CHAPTER 4: APPLICATION OF THE DEVELOPED IMAGE ANALYSIS MAIZE TRANSLUCENCY METHOD TO ESTIMATE THE YIELD OF DRY MILLED MAIZE PRODUCTS IN LABORATORY AND INDUSTRIAL SYSTEMS

4.1 OBJECTIVES

The objectives of the experiments described in this chapter were as follows:

- To test the validity of the developed image analysis maize translucency method (Chapter 3) as a tool for predicting the yield of vitreous endosperm products produced by laboratory and industrial milling tests
- To compare the formulas developed in three independent and different laboratory and industrial milling tests
- To compare the IA translucency measurement methods for predicting the yield of white and yellow milled maize products.

4.2 DEFINITIONS

Due to the fact that various terms are used in the literature to describe similar products or processes during maize milling, the following definitions of terminology were used in this study in order to allow for consistency:

Yield of milled products (or "milling yield) - weight of a specified product within a certain particle size and composition range, calculated as a percentage of the weight of the whole kernels, either cleaned or uncleaned depending on the mill's specifications (fully defined in section 1.1).

"Super" products – referring to a group of products consisting of reducing the particle size of the primary product, namely clean flaking grits. These products include the sum of the yields of the samp, rice, grits and super maize meal, or, in other words, the yields of flaking grits, coarse grits, medium grits, fine grits or "semolina" and maize meal or "cornmeal". These products all have fat contents of less than 1%,

unless otherwise specified (in some cases, fat contents of up to 1.5% are permissible).

Extraction at degermer – during degerming, the germ and bran are stripped from the endosperm and two fractions are obtained. The first fraction, large pieces of endosperm, also known as the "tail hominy", proceeds through the end of the degermer. This fraction is sifted and part of it is isolated as large flaking grits. The remainder is sent to the roller mills for reduction and cleaning into smaller fractions such as coarse, medium and fine grits. The "thru stock" stream, which is the second fraction obtained during degerming, contains mostly germ, bran, break flour and some small pieces of endosperm. It passes through a screen on the underside of the degermer (Alexander 1987). As it is more difficult to separate the small pieces of endosperm from this fraction, it is better to minimise this fraction and maize kernels with a lower tendency to break up into small particles will produce more "tail hominy" and less "thru stock" which ultimately leads to a higher yield of "super products". Extraction at degermer is therefore defined as the weight percentage of "tail hominy" as a percentage of the total weight of the two combined fractions.

Clean endosperm (super) products – endosperm products containing a low amount of fat, crude fibre and other contaminants, produced by the milling process.

Semolina – a convenient term to describe clean fine maize grits derived from vitreous endosperm with a particle size of 250 to 1000 microns and a low fat content. It is a term "borrowed" from the wheat milling process because of the resemblance in appearance of the fine vitreous endosperm maize grits to wheat semolina.

Dunst – a term to describe maize flour or "break flour", as described in Table 2.1, which is obtained from the opaque endosperm fraction after breaking open of the maize kernels.

4.3 MATERIALS AND METHODS

Three independent milling and different experiments were undertaken. In each experiment, image analysis translucency measurements of the maize were made

before milling as described in section 3.1. A range of products was produced in each of the three experiments. These products resembled ranges of vitreous endosperm products produced by the industrial dry milling process. Product yields were calculated on a weight percentage basis and the results were correlated with the translucency measurements. Accompanying analyses such as percentage floaters, fat content and other measurements were also made where applicable.

4.3.1 Experiment 1

Laboratory scale roller milling of 20 industrial white maize samples

4.3.1.1 Materials

Twenty samples of industrial white maize (mixed cultivars) obtained from various mills (100 kg each) were tested. The mills obtained the samples from different production areas in South Africa and samples were supplied in bulk by commercial farmers.

4.3.1.2 Methods

4.3.1.2.1 Image Analysis

Image analysis was done on 50 kernels (using an adapted mask to allow for 50 kernels instead of 49 as described in Chapter 3) selected from each of the 20 industrial samples, as described (section 3.1). Thickness was measured on each individual kernel instead of an average using the method described in section 3.1.6.2. Translucency values (%) before and after corrections for thickness and exposure were calculated for each sample. Measurements done on damaged kernels were discarded for statistical reasons. Measurements were done at the CSIR, Pretoria, South Africa on samples taken from each batch of maize before it was sent to the Federal Research Centre for Cereal and Potato Processing in Detmold, Germany for experimental milling tests.

4.3.1.2.2 Floating number (floaters, mass%)

Whole maize kernels were used and the floating number (similar to the percentage floaters test but at a different solution density of 1.25 instead of 1.275) was determined using the method described by Gerstenkorn (1991). Analysis was done at the Federal Research Centre for Cereal and Potato Processing. From a representative sample, 100 intact kernels were selected and placed into a sodium nitrite solution with a density of 1.25. The kernels were adjusted before the test to a moisture content of 12.0%. The solution was stirred for 30 seconds, and the floating and sunken kernels were taken out with a spoon. The kernels were then placed on filter paper, dried and weighed. The weight of the floating kernels was given as a percentage of the total weight of 100 kernels on a dry basis and the test was done in triplicate. The test was repeated if the deviation of two tests exceeded 10%.

4.3.1.2.3 *Fat and moisture contents*

Fat contents of products obtained during the experimental milling were measured using the Soxhlet method (AACC 30-20) (American Association of Cereal Chemists 2000) and moisture contents by using the oven drying method (AACC 44-18) (American Association of Cereal Chemists 2000). Analyses were done at the Federal Research Centre for Cereal and Potato Processing.

4.3.1.2.4 *Experimental milling of maize*

Experimental milling of the 20 industrial white maize samples was done at the Federal Research Centre for Cereal and Potato Processing. The method was as described by Gerstenkorn (1991). The milling procedure is given in detail in Figure 4.1. Maize was dampened to 20% moisture and allowed to stand (condition) for 18 hours. After conditioning, each sample was ground between two coarse-fluted rolls (maize laboratory mill roll specifications given in Figure 4.1), and the germ parts and "hulls" were separated using a centrifugal sifter. The grind (<3.3 mm) was put into a purifier in which the first grits fraction with a fat content lower than 1% was obtained. The separated material was then milled again in a Bühler experimental mill with fine fluted rolls. The milled product was then separated in a purifier into second and third grits fractions and also to first and second dunst fractions.

