	Protocatechuic acid	Chlorogenic acid	Vanillic acid	p-Coumaric acid	Ferulic acid	Sinapic acid
145	4.30±0.74 <sup>b</sup>	2.64±0.34 <sup>a</sup>	12.9±1.20 <sup>b</sup>	24.8±9.52 <sup>b</sup>	4.16±0.04 <sup>a</sup>	6.01±0.1 <sup>b</sup>	12.1±2.09 <sup>c</sup>
511	2.68±0.28 <sup>a</sup>	11.0±1.44 <sup>b</sup>	17.6±1.17 <sup>c</sup>	44.5±8.52 <sup>c</sup>	4.66±0.04 <sup>b</sup>	5.50±0.02 <sup>a</sup>	4.91±0.65 <sup>b</sup>
W14	12.3±0.20 <sup>c</sup>	19.5±2.04 <sup>c</sup>	9.86±0.15 <sup>a</sup>	1.53±0.20 <sup>a</sup>	5.10±0.05 <sup>c</sup>	6.14±0.05 <sup>bc</sup>	9.44±0.49 <sup>c</sup>
RAW	3.64±0.10 <sup>ab</sup>	17.4±0.09 <sup>c</sup>	9.91±0.24 <sup>a</sup>	7.79±0.79 <sup>ab</sup>	5.69±0.04 <sup>d</sup>	6.21±0.02 <sup>c</sup>	0.00 <sup>a</sup>
<b>Proso millet sample 3 (µg/g dry sample)</b>							
	Gallic acid	Protocatechuic acid	Chlorogenic acid	Vanillic acid	p-Coumaric acid	Ferulic acid	Sinapic acid
145	2.95±0.22 <sup>a</sup>	3.81±0.08 <sup>a</sup>	12.2±0.08 <sup>b</sup>	15.5±0.24 <sup>b</sup>	4.24±0.07 <sup>a</sup>	6.09±0.13 <sup>ab</sup>	18.43±0.28 <sup>c</sup>
511	4.16±0.09 <sup>b</sup>	11.2±1.66 <sup>ab</sup>	19.1±0.41 <sup>d</sup>	47.6±1.81 <sup>d</sup>	4.92±0.14 <sup>b</sup>	5.91±0.02 <sup>a</sup>	4.80±0.90 <sup>ab</sup>
W14	18.4±0.44 <sup>c</sup>	17.1±0.75 <sup>b</sup>	15.1±0.18 <sup>c</sup>	1.80±0.11 <sup>b</sup>	5.34±0.13 <sup>b</sup>	6.32±0.26 <sup>b</sup>	6.55±3.93 <sup>b</sup>
RAW	2.97±0.25 <sup>a</sup>	16.9±5.39 <sup>b</sup>	8.83±0.03 <sup>a</sup>	14.0±0.83 <sup>a</sup>	6.43±0.27 <sup>c</sup>	6.47±0.09 <sup>b</sup>	0.00 <sup>a</sup>
<b>Sorghum (µg/g dry sample)</b>							
	Gallic acid	Protocatechuic acid	Chlorogenic acid	Vanillic acid	p-Coumaric acid	Ferulic acid	Sinapic acid
145	29.1±4.00 <sup>a</sup>	4.85±0.63 <sup>a</sup>	11.3±0.12 <sup>a</sup>	13.6±1.68 <sup>b</sup>	4.31±0.07 <sup>a</sup>	5.50±0.02 <sup>a</sup>	13.5±0.15 <sup>c</sup>
511	31.0±2.01 <sup>a</sup>	4.53±0.40 <sup>a</sup>	3.88±2.74 <sup>b</sup>	174.2±1.78 <sup>b</sup>	20.5±0.20 <sup>c</sup>	5.36±0.02 <sup>a</sup>	19.2±0.60 <sup>d</sup>
W14	72.6±3.85 <sup>b</sup>	14.6±0.78 <sup>b</sup>	11.8±0.17 <sup>a</sup>	1.85±0.10 <sup>a</sup>	13.3±0.49 <sup>b</sup>	8.15±0.16 <sup>b</sup>	3.82±0.20 <sup>b</sup>
RAW	34.4±1.74 <sup>a</sup>	3.89±0.38 <sup>a</sup>	9.69±0.19 <sup>a</sup>	4.05±0.03 <sup>a</sup>	14.5±0.89 <sup>b</sup>	7.64±0.13 <sup>c</sup>	0.00 <sup>a</sup>

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 *Lb. brevis*; 511: ASCC511 *Lb. helveticus*; W14: W14 *Lb. casei*.

**Table 2.4 Results of ABTS radical scavenging assay**

	<b>PM1</b>	<b>PM2</b>	<b>PM3</b>	<b>Sor</b>
RAW	175.1±12.4 <sup>a</sup>	181.3±3.54 <sup>a</sup>	193.8±3.54 <sup>a</sup>	243.8±10.6 <sup>a</sup>
145	343.8±88.4 <sup>b</sup>	176.3±3.54 <sup>a</sup>	182.6±5.30 <sup>a</sup>	227.6±5.30 <sup>a</sup>
511	325.1±12.4 <sup>b</sup>	281.3±35.36 <sup>b</sup>	318.8±3.54 <sup>b</sup>	262.6±129.1 <sup>a</sup>
W14	323.8±10.6 <sup>b</sup>	312.6±8.84 <sup>b</sup>	318.8±17.7 <sup>b</sup>	371.3±7.07 <sup>a</sup>

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.

**Table 2.4 Results of DPPH radical scavenging assay**

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**DPPH Radical Scavenging Activity ( $\mu\text{g}$  Trolox/g dry weight)**

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	<b>PM1</b>	<b>PM2</b>	<b>PM3</b>	<b>Sor</b>
RAW	79.0 $\pm$ 15.6 <sup>a</sup>	70.0 $\pm$ 5.66 <sup>a</sup>	66.0 $\pm$ 14.1 <sup>a</sup>	133 $\pm$ 4.24 <sup>a</sup>
145	93.0 $\pm$ 7.07 <sup>a</sup>	82.0 $\pm$ 0.00 <sup>ab</sup>	94.0 $\pm$ 0.00 <sup>ab</sup>	137 $\pm$ 12.7 <sup>a</sup>
511	128 $\pm$ 11.3 <sup>b</sup>	95.5 $\pm$ 7.78 <sup>b</sup>	107 $\pm$ 1.41 <sup>b</sup>	146 $\pm$ 2.83 <sup>a</sup>
W14	156 $\pm$ 8.49 <sup>b</sup>	136 $\pm$ 14.1 <sup>c</sup>	144 $\pm$ 19.8 <sup>c</sup>	181 $\pm$ 4.24

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PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.

**Table 2.5 Results of FRAP assay**

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<b>Ferric-reducing antioxidant power (<math>\mu\text{g FeSO}_4/\text{g dry sample}</math>)</b>				
	<b>PM1</b>	<b>PM2</b>	<b>PM3</b>	<b>Sor</b>
RAW	15.50 $\pm$ 0.28 <sup>b</sup>	10.50 $\pm$ 0.14 <sup>b</sup>	15.00 $\pm$ 1.41 <sup>b</sup>	7.90 $\pm$ 0.14 <sup>c</sup>
145	10.9 $\pm$ 0.71 <sup>a</sup>	8.45 $\pm$ 0.21 <sup>ab</sup>	13.45 $\pm$ 1.77 <sup>b</sup>	3.75 $\pm$ 0.21 <sup>b</sup>
511	10.80 $\pm$ 1.13 <sup>a</sup>	5.20 $\pm$ 1.41 <sup>a</sup>	8.45 $\pm$ 0.35 <sup>a</sup>	3.00 $\pm$ 0.00 <sup>a</sup>
W14	9.95 $\pm$ 2.19 <sup>a</sup>	5.05 $\pm$ 2.33 <sup>a</sup>	8.75 $\pm$ 1.34 <sup>a</sup>	3.80 $\pm$ 0.00 <sup>c</sup>

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PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.



**Table 2.6 Results of amino acid profile in proso millet 1 samples**

	Essential amino acids								
	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
RAW	4.19±0.17 <sup>c</sup>	2.17±0.09 <sup>a</sup>	5.92±0.24 <sup>a</sup>	0.14±0.01 <sup>a</sup>	1.54±0.02 <sup>b</sup>	4.19±0.17 <sup>a</sup>	2.30±0.04 <sup>b</sup>	8.86±0.24 <sup>a</sup>	5.79±0.09 <sup>a</sup>
145	0.00 <sup>a</sup>	4.89±0.09 <sup>c</sup>	16.00±0.87 <sup>c</sup>	8.10±0.55 <sup>b</sup>	1.36±0.01 <sup>a</sup>	9.99±0.51 <sup>c</sup>	0.00 <sup>a</sup>	13.31±0.58 <sup>a,b</sup>	13.40±0.91 <sup>c</sup>
511	8.13±0.24 <sup>d</sup>	2.89±0.20 <sup>b</sup>	7.41±0.07 <sup>b</sup>	0.20±0.03 <sup>a</sup>	3.24±0.01 <sup>c</sup>	5.17±0.06 <sup>b</sup>	4.57±0.05 <sup>d</sup>	8.57±0.05 <sup>a</sup>	8.86±0.16 <sup>b</sup>
W14	0.85±0.04 <sup>b</sup>	1.85±0.04 <sup>a</sup>	8.24±0.06 <sup>b</sup>	0.16±0.01 <sup>a</sup>	3.44±0.07 <sup>d</sup>	5.87±0.05 <sup>b</sup>	3.24±0.01 <sup>c</sup>	8.73±0.69 <sup>a</sup>	8.70±0.01 <sup>b</sup>
	Nonessential amino acids								
	Ala	Arg	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
RAW	7.73±0.12 <sup>b</sup>	8.31±0.22 <sup>b</sup>	12.33±0.20 <sup>a</sup>	0.75±0.01 <sup>b</sup>	24.37±0.39 <sup>c</sup>	4.26±0.07 <sup>a</sup>	3.25±0.09 <sup>a</sup>	5.37±0.09 <sup>b</sup>	3.03±0.12 <sup>b</sup>
145	4.48±0.69 <sup>a</sup>	0.00 <sup>a</sup>	20.32±0.08 <sup>b</sup>	0.00 <sup>a</sup>	21.78±0.04 <sup>b</sup>	9.17±0.97 <sup>b</sup>	8.27±0.07 <sup>c</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>
511	35.97±0.72 <sup>d</sup>	19.33±0.63 <sup>d</sup>	12.49±0.25 <sup>a</sup>	1.18±0.22 <sup>c</sup>	20.21±0.24 <sup>a</sup>	11.29±0.14 <sup>c</sup>	7.41±0.47 <sup>b</sup>	9.87±0.07 <sup>d</sup>	4.78±0.01 <sup>d</sup>
W14	21.95±17.53 <sup>c</sup>	18.02±0.10 <sup>c</sup>	28.54±0.99 <sup>c</sup>	0.21±0.07 <sup>a</sup>	33.19±0.04 <sup>d</sup>	14.88±0.05 <sup>d</sup>	7.75±0.23 <sup>bc</sup>	9.14±0.06 <sup>c</sup>	3.54±0.01 <sup>c</sup>
	Other amino acids		Total						
	GABA	Orn							
RAW	5.08±0.20 <sup>a</sup>	0.14±0.01 <sup>a</sup>	111.34±2.64 <sup>a</sup>						
145	22.56±1.09 <sup>d</sup>	8.10±0.55 <sup>b</sup>	152.97±1.21 <sup>b</sup>						
511	14.00±0.08 <sup>d</sup>	0.20±0.03 <sup>a</sup>	190.28±1.56 <sup>c</sup>						
W14	11.54±0.00 <sup>b</sup>	0.16±0.01 <sup>a</sup>	193.36±0.33 <sup>c</sup>						

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.

His: Histidine; Ile: Isoleucine; Leu: Leucine; Lys: Lysine; Met: Methionine; Phe: Phenylalanine; Thr: Threonine; Trp: Tryptophan; Val: Valine; Ala: alanine; Arg: Arginine; Asp: Asparagine; Cys: Cysteine; Glu: Glutamic acid; Gly: Glycine; Pro: Proline; Ser: Serine; Tyr: Tyrosine; GABA:  $\gamma$ -aminobutyric acid; Orn: Ornithine.

**Table 2.7 Results of amino acid profile in proso millet 2 samples**

	Essential amino acids								
	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
RAW	1.19±0.02 <sup>b</sup>	1.34±0.04 <sup>a</sup>	3.42±0.10 <sup>a</sup>	2.46±0.05 <sup>c</sup>	1.18±0.03 <sup>b</sup>	2.52±0.07 <sup>a</sup>	1.63±0.02 <sup>b</sup>	4.52±0.09 <sup>b</sup>	3.72±0.04 <sup>a</sup>
145	0.00 <sup>a</sup>	1.89±0.30 <sup>b</sup>	6.61±1.01 <sup>b</sup>	0.00 <sup>a</sup>	0.59±0.02 <sup>a</sup>	3.58±0.38 <sup>b</sup>	0.00 <sup>a</sup>	4.41±1.04 <sup>a</sup>	5.37±0.71 <sup>b</sup>
511	2.45±0.00 <sup>c</sup>	1.61±0.00 <sup>ab</sup>	4.45±0.00 <sup>a</sup>	4.66±0.00 <sup>d</sup>	1.68±0.00 <sup>c</sup>	3.37±0.00 <sup>b</sup>	3.38±0.00 <sup>d</sup>	1.15±0.07 <sup>b</sup>	4.46±0.00 <sup>ab</sup>
W14	2.95±0.07 <sup>d</sup>	1.55±0.03 <sup>ab</sup>	6.84±0.20 <sup>b</sup>	0.88±0.09 <sup>b</sup>	3.32±0.08 <sup>d</sup>	4.67±0.20 <sup>c</sup>	2.71±0.02 <sup>c</sup>	5.00±0.07 <sup>b</sup>	7.38±0.20 <sup>c</sup>
	Nonessential amino acids								
	Ala	Arg	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
RAW	5.04±0.05 <sup>b</sup>	5.78±0.12 <sup>b</sup>	9.51±0.10 <sup>a</sup>	1.06±0.01 <sup>d</sup>	20.05±0.21 <sup>c</sup>	2.83±0.03 <sup>a</sup>	2.63±0.05 <sup>a</sup>	4.33±0.05 <sup>b</sup>	1.71±0.05 <sup>b</sup>
145	1.00±0.12 <sup>a</sup>	0.00 <sup>a</sup>	7.58±0.97 <sup>a</sup>	0.00 <sup>a</sup>	9.55±0.87 <sup>a</sup>	2.98±0.48 <sup>a</sup>	3.23±2.57 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>
511	27.41±0.00 <sup>d</sup>	13.52±0.00 <sup>c</sup>	13.34±9.82 <sup>a</sup>	0.59±0.00 <sup>c</sup>	13.43±0.00 <sup>b</sup>	6.57±0.00 <sup>b</sup>	8.89±2.24 <sup>b</sup>	8.02±0.00 <sup>d</sup>	3.16±0.00 <sup>c</sup>
W14	18.65±0.18 <sup>c</sup>	15.12±0.49 <sup>d</sup>	19.81±0.52 <sup>a</sup>	0.16±0.04 <sup>b</sup>	29.70±0.96 <sup>d</sup>	12.85±0.14 <sup>c</sup>	6.96±0.04 <sup>ab</sup>	7.80±0.13 <sup>c</sup>	3.37±0.13 <sup>d</sup>
	Other amino acids			Total					
	GABA	Orn							
RAW	3.25±0.09 <sup>a</sup>	0.08±0.00 <sup>a</sup>		78.24±1.23 <sup>a</sup>					
145	8.46±0.77 <sup>c</sup>	3.48±0.39 <sup>b</sup>		58.73±9.59 <sup>a</sup>					
511	6.80±0.00 <sup>b</sup>	0.38±0.00 <sup>a</sup>		129.33±11.99 <sup>b</sup>					
W14	6.92±0.20 <sup>b</sup>	0.09±0.02 <sup>a</sup>		156.74±3.67 <sup>c</sup>					

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.

