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Milling and Extrusion Characteristics of New Zealand Corn. Development of a Hardness Test and an On-Line Extruder Viscometer

A thesis

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Abstract

Ready to Eat (RTE) snack foods are commonly manufactured using single and twin screw extruders and corn grits as raw materials. Variations in product quality caused by grits from different hybrids and grain hardness have not been investigated. Furthermore, the relationship between rheological properties of the extrudate melt and the operating conditions in the extruder is not fully understood. Appropriate methods to determine corn grain hardness to characterise corn hybrids and the on-line viscosity of the extrudate melts have not yet been developed. These methods could provide sound and appropriate techniques to investigate the areas of milling and extrusion of corn based food products.

In this study, milling characteristics of 38 corn hybrids from the 92-93 season and 12 corn hybrids from the 94-95 season produced in New Zealand were studied. A modified Stenvert Hardness Test (SHT) using new parameters including milling energy and milling resistance time was developed. It was found that the modified SHT was simple and easy to use with low variability. The SHT milling energy can be used as an effective hardness index. It increased with grain bulk density and the ratio of hard to soft endosperm. All measured properties were highly dependent on the moisture content. For the same hybrid, SHT hardness increased and the grain bulk density decreased when the moisture content of the corn grains increased.

A roller-milling test was also developed to study the dry milling characteristics of these corn hybrids. During milling, the breaking force measured in the roller-milling test increased with grain hardness.

Analysis of particle size distributions in the ground samples after the modified Stenvert Hardness tests and the roller-milling tests showed that grit recovery rate increased with the grain hardness.

Grits produced from hybrids harvested in the 92-93 and the 94-95 seasons, along with other grits and starches commercially manufactured in New Zealand, were used for the extrusion experiments.

A new Slit-Die-Viscometer (SDV) was developed to measure the viscosity of extrudate melts on-line. Unlike many other viscometers used on-line, the operation of the new SDV did not interfere with the operating conditions of the extruder.

The rheological properties and the degree of starch gelatinisation were affected by the operating conditions of the extruder and the characteristics of the raw materials:

It was found that the melt viscosity decreased as moisture content increased. The apparent viscosity had a maximum value at barrel temperature of about 130°C, changed very little when screw speed increased at constant feed, and decreased slightly when the feed increased at constant screw speed.

The grits were less gelatinised at high moisture content. The degree of starch gelatinisation increased slightly with screw speed and linearly with barrel temperature between 90°C and 130°C. At barrel temperatures higher than 130°C, the extrudate was almost fully gelatinised.

Melts produced with starch of high amylopectin content had an overall lower viscosity with less shear thinning and a higher degree of starch gelatinisation than that produced with starch of high amylose content.

Grit size affected the rheological properties and the degree of starch gelatinisation. Melts produced from medium and coarse grits had a lower viscosity and a lower degree of starch gelatinisation than that produced with fine grits.

The effect of different hybrids of the same season on the rheological properties of the melt was negligible. However, the rheological properties were affected by the methods used to produce the grits. Grits from degermed grains had less oil and produced melts with lower viscosity and less shear thinning than grits from whole grains (higher oil content).

Table of Contents

	<i>Page</i>
Acknowledgements	ii
Abstract	iv
Table of Contents	vi
List of Figures	xi
List of Tables	xv
Nomenclature	xvii
Chapter 1 INTRODUCTION	1
Chapter 2: LITERATURE REVIEW (Milling)	6
2.1 Introduction	6
2.2 Structure of Corn Kernel	6
2.3 Moisture Content	9
2.4 Physical Properties of Corn Grain	9
2.4.1 Bulk Density and True Density	11
2.4.2 Ratio of Hard to Soft Endosperm.	11
2.4.3 Dynamic Impact Test.	12
2.4.4 Compression Test	12
2.4.5 Pearling Test, Grinding Test and Abrasive Milling Test.	13
2.4.6 Near-Infrared Reflectance (NIR).	14
2.4.7 Stenvert Hardness Test	15
2.4.8 Breakage Susceptibility	15
2.5 Dry-Milling Performance and Particle Size Distribution in Milled Corn.	16
2.6 Hybrids	18
2.7 Discussion and Summary	18