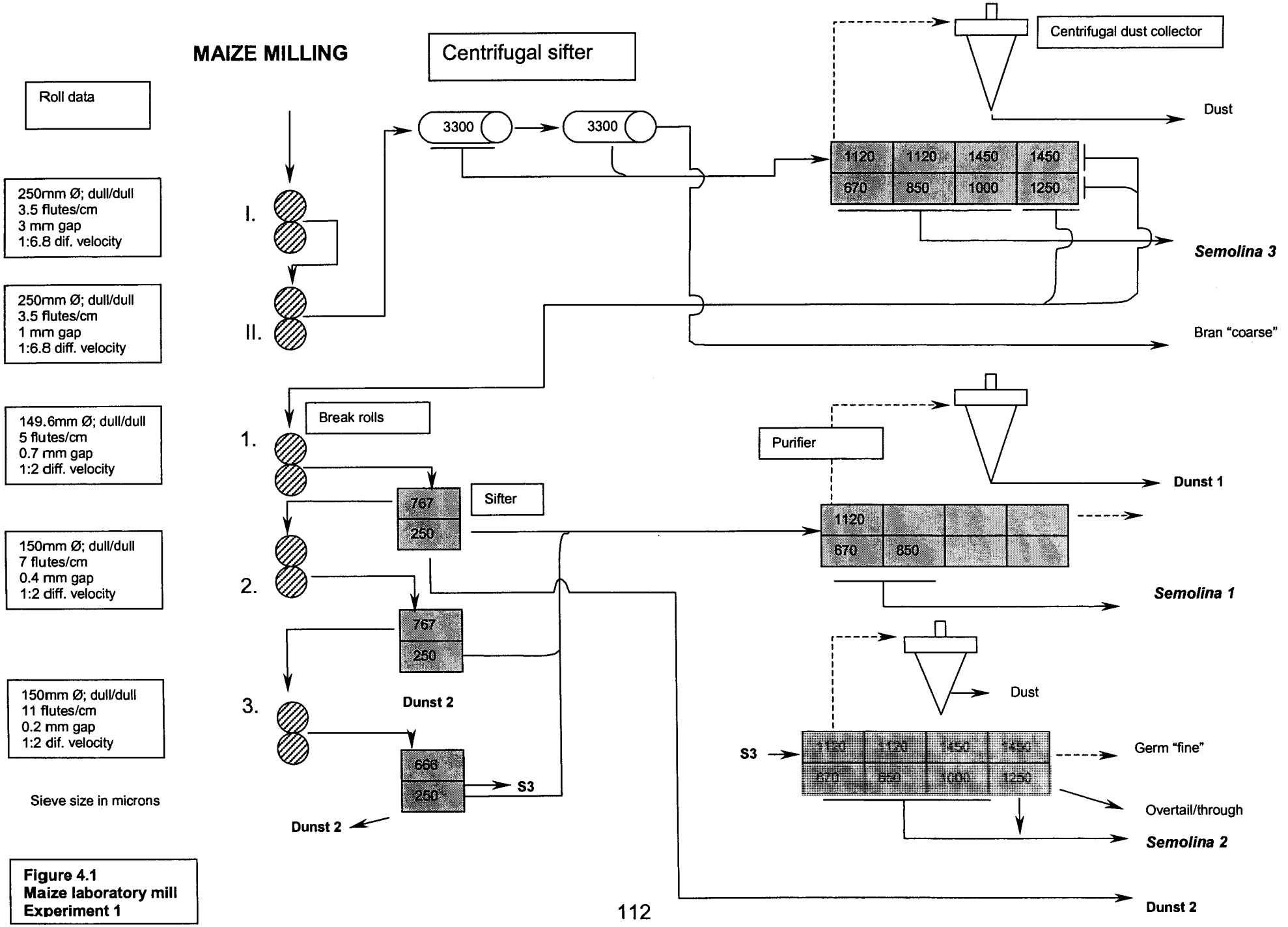

Figure 4.1
Maize laboratory mill
Experiment 1

4.3.1.2.5 Calculations and correlations

The yields of the milling process were calculated as follows:

- Total semolina yield (total yield of clean grits < 1000 microns) – the combined yield (%) of the first, second and third grits (semolina 1, semolina 2 and semolina 3) fractions with a particle size of more than 250 microns, but less than 1000 microns (Figure 4.1). The fat contents of the three combined grits fractions were in all cases less than 1.35%. The yield was calculated as a weight percentage of the combined three grits fractions calculated on a whole kernel weight basis.
- "Milling resistance" – this is an indication of the resistance of the vitreous endosperm to breakage. It was the weight percentage of the first semolina fraction (Figure 4.1) as calculated on a whole kernel weight basis.
- In both cases, yields were calculated on a moisture-free basis based on the weight of cleaned whole maize before milling. Moisture-free basis calculations were used to exclude the effects of moisture contents on the weight of the end products.

Translucency measurements were correlated with the following data obtained from the experimental milling:

- Total yield of clean grits (semolina), 250 - 1000 microns, including the fat content on an "as is" basis
- Total yield of clean grits (semolina), 250 - 1000 microns, on a fat free basis
- Milling resistance – as the yield of the first clean grit fraction (semolina 1), 250 - 850 microns.
- Floating number – correlations between translucency and floating number, and between floating number and total yield and milling resistance were determined.

4.4.2 Experiment 2

Industrial milling of eight white and two yellow maize samples

4.4.2.1 Materials

- Eight samples of industrial white maize (mixed cultivars) obtained from seven production areas in South Africa and one pure cultivar (SR 52), twelve tons of each
- Two samples of industrial yellow maize, one from South Africa and one imported from the USA (twelve tons of each)

4.4.2.2 Methods

4.4.2.2.1 Image Analysis

Image analysis was done on 50 kernels selected from each of the 10 samples as described in section 4.3.1.2.1. Thickness was measured on each individual kernel instead of an average using the method described in section 3.1.6.2. Samples were taken at the industrial milling test site. Measurements on damaged kernels were discarded for statistical reasons.

4.4.2.2.2 Moisture contents

Moisture contents of the whole maize before conditioning and of the conditioned maize before degerming were measured using the oven drying method AACC 44-18, (American Association of Cereal Chemists 2000). Measurements were done at the CSIR, Pretoria, South Africa.

4.4.2.2.3 Experimental milling of maize

A Bühler industrial maize mill was used for the trials (Tiger Milling Training Mill, Bloemfontein, South Africa). It had a capacity of 3 tons per hour with one degermer, one turbo sieve, two sets of break rolls, one set of break grinding rolls, three sets of reduction rolls and full sieving, aspiration and cleaning accessories capable of

manufacturing the whole range of industrially produced dry milling products (Tiger Milling Training mill, Bloemfontein, South Africa).

Approximately twelve tons of maize of each selected batch were transported to the milling site. The mill had two storage silos and the maize was divided into two batches. The batches of maize (approximately six tons) were drawn into the first conditioning bin and conditioned to 14% moisture for four hours. After the first conditioning, the maize pericarp surface was wetted to 18% moisture in a conveyor just prior to degerming (approximately five minutes between addition of water and milling).

Maize batches took two hours to be milled. To allow the mill to reach steady-state conditions, samples were taken and yields were calculated during the second hour of milling. Samples and calculations were done as follows:

- Moisture samples were taken after the second conditioning before the degermer stage
- The overtails and thrus at the degermer were collected for one minute at the beginning, middle and end of a 510 kg "batch" during milling. The two fractions were combined and weighed and the extraction at the degermer percentage calculated as the weight of the overtails divided by the combined weight of overtails and thrus.
- When 510 kg of maize had been milled, a warning signal was sounded indicating that the hominy chop (offal) collected during the 510 kg batch milling was to be put aside and weighed. Immediately after the signal the collection of the next 510 kg milling cycle's offal was commenced. Values for the weight of offal were taken during the second hour of milling.
- The mill was set to produce only one product, namely a maize meal with a specific set of specifications (see below). Fractions obtained from the vitreous endosperm were ground until the specified particle size distribution was reached and therefore no separate fractions of grits (coarse, medium or fine) were produced, as all fractions were expressed as maize meal. The yield was calculated in terms of maize meal (mass) as a percentage of

whole maize (mass) before conditioning and in this case before cleaning as well.

- A sieving test using a 500 µm opening sieve was done on the thru fraction of the degermer. The flour collected was weighed. The weight of the flour collected was calculated as a weight percentage on the weight of the thrus and represents the amount of break flour from the opaque endosperm produced by each sample of maize during degerming.

The maize meal produced had to conform to the following specifications:

Moisture – maximum of 14%, AACC 44-18, (American Association of Cereal Chemists 2000)
Fat, AACC 30-20, (American Association of Cereal Chemists 2000) – maximum of 2.3% (moisture-free base)
Ash, AACC 08-01, (American Association of Cereal Chemists 2000) – maximum of 1.36 (moisture-free base)
Particle size – minimum of 95% must go through a 500 µm opening sieve.