**Table 2.8 Results of amino acid profile in proso millet 3 samples**

	Essential amino acids								
	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
RAW	1.14±0.02 <sup>a</sup>	1.45±0.04 <sup>a</sup>	3.78±0.11 <sup>a</sup>	2.79±0.06 <sup>c</sup>	1.10±0.03 <sup>a</sup>	2.66±0.08 <sup>a</sup>	1.67±0.02 <sup>b</sup>	4.21±0.09 <sup>a</sup>	4.04±0.04 <sup>a</sup>
145	1.21±0.09 <sup>a</sup>	2.87±0.35 <sup>b</sup>	9.04±1.19 <sup>c</sup>	0.00 <sup>a</sup>	0.72±0.14 <sup>a</sup>	5.46±1.08 <sup>b</sup>	0.00 <sup>a</sup>	5.92±1.92 <sup>a</sup>	7.54±1.02 <sup>b</sup>
511	4.33±0.22 <sup>c</sup>	2.54±0.32 <sup>b</sup>	6.61±0.28 <sup>b</sup>	6.68±0.09 <sup>d</sup>	2.66±0.24 <sup>b</sup>	4.39±0.42 <sup>b</sup>	4.47±0.26 <sup>d</sup>	5.91±0.31 <sup>a</sup>	8.05±0.14 <sup>b</sup>
W14	3.49±0.10 <sup>b</sup>	1.72±0.02 <sup>a</sup>	7.53±0.04 <sup>bc</sup>	1.28±0.16 <sup>b</sup>	3.08±0.08 <sup>c</sup>	5.28±0.02 <sup>b</sup>	2.79±0.07 <sup>c</sup>	4.68±0.18 <sup>a</sup>	8.35±0.01 <sup>b</sup>
	Nonessential amino acids								
	Ala	Arg	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
RAW	5.90±0.06 <sup>a</sup>	5.70±0.12 <sup>b</sup>	7.21±0.08 <sup>a</sup>	0.63±0.01 <sup>b</sup>	17.66±0.19 <sup>a</sup>	3.19±0.03 <sup>a</sup>	2.44±0.05 <sup>b</sup>	3.78±0.04 <sup>b</sup>	1.84±0.05 <sup>b</sup>
145	3.21±0.52 <sup>a</sup>	0.00 <sup>a</sup>	8.84±0.12 <sup>a</sup>	0.00 <sup>a</sup>	12.97±1.71 <sup>a</sup>	5.19±0.64 <sup>b</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>
511	38.67±2.04 <sup>c</sup>	18.15±3.14 <sup>c</sup>	7.01±0.40 <sup>a</sup>	1.24±0.21 <sup>c</sup>	18.57±4.59 <sup>a</sup>	10.59±0.12 <sup>c</sup>	6.91±1.23 <sup>c</sup>	10.02±0.12 <sup>d</sup>	2.82±0.21 <sup>c</sup>
W14	20.13±0.25 <sup>b</sup>	17.66±0.65 <sup>c</sup>	20.99±1.48 <sup>b</sup>	0.08±0.00 <sup>a</sup>	30.29±1.03 <sup>b</sup>	14.01±0.13 <sup>d</sup>	7.89±0.13 <sup>c</sup>	8.45±0.29 <sup>c</sup>	3.51±0.31 <sup>d</sup>
	Other amino acids			Total					
	GABA	Orn							
RAW	3.95±0.11 <sup>a</sup>	0.07±0.00 <sup>a</sup>		75.24±1.22 <sup>a</sup>					
145	12.10±1.84 <sup>b</sup>	5.82±0.95 <sup>b</sup>		80.32±12.16 <sup>a</sup>					
511	9.28±4.79 <sup>ab</sup>	0.21±0.13 <sup>a</sup>		169.47±4.11 <sup>b</sup>					
W14	8.75±0.16 <sup>ab</sup>	0.10±0.02 <sup>a</sup>		170.08±3.56 <sup>b</sup>					

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 Lb. *brevis*; 511: ASCC511 Lb. *helveticus*; W14: W14 Lb. *casei*.

**Table 2.9 Results of amino acid profile in Sorghum sample**

	<b>Essential amino acids</b>								
	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val
RAW	1.06±0.04 <sup>a</sup>	1.23±0.05 <sup>a</sup>	2.00±3.86 <sup>a</sup>	4.07±0.16 <sup>ab</sup>	1.11±0.02 <sup>a</sup>	2.73±0.11 <sup>a</sup>	2.00±1.91 <sup>b</sup>	0.75±0.02 <sup>a</sup>	2.50±0.04 <sup>a</sup>
145	1.83±0.02 <sup>ab</sup>	3.27±1.30 <sup>a</sup>	10.55±2.56 <sup>b</sup>	3.74±2.08 <sup>ab</sup>	1.77±0.35 <sup>ab</sup>	6.57±0.73 <sup>c</sup>	0.00 <sup>a</sup>	1.30±0.05 <sup>a</sup>	8.27±0.14 <sup>b</sup>
511	3.62±1.60 <sup>b</sup>	2.27±0.92 <sup>a</sup>	5.85±1.91 <sup>a</sup>	5.86±1.61 <sup>a</sup>	2.30±0.84 <sup>ab</sup>	4.17±1.12 <sup>ab</sup>	4.08±0.98 <sup>c</sup>	3.52±3.38 <sup>a</sup>	6.42±2.71 <sup>b</sup>
W14	0.05±0.03 <sup>ab</sup>	1.14±0.07 <sup>a</sup>	5.65±0.36 <sup>a</sup>	0.39±0.01 <sup>b</sup>	2.76±0.17 <sup>b</sup>	5.11±0.19 <sup>bc</sup>	2.00±1.59 <sup>b</sup>	1.69±0.03 <sup>a</sup>	6.39±0.40 <sup>b</sup>
	<b>Nonessential amino acids</b>								
	Ala	Arg	Asp	Cys	Glu	Gly	Pro	Ser	Tyr
RAW	6.98±0.11 <sup>a</sup>	8.52±0.23 <sup>b</sup>	20.86±0.37 <sup>a</sup>	0.66±0.01 <sup>a</sup>	18.42±0.30 <sup>b</sup>	2.46±0.04 <sup>a</sup>	7.43±0.20 <sup>a</sup>	4.85±0.08 <sup>b</sup>	2.00±2.28 <sup>b</sup>
145	9.24±0.41 <sup>ab</sup>	0.00 <sup>a</sup>	10.47±11.13 <sup>a</sup>	0.49±0.17 <sup>a</sup>	0.00 <sup>a</sup>	5.29±0.29 <sup>ab</sup>	13.19±2.45 <sup>bc</sup>	0.00 <sup>a</sup>	0.00 <sup>a</sup>
511	33.04±7.14 <sup>c</sup>	17.43±5.27 <sup>c</sup>	36.41±3.14 <sup>a</sup>	1.00±0.59 <sup>a</sup>	18.00±6.11 <sup>b</sup>	9.02±3.20 <sup>b</sup>	9.42±1.89 <sup>ab</sup>	9.22±1.57 <sup>b</sup>	3.02±0.28 <sup>c</sup>
W14	18.76±1.62 <sup>b</sup>	17.41±0.35 <sup>c</sup>	20.43±12.02 <sup>b</sup>	0.12±0.01 <sup>a</sup>	2.57±1.82 <sup>c</sup>	9.58±0.83 <sup>b</sup>	14.38±0.29 <sup>c</sup>	7.71±0.67 <sup>c</sup>	3.59±0.23 <sup>d</sup>
	<b>Other amino acids</b>			<b>Total</b>					
	GABA	Orn							
RAW	2.00±7.04 <sup>a</sup>	0.33±0.01 <sup>a</sup>		99.04±2.31 <sup>a</sup>					
145	26.99±3.32 <sup>b</sup>	11.88±0.13 <sup>b</sup>		114.86±12.01 <sup>a</sup>					
511	6.55±0.45 <sup>a</sup>	0.27±0.20 <sup>a</sup>		159.05±26.91 <sup>b</sup>					
W14	8.8±0.33 <sup>a</sup>	0.45±0.20 <sup>a</sup>		174.37±11.50 <sup>b</sup>					

PM: proso millet sample; Sor: sorghum sample; 145: NPS-QW-145 *Lb. brevis*; 511: ASCC511 *Lb. helveticus*; W14: W14 *Lb. casei*.

Table 4. 1: Amylose content of fermented proso millet starch samples.

Sample ID	Amylose Content	Sample ID	Amylose Content
Raw-waxy	3.98±0.06 <sup>fg</sup>	RAW-NONWAXY	26.10±0.68 <sup>def</sup>
SAWD1	3.20±0.00 <sup>abc</sup>	SAND1	23.78±0.72 <sup>abcdef</sup>
SAWD2	3.37±0.08 <sup>bcd</sup>	SAND2	24.77±0.60 <sup>bcdef</sup>
SAWD3	2.83±0.00 <sup>a</sup>	SAND3	24.29±1.79 <sup>bcdef</sup>
SAWD4	2.98±0.38 <sup>ab</sup>	SAND4	24.14±0.72 <sup>bcdef</sup>
SAWD5	2.74±0.12 <sup>a</sup>	SAND5	25.10±0.90 <sup>cdef</sup>
SPWD1	3.88±0.12 <sup>efg</sup>	SPND1	23.54±0.21 <sup>abcde</sup>
SPWD2	4.14±0.36 <sup>g</sup>	SPND2	22.15±0.21 <sup>abc</sup>
SPWD3	3.97±0.04 <sup>fg</sup>	SPND3	22.06±0.09 <sup>ab</sup>
SPWD4	3.68±0.40 <sup>cdefg</sup>	SPND4	24.47±0.77 <sup>bcdef</sup>
SPWD5	3.88±0.12 <sup>efg</sup>	SPND5	24.11±1.36 <sup>bcdef</sup>
SFWD1	3.77±0.20 <sup>defg</sup>	SFND1	23.30±0.04 <sup>abcd</sup>
SFWD2	3.50±0.28 <sup>cdef</sup>	SFND2	20.85±1.79 <sup>a</sup>
SFWD3	3.57±0.28 <sup>cdef</sup>	SFND3	23.99±0.17 <sup>bcdef</sup>
SFWD4	3.48±0.12 <sup>cdef</sup>	SFND4	26.64±3.58 <sup>f</sup>
SFWD5	3.44±0.22 <sup>bcde</sup>	SFND5	26.34±0.09 <sup>ef</sup>

SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days

Table 4. 2: pH value and viable cell number of fermented proso millet mixture.

Sample ID	pH	Sample ID	pH
SAWD1	7.08	SAND1	5.35
SAWD2	6.94	SAND2	4.32
SAWD3	6.81	SAND3	4.13
SAWD4	6.55	SAND4	4.05
SAWD5	4.87	SAND5	4.08
SPWD1	6.82	SPND1	6.35
SPWD2	6.81	SPND2	4.95
SPWD3	4.99	SPND3	4.52
SPWD4	4.76	SPND4	3.52
SPWD5	3.66	SPND5	3.43
SFWD1	7.38	SFND1	6.57
SFWD2	7.22	SFND2	4.69
SFWD3	7.25	SFND3	3.96
SFWD4	6.65	SFND4	3.80
SFWD5	5.37	SFND5	3.59

SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days

Table 4. 3: Thermal properties of fermented waxy proso millet starch.

	Onset temperature (°C)	Peak temperature (°C)	Endset temperature (°C)	Enthalpy(J/g)
Raw Waxy	67.71±0.11 <sup>e</sup>	73.19±0.11 <sup>d</sup>	78.68±0.02 <sup>c</sup>	13.77±0.35 <sup>a</sup>
SAWD1	66.60±0.17 <sup>abcd</sup>	72.14±0.21 <sup>ab</sup>	78.01±0.27 <sup>ab</sup>	14.30±0.38 <sup>abc</sup>
SAWD2	66.63±0.10 <sup>abcd</sup>	72.20±0.06 <sup>abc</sup>	78.03±0.03 <sup>ab</sup>	15.20±0.08 <sup>abcd</sup>
SAWD3	66.38±0.14 <sup>abc</sup>	72.13±0.09 <sup>ab</sup>	77.91±0.23 <sup>ab</sup>	15.02±0.41 <sup>abcd</sup>
SAWD4	66.42±0.11 <sup>abc</sup>	72.12±0.08 <sup>ab</sup>	77.51±0.40 <sup>a</sup>	15.24±0.27 <sup>abcd</sup>
SAWD5	66.92±0.18 <sup>d</sup>	72.33±0.14 <sup>abc</sup>	77.97±0.08 <sup>ab</sup>	15.99±0.24 <sup>cd</sup>
SFWD1	66.52±0.10 <sup>abcd</sup>	72.38±0.01 <sup>abc</sup>	78.20±0.04 <sup>bc</sup>	14.70±0.09 <sup>abcd</sup>
SFWD2	66.63±0.22 <sup>abcd</sup>	72.39±0.23 <sup>abc</sup>	77.95±0.46 <sup>ab</sup>	15.74±0.56 <sup>cd</sup>
SFWD3	66.76±0.06 <sup>bcd</sup>	72.46±0.06 <sup>bc</sup>	77.96±0.01 <sup>ab</sup>	16.09±0.01 <sup>d</sup>
SFWD4	66.86±0.01 <sup>cd</sup>	72.44±0.01 <sup>bc</sup>	77.97±0.01 <sup>ab</sup>	15.53±0.07 <sup>abcd</sup>
SFWD5	66.41±0.59 <sup>abc</sup>	72.13±0.44 <sup>ab</sup>	78.00±0.27 <sup>ab</sup>	15.83±0.35 <sup>cd</sup>
SPWD1	66.18±0.02 <sup>a</sup>	71.96±0.06 <sup>a</sup>	77.50±0.05 <sup>a</sup>	15.07±0.23 <sup>abcd</sup>
SPWD2	66.67±0.18 <sup>abcd</sup>	72.34±0.11 <sup>abc</sup>	77.47±0.16 <sup>a</sup>	13.88±2.39 <sup>ab</sup>
SPWD3	66.35±0.12 <sup>ab</sup>	72.36±0.21 <sup>abc</sup>	77.81±0.57 <sup>ab</sup>	14.24±0.94 <sup>abc</sup>
SPWD4	66.52±0.18 <sup>abcd</sup>	72.22±0.25 <sup>abc</sup>	78.32±0.39 <sup>bc</sup>	13.93±0.85 <sup>ab</sup>
SPWD5	66.94±0.25 <sup>d</sup>	72.62±0.30 <sup>c</sup>	78.69±0.14 <sup>c</sup>	15.62±0.36 <sup>bcd</sup>

SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days



Table 4. 4: Thermal properties of fermented non-waxy proso millet starch.

	Onset temperature (°C)	Peak temperature (°C)	Endset temperature (°C)	Enthalpy(J/g)
Raw-non-waxy	71.25±0.25 <sup>cd</sup>	75.17±0.32 <sup>f</sup>	79.06±0.53 <sup>d</sup>	13.75±0.79 <sup>a</sup>
SAND1	70.30±0.02 <sup>a</sup>	74.36±0.08 <sup>a</sup>	77.91±0.30 <sup>a</sup>	14.01±0.15 <sup>ab</sup>
SAND2	70.61±0.05 <sup>abc</sup>	74.45±0.08 <sup>abc</sup>	78.10±0.08 <sup>ab</sup>	14.20±0.00 <sup>abc</sup>
SAND3	70.56±0.25 <sup>abc</sup>	74.54±0.21 <sup>abcd</sup>	78.32±0.42 <sup>abc</sup>	14.58±0.09 <sup>abcd</sup>
SAND4	70.29±0.01 <sup>a</sup>	74.54±0.05 <sup>abcd</sup>	78.31±0.13 <sup>abc</sup>	14.90±0.16 <sup>cd</sup>
SAND5	70.35±0.18 <sup>ab</sup>	74.50±0.11 <sup>abcd</sup>	78.12±0.41 <sup>ab</sup>	14.73±0.31 <sup>bcd</sup>
SFND1	70.51±0.03 <sup>ab</sup>	74.39±0.11 <sup>ab</sup>	78.20±0.37 <sup>abc</sup>	13.79±0.12 <sup>a</sup>
SFND2	70.59±0.16 <sup>abc</sup>	74.60±0.01 <sup>abcd</sup>	78.26±0.22 <sup>abc</sup>	13.82±0.08 <sup>a</sup>
SFND3	70.93±0.25 <sup>abcd</sup>	74.76±0.20 <sup>cd</sup>	78.43±0.06 <sup>abc</sup>	14.58±0.46 <sup>abcd</sup>
SFND4	70.72±0.01 <sup>abc</sup>	74.79±0.02 <sup>cd</sup>	78.17±0.06 <sup>ab</sup>	14.70±0.55 <sup>bcd</sup>
SFND5	70.59±1.10 <sup>abc</sup>	75.11±0.08 <sup>ef</sup>	78.69±0.06 <sup>bcd</sup>	14.80±0.01 <sup>bcd</sup>
SPND1	70.47±0.02 <sup>ab</sup>	74.59±0.01 <sup>abcd</sup>	78.34±0.04 <sup>abc</sup>	14.19±0.25 <sup>cd</sup>
SPND2	70.95±0.08 <sup>abcd</sup>	74.81±0.09 <sup>de</sup>	78.61±0.08 <sup>bcd</sup>	15.14±0.18 <sup>d</sup>
SPND3	71.61±0.09 <sup>d</sup>	75.14±0.07 <sup>f</sup>	78.84±0.11 <sup>cd</sup>	14.47±0.36 <sup>abcd</sup>
SPND4	70.99±0.14 <sup>abcd</sup>	74.73±0.02 <sup>bcd</sup>	78.40±0.02 <sup>abc</sup>	15.02±0.05 <sup>cd</sup>
SPND5	71.04±0.03 <sup>bcd</sup>	74.82±0.00 <sup>de</sup>	78.41±0.15 <sup>abc</sup>	15.14±0.37 <sup>d</sup>

SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days

Table 4. 5: Pasting properties of fermented waxy proso millet starch.

	Peak Visco (RVU)	Hold Visco (RVU)	Final Visco (RVU)
Raw-waxy	116.80±0.88 <sup>bc</sup>	85.00±0.95 <sup>c</sup>	103.92±2.00 <sup>cd</sup>
SAWD1	132.38±2.30 <sup>g</sup>	89.96±1.00 <sup>cde</sup>	100.67±1.65 <sup>c</sup>
SAWD2	131.46±0.77 <sup>fg</sup>	89.96±1.00 <sup>efg</sup>	106.08±1.06 <sup>de</sup>
SAWD3	127.29±0.06 <sup>e</sup>	89.63±0.29 <sup>defg</sup>	112.25±0.59 <sup>fg</sup>
SAWD4	129.09±2.60 <sup>ef</sup>	86.75±3.54 <sup>cd</sup>	107.04±1.82 <sup>de</sup>
SAWD5	127.00±0.12 <sup>e</sup>	92.00±0.21 <sup>g</sup>	109.42±0.36 <sup>ef</sup>
SFWD1	122.33±1.14 <sup>d</sup>	85.17±0.86 <sup>c</sup>	104.25±0.85 <sup>cd</sup>
SFWD2	118.80±0.88 <sup>c</sup>	89.84±1.18 <sup>efg</sup>	109.25±2.23 <sup>ef</sup>
SFWD3	118.38±1.24 <sup>c</sup>	90.63±0.88 <sup>defg</sup>	110.42±3.66 <sup>ef</sup>
SFWD4	114.67±0.59 <sup>b</sup>	87.80±1.24 <sup>fg</sup>	106.59±2.60 <sup>de</sup>
SFWD5	116.88±0.42 <sup>bc</sup>	87.04±1.47 <sup>cdef</sup>	106.84±1.65 <sup>de</sup>
SPWD1	145.96±1.36 <sup>i</sup>	105.61±0.27 <sup>h</sup>	128.29±1.36 <sup>h</sup>
SPWD2	137.00±2.36 <sup>h</sup>	91.30±0.53 <sup>g</sup>	114.25±0.59 <sup>g</sup>
SPWD3	117.46±1.82 <sup>bc</sup>	75.50±1.65 <sup>b</sup>	86.13±1.48 <sup>b</sup>
SPWD4	129.71±1.36 <sup>efg</sup>	85.21±1.24 <sup>c</sup>	100.75±3.30 <sup>c</sup>
SPWD5	104.00±0.11 <sup>a</sup>	70.00±0.82 <sup>a</sup>	77.71±1.36 <sup>a</sup>

SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days

Table 4. 6: Pasting properties of fermented non-waxy proso millet starch.