	<i>Page</i>
Chapter 3 MILLING EXPERIMENTS: MATERIALS AND METHODS.....	20
3.1 Materials.....	20
3.1.1 Hybrids of the 92-93 Season	20
3.1.2 Hybrids of the 94-95 Season.....	21
3.2 Analytical and Test Methods	23
3.2.1 Physical Properties of Grain.....	23
Oil Content	23
Protein Content.....	24
Moisture Content.....	24
Hard to Soft Endosperm Ratio	25
3.2.2 Milling Tests	25
The Modified Stenvert Hardness Test	25
Roller Milling	30
3.2.3 Sieving Tests	33
3.2.4 ANOVA and Multivariate Analysis	33
 Chapter 4 RESULTS AND DISCUSSION: HARDNESS MEASUREMENTS	
AND MILLING CHARACTERISTICS OF CORN GRAIN	35
4.1 Introduction	35
4.2 Results and Discussion	35
4.2.1 Hardness Tests for Corn Samples Harvested in the 92-93 Season	35
4.2.1.1 SHT and Properties of Different Hybrids	35
4.2.1.2 Principal Component Analysis.....	42
4.2.1.3 Cluster Analysis of Different Hybrids	45
4.2.2 Effect of Moisture Content on Grain Hardness and Bulk	
Density for 12 Samples Harvested in the 94-95 Season.....	47
4.2.2.1 Effect of Moisture Content on Bulk Density	47
4.2.2.2 Effect of Moisture Content on the SHT Milling Energy	51
4.2.3 Particle Size Distribution of SHT Samples	56
4.2.4 Roller Milling Test.....	59

	<i>Page</i>
4.2.4.1 Grain Breaking Force in Roller Milling.....	59
4.2.4.2 Particle Size Distribution of Samples from Roller Milling	62
4.3 Conclusions	64
Chapter 5 LITERATURE REVIEW: Extrusion Processing.....	65
5.1 Introduction	65
5.2 Rheological Model of the Melt and Product Expansion	68
5.2.1 Rheological Model of the Melt	68
5.2.2 Viscosity and Expansion	69
5.3 Effect of Raw Materials and the Operation Conditions of the Extruder on the Rheological Properties of Melts	70
5.3.1 Raw Material	70
5.3.1.1 Starch	71
The Roles of Starch.....	71
Structure Changes in a Non-Shearing Environment	71
Structure Changes during Extrusion.....	74
5.3.1.2 Amylose/Amylopectin Ratio.....	75
5.3.1.3 Protein and Oils	78
5.3.1.4 Corn Grits and Grains.....	79
5.3.2 Operating Conditions	79
5.3.2.1 Moisture Content	80
5.3.2.2 Barrel and Die Temperatures	81
5.3.2.3 Effect of Screw Speed, Feed Rate and Degree of Fill	83
5.3.2.4 Screw Configuration and Die-Block Design	84
5.4 On-Line Measurements of Rheological Properties	85
5.4.1 Capillary Viscometer.....	86
5.4.1.1 Capillary Die.....	87
5.4.1.2 Capillary Viscometer with Pressure Transducers Mounted along the Capillary Tube	88
5.4.1.3 Disadvantages of Capillary Viscometer.....	88