Due to an unforeseen problem in the mill during the milling of the SR52 white cultivar, not enough maize was available to allow the mill to reach steady-state, in order to calculate the yield of maize meal. Therefore, only nine samples of maize (instead of ten) were used for the measurement of the yield of maize meal. Two or three 510 kg test runs were measured for each batch depending on the amount of maize available after steady-state was reached.

Due to the fact that the mill belonged to a private company, a detailed flow chart of the design of the mill cannot be given here, but a summary of the process used is given below:

Step 1 – weighing before conditioning and cleaning
Step 2 – first conditioning bin (4 hours, 14% moisture)
Step 3 – second conditioning bin (5 minutes, 18% moisture)
Step 4 – conditioned maize through a magnet before milling
Step 5 – degerming to produce thru and overtails fractions (5 mm screen)

Step 6 – thrus to turbo sieve to produce offal fraction (coarse) and mixed fraction for aspirator

Step 7 – overtails to sieve for division into two fractions for aspiration and for the first and second break rolls

Step 8 – after the first and second breaks, products sieved, aspirated and gradually reduced using the remaining sets of one break grinding roll set and three reduction roll sets. The mill also had a purifier and aspiration system suitable for separating smaller grit particles from the similar sized germ and bran particles.

The whole mill was designed and built by Bühler (Uzwil, Switzerland) and all units in the mill consisted of Bühler manufactured units designed for the dry milling of maize. Systems were similar to the industrial systems in most industrial mills in South Africa.

4.4.2.2.4 Calculations and correlations

Translucency measurements were correlated with the following milling data:

- Extraction at degermer (weight of overtails/(weight of thrus plus overtails))
- Total extraction of maize meal (all endosperm extracted was used for producing maize meal). Two products were produced during milling namely maize meal and offal. Two calculations were done, namely yield of maize meal without moisture correction (as is basis) and yield of special maize meal on a dry basis.
- Percentage of break flour in the thrus fraction (weight percentage) after degerming

4.4.3 Experiment 3
Laboratory scale milling of 12 yellow maize samples

4.4.3.1 Materials

Twelve samples of industrial yellow maize cultivars planted and produced by a seed company (10 kg of each) (Monsanto, South Africa)

4.4.3.2 Methods

4.4.3.2.1 Image Analysis

Image analysis was done on 50 kernels selected from each of the 10 samples as described in section 4.3.1.2.1. Thickness was measured on each individual kernel instead of an average as described in section 3.1.6.2. Samples were taken at the industrial milling test site. Measurements on damaged kernels were discarded for statistical reasons.

4.4.3.2.2 Moisture contents

Moisture contents of the whole maize before conditioning and of the conditioned maize before degerming were measured by using an oven drying method, AACC 44-18, (American Association of Cereal Chemists 2000).

4.4.3.2.3 Degerming of maize

A small pilot-scale Beall-type maize degerminator designed and built by the CSIR (Pretoria, South Africa) capable of degerming 60 kg of maize per hour (see Figure 4.2 for a line diagram) was used.

Yellow maize (10 kg of each sample) was conditioned before degerming. Conditioning was done in two stages, namely a first stage (14% moisture for 16 hours) and a second stage (18% moisture for 30 minutes). After conditioning, maize was fed into the degermer using a vibratory feeder at a feeding rate of 1 kg per minute. The degermer's rotating cone rotated at a speed of 900 rpm. The gap was set at 2 cm between the cone and plate and a resistance weight of 1 kg was used on the exit plate. The exit plate covered the overtails end of the degermer and depending on the weight attached to it, could only be lifted by the pressure of the outgoing degermed maize. The heavy resistance weight allowed maize to be broken

up into smaller pieces and also allowed maize to be degermed more thoroughly. The weight was kept constant for all the samples. In this experiment, the screen normally used to separate thrus from overtails was replaced by a solid plate with knobs. This was done because of the difficulty of quantitatively cleaning the degermer with a screen fitted, especially with small samples. As the samples were derived from cultivar tests at a seed producing company, larger samples could not be provided. The plate arrangement allowed the production of a single mixed fraction consisting of the thrus and overtails and they were separated further by sieving and aspiration as a combined fraction.

After degerming, samples were sieved using the following sieve opening sizes: 3.9 mm, 3.6 mm, 3.3 mm, 2.9 mm, 2.4 mm, 1.01 mm and fines (thrus from the 1.01 mm sieve). Grits obtained from each fraction were then aspirated using a laboratory aspirator. This was done to separate the grits from the bran and germ particles. The yield of grits was calculated as a weight percentage of grits based on the weight of the whole maize which had a moisture content of 12 - 14%) before degerming and conditioning. Moisture contents of the grits were between 13 and 14% after sieving and aspiration, as drying occurred during the operations. Germ and bran obtained from the aspiration steps were combined with the fines fraction (thru 1.01 mm) to obtain an offal fraction. However, the fines fraction itself consisted of break flour only, as it was formed from the opaque endosperm of the maize during the degerming process. Milling was not done after degerming, as correlating translucency against the yield and size of flaking grits obtained was the primary aim of this experiment.

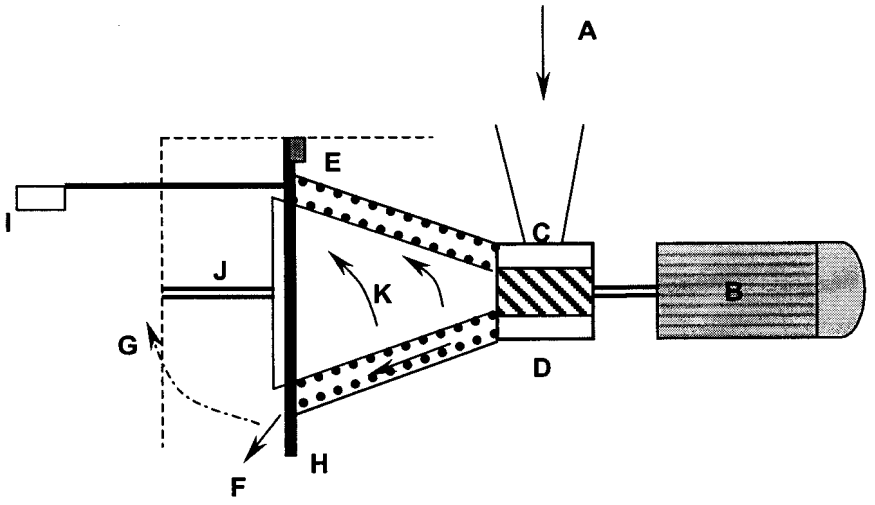

Figure 4.2 Line diagram of pilot scale Beall-type degermer: A is the flow of incoming conditioned whole maize; B is the motor turning the axis; C is the feed section with a screw feeder; D is the degerming section with maize being degermed in the area between the cone and the plate (knobbed area); E is a hinge for the resistance plate; F is the outgoing degermed maize (thru and overtail fractions combined); G is the direction of the resistance plate H being pushed away by the outgoing maize; I is the weight container for adding a specific weight onto the resistance plate and J is the axis of the unit rotating with the inner cone, with K the inner cone

In Figure 4.2, solid arrows show the direction of the maize moving between the rotating cone and static housing while being degermed. The cone surface and inner surface of the housing around the cone are both fitted with steel knobs to allow for a running and shearing action. Note that the cone K rotates freely and independently from the housing and protrudes through an opening inside the resistance plate.