	Peak Visco (RVU)	Hold Visco (RVU)	Final Visco (RVU)
Raw Non-waxy	71.34±1.65 <sup>j</sup>	40.63±1.00 <sup>a</sup>	82.04±2.18 <sup>h</sup>
SAND1	60.34±0.47 <sup>de</sup>	45.04±0.06 <sup>cd</sup>	66.54±1.71 <sup>g</sup>
SAND2	60.84±2.71 <sup>fg</sup>	48.54±1.47 <sup>fg</sup>	64.17±0.94 <sup>ef</sup>
SAND3	67.09±0.12 <sup>h</sup>	51.96±0.30 <sup>h</sup>	65.17±0.12 <sup>fg</sup>
SAND4	60.96±0.76 <sup>e</sup>	47.92±0.47 <sup>ef</sup>	59.54±0.30 <sup>d</sup>
SAND5	64.50±0.95 <sup>f</sup>	51.13±0.77 <sup>h</sup>	67.21±1.24 <sup>g</sup>
SFND1	69.38±1.12 <sup>ij</sup>	46.04±1.00 <sup>de</sup>	90.81±0.32 <sup>j</sup>
SFND2	64.29±0.30 <sup>f</sup>	54.17±3.06 <sup>i</sup>	62.95±0.81 <sup>e</sup>
SFND3	59.80±0.88 <sup>de</sup>	45.71±0.65 <sup>cd</sup>	55.17±0.12 <sup>c</sup>
SFND4	58.46±0.30	45.50±0.11 <sup>cd</sup>	54.21±0.18 <sup>c</sup>
SFND5	56.05±0.53 <sup>c</sup>	43.59±0.23 <sup>bc</sup>	49.09±0.47 <sup>b</sup>
SPND1	68.34±0.59 <sup>hi</sup>	48.88±0.18 <sup>fg</sup>	88.67±1.41 <sup>i</sup>
SPND2	66.75±0.59 <sup>gh</sup>	50.54±0.06 <sup>gh</sup>	59.42±0.59 <sup>d</sup>
SPND3	47.50±0.11 <sup>a</sup>	39.75±0.02 <sup>a</sup>	46.13±0.06 <sup>a</sup>
SPND4	52.13±0.29 <sup>b</sup>	41.92±0.23 <sup>ab</sup>	47.71±0.18 <sup>ab</sup>
SPND5	53.50±0.11 <sup>b</sup>	41.84±0.12 <sup>ab</sup>	47.30±0.18 <sup>ab</sup>

SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days

Table 4. 7: Textural properties of fermented waxy proso millet starch.

	Hardness (g)	Adhesiveness (g · s)	Springiness	Cohesiveness
Raw Waxy	6.82±1.09 <sup>bcd</sup>	-0.32±0.10 <sup>defg</sup>	0.65±0.57 <sup>ab</sup>	0.65±0.00 <sup>bc</sup>
SAWD1	9.20±0.53 <sup>ef</sup>	-2.12±0.36 <sup>a</sup>	0.98±0.01 <sup>b</sup>	0.65±0.00 <sup>bc</sup>
SAWD2	6.42±0.31 <sup>bc</sup>	N.D	1.04±0.02 <sup>b</sup>	0.79±0.05 <sup>c</sup>
SAWD3	6.61±0.27 <sup>bcd</sup>	-0.50±0.13 <sup>cd</sup>	1.00±0.00 <sup>b</sup>	0.77±0.02 <sup>c</sup>
SAWD4	7.41±1.12 <sup>bcde</sup>	-0.41±0.04 <sup>cdef</sup>	0.99±0.00 <sup>b</sup>	0.70±0.02 <sup>bc</sup>
SAWD5	6.84±1.32 <sup>bcd</sup>	-0.22±0.05 <sup>defg</sup>	1.08±0.10 <sup>b</sup>	0.74±0.01 <sup>c</sup>
SFWD1	10.58±1.12 <sup>f</sup>	-1.02±0.26 <sup>b</sup>	0.64±0.55 <sup>ab</sup>	0.58±0.01 <sup>bc</sup>
SFWD2	10.58±0.63 <sup>f</sup>	-0.31±0.27 <sup>defg</sup>	0.67±0.58 <sup>ab</sup>	0.68±0.01 <sup>bc</sup>
SFWD3	8.45±1.21 <sup>cde</sup>	-0.26±0.23 <sup>defg</sup>	0.70±0.61 <sup>ab</sup>	0.71±0.02 <sup>bc</sup>
SFWD4	6.89±1.38 <sup>bcd</sup>	-0.14±0.13 <sup>defg</sup>	0.66±0.57 <sup>ab</sup>	0.69±0.01 <sup>bc</sup>
SFWD5	6.91±0.27 <sup>bcd</sup>	-0.05±0.04 <sup>defg</sup>	0.66±0.57 <sup>ab</sup>	0.46±0.39 <sup>b</sup>
SPWD1	9.28±0.20 <sup>ef</sup>	-0.10±0.01 <sup>efg</sup>	1.00±0.00 <sup>b</sup>	0.65±0.01 <sup>bc</sup>
SPWD2	8.31±0.00 <sup>cde</sup>	N.D	N.D	N.D
SPWD3	2.29±0.00 <sup>a</sup>	N.D	N.D	N.D
SPWD4	5.47±0.19 <sup>b</sup>	-0.44±0.01 <sup>cde</sup>	0.97±0.01 <sup>b</sup>	0.60±0.02 <sup>bc</sup>
SPWD5	6.64±1.24 <sup>bcd</sup>	-0.71±0.12 <sup>bc</sup>	0.98±0.00 <sup>b</sup>	0.62±0.02 <sup>bc</sup>

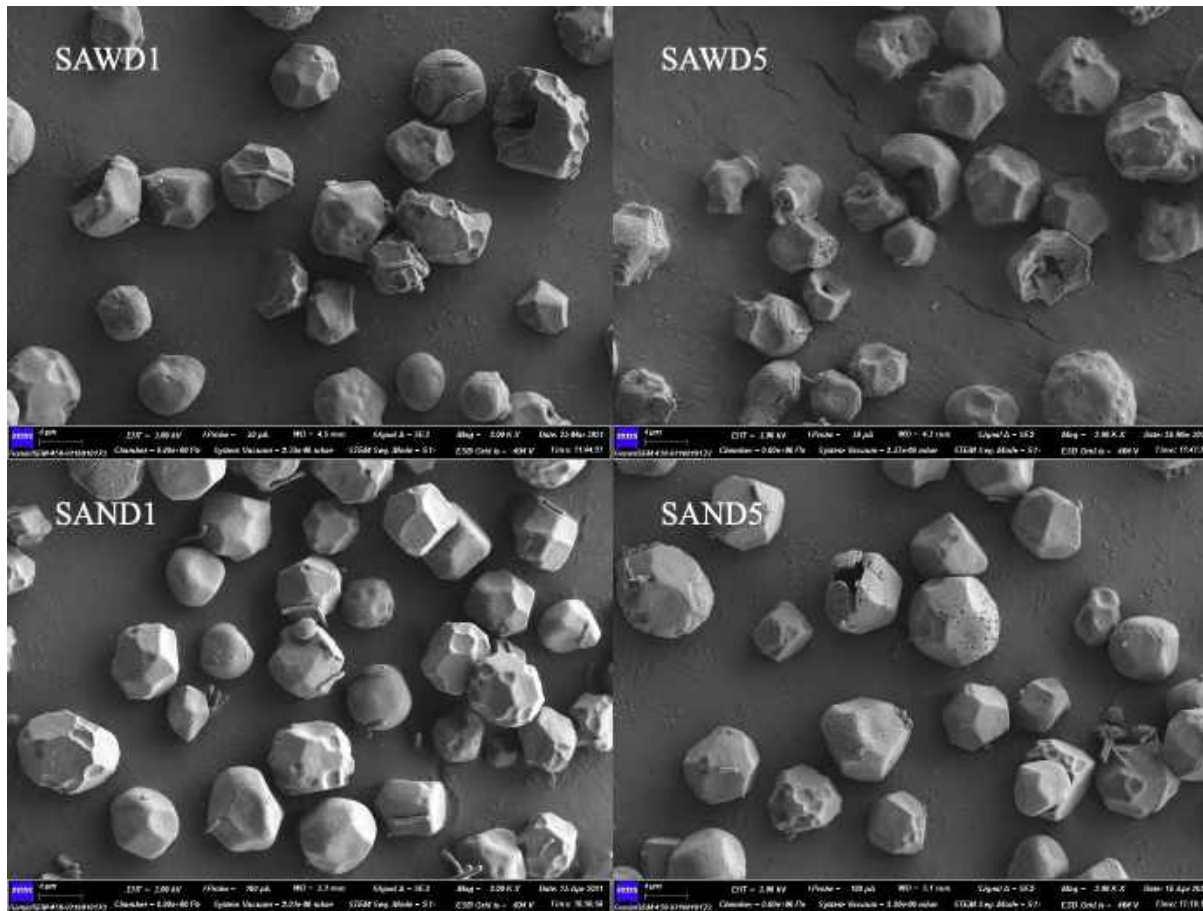
SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days

Table 4. 8: Textural properties of fermented non-waxy proso millet starch.

	Hardness (g)	Adhesiveness (g · s)	Springiness	Cohesiveness
Raw Non-waxy	36.30±0.79 <sup>a</sup>	-130.15±7.79 <sup>h</sup>	1.12±0.12 <sup>d</sup>	0.45±0.00 <sup>a</sup>
SAWD1	51.07±5.17 <sup>ef</sup>	-277.00±3.66 <sup>b</sup>	1.09±0.01 <sup>cd</sup>	0.44±0.00 <sup>a</sup>
SAWD2	50.72±1.85 <sup>f</sup>	-233.72±28.54 <sup>cd</sup>	1.16±0.00 <sup>d</sup>	0.44±0.04 <sup>a</sup>
SAWD3	48.93±2.99 <sup>f</sup>	-254.08±8.86 <sup>bc</sup>	0.95±0.05 <sup>ab</sup>	0.48±0.01 <sup>ab</sup>
SAWD4	45.93±2.99 <sup>ef</sup>	-339.54±10.46 <sup>a</sup>	1.07±0.12 <sup>bcd</sup>	0.54±0.02 <sup>def</sup>
SAWD5	45.33±2.39 <sup>cde</sup>	-351.10±19.83 <sup>a</sup>	1.08±0.10 <sup>cd</sup>	0.55±0.01 <sup>f</sup>
SFND1	37.61±1.23 <sup>ab</sup>	-170.96±3.46 <sup>gh</sup>	0.97±0.00 <sup>abc</sup>	0.53±0.01 <sup>cdef</sup>
SFND2	46.40±2.49 <sup>def</sup>	-165.75±3.89 <sup>gh</sup>	0.97±0.01 <sup>abc</sup>	0.54±0.02 <sup>def</sup>
SFND3	37.13±1.23 <sup>bcd</sup>	-185.56±2.97 <sup>fg</sup>	0.91±0.02 <sup>a</sup>	0.50±0.03 <sup>bc</sup>
SFND4	40.69±1.63 <sup>a</sup>	-219.92±31.41 <sup>cdef</sup>	0.90±0.01 <sup>a</sup>	0.50±0.00 <sup>bcd</sup>
SFND5	38.10±1.25 <sup>abc</sup>	-213.69±8.00 <sup>def</sup>	0.89±0.01 <sup>a</sup>	0.51±0.00 <sup>bcd</sup>
SPWD1	47.01±2.52 <sup>ab</sup>	-173.21±3.50 <sup>gh</sup>	0.99±0.00 <sup>abc</sup>	0.54±0.01 <sup>cdef</sup>
SPWD2	43.23±1.55 <sup>def</sup>	-167.93±3.94 <sup>gh</sup>	0.99±0.01 <sup>abc</sup>	0.55±0.02 <sup>ef</sup>
SPWD3	37.62±1.25 <sup>cd</sup>	-188.00±3.01 <sup>efg</sup>	0.92±0.02 <sup>a</sup>	0.50±0.03 <sup>bcd</sup>
SPWD4	41.22±1.65 <sup>ab</sup>	-222.82±31.82 <sup>cde</sup>	0.91±0.01 <sup>a</sup>	0.51±0.00 <sup>bcde</sup>
SPWD5	48.72±0.32 <sup>abc</sup>	-216.51±8.10 <sup>def</sup>	0.90±0.01 <sup>a</sup>	0.51±0.00 <sup>bcdef</sup>

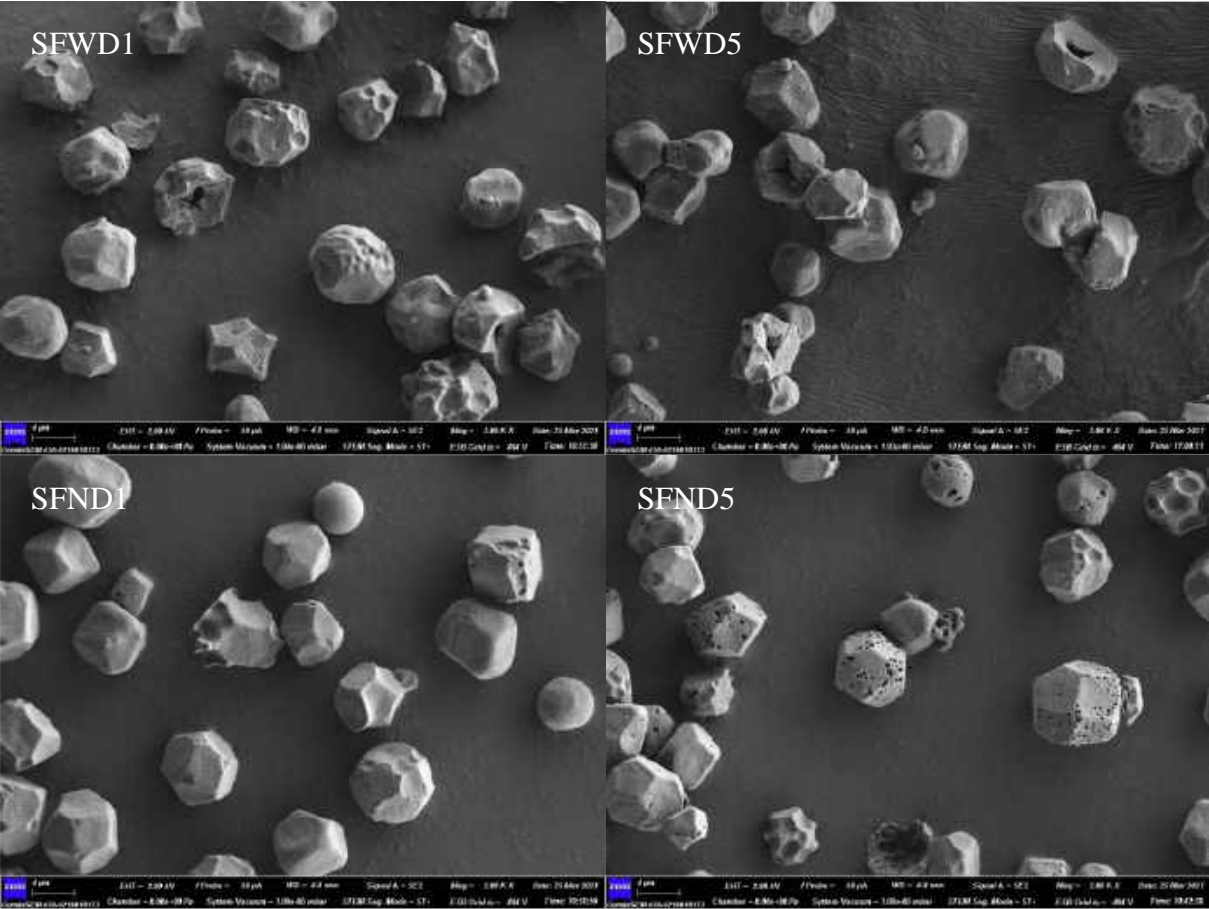
SA = fermented by *Lb. amylovorus*; SF = fermented by *Lb. fermentum*; SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days

Figure 4. 1: The SEM pictures for *Lb. amylovorus* fermented waxy and non-waxy samples for one day and five days.