	<i>Page</i>
5.4.2 Slit-Die Viscometer (SDV).....	89
5.4.3 Interference between On-Line Viscosity Measurements and the Operating Conditions of the Extruder.....	89
5.4.4 Improvements on On-Line Viscosity Measurement.....	92
5.5 Summary	94
 Chapter 6 EXTRUSION EXPERIMENTS: MATERIALS AND METHODS.....	 95
6.1 Materials.....	95
6.1.1 Normal Corn Grits.....	95
6.1.2 Starches of Different Amylose/Amylopectin Ratio.....	96
6.1.3 Grits of Different Sizes	96
6.1.4 Grits from Different Hybrids of the 92-93 Season	97
6.1.5 Grits from Different Hybrids of the 94-95 Season	98
6.2 Methods.....	99
6.2.1 Extruder	99
6.2.2 The New Slit-Die-Viscometer (SDV)	100
6.2.3 Data Acquisition and Control System	102
6.2.4 Calibration of Pressure Transducers and Slit-Die-Viscometer	102
6.2.5 Rheological Parameters Calculation.....	103
6.2.6 Calculation of the Specific Mechanical Energy (SME)	104
6.2.7 Residence Time Distribution (RTD)	104
6.2.8 Grit Density	106
6.2.9 Extrusion Sample Collection and Drying.....	106
6.2.10 Degree of Starch Gelatinization	107
6.3 Experimental Approach.....	107
 Chapter 7 EXPERIMENTAL RESULTS AND DISCUSSION (extrusion).....	 109
7.1 Introduction	109
7.2 Effects of Operating Conditions	110

	<i>Page</i>
7.2.1 Moisture Content.....	110
7.2.1.1 Pressure Distribution in the SDV.....	110
7.2.1.2 Effect on Melt Viscosity and Extruder Operational Parameters	111
7.2.1.3 Effect on Degree of Starch Gelatinisation	112
7.2.2 Barrel Temperature (Last Two Barrel Sections).....	119
7.2.3 Degree of fill - Screw Speed and Feed Rate.....	126
7.2.3.1 Effect of Screw Speed at Constant Feed Rate	126
7.2.3.2 Effect of Feed Rate at Constant Screw Speed	132
7.2.3.3 Effect of Degree of Fill.....	136
7.3 Effect of the Measurement Temperature	140
7.4 Effect of the Raw Material Properties	143
7.4.1 Amylose/Amylopectin Ratio.....	143
7.4.2 Grit Size.....	146
7.4.3 Effect of Hybrid.....	149
7.5 Summary	156
 Chapter 8 ACHIEVEMENTS, OVERALL CONCLUSIONS AND RECOMMENDATIONS	 158
8.1 Major Achievements	158
8.2 Summary of Conclusions.....	159
8.3 Recommendation for Future Work.....	162
 References	 163
 Appendix A Data Acquisition System for Milling	 173
Appendix B Theory of Slit Viscometry	179
Appendix C Data Acquisition System for Extrusion Test	182
Appendix D Engineering Drawings for the New Slit-Die-Viscometer	186
Appendix E Peer Review Publications.....	195

List of Figures

<i>Figure Number</i>	<i>Figure Caption</i>	<i>Page</i>
Figure 2.1	A schematic sectional plot of a yellow dent corn kernel.	8
Figure 3.1	Schematic of the SHT and roller milling data acquisition system	26
Figure 3.2	True transient power changes of SHT milling of two typical corn hybrids.....	27
Figure 3.3	Schematic diagram of the roller mill and its load cell.	32
Figure 4.1	Relation between the hard/soft endosperm ratio and the milling energy of the 38 hybrids.	40
Figure 4.2	Relation between the hard/soft endosperm ratio and the milling resistance time of the 38 hybrids.	40
Figure 4.3	Relation between the hard/soft endosperm ratio and the bulk density of the 38 hybrids.	41
Figure 4.4	Plot of hybrids grouped by cluster analysis.....	46
Figure 4.5	Effect of moisture content on bulk density.	49
Figure 4.6	Master curve for effect of moisture content on bulk density.	50
Figure 4.7	Effect of moisture content on SHT milling energy.....	52
Figure 4.8	Plot of values of CID and EID. in Table 4.5 for the 12 hybrids of 94-95 season.	54
Figure 4.9	Compare of the experimental data and the model.	55
Figure 4.10	Particle size distribution of ground SHT samples.....	57
Figure 4.11	Relation between grit recovery rate and SHT hardness.....	58
Figure 4.12	Effect of moisture content on grit recovery rate on hard and soft hybrids.....	58
Figure 4.13	Plot for transient roller milling breaking force in the first-break milling.	60
Figure 4.14	Plot for transient roller milling breaking force in the second-break milling.	61