4.4.3.2.4 Calculations and correlations

Translucencies were correlated with the following data from the degermer:

- Yield of large grits (>3.9 mm) as a weight percentage of whole maize before conditioning
- Yield (weight percentages) of combined grits fractions > 3.6 mm and >3.3 mm (typical ranges for breakfast cereal flaking grits) (Alexander 1987)
- Total endosperm (grits > 1.01 mm)

4.4.4 Statistical analysis

Correlations and linear regression calculations were done and tests for significance were calculated. Slopes of the regression models fitted were also tested for significance. Residuals of image analysis data were normally distributed and therefore no significant differences existed between mean and median values of the data. Hence, only the mean and standard deviation values were calculated for all data. The correlation coefficient r was determined as a measure of the stochastic dependence of the dependent and independent variables used for determining relationships between image analysis measurements and milling yield data. The z-transformation calculation was used for testing whether two correlation coefficients differed significantly from each other where applicable (Diem and Seldrup, 1982). A standard error of the regression slope was calculated along with a t-test to determine if the slope differed significantly from the horizontal or not. With this specific test, conclusions can be drawn from the data independent of the units of the measurements. A relationship may have a significant slope, but may seem flat on a line diagram because of the units of measurements or vice versa. Analysis of variance was done where applicable and Duncan groupings were calculated ($p<0.05$) to indicate significant differences between measurements. Correlations and t-tests were single-tailed since the relationships were predicted. The exposure only corrections were not shown in the results, only the effect of thickness and the combined effect of thickness and exposure.

4.5 RESULTS

4.5.1 Experiment 1

4.5.1.1 Image Analysis

Image analysis data are summarised in Table 4.1. Statistically significant differences were found for both Translucency 1 and 2 measurements (Table 4.1), indicating that the data were suitable for further analysis by linear regression. Morphology data

(thickness, total area and germ area) also showed statistically significant differences among the 20 samples.

Table 4.1 IA translucency and morphology data on twenty industrial white maize samples (45–50* kernels per sample)

Sample no		Tra (mm^2)	Trb (mm^2)	Trc (mm^2)	Tr1 (%)	Tr2 (%)	Thickness (mm)	Total area (mm^2)	Germ area (mm^2)
		**							
1	Mean	49.5^{abc}	59.0^{abc}	37.5^{ab}	36.0^{bc}	53.7^{ab}	4.9^{abcdef}	102.5^{abcd}	33.5^{abc}
	Std Dev	12.4	14.9	10.9	8.7	12.4	0.7	11.4	6.1
2	Mean	43.1^{defg}	50.8^{efghi}	30.7^{defg}	31.6^{def}	46.6^{efgh}	4.8^{abcdef}	95.9^{efg}	30.5^{defg}
	Std Dev	11.3	13.9	10.1	8.2	12.0	0.6	11.3	5.5
3	Mean	43.0^{defg}	53.1^{cdef}	33.4^{bcde}	32.6^{cde}	47.6^{cdefg}	5.1^{ab}	102.6^{abcd}	31.3^{bcdef}
	Std dev	9.8	14.1	9.4	8.6	13.8	0.5	10.9	5.1
4	Mean	36.7^{hi}	43.7^{ijk}	27.1^{fgh}	26.9^{hi}	40.5^{ij}	4.9^{abcd}	98.3^{bcde}	31.2^{bcde}
	Std Dev	7.2	8.5	6.2	5.1	8.5	0.8	17.9	7.8
5	Mean	38.4^{ghi}	47.6^{fghij}	29.2^{efg}	29.4^{efgh}	42.1^{ghji}	5.1^{a}	98.8^{def}	29.3^{efghi}
	Std Dev	5.8	10.2	7.2	6.1	9.3	0.8	8.4	5.4
6	Mean	47.8^{bcd}	57.6^{bcd}	37.0^{ab}	35.0^{bcd}	52.7^{abcd}	4.9^{abcde}	105.1^{abc}	34.4^{a}
	Std Dev	9.3	13.6	10.7	7.8	12.0	0.6	13.1	5.2
7	Mean	47.2^{bcde}	55.5^{bcde}	35.7^{abc}	33.8^{bcd}	50.3^{bcde}	4.8^{abcdef}	105.2^{ab}	33.7^{ab}
	Std Dev	7.4	11.5	8.9	6.7	10.4	0.7	11.5	5.7
8	Mean	44.8^{cdef}	50.8^{efghi}	30.7^{defg}	31.6^{def}	47.2^{defg}	4.7^{def}	96.7^{efg}	31.1^{cdef}
	Std Dev	11.0	12.2	8.0	7.5	12.7	0.6	8.7	5.4
9	Mean	35.0^{i}	39.8^{k}	23.6^{h}	24.9^{i}	37.0^{j}	4.6^{ef}	94.9^{efg}	30.4^{defg}
	Std Dev	8.4	10.6	6.9	6.6	10.5	0.5	13.1	6.2
10	Mean	37.8^{hi}	45.2^{hijk}	27.5^{fgh}	28.0^{fghi}	40.8^{ij}	4.8^{abcdef}	97.0^{efg}	30.0^{defgh}
	Std Dev	12.4	17.7	12.4	10.5	14.7	0.8	11.2	5.2
11	Mean	53.0^{a}	64.5^{a}	39.2^{a}	40.1^{a}	57.7^{a}	5.0^{abc}	97.2^{efg}	29.6^{efghi}
	Std Dev	10.5	13.1	10.2	7.6	11.0	0.5	12.2	5.3
12	Mean	50.7^{ab}	60.4^{ab}	37.2^{ab}	37.3^{ab}	53.1^{abc}	4.9^{abcdef}	99.7^{def}	29.1^{fghi}
	Std Dev	11.1	13.8	9.4	8.5	13.3	0.6	9.9	5.1
13	Mean	45.4^{cde}	55.8^{bcde}	36.0^{abc}	33.9^{bcd}	49.3^{bcdef}	5.1^{ab}	105.9^{a}	32.4^{abcd}
	Std Dev	11.5	15.1	10.3	9.1	14.3	0.6	9.7	4.6
14	Mean	43.1^{defg}	48.7^{efghij}	28.6^{defg}	30.5^{defg}	43.3^{fghi}	4.7^{bcdef}	92.3^{efg}	26.8^{i}
	Std Dev	12.5	15.9	10.7	9.6	13.2	0.6	11.8	4.0
15	Mean	45.2^{cdef}	51.1^{efgh}	31.8^{cdef}	31.5^{defg}	44.7^{efghi}	4.6^{f}	99.9^{cde}	29.3^{efghi}
	Std Dev	12.4	16.2	11.3	9.7	13.7	0.6	11.4	5.0
16	Mean	42.6^{efg}	52.0^{defg}	33.7^{bcd}	31.5^{def}	45.1^{efghi}	5.0^{ab}	106.9^{a}	31.4^{bcdef}
	Std Dev	7.7	12.1	8.8	7.2	11.5	0.8	12.6	5.5
17	Mean	38.4^{ghi}	47.8^{fghij}	28.6^{fg}	29.8^{efgh}	42.6^{ghij}	5.1^{a}	96.3^{efg}	28.3^{ghi}
	Std Dev	6.3	11.3	7.3	7.1	11.3	0.8	11.1	4.9
18	Mean	38.3^{ghi}	44.5^{ijk}	26.1^{gh}	27.9^{fghi}	40.2^{ij}	4.7^{cdef}	92.5^{g}	27.8^{hi}
	Std Dev	8.3	10.7	7.7	6.3	9.5	0.5	8.8	5.1
19	Mean	37.1^{hi}	44.2^{ijk}	26.1^{gh}	27.7^{ghi}	39.7^{ij}	4.9^{abcdef}	94.1^{fg}	27.5^{hi}
	Std Dev	6.3	9.5	6.5	5.8	9.7	0.6	11.4	4.3
20	Mean	40.4^{fgh}	46.0^{ghij}	27.9^{fgh}	28.6^{fghi}	41.1^{hij}	4.6^{ef}	96.9^{efg}	29.0^{fghi}
	Std Dev	8.1	9.8	7.3	5.7	8.4	0.4	9.7	4.6