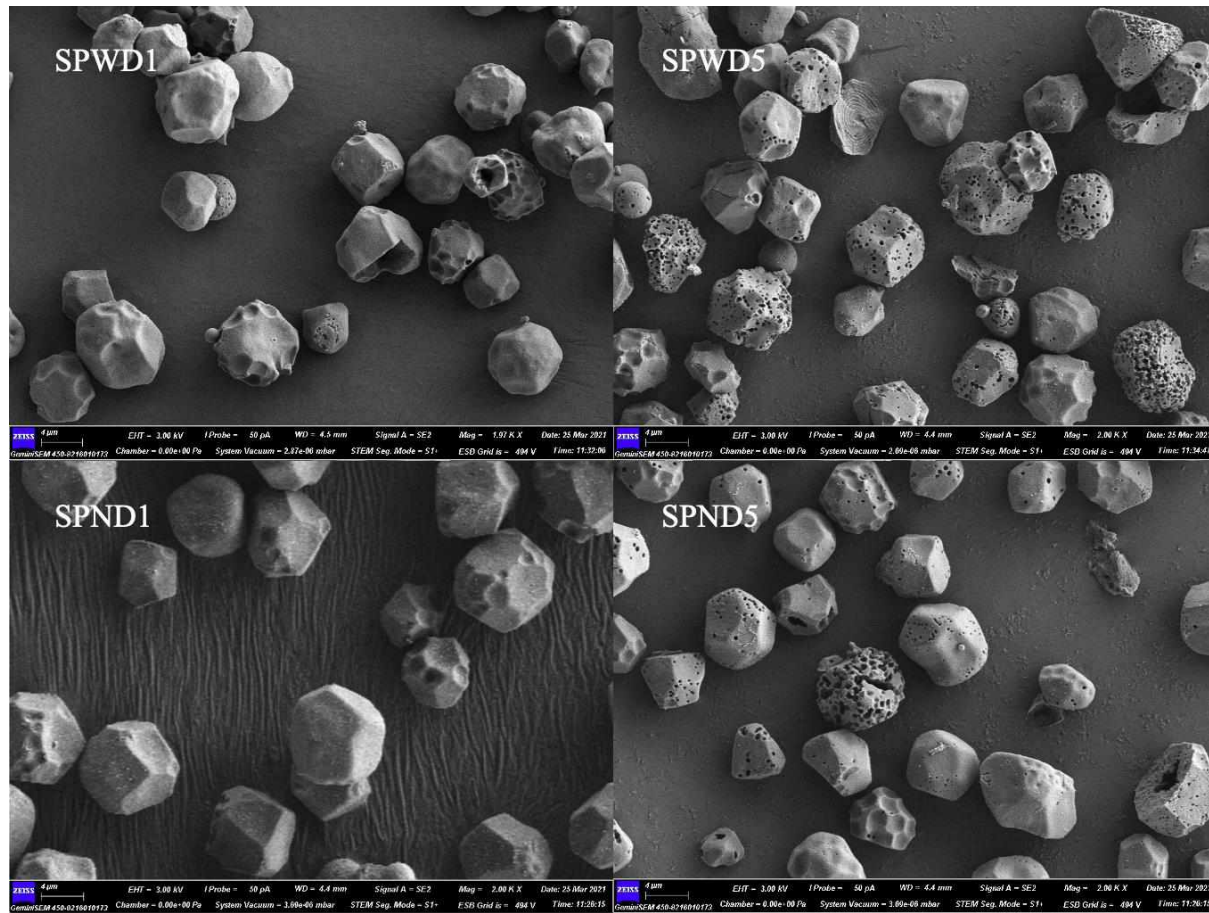
SA = fermented by *Lb. amylovorus*; W = waxy; N = non-waxy; D = fermentation days.

Figure 4. 2: The SEM pictures for *Lb. fermentum* fermented waxy and non-waxy samples for one day and five days.



SF = fermented by *Lb. fermentum*; W = waxy; N = non-waxy; D = fermentation days.

Figure 4. 3: The SEM pictures for *Lb.plantarum* fermented waxy and non-waxy samples for one day and five days.



SP = fermented by *Lb. plantarum*; W = waxy; N = non-waxy; D = fermentation days.



1 **Chapter 6 The rheological properties of single lactic acid bacterium strain**

2 **fermented proso millet starch**

3 **Abstract**

4 In this study, one waxy and one non-waxy proso millet starch were fermented by  
5 *Lb. amylovorus*, *Lb. fermentum*, and *Lb. plantarum* for one to five days. The  
6 crystallinities of the fermented proso millet starch samples were determined by XRD,  
7 and they were found significantly smaller than the raw samples. the particle size of  
8 the starch granules was measured by a mastersizer and decreased particle size  
9 distribution curves were observed. The steady shear properties of waxy and non-waxy  
10 starch samples were affected by fermentation oppositely.

11 **6.1 Introduction**

12 Fermented cereal products are widely consumed around the world, different  
13 types of cereal such as maize, sorghum, millet, pearl millet and rice are commonly  
14 applied as raw material (Guyot, 2012). Most of the fermented cereal products were  
15 prepared in household, and backslopping method is the common method for  
16 microorganism inoculation. Suanzhou is a natural fermented proso millet gruel  
17 producing in the north of China, the raw material proso millet (*Panicum miliaceum*.  
18 L) has a long history of cultivation in China (Qin et al., 2016; Lu et al., 2009). There  
19 was a previous identified the dominant microorganisms in Suanzhou is Lactic acid  
20 bacteria (LAB), and three LAB selected in this study was reported existing in  
21 Suanzhou samples (Qin et al., 2016). Due to proso millet is rich in starch, and the  
22 starch content is in the range of 57.69% to 74.70% (Wang et al., 2018). Starch will

23 have important roles in the textural properties of Suanzhou. There are several LAB  
24 were proven having the ability to produce lactic acid from starch directly, this group  
25 of LAB are called as Amylolytic LAB(ALAB), ALAB can synthesis amylolytic  
26 enzymes to hydrolysis and degrade starch (Reddy et al 2008). The amylolytic  
27 enzymes could have various effects on the structure of internal and external  
28 structures. In this study, X-Ray diffraction (XRD) pattern, particle size distribution of  
29 the starch granules and the rheological properties were studied to elucidate the effect  
30 of LAB fermentation on the proso millet starch paste flow behavior.

## 31 **6.2 Materials and method**

### 32 **6.2.1 Materials**

33 The starch samples were prepared following the method described in Chapter 4.  
34 There were one non-waxy and waxy proso millet starch samples fermented by three  
35 LAB: *Lactobacillus amylovorus*, *Lb. fermentum*, and *Lb. plantarum*, separately.

### 36 **6.2.2 Determination of particle sized distribution**

37 A mastersizer (Mastersizer 3000 Laser Diffraction Particle Size Analyzer  
38 (Malvern Instruments, Malvern, UK) was used to measure the particle size  
39 distribution of the fermented starch samples, and water was applied as dispersant.

### 40 **6.2.3 Determination of X-ray diffraction pattern of starch samples**

41 The X-ray diffraction (XRD) pattern was analyzed by a benchtop X-ray  
42 diffractometer (MiniFlex, Rigaku Americas Corporation, The Woodlands, TX)  
43 providing Cu-Ka (1.54 Å) radiation. The accelerating voltage was set at 40 kV and the  
44 current was set at 15 mA. The scanning  $2\theta$  angle was set at the range of  $5^\circ$  to  $35^\circ$ , the

45 step size was set as 0.01, and the rate of scanning was set as 1°/min.

#### 46 **6.2.4 Determination of steady shear properties**

47 A DHR-1 rheometer (TA instruments, Wilmington, DE) equipped with a  
48 diameter of parallel plate geometry was used to determine the steady shear properties.  
49 The method was previously described in the Chapter 5.

#### 50 **6.2.5 Determination of dynamic oscillatory properties**

51 The dynamic oscillatory properties were measured by a DHR-1 rheometer (TA  
52 instruments, Wilmington, DE) equipped with a diameter of parallel plate geometry.  
53 The method was described in the previous Chapter 5. Briefly, the heating process was  
54 performed in the temperature range of 25°C to 95°C with the heating speed of  
55 2°C/min. The temperature was set at 25°C, and frequency sweep was set at the range  
56 of 0.1 to 20 Hz. Storage modulus ( $G'$ ) and loss modulus ( $G''$ ), and loss tangent were  
57 recorded.

#### 58 **6.2.6 Statistic analysis**

59 The data collected in this study was duplicated, and a SPSS software for  
60 Macintosh (SPSS 23.0, SPSS Inc., Chicago, IL) was used to perform the statistical  
61 analysis.

### 62 **6.3 Result and discussion**

#### 63 **6.3.1 The result of particle size distribution of starch granules**

64 The result of particle size distribution was listed in the Tables 6.1, 6.2 and 6.3.  
65 The particle size distribution curves were shown in Figure 6.1, 6.2 and 6.3. In the  
66 Figure 6.1, the waxy samples fermented by *Lb. amylovorus* were shown double peak

67 curves. In the peak A, raw samples showed a largest width, the width was decreasing,  
68 and the height was higher with the increasing fermentation period. During  
69 fermentation, the smallest particles will be digested and degraded to smaller soluble  
70 sugars. The right side of peak A was found moving to left, which could be explain as  
71 the hydrolysis of larger granules, so the ratio of which was decreased. The shape of  
72 peak B was not much altered, which might result to the digestion speed of large starch  
73 granules were very slow due to the smaller specific surface area, so the ration was not  
74 much influence. The non-waxy samples fermented by *Lb. amylovorus* also showed  
75 double-peak curves, but the non-fermented samples were not found the larger particle  
76 size peak. The reason of peak B should be related to the greater swelling of starch  
77 granules during fermentation. Díaz et al. (2018) also report the similar double peak  
78 curves of the fermented starch granule particle size distribution, they also supposed  
79 the increase portion of larger size granules was due to the variation in swelling  
80 properties caused by enzymes and organic acid. The pH was decreased after  
81 fermentation as mentioned in Chapter 4, organic acids were produced as metabolites,  
82 both organic acids and enzymes could cause erosion on starch granule surface which  
83 contributed to the swelling properties.

84       However, for non-waxy samples fermented by *Lb. fermentum* and *Lb. plantarum*,  
85 single-peak curves were observed for all the fermented and non-fermented samples.  
86 After fermentation, the peaks became narrow and tall, which could also be explained  
87 as the effect of enzyme leading to the degradation of larger granules to middle size  
88 and the hydrolysis of smaller granules to soluble sugars. A similar phenomenon was

89 observed in the fermentation of corn starch with *Saccharomyces cerevisiae* (Reyes et  
90 al, 2016).

### 91 **6.3.2 The result of X-ray diffraction patterns**

92 The X-Ray diffractograms were shown in Figures 5.5, 5.6 and 5.7, the fermented  
93 and non-fermented samples were all indicating a typical A pattern, which was in line  
94 with the finding of Zheng et al. (2020). The peak positions of  $2\theta$  angles were not  
95 influence, Ye et al also reported that the  $2\theta$  angle positions of natural fermented sweet  
96 potato starch were not altered even for 12 months fermentation. For the fermented  
97 waxy samples, the peaks height was observed that lower than the raw samples,  
98 fermentation affect the intensities of the peaks. A weakened peak at  $5.6^\circ$  was also  
99 observed in the 12-month fermented sweet potato starch, the possible result to the  
100 differences on short length scale organization (Ye et al., 2019). The result of  
101 crystallinity was listed in the Table 6.3, the crystallinities of waxy and non-waxy  
102 samples were decreased, which was similar to the findings of samples collected from  
103 fermented proso millet starch (Chapter 5). Rice starch shares the same type A starch  
104 crystallites as proso millet starch, the effects of *Lb. fermentum*, *Candida santamariae*  
105 and cocktail of both all decreased the crystallinities of the fermented rice starch (Li et  
106 al., 2019). Unlike sweet potato starch, the type A starch crystallite is long range  
107 orders, intra- and inter-molecular hydrogen bonds link inter-helical water molecules  
108 together with short-range helices to form a monoclinic crystal unit, and the type A  
109 crystallites were built with many of these monoclinic crystal units (Pérez & Bertoft,  
110 2010), fermentations were found having an effect to disrupt the network of hydrogen

111 bonds in starch crystallites, which led to a decrease of crystallinity (Li et al., 2019)

### 112 **6.3.3 Steady shear properties**

113 Both power law and Herschel-Bulkley models were applied, shear rate and shear  
114 stress were fitted to the models as independent and dependent variables, respectively.

115 In the power law equation ( $\sigma = K \cdot \gamma^n$ ),  $K$  is the consistency indices, and  $n$  is the

116 behavior indices. As shown in Table 6.4,  $K$  of fermented waxy samples were

117 significantly increased and the  $n$  values were decrease in the upward and downward

118 curve. However, the  $K$  value of the fermented non-waxy samples were slightly

119 decreased in the upward curve, but not significantly. The  $n$  values of the *Lb.*

120 *amylovorus* and *Lb. fermentum* samples were significantly decreased in the upward

121 curve, but no obvious difference was found in the *Lb. plantarum* samples. But those

122 of the downward curve were quite different, a significant decrease was observed. All

123 the  $n$  values were in the range if 0 to 1, which indicated that all the fermented and

124 non-fermented starch pasted sharing a shear-thinning character. The  $n$  values reflect

125 different degree of shear-thinning of starch paste, the lower shear-thinning character

126 of the starch, the larger  $n$  value of the starch of the starch paste (Li & Zhu, 2018).

127 During LAB fermentation, pH values were reduced as previous reporting in Chapter

128 4, different types of organic acids are produced, and lactic acid was the predominant

129 metabolites (in Chapter 2). There were several studies (Lorri & Svanberg, 1993;

130 Masha et al, 1998; Van Der Maarel, et al., 2002) reporting that no significant effects

131 on the shear-thinning character of fermented starch samples were observed; they

132 believed the effect of acid hydrolysis was not strong enough to break the glycosidic

133 bonds thus thinning starch paste. However, even for the same strain of LAB, the  
134 fermentation effect can be various depending on the different starch samples, two  
135 samples belonging to the same species could be affected differently with different  
136 amylose content as the shown in Table 6.4 and 6.6. Not only glycosidic bonds, but  
137 there were also many other linkages in the starch granules such like hydrogen bonds  
138 having their roles on the structure of starch granules, so that leading to ununiformed  
139 physicochemical properties.

140 In Tables 6.5 and 6.7 showed the data fitted to the Herschel-Bulkley models. The  
141 reason of using Herschel-Bulkley model is the  $R^2$  of several samples fitted by the  
142 power law model was low. Herschel-Bulkley model is a three-parameter equation, a  
143  $\sigma_0$  (yield stress) was introduced.  $\sigma_0$  is the minimum force needed to start a flow  
144 (Mezger, 2006). A greater  $R^2$  was shown in the Tables 6.5 and 6.7, which meant better  
145 fits than the power law model. The power law model cannot describe the points at  
146 very low shear rate properly, whereas the Herschel-Bulkley can conducting the fitting  
147 better. The non-waxy samples fermented by *Lb. amylovorus* showed enhanced  $\sigma_0$ , the  
148 values were increased from  $4.95 \pm 0.36$  Pa to the range of  $6.00 \pm 0.13$  to  $7.16 \pm 0.16$  Pa,  
149 which meant that the fermented samples required a bigger force to initiate the flow.

150 The flow curves of fermented starch paste samples were shown in Figures 5.7,  
151 5.8, and 5.9. Fermentation had opposite effects on waxy and non-waxy samples as  
152 shown in the figures, the fermented waxy samples were below the non-fermented  
153 samples, whereas the fermented non-waxy samples were higher than the non-  
154 fermented samples. These curves indicated that the waxy samples tend to behave a

155 lower shear stress comparing to the raw samples, but the non-waxy samples tended to  
156 have a higher shear stress after LAB fermentation.

#### 157 **6.3.4 Dynamic oscillation properties**

158 In the result of Dynamic oscillation properties, the storage modulus ( $G'$ ) and the  
159 loss modulus ( $G''$ ) were recorded.  $G'$  reflects the elastic property, and the  $G''$  reflect  
160 the viscous properties

161 The results dynamic oscillation properties were shown in Tables 6.8 and 6.9. All  
162 the starch pastes samples had a larger  $G'$  than  $G''$ , so the starch paste showed a  
163 viscoelastic property, which was similar to sour cassava starch (Díaz et al., 2018).

164 The temperature needed to achieve the highest storage modulus ( $T_{G'_{\max}}$ ) was  
165 significantly increased after fermentation of the waxy samples fermented by *Lb.*  
166 *amylovorus* and *Lb. fermentum*, but as for the non-waxy samples the  $T_{G'_{\max}}$  was not  
167 significantly affected. The peak storage modulus ( $G'_{\max}$ ) of waxy samples were  
168 significantly decreased from 1661.1 Pa to the range of 647.8 to 1215.5 Pa, and the  $G'$   
169  $_{\max}$  of non-waxy samples were also slightly decreased, while there were also many  
170 samples were not altered significantly.

#### 171 **6.4 Conclusion**

172 In this study, the crystallinities of all the fermented starch samples were found  
173 decreased compared, and also the  $2\theta$  intensity peak of the fermented waxy samples  
174 were found lower that the raw starch. The particle size distribution of waxy samples  
175 was found to have double-peak curves, and all the curves were found left-moving  
176 compared to the raw samples. The flow curves of fermented waxy samples and non-



177 waxy samples were found opposite trends. The waxy fermented samples had a lower  
178 shear stress than the raw samples, and fermentation enhanced the shear stress of non-  
179 waxy samples under the same shear rate. In this study, the rheological properties of  
180 fermented starch were modified differently by three different LAB strains.

## 181 **6.5 Reference**

182 Díaz, A., Dini, C., Viña, S. Z., & García, M. A. (2018). Technological properties of sour  
183 cassava starches: Effect of fermentation and drying processes. *LWT*, *93*, 116-123.

184 Guyot, J. P. (2012). Cereal-based fermented foods in developing countries: ancient foods  
185 for modern research. *International Journal of Food Science & Technology*, *47*(6),  
186 1109-1114.

187 Guyot, J. P. (2012). Cereal-based fermented foods in developing countries: ancient foods  
188 for modern research. *International Journal of Food Science & Technology*, *47*(6),  
189 1109-1114.

190 Li, G., & Zhu, F. (2018). Effect of high pressure on rheological and thermal properties of  
191 quinoa and maize starches. *Food Chemistry*, *241*, 380-386.

192 Li, N., Zhang, B., Zhao, S., Niu, M., Jia, C., Huang, Q., Liu, Y & Lin, Q. (2019).

193 Influence of Lactobacillus/Candida fermentation on the starch structure of rice and  
194 the related noodle features. *International Journal of Biological Macromolecules*, *121*,  
195 882-888.