<i>Figure Number</i>	<i>Figure Caption</i>	<i>Page</i>
Figure 4.15	Particle size distribution of samples from roller milling, second break.....	63
Figure 5.1	List of extrusion parameters.	66
Figure 5.2	A schematic representation of starch gelatinization in the presence of excess water.....	73
Figure 5.3	Schematic representation of amylose and amylopectin molecules.....	76
Figure 6.1	Particle size distribution of grits used in extrusion trials to investigate the effect of grit size on melt viscosity.	96
Figure 6.2	Schematic of the twin screw co-rotating extruder Cleextral BC21.....	99
Figure 6.3	Schematic of the screw configuration used.....	100
Figure 6.4	Schematic diagram of the new SDV and the adapter.	101
Figure 6.5	Viscosity of Polycell measured using the SDV, a capillary viscometer (two different capillary sizes) and a rotational viscometer.	103
Figure 6.6	Measurements of the residence time distribution.	105
Figure 7.1	Pressure profiles along the SDV slit for various shear rates at 31.7% moisture content.....	113
Figure 7.2	Pressure profiles along the SDV slit for various shear rates at 35.0% moisture content.....	113
Figure 7.3	Pressure profiles along the SDV slit for various shear rates at 40.0% moisture content.....	114
Figure 7.4	Flow curves for melts produced at three different moisture levels.....	117
Figure 7.5	Plots of viscosity versus shear rate for melts produced at three different moisture levels.	117
Figure 7.6	A plot of the effect of extruder barrel temperature (last two barrel sections) on the degree of starch gelatinisation.....	121
Figure 7.7	Effect of barrel temperatures (last two sections) on melt viscosity measured at 120°C.....	122

<i>Figure Number</i>	<i>Figure Caption</i>	<i>Page</i>
Figure 7.8	Effect of barrel temperature on apparent viscosity calculated at different shear rates.....	123
Figure 7.9	Effect of barrel temperature on SME.	124
Figure 7.10	Effect of barrel temperature on torque.	124
Figure 7.11	Effect of barrel temperature on die pressure (P_{die}) and thrust pressure (P_{thrust}).....	125
Figure 7.12	The effect of screw speed on SME at a constant feed rate of 9.5kg/h.	129
Figure 7.13	The effect of screw speed on screw torque at a constant feed rate of 9.5kg/h.	129
Figure 7.14	The effect of screw speed on the melt viscosity measured at 120°C. Feed rate was kept constant at 9.5kg/h.....	130
Figure 7.15	Viscosity of the melt in the extruder barrel at the three screw speeds.	131
Figure 7.16	Complete flow curve of a pseudoplastic fluid.	131
Figure 7.17	The effect of feed rate on torque at a constant screw speed 450rpm.....	134
Figure 7.18	The effect of feed rate on SME at a constant screw speed 450rpm.....	134
Figure 7.19	The effect of feed rate on the melt viscosity at a constant screw speed 450rpm.....	135
Figure 7.20	The effect of constant degree of fill on the melt viscosity, measured by the new SDV and by van Lengerich's approach.	138
Figure 7.21	The effect of screw speed on SME at constant degree of fill.	139
Figure 7.22	The effect of screw speed on torque at constant degree of fill.	139
Figure 7.23	The effect of SDV temperature on the rheological properties of the melt.....	141
Figure 7.24	The effect of amylose/amylopectin ratio on the melt viscosity.	145
Figure 7.25	Viscosity of the melt produced from the grits of three sizes at 400rpm screw speed.	147