Tra – translucent area without corrections
Trb – translucent area with thickness corrections
Trc – translucent area with thickness and exposure corrections
Tr1% - Translucent area % formula 1(thickness and exposure corrections)
Tr2% - Translucent area % formula 2 (thickness and exposure corrections)

Formula 1: Translucency 1 = $\frac{\text{True translucent area } (mm^2)}{\text{Whole kernel area } (mm^2)} \times \frac{100}{1}$

Formula 2: Translucency 2 = $\frac{\text{True translucent area } (mm^2)}{\text{Endosperm area } (mm^2)} \times \frac{100}{1}$

* Damaged kernels were excluded from a total batch of 50 measurements, causing final sample size to vary
** Means with different letters are statistically significantly different ($p<0.05$) within a column

4.5.1.2 Experimental maize milling data

Table 4.2 Floating number, fat content and product yield (calculated on a moisture-free base) obtained during experimental milling of 20 industrial white maize samples

Sample no	Floating number (weight %)	Fat content (%) of whole maize	Fat content of total semolina* (%)	Yield of semolina 1** (weight %)	Total semolina (grit) yield (weight %, grits between 250 and 1000 µm)	Total semolina (grit) yield (weight %, grits between 250 and 1000 µm, calculated at 0% fat)
1	58	3.67	1.19	35.6	62.3	61.6
2	72	4.02	1.09	35.2	60.4	59.7
3	71	3.98	1.14	34.4	60.7	60.0
4	74	3.76	1.15	34.6	62.2	61.5
5	74	3.48	1.22	35.3	60.9	60.2
6	57	4.36	1.32	36.1	61.4	60.6
7	68	4.22	1.35	35.0	60.4	59.6
8	74	4.05	1.26	34.1	60.4	59.6
9	82	3.72	1.04	33.0	58.4	57.8
10	83	3.81	0.96	34.2	59.6	59.0
11	59	4.42	1.15	38.0	61.0	60.3
12	66	3.88	1.13	35.8	60.8	60.1
13	69	3.96	1.17	34.9	61.6	60.9
14	79	3.78	1.18	34.2	59.7	59.0
15	78	3.75	1.09	34.6	59.9	59.2
16	64	3.97	1.25	36.4	61.5	60.7
17	77	3.80	1.09	35.9	60.4	59.7
18	87	3.70	1.06	34.7	60.3	59.7
19	83	3.30	1.11	34.9	60.7	60.0
20	84	3.52	1.19	34.0	58.9	58.2

* Total semolina refers to all cleaned grits between 250 and 1000 μm

** Semolina 1 is produced from the cleaned large vitreous endosperm grits obtained after the first breaking (rolls I and II, Figure 4.1). The clean grits were larger than 1mm before being reduced to the semolina 1 fraction. Semolina 1 grits were smaller than 767μm and bigger than 250 μm

Analytical results and experimental milling data of the maize samples before milling are summarised in Table 4.2. Fat contents are shown of the whole maize kernels before milling and of the combined total semolina (grits between 250 and 1000 µm) yield after milling. The total semolina yield is given including fat and also calculated on a fat free basis in order to determine if the fat content had a significant effect on the yield of the maize grits. All yields were calculated on a dry basis.

4.5.1.3 Correlations

Table 4.3 Product moment correlation coefficient (r) and R^2 matrixes for milled white maize products and image analysis translucency measurements, with and without corrections for thickness and exposure, experiment 1 (n = 20)

Treatment	Tr1a	Tr2a	Tr1b	Tr2b	Tr1c	Tr2c
Semolina 1(weight %) r	0.55*	0.50*	0.73***	0.69***	0.74***	0.70***
Semolina 1 (weight %) R^2	0.30	0.25	0.53	0.48	0.54	0.48
Total semolina (grits) yield, no fat corrections (weight %) r	0.18	0.21	0.37	0.41	0.48*	0.52*
Total semolina (grits) yield, no fat corrections (weight %) R^2	0.03	0.04	0.14	0.17	0.23	0.27
Total semolina (grits) yield, 0% fat (weight %) r	0.17	0.20	0.36	0.40	0.47*	0.50*
Total semolina (grits) yield, 0% fat (weight %) R^2	0.03	0.04	0.13	0.16	0.22	0.25
Floating number (weight %) r	-0.63**	-0.68**	-0.73***	-0.78****	-0.84****	-0.88****
Floating number (weight %) R^2	0.40	0.46	0.52	0.61	0.70	0.78

Tr1a – Translucency formula 1 without corrections
Tr1b – Translucency formula 2 without corrections
Tr2a – Translucency formula 1 with thickness corrections
Tr2b – Translucency formula 2 with thickness corrections
Tr1c – Translucency formula 1 with thickness and exposure corrections
Tr2c – Translucency formula 2 with thickness and exposure corrections

Formula 1: Translucency 1 = $\frac{\text{True translucent area (mm}^2\text{)}}{\text{Whole kernel area (mm}^2\text{)}} \times \frac{100}{1}$

Formula 2: Translucency 2 = $\frac{\text{True translucent area (mm}^2\text{)}}{\text{Endosperm area (mm}^2\text{)}} \times \frac{100}{1}$

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.0001$ for level of significance of the correlation coefficient

Average to good correlations (Table 4.3) were obtained between semolina 1 and translucency and these values increased significantly after the application of thickness and exposure corrections. Good correlations were obtained between floating number and translucency and the values also increased after corrections for thickness as well as exposure. Although initial correlations between total semolina yield (both with fat and without fat) and translucency were poor, significant increases were obtained after applying corrections for thickness and exposure, therefore producing significant correlations ($p<0.05$). Although small differences existed between correlation coefficients calculated based on translucency 1 (% of whole kernel) and translucency 2 (% of endosperm) as seen in Table 4.3, none of these differences were significant when the pairs of r-values were compared.

Scatterplots and fitted regression lines of all correlations between translucency and product yield except semolina yield at 0% fat content are given in Figures 4.3 to 4.8. The linear regression lines show the actual effect that correction factors had on the changing of slopes and correlation coefficients after corrections for thickness and exposure. The placing of the translucency measurements within the middle of the scale range after corrections for exposure compared to having the uncorrected measurements at the higher end of the scale is also clearly visible in all the Figures. Exposure correction had a greater effect on the increase of the slopes of the regression lines than the corrections for thickness (Figures 4.3 to 4.8), while the effect of thickness correction was generally greater on the increase of r-values than the effect of exposure (Table 4.3). The slope always increased after exposure correction, while with thickness correction, the slope either remained the same or increased only slightly. Both the slope and the r-value increases after applying the two correction factors indicated stronger relationships and the trend occurred in all cases.