196 Lorri, W., & Svanberg, U. (1993). Lactic acid-fermented cereal gruels: viscosity and flour  
197 concentration. *International Journal of Food Sciences and Nutrition*, *44*(3), 207-213.

198 Lu, H., Zhang, J., Liu, K., Wu, N., Li, Y., Zhou, K., Ye, M., Zhang, T., Zhang, H., Yang,

199 X., Shen, L., Xu, D., & Li, Q. (2009). Earliest domestication of common millet  
200 (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. *Proceedings of the*  
201 *National Academy of Sciences of the United States of America*, 106, 7367–7372.

202 Masha, G. G. K., Ipsen, R., Petersen, M. A., & Jakobsen, M. (1998). Microbiological,  
203 rheological and aromatic characteristics of fermented Uji (an East African Sour  
204 Porridge). *World Journal of Microbiology and Biotechnology*, 14(3), 451-456.

205 Mezger, T. G. (2006). *The rheology handbook: For users of rotational and oscillatory*  
206 *rheometers* (2nd revised edition). Hannover, Germany: Vincentz Network GmbH &  
207 Co. KG.

208 Pérez, S., & Bertoft, E. (2010). The molecular structures of starch components and their  
209 contribution to the architecture of starch granules: A comprehensive review. *Starch-*  
210 *Stärke*, 62(8), 389-420.

211 Qin, H., Sun, Q., Pan, X., Qiao, Z., & Yang, H. (2016). Microbial diversity and  
212 biochemical analysis of Suanzhou: a traditional Chinese fermented cereal  
213 gruel. *Frontiers in Microbiology*, 7, 1311.

214 Reyes, I., Cruz-Sosa, F., Roman-Guerrero, A., Vernon-Carter, E. J., & Alvarez-Ramirez, J.  
215 (2016). Structural changes of corn starch during *Saccharomyces cerevisiae*  
216 fermentation. *Starch-Stärke*, 68(9-10), 961-971.

217 Van Der Maarel, M. J., Van der Veen, B., Uitdehaag, J. C., Leemhuis, H., & Dijkhuizen, L.  
218 (2002). Properties and applications of starch-converting enzymes of the  $\alpha$ -amylase  
219 family. *Journal of Biotechnology*, 94(2), 137-155.

220 Wang, R., Wang, H., Liu, X., Ji, X., Chen, L., Lu, P., ... & Qiao, Z. (2018). Waxy allelic

221 diversity in common millet (*Panicum miliaceum* L.) in China. *The Crop Journal*,  
222 6(4), 377-385.

223 Zheng, M. Z., Xiao, Y., Yang, S., Liu, H. M., Liu, M. H., Yaqoob, S., Xu, X.Y. & Liu, J. S.  
224 (2020). Effects of heat–moisture, autoclaving, and microwave treatments on  
225 physicochemical properties of proso millet starch. *Food Science & Nutrition*, 8(2),  
226 735-743.

227

**Table 6.1** Particle size distribution of waxy starch samples

Sample Name	D [3,2]	D [4,3]	Dx (10)	Dx (50)	Dx (90)
Raw-Waxy	7.97±0.00 <sup>ab</sup>	8.93±0.01 <sup>ab</sup>	5.39±0.00 <sup>abcd</sup>	8.44±0.00 <sup>ab</sup>	13.2±0.01 <sup>a</sup>
SAWD1	8.71±0.17 <sup>g</sup>	11.6±0.21 <sup>b</sup>	5.59±0.26 <sup>bcde</sup>	9.16±0.10 <sup>f</sup>	16.2±0.64 <sup>a</sup>
SAWD2	8.17±0.01 <sup>abcde</sup>	9.16±0.03 <sup>ab</sup>	5.53±0.05 <sup>abcde</sup>	8.63±0.01 <sup>cd</sup>	13.6±0.14 <sup>a</sup>
SAWD3	8.13±0.01 <sup>abcd</sup>	9.01±0.03 <sup>ab</sup>	5.61±0.02 <sup>cde</sup>	8.55±0.02 <sup>bc</sup>	13.1±0.12 <sup>a</sup>
SAWD4	8.06±0.01 <sup>abc</sup>	8.86±0.02 <sup>ab</sup>	5.62±0.02 <sup>de</sup>	8.44±0.01 <sup>ab</sup>	12.7±0.07 <sup>a</sup>
SAWD5	8.07±0.00 <sup>abc</sup>	8.84±0.02 <sup>ab</sup>	5.66±0.03 <sup>e</sup>	8.43±0.01 <sup>ab</sup>	12.6±0.06 <sup>a</sup>
SFWD1	8.55±0.09 <sup>fg</sup>	10.9±0.12 <sup>ab</sup>	5.36±0.10 <sup>abc</sup>	9.15±0.09 <sup>f</sup>	16.6±0.26 <sup>a</sup>
SFWD2	8.29±0.00 <sup>cde</sup>	9.41±0.03 <sup>ab</sup>	5.51±0.02 <sup>abcde</sup>	8.81±0.01 <sup>e</sup>	14.2±0.09 <sup>a</sup>
SFWD3	8.39±0.29 <sup>ef</sup>	10.3±0.73 <sup>ab</sup>	5.48±0.29 <sup>abcde</sup>	8.87±0.18 <sup>e</sup>	14.9±0.13 <sup>a</sup>
SFWD4	8.25±0.01 <sup>cde</sup>	9.42±0.06 <sup>ab</sup>	5.44±0.05 <sup>abcde</sup>	8.80±0.02 <sup>de</sup>	14.3±0.18 <sup>a</sup>
SFWD5	8.20±0.01 <sup>bcde</sup>	9.30±0.04 <sup>ab</sup>	5.46±0.02 <sup>abcde</sup>	8.72±0.02 <sup>cde</sup>	14.0±0.11 <sup>a</sup>
SPWD1	9.76±0.30 <sup>i</sup>	19.83±4.88 <sup>d</sup>	5.48±0.02 <sup>abcde</sup>	10.3±0.25 <sup>h</sup>	44.0±18.01 <sup>c</sup>
SPWD2	9.15±0.21 <sup>h</sup>	15.1±2.70 <sup>c</sup>	5.37±0.00 <sup>abcd</sup>	9.73±0.17 <sup>g</sup>	25.4±6.50 <sup>b</sup>
SPWD3	8.41±0.13 <sup>ef</sup>	11.1±0.41 <sup>ab</sup>	5.35±0.22 <sup>ab</sup>	8.90±0.09 <sup>e</sup>	15.8±0.66 <sup>a</sup>
SPWD4	8.33±0.11 <sup>def</sup>	10.8±0.20 <sup>ab</sup>	5.30±0.21 <sup>a</sup>	8.85±0.06 <sup>e</sup>	15.7±0.72 <sup>a</sup>
SPWD5	7.94±0.02 <sup>a</sup>	8.78±0.04 <sup>a</sup>	5.47±0.01 <sup>abcde</sup>	8.36±0.03 <sup>a</sup>	12.7±0.11 <sup>a</sup>

**Table 6.2** Particle size distribution of non-waxy starch samples

Sample Name	D [3,2]	D [4,3]	Dx (10)	Dx (50)	Dx (90)
Raw-Nonwaxy	7.61±0.00 <sup>j</sup>	8.52±0.00 <sup>j</sup>	5.20±0.00 <sup>cd</sup>	8.04±0.00 <sup>l</sup>	12.6±0.01 <sup>j</sup>
SAND1	7.31±0.00 <sup>d</sup>	7.97±0.02 <sup>d</sup>	5.21±0.02 <sup>d</sup>	7.62±0.01 <sup>e</sup>	11.2±0.07 <sup>e</sup>
SAND2	7.73±0.01 <sup>l</sup>	10.2±0.03 <sup>l</sup>	5.40±0.00 <sup>e</sup>	7.87±0.01 <sup>i</sup>	12.1±0.03 <sup>h</sup>
SAND3	7.35±0.01 <sup>ef</sup>	8.13±0.01 <sup>f</sup>	5.09±0.01 <sup>a</sup>	7.72±0.01 <sup>g</sup>	11.8±0.02 <sup>g</sup>
SAND4	7.27±0.01 <sup>c</sup>	7.96±0.02 <sup>d</sup>	5.14±0.03 <sup>b</sup>	7.60±0.01 <sup>de</sup>	11.3±0.08 <sup>e</sup>
SAND5	7.55±0.01 <sup>i</sup>	8.43±0.01 <sup>i</sup>	5.16±0.03 <sup>bc</sup>	7.96±0.00 <sup>j</sup>	12.4±0.06 <sup>i</sup>
SFND1	7.41±0.02 <sup>h</sup>	8.28±0.09 <sup>g</sup>	5.05±0.05 <sup>a</sup>	7.82±0.00 <sup>h</sup>	12.2±0.25 <sup>h</sup>
SFND2	7.37±0.00 <sup>g</sup>	7.82±0.02 <sup>bc</sup>	5.49±0.03 <sup>fg</sup>	7.59±0.05 <sup>d</sup>	10.5±0.06 <sup>cd</sup>
SFND3	7.35±0.01 <sup>ef</sup>	7.78±0.01 <sup>b</sup>	5.51±0.00 <sup>g</sup>	7.56±0.01 <sup>c</sup>	10.4±0.01 <sup>c</sup>
SFND4	7.36±0.01 <sup>fg</sup>	7.84±0.02 <sup>c</sup>	5.45±0.01 <sup>f</sup>	7.59±0.01 <sup>d</sup>	10.6±0.06 <sup>d</sup>
SFND5	7.34±0.01 <sup>e</sup>	8.05±0.02 <sup>e</sup>	5.16±0.03 <sup>bc</sup>	7.68±0.01 <sup>f</sup>	11.5±0.08 <sup>f</sup>
SPND1	7.69±0.00 <sup>k</sup>	8.36±0.02 <sup>h</sup>	5.47±0.02 <sup>fg</sup>	8.00±0.01 <sup>k</sup>	11.8±0.08 <sup>g</sup>
SPND2	7.07±0.01 <sup>a</sup>	7.59±0.01 <sup>a</sup>	5.17±0.03 <sup>bc</sup>	7.33±0.00 <sup>a</sup>	10.5±0.05 <sup>c</sup>
SPND3	7.21±0.00 <sup>b</sup>	7.64±0.01 <sup>a</sup>	5.40±0.02	7.42±0.00 <sup>b</sup>	10.2±0.04 <sup>b</sup>
SPND4	7.22±0.00 <sup>b</sup>	7.62±0.00 <sup>a</sup>	5.46±0.00 <sup>f</sup>	7.41±0.00 <sup>b</sup>	10.0±0.00 <sup>a</sup>
SPND5	7.94±0.02 <sup>m</sup>	8.78±0.04 <sup>k</sup>	5.47±0.01 <sup>fg</sup>	8.36±0.03 <sup>m</sup>	12.7±0.11 <sup>j</sup>



Sample ID	Crystallinity	Sample ID	Crystallinity
Raw Non-waxy	27.5%	Raw-waxy	33.8%
SAND1	26.3%	SAWD1	31.9%
SAND2	25.9%	SAWD2	31.0%
SAND3	27.5%	SAWD3	30.9%
SAND4	26.0%	SAWD4	29.4%
SAND5	26.1%	SAWD5	30.7%
SPND1	26.2%	SPWD1	31.0%
SPND2	27.3%	SPWD2	29.5%
SPND3	25.7%	SPWD3	30.8%
SPND4	26.1%	SPWD4	31.2%
SPND5	25.1%	SPWD5	30.1%
SFND1	26.2%	SFWD1	30.7%
SFND2	26.9%	SFWD2	29.3%
SFND3	26.8%	SFWD3	30.6%
SFND4	26.2%	SFWD4	30.0%
SFND5	25.3%	SFWD5	29.4%

**Table 6.3** Crystallinity of fermented proso millet starch.

**Table 6.4** The power law parameters of waxy fermented proso millet starch samples

	Upward			Downward		
	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>
RW	2.44±0.56 <sup>a</sup>	0.486±0.012 <sup>ef</sup>	0.999	1.54±0.26 <sup>a</sup>	0.542±0.003 <sup>f</sup>	0.999
SAWD1	7.21±0.32 <sup>b</sup>	0.420±0.009 <sup>d</sup>	0.994	2.98±0.09 <sup>bc</sup>	0.523±0.001 <sup>e</sup>	0.994
SAWD2	7.18±0.58 <sup>b</sup>	0.414±0.002 <sup>d</sup>	0.993	2.99±0.32 <sup>bc</sup>	0.516±0.018 <sup>de</sup>	0.993
SAWD3	7.12±0.07 <sup>b</sup>	0.413±0.004 <sup>d</sup>	0.994	3.02±0.00 <sup>bc</sup>	0.513±0.000 <sup>d</sup>	0.994
SAWD4	7.01±0.21 <sup>b</sup>	0.420±0.004 <sup>d</sup>	0.995	3.04±0.03 <sup>bc</sup>	0.517±0.000 <sup>de</sup>	0.995
SAWD5	7.36±0.53 <sup>b</sup>	0.404±0.001 <sup>cd</sup>	0.994	2.82±0.18 <sup>bc</sup>	0.517±0.000 <sup>de</sup>	0.994
SFWD1	10.1±0.64 <sup>cd</sup>	0.365±0.001 <sup>a</sup>	0.998	3.76±0.31 <sup>c</sup>	0.488±0.017 <sup>ab</sup>	0.998
SFWD2	10.5±0.84 <sup>d</sup>	0.367±0.010 <sup>a</sup>	0.996	3.90±0.07 <sup>c</sup>	0.489±0.026 <sup>ab</sup>	0.996
SFWD3	11.3±0.48 <sup>d</sup>	0.357±0.011 <sup>a</sup>	0.996	3.97±0.13 <sup>c</sup>	0.488±0.000 <sup>a</sup>	0.996
SFWD4	10.9±0.51 <sup>d</sup>	0.363±0.004 <sup>a</sup>	0.993	3.62±0.06 <sup>bc</sup>	0.497±0.000 <sup>bc</sup>	0.993
SFWD5	7.27±2.07 <sup>b</sup>	0.372±0.004 <sup>ab</sup>	0.996	2.67±0.65 <sup>abc</sup>	0.496±0.001 <sup>abc</sup>	0.996
SPWD1	9.97±1.12 <sup>cd</sup>	0.372±0.005 <sup>ab</sup>	0.994	3.50±0.24 <sup>bc</sup>	0.50±0.001 <sup>c</sup>	0.994
SPWD2	8.07±1.65 <sup>bc</sup>	0.390±0.024 <sup>bc</sup>	0.998	3.53±0.02 <sup>bc</sup>	0.499±0.024 <sup>ab</sup>	0.998
SPWD3	3.26±1.77 <sup>a</sup>	0.493±0.006 <sup>f</sup>	0.998	3.13±1.95 <sup>bc</sup>	0.499±0.014 <sup>c</sup>	0.998
SPWD4	7.43±0.48 <sup>b</sup>	0.405±0.006 <sup>cd</sup>	0.999	3.72±0.09 <sup>c</sup>	0.490±0.003 <sup>ab</sup>	0.999
SPWD5	3.64±0.07 <sup>a</sup>	0.470±0.005 <sup>e</sup>	0.998	2.33±0.13 <sup>ab</sup>	0.523±0.001 <sup>e</sup>	0.998



**Table 6.5** The Heschel-Bulkley parameters of waxy fermented proso millet starch samples

	Upward (Origin)				Downward (Origin)			
	$\sigma_o$ (Pa )	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>	$\sigma_o$ (Pa )	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>
RW	1.24±0.43 <sup>bc</sup>	1.96±0.38 <sup>a</sup>	0.516±0.01 <sup>h</sup>	1.000	1.90±0.35	1.00±0.16 <sup>a</sup>	0.603±0.002 <sup>h</sup>	1.000
SAWD1	2.72±0.12 <sup>fg</sup>	5.86±0.32 <sup>bcd</sup>	0.449±0.01 <sup>ef</sup>	0.995	3.92±0.32	1.80±0.02 <sup>ab</sup>	0.594±0.002 <sup>g</sup>	0.999
SAWD2	2.57±0.03 <sup>efg</sup>	5.87±0.58 <sup>bcd</sup>	0.442±0.00 <sup>ef</sup>	0.994	3.57±0.35	1.85±0.20 <sup>ab</sup>	0.584±0.002 <sup>f</sup>	0.999
SAWD3	2.12±0.05 <sup>ef</sup>	6.02±0.09 <sup>bcd</sup>	0.436±0.00 <sup>def</sup>	0.995	3.23±0.01	2.59±0.89 <sup>b</sup>	0.574±0.000 <sup>c</sup>	0.999
SAWD4	2.32±0.04 <sup>efg</sup>	5.85±0.16 <sup>bcd</sup>	0.445±0.00 <sup>ef</sup>	0.995	3.46±0.04	1.93±0.01 <sup>ab</sup>	0.581±0.000 <sup>f</sup>	0.999
SAWD5	2.18±0.26 <sup>efg</sup>	6.17±0.66 <sup>bcde</sup>	0.425±0.01 <sup>cde</sup>	0.995	3.00±0.25	1.86±0.10 <sup>ab</sup>	0.576±0.001 <sup>e</sup>	1.000
SFWD1	1.36±0.07 <sup>c</sup>	9.25±1.01 <sup>ef</sup>	0.377±0.00 <sup>ab</sup>	0.998	3.51±0.31	2.47±0.19 <sup>b</sup>	0.548±0.001 <sup>ab</sup>	0.999
SFWD2	1.96±0.33 <sup>de</sup>	9.28±1.01 <sup>ef</sup>	0.384±0.01 <sup>abc</sup>	0.996	3.75±0.03	2.52±0.06 <sup>b</sup>	0.550±0.004 <sup>b</sup>	0.999
SFWD3	1.52±0.14 <sup>cd</sup>	10.3±0.54 <sup>f</sup>	0.377±0.01 <sup>a</sup>	0.997	3.68±0.11	2.61±0.09 <sup>b</sup>	0.547±0.000 <sup>ab</sup>	0.999
SFWD4	2.36±0.29 <sup>efg</sup>	9.39±0.66 <sup>ef</sup>	0.382±0.01 <sup>abc</sup>	0.993	3.73±0.08	2.31±0.04 <sup>b</sup>	0.560±0.000 <sup>cd</sup>	0.999
SFWD5	2.21±0.29 <sup>efg</sup>	5.93±1.87 <sup>bcd</sup>	0.400±0.01 <sup>abcd</sup>	0.997	2.62±0.61	1.74±0.43 <sup>ab</sup>	0.556±0.000 <sup>c</sup>	0.999
SPWD1	2.79±0.65 <sup>g</sup>	8.30±1.47 <sup>def</sup>	0.398±0.01 <sup>abcd</sup>	0.995	3.61±0.24	2.25±0.15 <sup>b</sup>	0.563±0.001 <sup>d</sup>	0.999
SPWD2	0.74±0.06 <sup>ab</sup>	7.64±1.65 <sup>cdef</sup>	0.397±0.03 <sup>abcd</sup>	0.998	3.11±0.12	2.38±0.01 <sup>b</sup>	0.545±0.004 <sup>a</sup>	0.999
SPWD3	0.37±0.18 <sup>a</sup>	4.78±4.17 <sup>abc</sup>	0.468±0.06 <sup>fg</sup>	1.000	2.60±1.77	2.19±1.28 <sup>b</sup>	0.547±0.007 <sup>ab</sup>	1.000
SPWD4	1.04±0.03 <sup>bc</sup>	6.86±0.48 <sup>cde</sup>	0.416±0.01 <sup>cdef</sup>	0.999	3.24±0.10	2.53±0.05 <sup>b</sup>	0.544±0.000 <sup>a</sup>	1.000
SPWD5	1.16±0.22 <sup>bc</sup>	3.16±0.17 <sup>ab</sup>	0.489±0.00 <sup>gh</sup>	0.999	1.74±0.04	1.77±0.11 <sup>ab</sup>	0.562±0.002 <sup>d</sup>	1.000

