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

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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).

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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)
Dp	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, $Pa{\cdot}s^n$
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, *rpm*
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