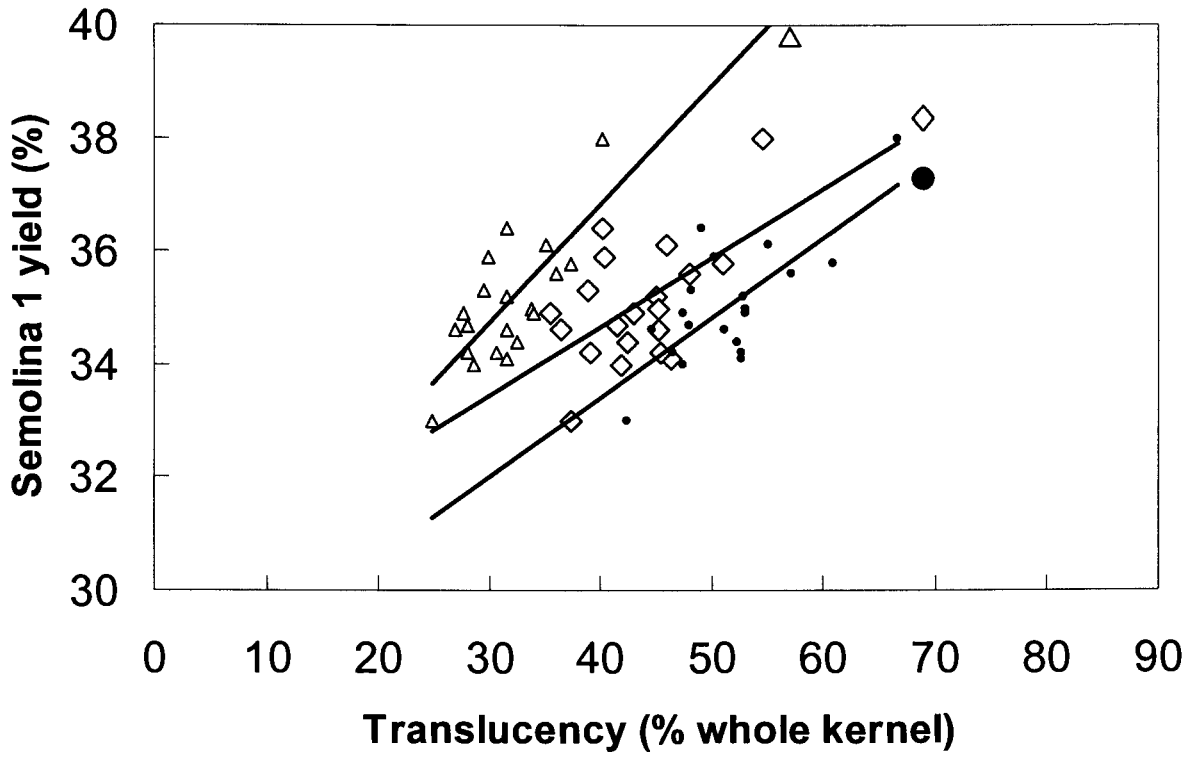

Figure 4.3 Effect of applying correction factors (CFs) on the relationship between the yield of semolina (grits) fraction 1 (mass %) as determined by laboratory milling (Experiment 1) and translucent area (% of whole kernel) of 20 industrial white maize batches determined by image analysis. "◊", before CFs (y = 0.12x + 30, r = 0.55); "●", after thickness CF (y = 0.14x + 28, r = 0.73); "△", after thickness and exposure CFs (y = 0.21x + 28, r = 0.74), n = 20. r-values did not differ significantly from each other ($p \geq 0.05$) (Fisher test)

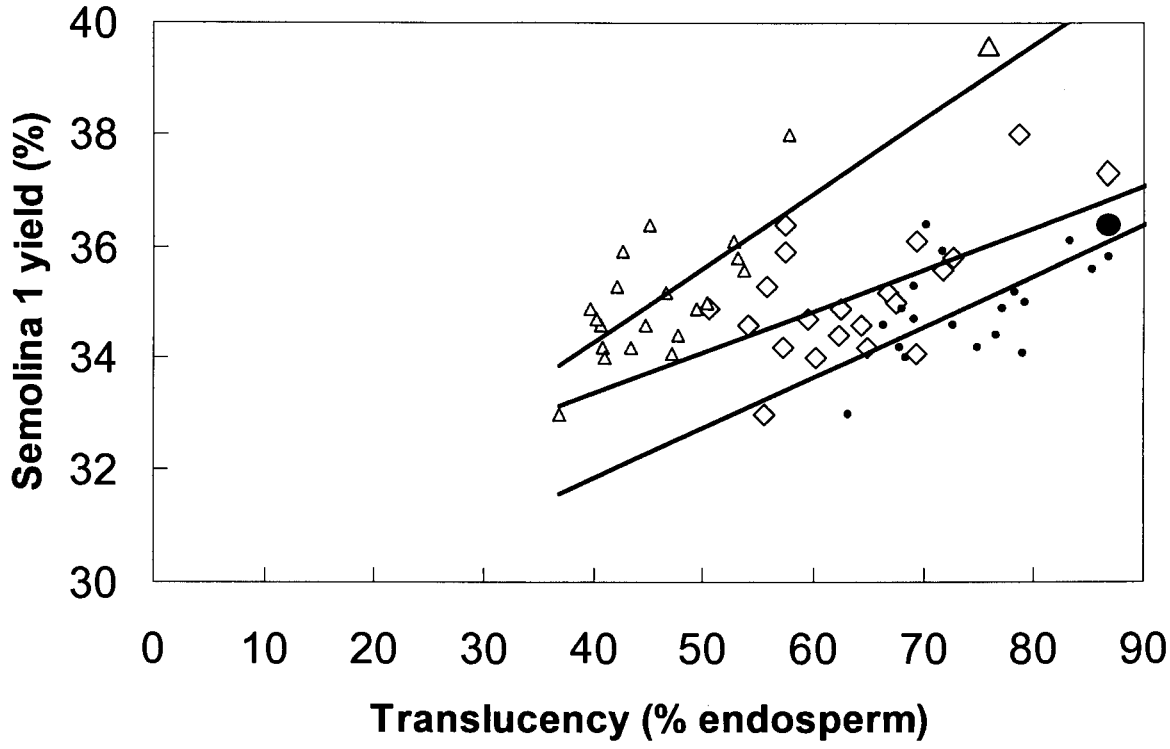

Figure 4.4 Effect of applying correction factors (CFs) on the relationship between the yield of the semolina (grits) fraction 1 (mass %) as determined by laboratory milling (Experiment 1) and translucent area (% of endosperm) of 20 industrial white maize samples as determined using image analysis. "◊", before CFs (y = 0.07x + 30, r = 0.50); "•", after thickness CF (y = 0.09x + 28, r = 0.69); "△", after thickness and exposure CFs (y = 0.13x + 29, r = 0.70), n = 20. r values of the three graphs did not differ significantly from each other ($p \geq 0.05$) (Fisher test)