**Table 6.6** The power law parameters of non-waxy fermented proso millet starch samples

	Upward			Downward		
	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>
RN	4.66±0.19 <sup>cde</sup>	0.448±0.006 <sup>f</sup>	0.992	3.52±0.20 <sup>abcd</sup>	0.479±0.001 <sup>g</sup>	0.992
SAND1	4.20±0.19 <sup>bcde</sup>	0.412±0.015 <sup>ef</sup>	0.969	3.85±0.55 <sup>cd</sup>	0.427±0.002 <sup>f</sup>	0.982
SAND2	4.81±0.18 <sup>de</sup>	0.372±0.040 <sup>bcd</sup>	0.962	3.76±0.14 <sup>bcd</sup>	0.411±0.003 <sup>def</sup>	0.981
SAND3	4.26±0.13 <sup>bcde</sup>	0.398±0.035 <sup>bcd</sup>	0.976	3.91±0.02 <sup>d</sup>	0.409±0.001 <sup>def</sup>	0.980
SAND4	4.42±0.20 <sup>bcde</sup>	0.386±0.051 <sup>b</sup>	0.970	3.63±0.33 <sup>abcd</sup>	0.414±0.002 <sup>ef</sup>	0.980
SAND5	4.63±0.34 <sup>cde</sup>	0.378±0.087 <sup>d</sup>	0.973	3.78±0.21 <sup>bcd</sup>	0.408±0.000 <sup>de</sup>	0.981
SFND1	3.75±0.64 <sup>ab</sup>	0.346±0.191 <sup>bc</sup>	0.988	3.44±0.28 <sup>abcd</sup>	0.467±0.007 <sup>g</sup>	0.992
SFND2	3.99±0.21 <sup>abc</sup>	0.386±0.111 <sup>bcd</sup>	0.982	3.33±0.27 <sup>abcd</sup>	0.411±0.015 <sup>def</sup>	0.986
SFND3	3.62±0.94 <sup>ab</sup>	0.377±0.0217 <sup>d</sup>	0.984	3.13±0.58 <sup>abc</sup>	0.397±0.012 <sup>cde</sup>	0.987
SFND4	5.00±0.90 <sup>e</sup>	0.381±0.094 <sup>a</sup>	0.982	4.64±0.05 <sup>e</sup>	0.390±0.010 <sup>bc</sup>	0.979
SFND5	3.76±0.13 <sup>ab</sup>	0.374±0.016 <sup>cd</sup>	0.987	3.24±0.06 <sup>abcd</sup>	0.395±0.009 <sup>cd</sup>	0.986
SPND1	3.36±0.43 <sup>a</sup>	0.458±0.027 <sup>ef</sup>	0.986	2.92±0.44 <sup>a</sup>	0.476±0.005 <sup>g</sup>	0.993
SPND2	4.36±0.41 <sup>bcde</sup>	0.456±0.035 <sup>e</sup>	0.973	3.56±0.09 <sup>abcd</sup>	0.386±0.007 <sup>bc</sup>	0.984
SPND3	3.99±0.16 <sup>abcd</sup>	0.435±0.041 <sup>f</sup>	0.975	3.05±0.09 <sup>ab</sup>	0.374±0.005 <sup>ab</sup>	0.984
SPND4	4.13±0.35 <sup>abcd</sup>	0.436±0.036 <sup>f</sup>	0.983	3.75±0.66 <sup>bcd</sup>	0.368±0.017 <sup>a</sup>	0.978
SPND5	3.91±0.12 <sup>abc</sup>	0.439±0.011 <sup>f</sup>	0.984	3.30±0.07 <sup>abcd</sup>	0.383±0.003 <sup>abc</sup>	0.985

**Table 6.7** The Heschel-Bulkley parameters of waxy fermented proso millet starch samples

	Upward (Origin)				Downward (Origin)			
	$\sigma_o$ (Pa )	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>	$\sigma_o$ (Pa )	K(Pa·S <sup>n</sup> )	n	R <sup>2</sup>
RN	4.95±0.36 <sup>bcdef</sup>	2.59±0.17 <sup>e</sup>	0.530±0.002 <sup>a</sup>	0.999	4.48±0.13 <sup>bcd</sup>	1.87±0.15 <sup>d</sup>	0.568±0.003 <sup>e</sup>	1.000
SAND1	6.83±0.41 <sup>hi</sup>	1.19±0.19 <sup>ab</sup>	0.592±0.001 <sup>a</sup>	0.999	5.40±0.87 <sup>de</sup>	1.49±0.17 <sup>abc</sup>	0.561±0.003 <sup>e</sup>	0.999
SAND2	7.16±0.16 <sup>i</sup>	1.16±0.02 <sup>a</sup>	0.575±0.006 <sup>a</sup>	0.999	5.12±0.33 <sup>de</sup>	1.38±0.01 <sup>ab</sup>	0.552±0.004 <sup>de</sup>	1.000
SAND3	6.00±0.13 <sup>fgh</sup>	1.38±0.03 <sup>abc</sup>	0.575±0.006 <sup>a</sup>	1.000	5.39±0.09 <sup>de</sup>	1.41±0.05 <sup>ab</sup>	0.553±0.004 <sup>de</sup>	1.000
SAND4	6.32±0.07 <sup>ghi</sup>	1.30±0.20 <sup>abc</sup>	1.001±0.615 <sup>b</sup>	1.000	5.08±0.50 <sup>de</sup>	1.31±0.09 <sup>a</sup>	0.558±0.001 <sup>e</sup>	1.000
SAND5	6.24±0.12 <sup>ghi</sup>	1.41±0.01 <sup>abc</sup>	0.545±0.006 <sup>a</sup>	1.000	5.06±0.34 <sup>de</sup>	1.41±0.05 <sup>ab</sup>	0.547±0.002 <sup>cde</sup>	1.000
SFND1	5.35±0.27 <sup>defg</sup>	1.72±0.27 <sup>cd</sup>	0.569 ±0.017 <sup>a</sup>	0.999	4.52±0.01 <sup>cd</sup>	1.75±0.16 <sup>cd</sup>	0.558±0.001 <sup>e</sup>	1.000
SFND2	4.63±0.65 <sup>abcde</sup>	1.60±0.36 <sup>abcd</sup>	0.517±0.036 <sup>a</sup>	1.000	3.98±0.01 <sup>abc</sup>	1.43±0.14 <sup>ab</sup>	0.562±0.008 <sup>bc</sup>	0.992
SFND3	3.83±0.50 <sup>ab</sup>	1.53±0.48 <sup>abcd</sup>	0.499±0.030 <sup>a</sup>	0.999	3.39±0.63 <sup>ab</sup>	1.40±0.19 <sup>ab</sup>	0.509±0.005 <sup>a</sup>	1.000
SFND4	5.72±0.42 <sup>efgh</sup>	1.97±0.02 <sup>d</sup>	0.512±0.013 <sup>a</sup>	0.999	5.89±0.66 <sup>e</sup>	1.66±0.13 <sup>bcd</sup>	0.534±0.023 <sup>cd</sup>	0.999
SFND5	3.74±0.06 <sup>a</sup>	1.69±0.16 <sup>cd</sup>	0.487±0.007 <sup>a</sup>	1.000	3.53±0.08 <sup>abc</sup>	1.43±0.03 <sup>ab</sup>	0.509±0.003 <sup>a</sup>	1.000
SPND1	4.79±1.36 <sup>abcde</sup>	1.51±0.04 <sup>abcd</sup>	0.571±0.019 <sup>a</sup>	0.999	3.42±0.80 <sup>abc</sup>	1.63±0.13 <sup>bcd</sup>	0.558±0.005 <sup>e</sup>	1.000
SPND2	5.31±0.33 <sup>cdefg</sup>	1.35±0.17 <sup>abc</sup>	0.520±0.008 <sup>a</sup>	0.999	3.95±0.09 <sup>abc</sup>	1.49±0.17 <sup>abc</sup>	0.509±0.003 <sup>a</sup>	0.999
SPND3	4.33±0.57 <sup>abcd</sup>	1.34±0.11 <sup>abc</sup>	0.488±0.022 <sup>a</sup>	0.999	3.22±0.37 <sup>a</sup>	1.27±0.05 <sup>a</sup>	0.496±0.016 <sup>a</sup>	1.000
SPND4	4.18±0.57 <sup>abc</sup>	1.67±0.01 <sup>cd</sup>	0.481±0.008 <sup>a</sup>	0.999	4.40±0.86 <sup>bcd</sup>	1.32±0.08 <sup>a</sup>	0.513±0.000 <sup>ab</sup>	1.000
SPND5	3.92±0.15 <sup>ab</sup>	1.64±0.04 <sup>bcd</sup>	0.481±0.002 <sup>a</sup>	1.000	3.61±0.13 <sup>abc</sup>	1.38±0.02 <sup>ab</sup>	0.505±0.004 <sup>a</sup>	1.000

**Table 6.8** The result of the dynamic rheological properties of waxy samples

	$T_{G'_{max}}$ (°C)	$G'_{max}$ (Pa)	$Tan\delta_{G'_{max}}$	$G'_{99\text{ }^\circ\text{C}}$ (Pa)	$Tan\delta_{99\text{ }^\circ\text{C}}$	$G'_{25\text{ }^\circ\text{C}}$ (Pa)	$Tan\delta_{25\text{ }^\circ\text{C}}$	$G'_{0.1\text{ Hz}}$ (Pa)	$Tan\delta_{0.1\text{ Hz}}$	$G'_{20\text{ Hz}}$ (Pa)	$Tan\delta_{20\text{ Hz}}$
Raw-Waxy	72.8 <sup>ab</sup>	1661.1 <sup>e</sup>	0.177 <sup>abc</sup>	126.4 <sup>ef</sup>	0.201 <sup>fg</sup>	117.8 <sup>f</sup>	0.402 <sup>d</sup>	80.9 <sup>efg</sup>	0.221	266.8 <sup>h</sup>	0.742 <sup>cd</sup>
SAWD1	74.7 <sup>cde</sup>	900.2 <sup>bcd</sup>	0.170 <sup>abc</sup>	168.8 <sup>g</sup>	0.137 <sup>a</sup>	142.3 <sup>g</sup>	0.267 <sup>a</sup>	110.2 <sup>h</sup>	0.139	254.1 <sup>gh</sup>	0.529 <sup>a</sup>
SAWD2	75.6 <sup>fg</sup>	724.8 <sup>bc</sup>	0.163 <sup>ab</sup>	127.5 <sup>ef</sup>	0.160 <sup>bc</sup>	108.5 <sup>ef</sup>	0.325 <sup>abc</sup>	79.5 <sup>efg</sup>	0.178	243.7 <sup>fg</sup>	0.549 <sup>a</sup>
SAWD3	74.8 <sup>cde</sup>	937.1 <sup>bcd</sup>	0.184 <sup>abcde</sup>	125.4 <sup>ef</sup>	0.170 <sup>bcd</sup>	106.6 <sup>def</sup>	0.370 <sup>bcd</sup>	74.8 <sup>ef</sup>	0.216	223.5 <sup>def</sup>	0.700 <sup>bc</sup>
SAWD4	74.9 <sup>def</sup>	838.9 <sup>bc</sup>	0.183 <sup>abcd</sup>	135.7 <sup>f</sup>	0.157 <sup>b</sup>	117.6 <sup>f</sup>	0.316 <sup>ab</sup>	86.6 <sup>g</sup>	0.178	245.7 <sup>fgh</sup>	0.549 <sup>a</sup>
SAWD5	75.4 <sup>efg</sup>	647.8 <sup>b</sup>	0.194 <sup>bode</sup>	100.1 <sup>c</sup>	0.186 <sup>def</sup>	106.2 <sup>def</sup>	0.347 <sup>bcd</sup>	74.7 <sup>ef</sup>	0.219	217.8 <sup>cde</sup>	0.610 <sup>ab</sup>
SPWD1	72.4 <sup>a</sup>	1215.5 <sup>d</sup>	0.157 <sup>a</sup>	102.0 <sup>c</sup>	0.210 <sup>g</sup>	94.1 <sup>cde</sup>	0.403 <sup>d</sup>	63.9 <sup>cd</sup>	0.23	217.9 <sup>cde</sup>	0.714 <sup>c</sup>
SPWD2	73.1 <sup>ab</sup>	846.2 <sup>bc</sup>	0.190 <sup>bode</sup>	60.3 <sup>ab</sup>	0.284 <sup>h</sup>	62.5 <sup>a</sup>	0.577 <sup>f</sup>	38.2 <sup>ab</sup>	0.322	169.7 <sup>a</sup>	0.827 <sup>de</sup>
SPWD3	75.7 <sup>g</sup>	346.8 <sup>a</sup>	0.277 <sup>g</sup>	50.9 <sup>a</sup>	0.376 <sup>i</sup>	58.6 <sup>a</sup>	0.610 <sup>f</sup>	32.1 <sup>a</sup>	0.426	170.8 <sup>a</sup>	0.952 <sup>g</sup>
SPWD4	72.8 <sup>ab</sup>	1051.2 <sup>cd</sup>	0.194 <sup>bode</sup>	68.6 <sup>b</sup>	0.278 <sup>h</sup>	73.0 <sup>ab</sup>	0.513 <sup>e</sup>	44.5 <sup>b</sup>	0.319	197.1 <sup>bc</sup>	0.854 <sup>ef</sup>
SPWD5	73.3 <sup>b</sup>	887.1 <sup>bcd</sup>	0.240 <sup>f</sup>	61.6 <sup>ab</sup>	0.354 <sup>i</sup>	67.3 <sup>a</sup>	0.615 <sup>f</sup>	36.9 <sup>ab</sup>	0.414	206.5 <sup>bcd</sup>	0.941 <sup>fg</sup>
SFWD1	74.6 <sup>cde</sup>	861.8 <sup>bc</sup>	0.216 <sup>ef</sup>	107.7 <sup>cd</sup>	0.190 <sup>ef</sup>	90.0 <sup>cd</sup>	0.394 <sup>cd</sup>	61.0 <sup>c</sup>	0.235	193.2 <sup>b</sup>	0.729 <sup>c</sup>
SFWD2	74.0 <sup>c</sup>	824.0 <sup>bc</sup>	0.214 <sup>def</sup>	120.5 <sup>de</sup>	0.173 <sup>bode</sup>	106.8 <sup>def</sup>	0.388 <sup>cd</sup>	71.0 <sup>cde</sup>	0.216	207.1 <sup>bcd</sup>	0.698 <sup>bc</sup>
SFWD3	74.7 <sup>cde</sup>	780.5 <sup>bc</sup>	0.196 <sup>bode</sup>	109.4 <sup>cd</sup>	0.178 <sup>cde</sup>	88.2 <sup>bc</sup>	0.365 <sup>bcd</sup>	63.2 <sup>cd</sup>	0.226	186.3 <sup>ab</sup>	0.740 <sup>cd</sup>
SFWD4	74.4 <sup>cd</sup>	918.5 <sup>bcd</sup>	0.211 <sup>def</sup>	137.1 <sup>f</sup>	0.157 <sup>b</sup>	119.9 <sup>f</sup>	0.355 <sup>bcd</sup>	84.7 <sup>fg</sup>	0.206	234.9 <sup>efg</sup>	0.687 <sup>bc</sup>
SFWD5	75.0 <sup>defg</sup>	869.9 <sup>bc</sup>	0.200 <sup>cde</sup>	116.7 <sup>de</sup>	0.175 <sup>bode</sup>	104.6 <sup>cdef</sup>	0.379 <sup>bcd</sup>	71.9 <sup>de</sup>	0.226	229.7 <sup>def</sup>	0.664 <sup>bc</sup>