<i>Figure Number</i>	<i>Figure Caption</i>	<i>Page</i>
Figure A.1	Flow chart of the data acquisition program for milling tests. Part I.	174
Figure A.2	Flow chart of the data acquisition program for milling tests. Part II.	175
Figure A.3	Flow chart of the data acquisition program for milling tests. Part III.	176
Figure A.4	Flow chart of the data acquisition program for milling tests. Part IV.	177
Figure A.5	Flow chart of the data acquisition program for milling tests. Part V.	178
Figure B.1	Two-dimensional slit flow model.....	179
Figure C.1	Schematic diagram of the data acquisition program for extrusion tests.....	183
Figure C.2	Flow chart of the data acquisition program for extrusion tests. Part I.	184
Figure C.3	Flow chart of the data acquisition program for extrusion tests. Part II.	185

List of Tables

<i>Table Number</i>	<i>Table Caption</i>	<i>Page</i>
Table 3.1	Hybrids names, moisture contents, and bulk densities for samples from the 92-93 season.....	22
Table 3.2	Hybrids names for samples harvested in the 94-95 season.....	23
Table 4.1	Experimental data for hybrids of the 92-93 season, ranked by bulk density.	37
Table 4.2	Correlation matrix using SHT parameters, moisture content, bulk density and hard to soft endosperm ratio.....	38
Table 4.3	Correlation matrix for the SHT parameters, hard to soft endosperm ratio and principal component PC1.....	43
Table 4.4	Rankings of hybrids according to the principal component PC1 and other parameters.....	44
Table 4.5	Values of the hybrid-dependant parameters EID and CID given in equation (4.5) for the 12 hybrids of the 94-95 season.....	53
Table 4.6	Average force of roller milling 12 hybrids.....	61
Table 6.1	Particle size distribution of normal corn grits.	95
Table 6.2	Moisture content and true density of different size grits.....	97
Table 6.3	Moisture, oil and protein contents of grits obtained from the 94-95 season.	98
Table 7.1	R ² of linear regression for pressure profiles in the SDV at different shear rates.....	115
Table 7.2	Effect of moisture content on extruder operating conditions.	116
Table 7.3	Values of power law index n and consistency K of melts produced by extrusion at three moisture contents.....	118
Table 7.4	Degree of starch gelatinisation of melts produced by extrusion at different moisture contents (95% confidence interval).....	118

<i>Table Number</i>	<i>Table Caption</i>	<i>Page</i>
Table 7.5	Rheological properties of the melt produced at different barrel temperatures.....	123
Table 7.6	Rheological properties and degree of starch gelatinisation of the melts at different screw speeds at a constant feed rate 9.5kg/h.	130
Table 7.7	The effect of feed rate on the rheological properties and the degree of starch gelatinisation at a constant screw speed 450rpm.	135
Table 7.8	Screw speeds and feed rates used and corresponding rheological properties and degree of starch gelatinisation of the melt.	138
Table 7.9	The effect of SDV temperature on the operating conditions of the extruder.	142
Table 7.10	The effect of SDV temperature on degree of starch gelatinisation.....	142
Table 7.11	The effect of amylose/amylopectin ratio on the rheological properties of the melt and SME.....	145
Table 7.12	The effect of amylose/amylopectin ratio on the degree of starch gelatinisation.....	145
Table 7.13	Operating conditions for the three grits extruded.	148
Table 7.14	The effect of grit size on the degree of starch gelatinisation.	148
Table 7.15	The rheological properties, SME, and degree of starch gelatinisation for 11 hybrids from the 92-93 season.....	152
Table 7.16	The rheological properties, SME, and degree of starch gelatinisation for 17 hybrids from the 94-95 season.....	153
Table 7.17	The ANOVA test for samples from the 92-93 and 94-95 seasons. Critical F value at 0.05 level of significance is 4.4.	154
Table 7.18	Correlation coefficients between operating variables, rheological properties, degree of starch gelatinisation, and grain quality of the 11 hybrids from the 92-93 season.	154
Table 7.19	Correlation coefficients between operating variables, rheological properties, degree of starch gelatinisation, and grain quality of the 17 hybrids from the 94-95 season.	155