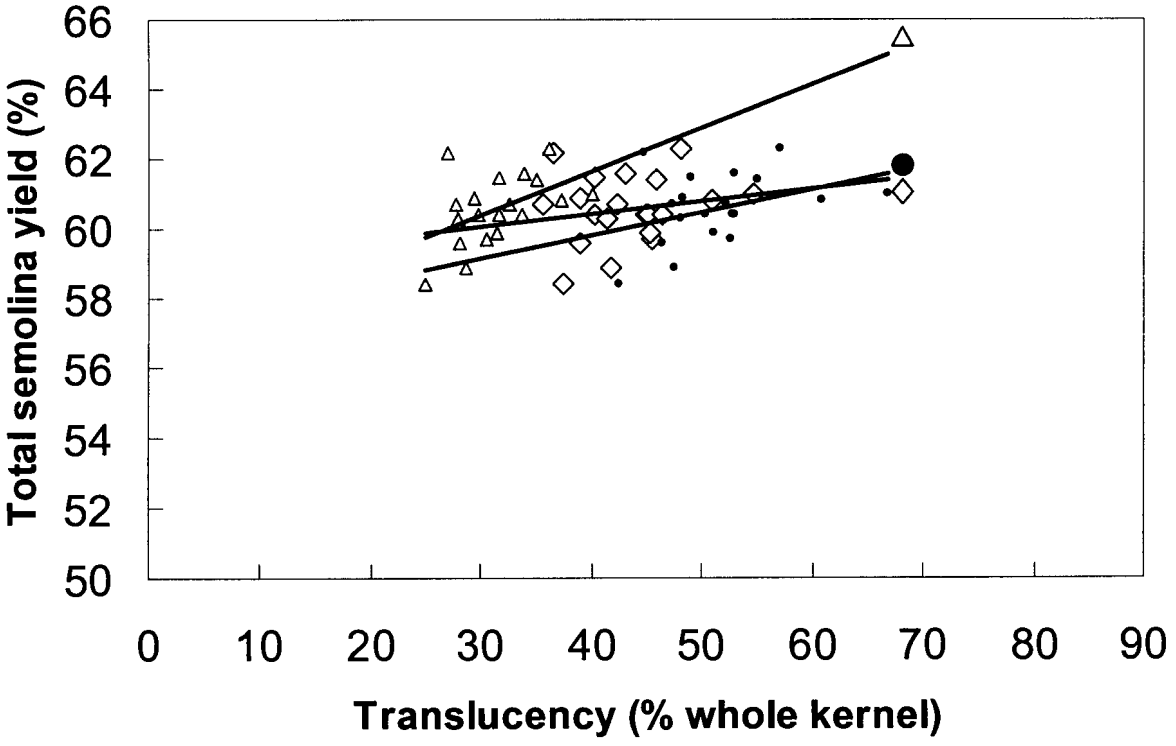

Figure 4.5 Effect of applying correction factors (CFs) on the relationship between the total yield of the semolina (mass %) before corrections for fat content as determined by laboratory milling (Experiment 1) and translucent area (% of whole maize) of 20 industrial white maize batches as determined using image analysis. "◊", before CFs (y = 0.04x + 59, r = 0.18); "●", after thickness CF (y = 0.07x + 57, r = 0.37); "△", after thickness and exposure CFs (y = 0.13x + 57, r = 0.48), n = 20. r-values did not differ significantly from each other ($p \geq 0.05$) (Fisher test)

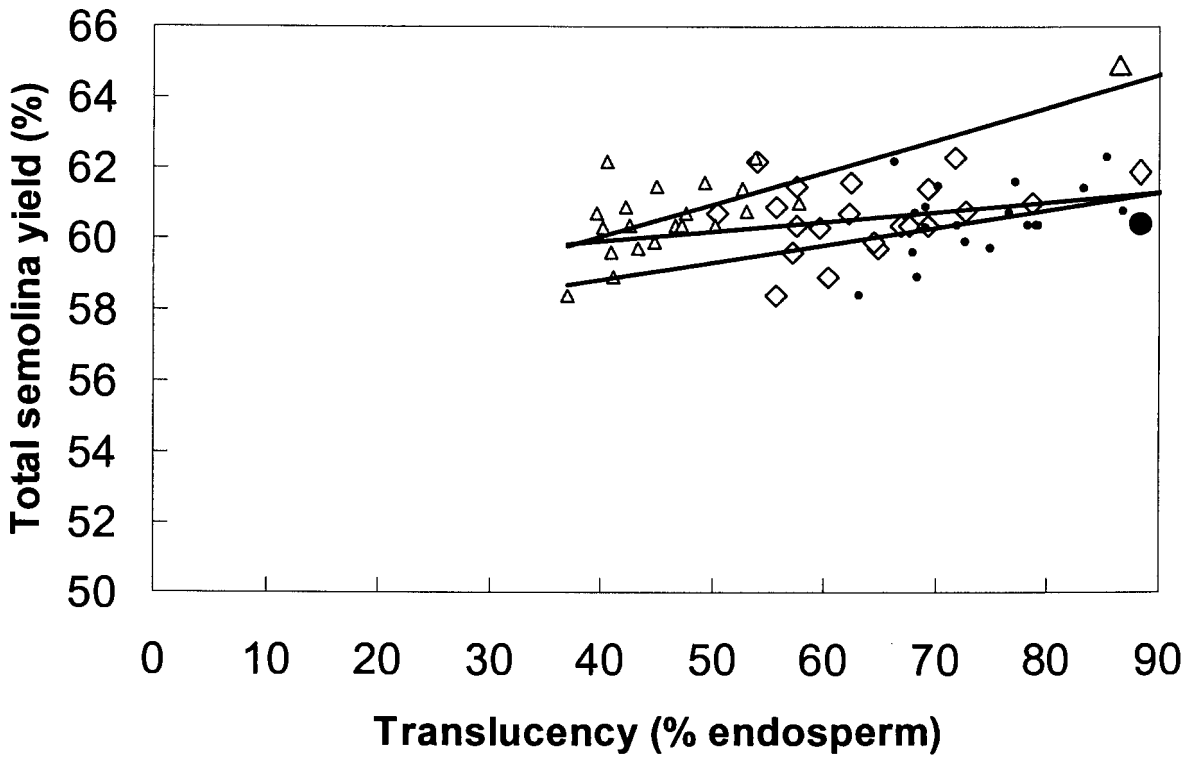

Figure 4.6 Effect of applying correction factors (CFs) on the relationship between the total yield of the semolina (mass %) on a fat free basis as determined by laboratory milling (Experiment 1) and translucent area (% of endosperm) of 20 industrial white maize batches as determined using image analysis. "◊", before CFs (y = 0.03x + 59, r = 0.21); "●", after thickness CF (y = 0.05x + 57, r = 0.41); "△", after thickness and exposure CFs (y = 0.09x + 56, r = 0.52), n = 20. r-values did not differ significantly from each other ($p \geq 0.05$) (Fisher test)