**Table 6.9** The result of the dynamic rheological properties of non-waxy samples

	$T_{G'_{max}}$ (°C)	$G'_{max}$ (Pa)	$Tan\delta_{G'_{max}}$	$G'_{90\text{ }^\circ\text{C}}$ (Pa)	$Tan\delta_{90\text{ }^\circ\text{C}}$	$G'_{25\text{ }^\circ\text{C}}$ (Pa)	$Tan\delta_{25\text{ }^\circ\text{C}}$	$G'_{0.1\text{ Hz}}$ (Pa)	$Tan\delta_{0.1\text{ Hz}}$	$G'_{20\text{ Hz}}$ (Pa)	$Tan\delta_{20\text{ Hz}}$
<b>Raw-Nonwaxy</b>	79.4 <sup>ab</sup>	5990.1 <sup>fg</sup>	0.105 <sup>bcde</sup>	3641.9 <sup>cde</sup>	0.0698 <sup>bdefg</sup>	11578.1 <sup>f</sup>	0.0262 <sup>a</sup>	11635.1 <sup>f</sup>	0.0194 <sup>a</sup>	12875.5 <sup>e</sup>	0.0608 <sup>a</sup>
<b>SAND1</b>	82.2 <sup>abcd</sup>	4478.8 <sup>cd</sup>	0.095 <sup>bc</sup>	3462.7 <sup>cd</sup>	0.0662 <sup>bcd</sup>	9774.6 <sup>cdef</sup>	0.0264 <sup>a</sup>	9632.3 <sup>cdef</sup>	0.0153 <sup>a</sup>	10772.6 <sup>bode</sup>	0.0625 <sup>a</sup>
<b>SAND2</b>	82.7 <sup>abcd</sup>	5247.6 <sup>def</sup>	0.100 <sup>bcd</sup>	4176.8 <sup>ef</sup>	0.0653 <sup>bc</sup>	9474.6 <sup>bdef</sup>	0.0284 <sup>a</sup>	9317.2 <sup>cde</sup>	0.0217 <sup>a</sup>	10464.1 <sup>bode</sup>	0.0665 <sup>a</sup>
<b>SAND3</b>	83.0 <sup>abcd</sup>	3393.1 <sup>ab</sup>	0.098 <sup>bc</sup>	2715.8 <sup>ab</sup>	0.0669 <sup>bdef</sup>	7204.4 <sup>ab</sup>	0.0289 <sup>a</sup>	7085.6 <sup>ab</sup>	0.0174 <sup>a</sup>	7984.1 <sup>ab</sup>	0.0681 <sup>a</sup>
<b>SAND4</b>	82.9 <sup>abcd</sup>	4097.6 <sup>abc</sup>	0.098 <sup>bc</sup>	3219.5 <sup>bc</sup>	0.0666 <sup>bode</sup>	7741.3 <sup>abc</sup>	0.0287 <sup>a</sup>	7592.1 <sup>abc</sup>	0.0206 <sup>a</sup>	8578.5 <sup>abc</sup>	0.0703 <sup>a</sup>
<b>SAND5</b>	83.5 <sup>bod</sup>	4504.3 <sup>cd</sup>	0.116 <sup>de</sup>	3598.2 <sup>cde</sup>	0.0761 <sup>g</sup>	9459.7 <sup>bdef</sup>	0.0732 <sup>b</sup>	8856.2 <sup>bod</sup>	0.0600 <sup>b</sup>	10979.2 <sup>cde</sup>	0.1230 <sup>b</sup>
<b>SPND1</b>	79.8 <sup>abc</sup>	5183.9 <sup>def</sup>	0.091 <sup>b</sup>	3844.7 <sup>cdef</sup>	0.0631 <sup>b</sup>	11256.9 <sup>ef</sup>	0.0265 <sup>a</sup>	11293.3 <sup>ef</sup>	0.0164 <sup>a</sup>	12475.2 <sup>de</sup>	0.0608 <sup>a</sup>
<b>SPND2</b>	81.0 <sup>abc</sup>	6221.3 <sup>gh</sup>	0.092 <sup>b</sup>	4408.0 <sup>f</sup>	0.0558 <sup>a</sup>	9186.9 <sup>bode</sup>	0.0257 <sup>a</sup>	9310.2 <sup>cde</sup>	0.0170 <sup>a</sup>	10302.9 <sup>bode</sup>	0.0598 <sup>a</sup>
<b>SPND3</b>	78.9 <sup>a</sup>	6974.7 <sup>h</sup>	0.076 <sup>a</sup>	5237.5 <sup>g</sup>	0.0511 <sup>a</sup>	10335.6 <sup>def</sup>	0.0264 <sup>a</sup>	10443.1 <sup>def</sup>	0.0181 <sup>a</sup>	11524.1 <sup>cde</sup>	0.0616 <sup>a</sup>
<b>SPND4</b>	83.4 <sup>bcd</sup>	3175.4 <sup>a</sup>	0.093 <sup>b</sup>	2433.4 <sup>a</sup>	0.0701 <sup>bdefg</sup>	6660.7 <sup>a</sup>	0.0297 <sup>a</sup>	6282.8 <sup>a</sup>	0.0129 <sup>a</sup>	7024.8 <sup>a</sup>	0.0607 <sup>a</sup>
<b>SPND5</b>	84.0 <sup>cd</sup>	3413.7 <sup>ab</sup>	0.095 <sup>bc</sup>	2746.3 <sup>ab</sup>	0.0715 <sup>cdefg</sup>	6745.7 <sup>a</sup>	0.0395 <sup>ab</sup>	6209.2 <sup>a</sup>	0.0166 <sup>a</sup>	6921.9 <sup>a</sup>	0.0615 <sup>a</sup>
<b>SFND1</b>	86.4 <sup>d</sup>	4672.5 <sup>cd</sup>	0.111 <sup>cde</sup>	3261.1 <sup>bcd</sup>	0.0740 <sup>defg</sup>	10608.4 <sup>def</sup>	0.028 <sup>a</sup>	10466.6 <sup>def</sup>	0.0154 <sup>a</sup>	11755.1 <sup>de</sup>	0.0675 <sup>a</sup>
<b>SFND2</b>	81.5 <sup>abc</sup>	5423.9 <sup>defg</sup>	0.119 <sup>e</sup>	3540.6 <sup>cde</sup>	0.0744 <sup>efg</sup>	9992.7 <sup>cdef</sup>	0.0271 <sup>a</sup>	9817.4 <sup>def</sup>	0.0185 <sup>a</sup>	10958.5 <sup>cde</sup>	0.0629 <sup>a</sup>
<b>SFND3</b>	82.1 <sup>abcd</sup>	5738.2 <sup>efg</sup>	0.098 <sup>bc</sup>	3944.9 <sup>def</sup>	0.0691 <sup>bdefg</sup>	9686.3 <sup>cdef</sup>	0.0257 <sup>a</sup>	9541.4 <sup>def</sup>	0.0208 <sup>a</sup>	10663.4 <sup>bode</sup>	0.0655 <sup>a</sup>
<b>SFND4</b>	83.2 <sup>abcd</sup>	4204.1 <sup>bc</sup>	0.100 <sup>bcd</sup>	3257.9 <sup>bcd</sup>	0.0748 <sup>fg</sup>	8680.0 <sup>abcd</sup>	0.0299 <sup>a</sup>	8550.1 <sup>bod</sup>	0.0308 <sup>ab</sup>	9649.7 <sup>abcd</sup>	0.0704 <sup>a</sup>
<b>SFND5</b>	82.9 <sup>abcd</sup>	4920.5 <sup>cde</sup>	0.103 <sup>bode</sup>	3794.3 <sup>cdef</sup>	0.0713 <sup>cdefg</sup>	91 <sup>bode</sup>	0.0289 <sup>a</sup>	9018.3 <sup>bod</sup>	0.0188 <sup>a</sup>	10127.9 <sup>bode</sup>	0.0681 <sup>a</sup>

**Figure 6.1** Particle size distribution of *Lb. amylovorus* fermented proso millet starch samples

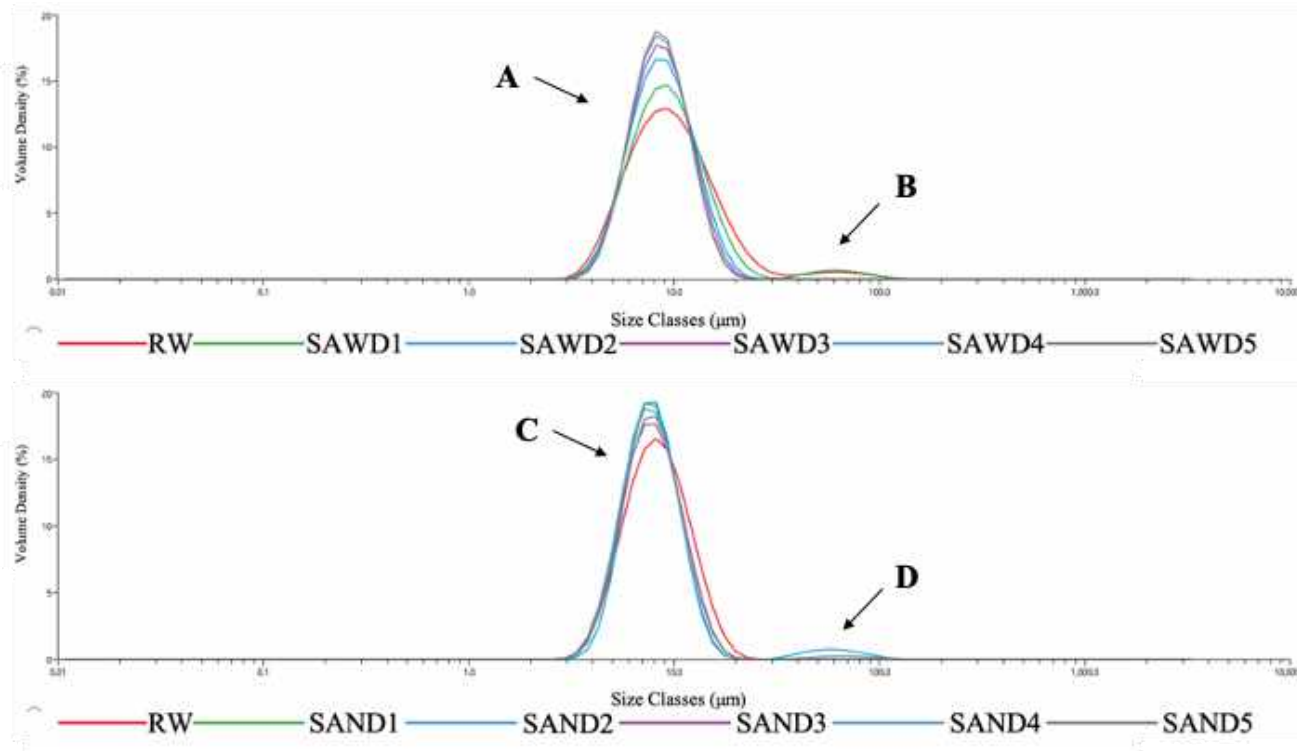


Figure 5.2 Particle size distribution of *Lb.plantarum* fermented proso millet starch samples

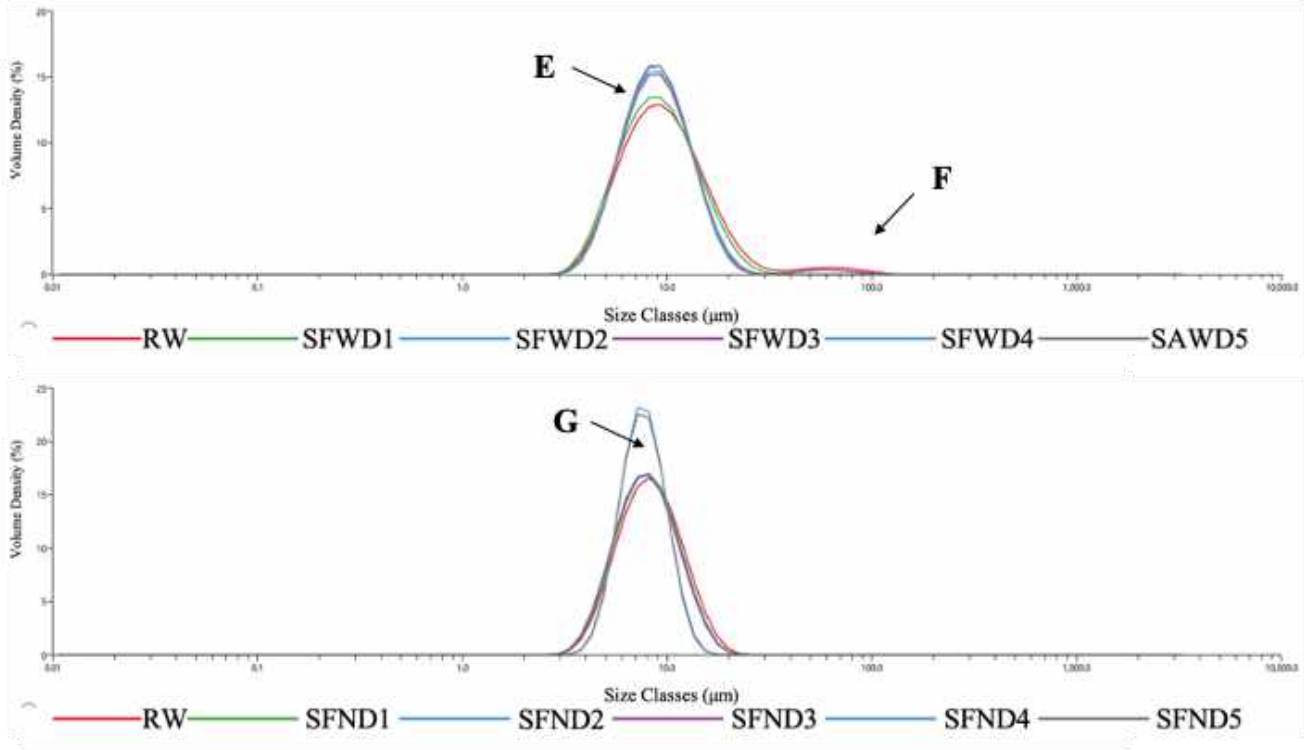


Figure 5.3 Particle size distribution of *Lb. plantarum* fermented proso millet starch samples

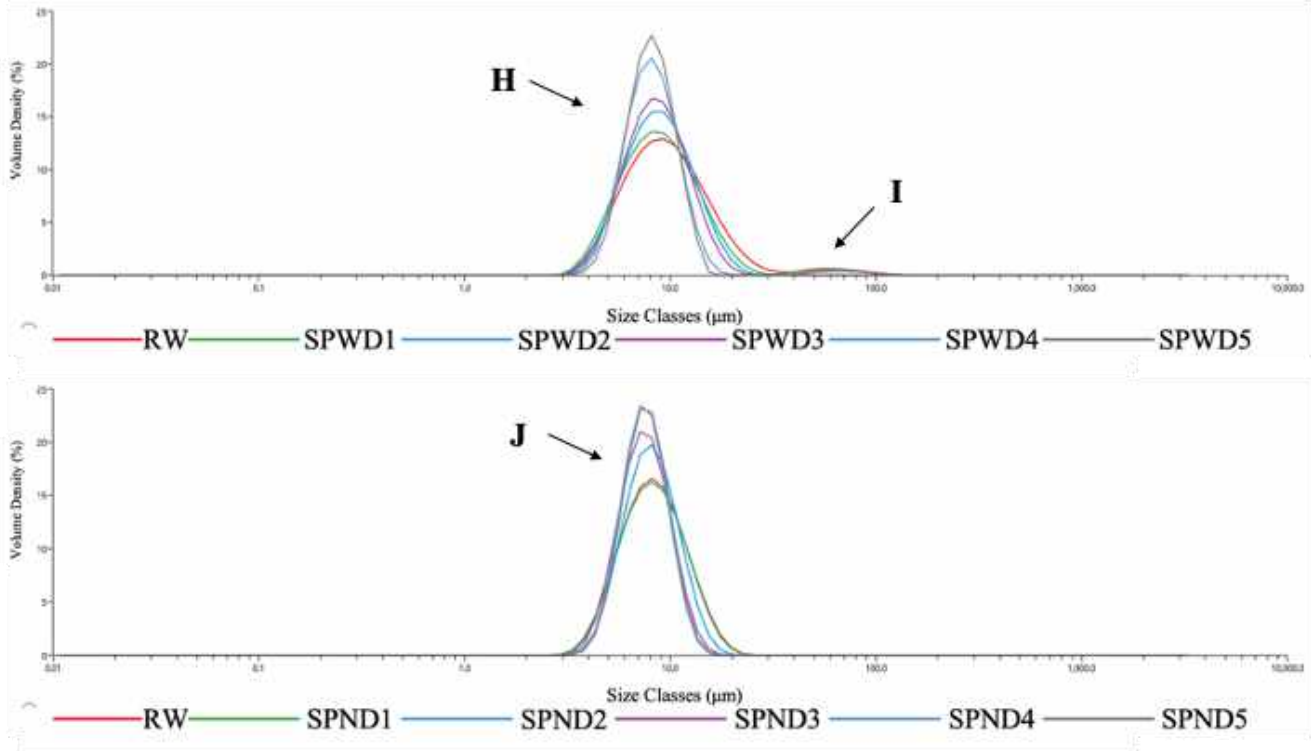




Figure 5.4 X-Ray diffractogram of *Lb. amylovorus* fermented starch sample.