Nomenclature

Abbreviations:

BCFM	broken corn and foreign material
BD	Grain bulk density
CIMMYT	International Centre for Maize and Wheat Improvement
Com	commercial corn inbred
COV	coefficients of variation
DSC	Differential Scanning Calorimetry
ED	European yellow dent corn inbred
EF	European flint corn inbred
EI	a radial expansion index
H/S	a hard to soft endosperm ratio for corn kernel
HD	Hungarian yellow dent corn inbred
HT	highland tropical corn inbred
LDPE	low density polyethylene
LEI	Longitudinal Expansion Index measured in the axial direction
MEF	Milling Evaluation Factor in dry milling
MC	moisture content
NIR	Near-Infrared Reflectance
PCA	principal component analysis
RT	resistance time in the modified Stenvert Hardness Test
RTD	the Residence Time Distribution in extrusion
RTE	Ready-to-Eat snack
SBT	Stein Breakage Tester
SDV	Slit-Die-Viscometer
SEI	Sectional Expansion Index measured in the radial direction
SHT	Stenvert Hardness Test
SME	Specific Mechanical Energy in extrusion, W·h/kg
STD	standard deviation
US	United States Corn Belt Dent inbred
WBT	Wisconsin Breakage Tester

dwb	dry weight basis
wwb	wet weight basis

Symbols:

$\dot{\gamma}$	shear rate, 1/s
$\dot{\gamma}_{app}$	apparent shear rate, 1/s
τ	shear stress, Pa
ϕ	electric power factor
$(\mu_a)_d$	apparent viscosity of the melt at the die, Pa·s
η_{app}	the apparent viscosity, Pa·s
ρ_d	the density of the extrudate inside the die, kg/m ³
ρ_e	the density of the expanded extrudate, kg/m ³
ρ_g	The density of the grit, kg/m ³
ΔP	pressure difference, Pa
$\partial P / \partial Z$	the pressure gradient along flow direction on slit, Pa/m
τ_w	the shear stress at the slit wall, Pa
+a*	the red colour co-ordinate
A_1	The absorbance at 600nm of the gelatinised sample in a spectrophotometer
A_2	The absorbance at 600nm of the total soluble starch sample in a spectrophotometer
C_{ID}	a hybrid dependent coefficients, joules (J)
D_p	effective particle size (diameter) of corn grits, mm
d	variability range
E	The SHT milling energy, J
E_{ID}	a hybrid dependent coefficients, J
F_{hybrid}	a hybrid dependent shift factor, kg/hl
G	weight, kg
Gr	the grit recover rate ranging from 0.699 to 1.47mm
H	the height of the slit of the SDV, m
I	electric current, A

I_0	the initial current of the mill motor at empty load at the defined speed, A
K	the power law consistency index, Pa·s ⁿ
L	the length between two neighbouring pressure transducers of the SDV
$L^*a^*b^*$	the absolute chromaticity colour space for a Minolta Chroma Meter CR-200)
N	screw speed, <i>rpm</i>
n	the power law index.
P	pressure, Pa
P	power, W
Q	the extruder throughput, kg/h
Q	the volume flow rate in SDV or capillary viscometer, m ³ /s
R	the radius of the capillary, m
t_{end}	end time, s
Tq	screw torque, N·m
Tq_0	the screw torque at empty load, N·m
t_{start}	the starting time, s
u	the flow viscosity, Pa·s
V	the volume, m ³
V	voltage, V
W	the width of the slit of the SDV, m

subscripts:

d	conditions at the die
e	conditions of the extrudate
m	mixture
g	grits
w	water
max	the upper limit
min	the lower limit
0	initial values