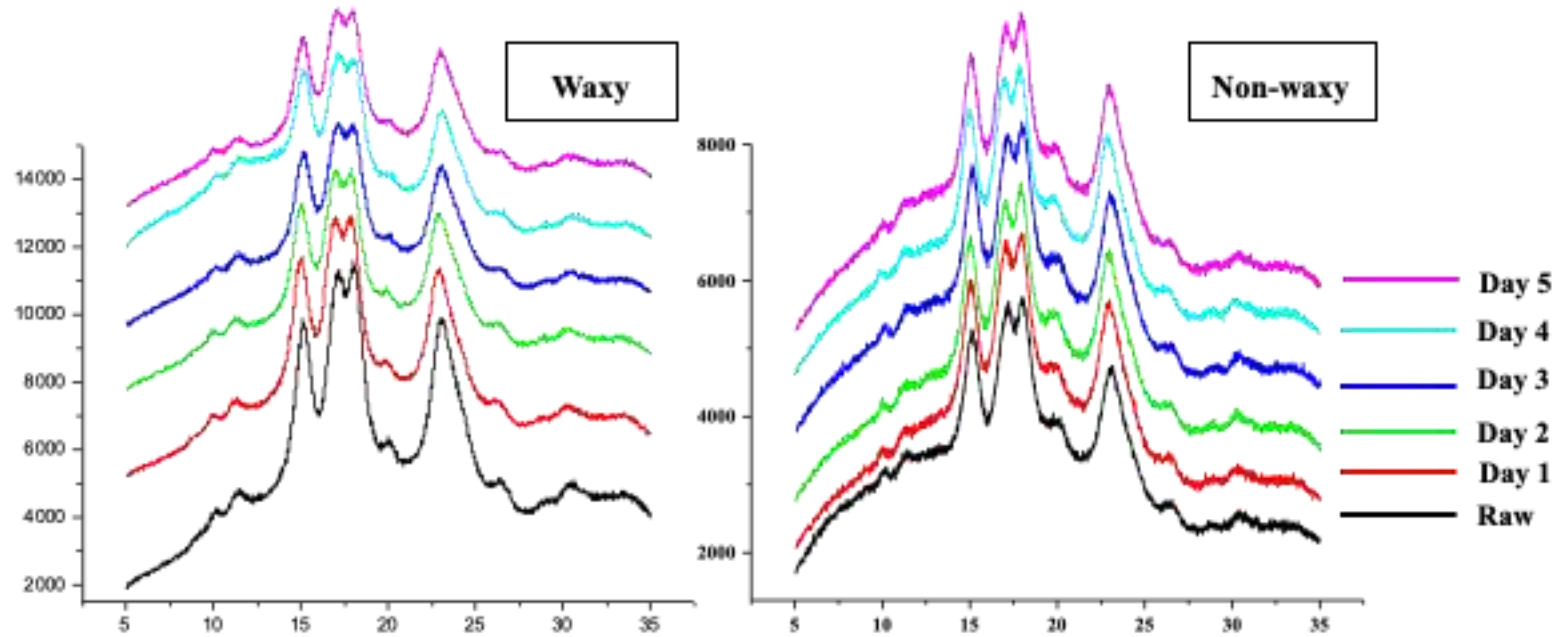


Figure 5.5 X-Ray diffractogram of *Lb. fermentum* fermented starch sample.

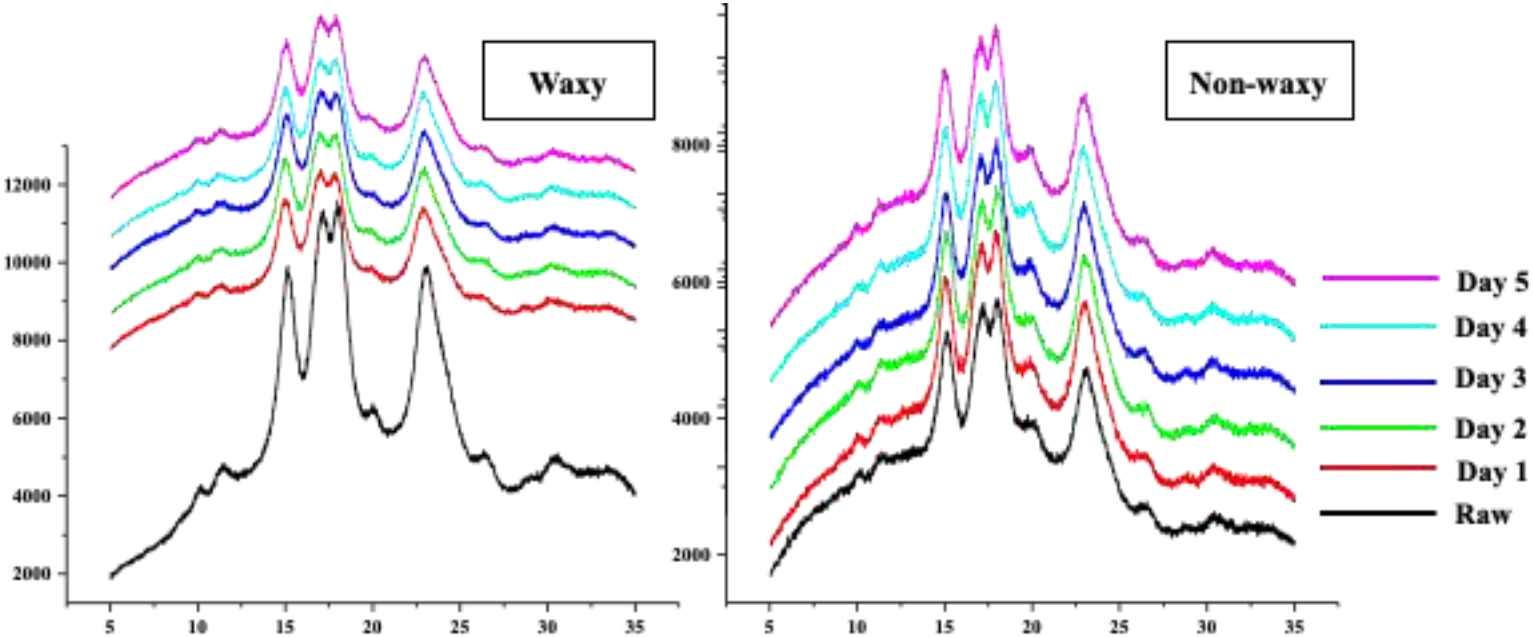
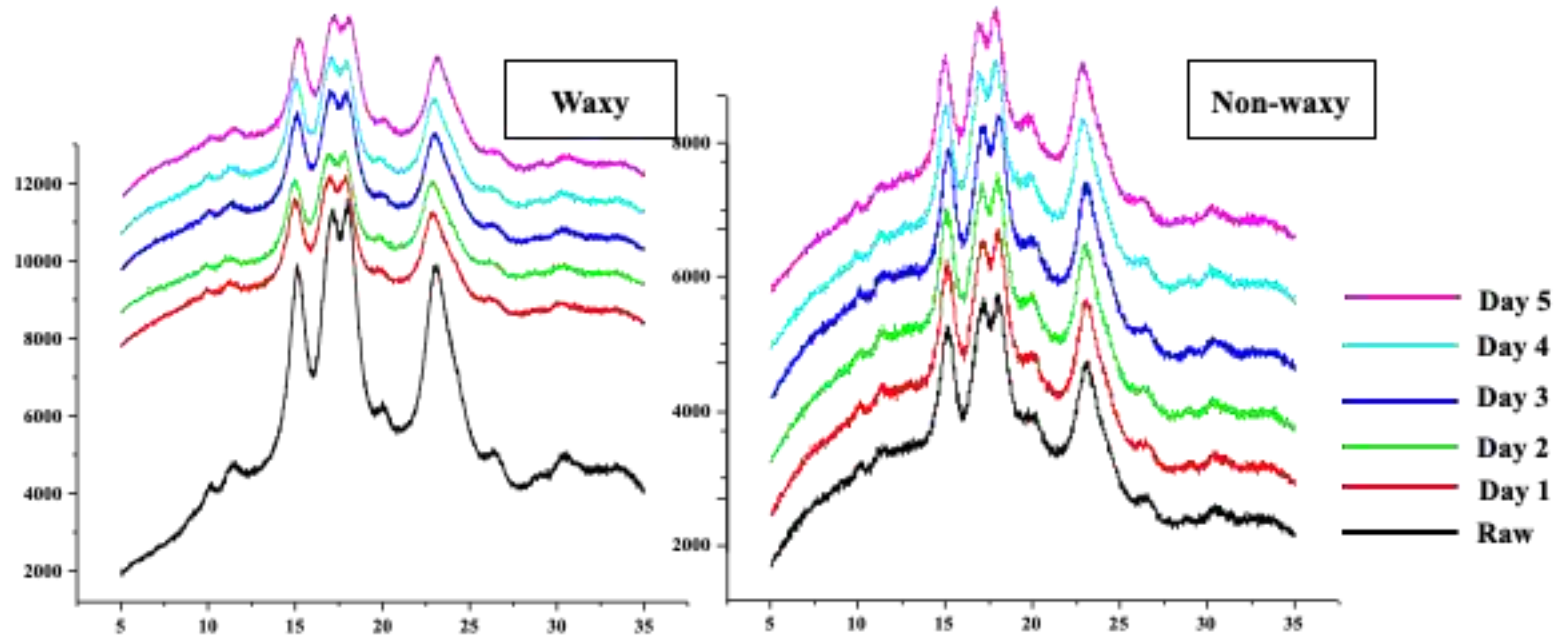


Figure 5.6 X-Ray diffractogram of *Lb. plantarum* fermented starch sample.



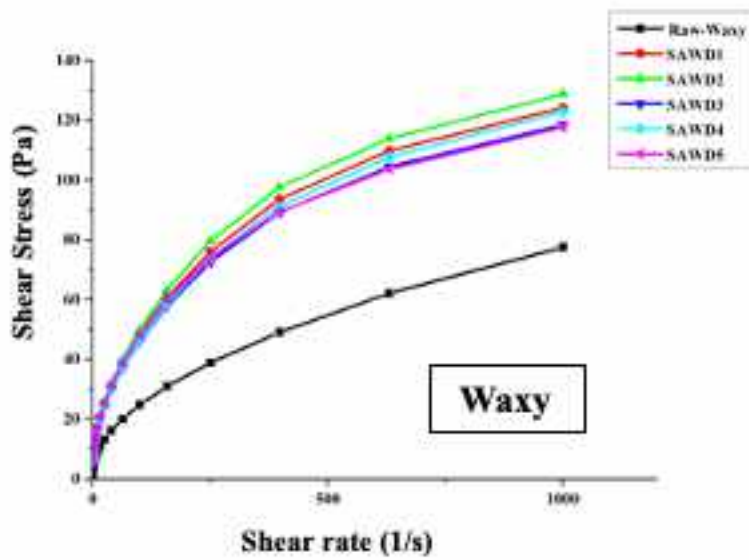
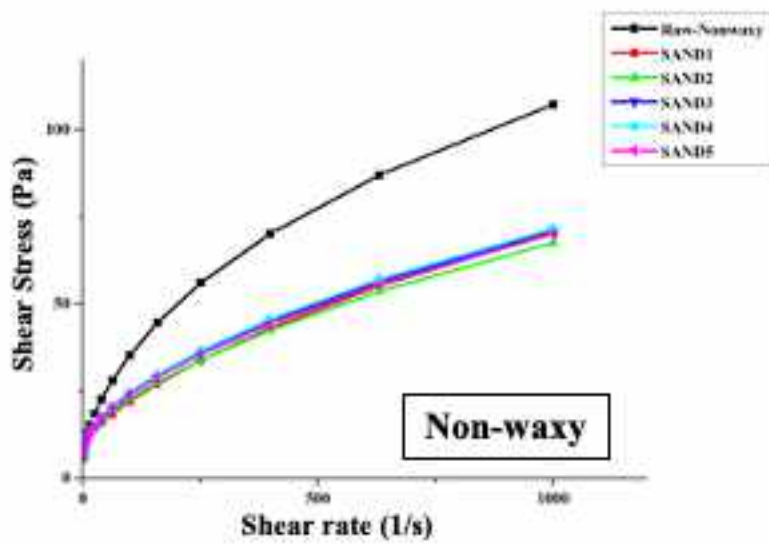


Figure 5.7 Flow curves of *Lb. amylovorus* fermented proso millet starch graph (Upward)

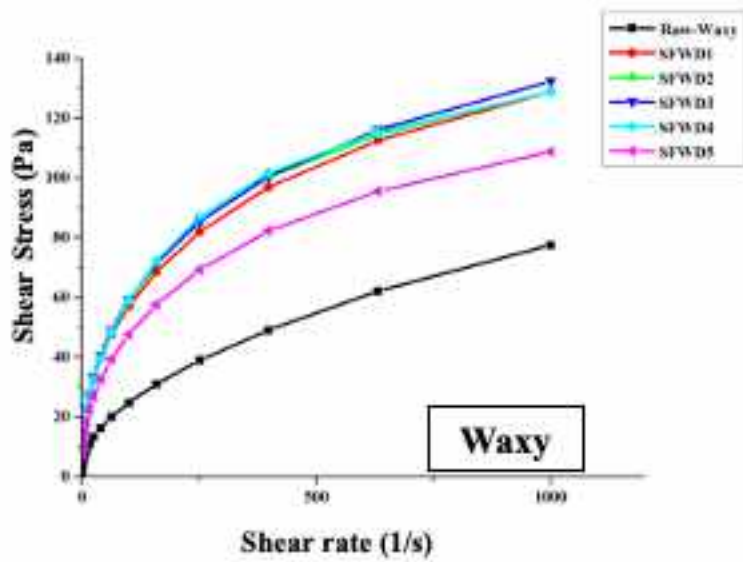
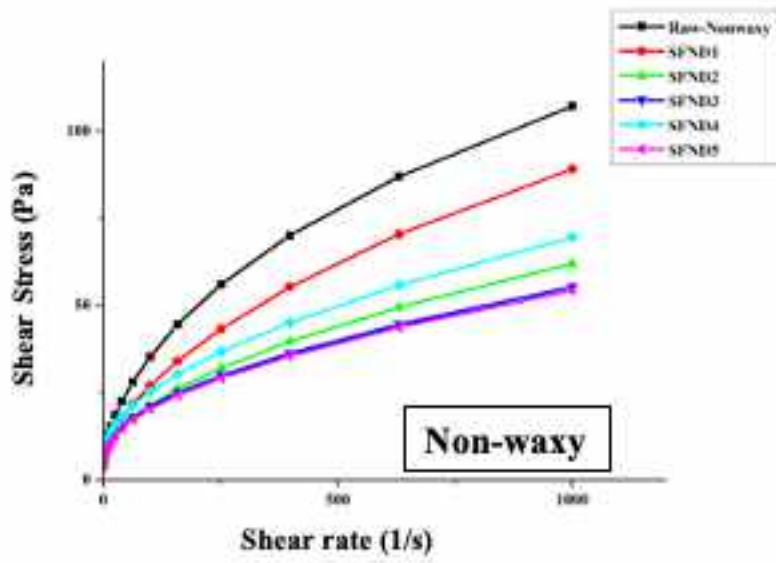


Figure 5.8 Flow curves of *Lb. fermentum* fermented proso millet starch graph (Upward)

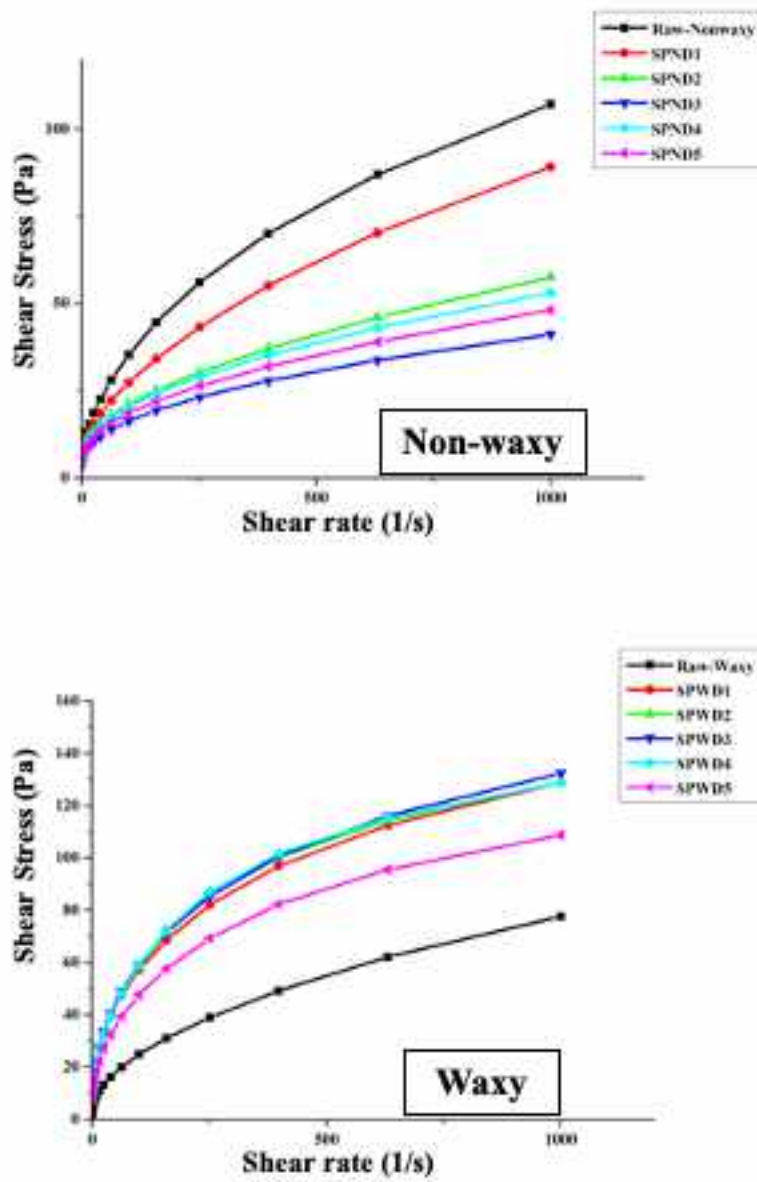


Figure 5.9 Flow curves of *Lb. plantarum* fermented proso millet starch graph (Upward)