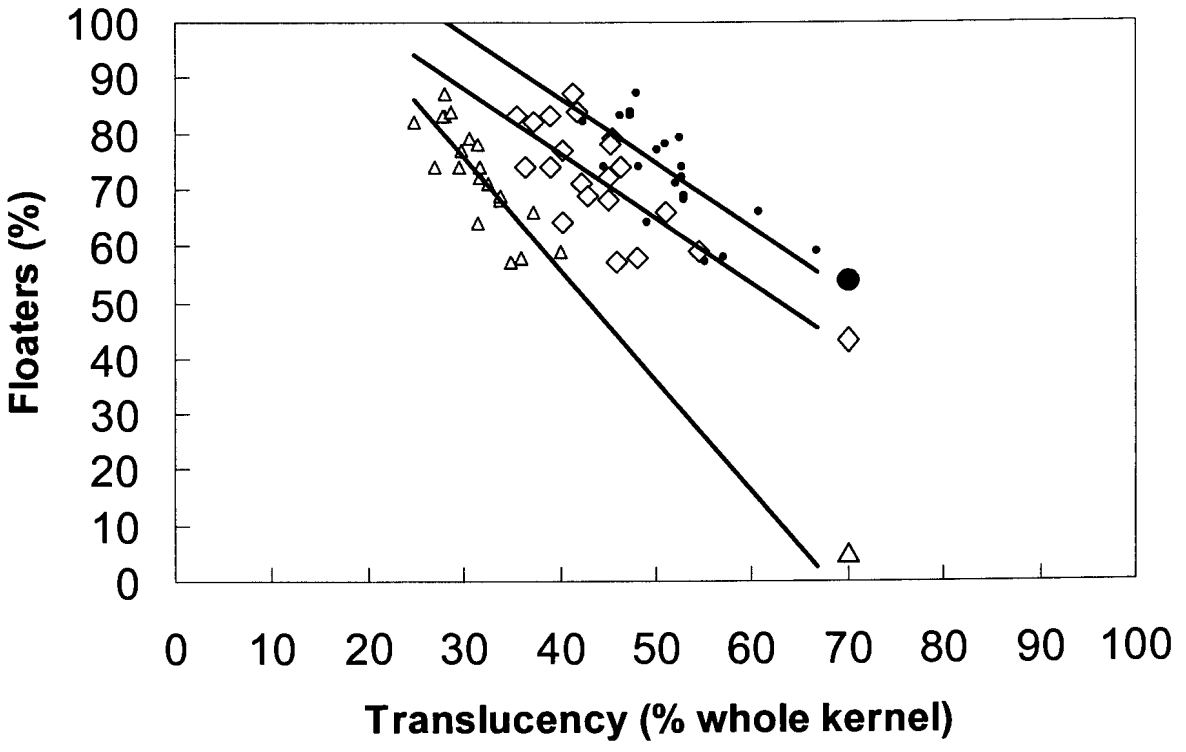

Figure 4.7 Effect of applying correction factors (CFs) on the relationship between floaters (mass %) and translucent area (% of whole kernel) of 20 industrial white maize batches determined by using image analysis. "◊", before CFs (y = -1.16x + 123, r = -0.63); "●", after thickness CF (y = -1.16x + 133, r = -0.73); "△", after thickness and exposure CFs (y = -2x + 136, r = -0.84), n = 20. r-values did not differ significantly ($p \geq 0.05$) (Fisher test)

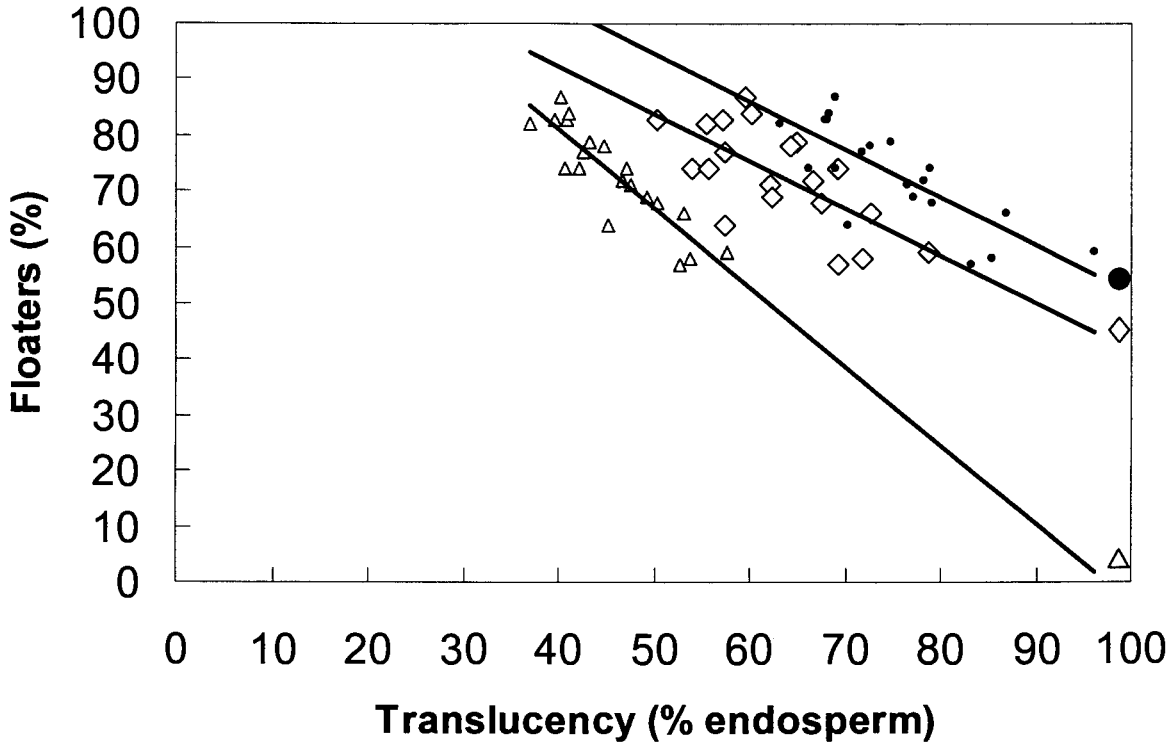

Figure 4.8 Effect of applying correction factors (CFs) on the relationship between floaters (mass %) and translucent area (% of endosperm) of 20 industrial white maize batches as determined by image analysis. "◊", before CFs (y = -0.84x + 126, r = -0.68); "●", after thickness CF (y = -0.86x + 138, r = -0.78); "△", after thickness and exposure CFs (y = -1.41x + 138, r =-0.88), n = 20. r-values did not differ significantly from each other ($p \geq 0.05$) (Fisher test)

4.5.2 Experiment 2

4.5.2.1 Image Analysis

Image analysis data are summarised in Table 4.4.

Table 4.4 Image analysis translucency and morphology measurements on eight industrial white maize samples and two industrial yellow maize samples (45 – 50* kernels per sample)

Sample no		Tra (mm^2)	Trb (mm^2)	Trc (mm^2)	Tr1 (%)	Tr2 (%)	Thickness (mm)	Total area (mm^2)	Germ area (mm^2)
		**							
1	Mean	57.3^{bc}	82.5^{ab}	53.5^{ab}	50.0^{ab}	72.0^{a}	6.0^{a}	106.1^{bc}	31.9^{bc}
	Std Dev	14.9	24.6	18.0	14.4	20.2	0.9	11.0	3.5
2	Mean	64.2^{a}	81.2^{ab}	54.1^{ab}	48.8^{ab}	63.4^{bc}	5.2^{cde}	110.0^{b}	24.9^{d}
	Std Dev	14.5	24.0	17.6	14.0	18.4	0.9	10.0	4.7
3	Mean	60.9^{ab}	75.4^{bc}	50.2^{bc}	45.2^{bc}	67.7^{abc}	5.1^{de}	109.4^{b}	35.2^{a}
	Std dev	14.9	21.5	17.4	12.0	17.1	0.8	14.8	6.2
4	Mean	52.0^{c}	63.8^{d}	41.5^{de}	38.6^{d}	55.5^{d}	5.1^{de}	106.7^{bc}	31.9^{bc}
	Std Dev	16.3	21.2	15.4	12.5	18.2	0.8	11.4	3.4
5	Mean	61.8^{ab}	80.4^{ab}	53.6^{ab}	48.2^{ab}	69.5^{ab}	5.5^{bc}	110.4^{b}	33.1^{b}
	Std Dev	16.2	26.6	19.5	15.6	22.4	0.8	12.4	4.4
6	Mean	64.0^{a}	88.9^{a}	58.2^{a}	53.7^{a}	70.2^{ab}	5.8^{ab}	107.4^{bc}	24.9^{d}
	Std Dev	14.7	23.5	17.1	13.7	17.8	1.1	9.4	4.6
7	Mean	52.9^{c}	69.0^{cd}	44.4^{cd}	42.0^{cd}	60.3^{cd}	5.4^{cd}	104.9^{bc}	31.4^{bc}
	Std Dev	14.5	22.3	15.8	13.2	19.5	0.7	9.1	5.1
8	Mean	41.0^{d}	50.1^{e}	35.2^{e}	29.5^{e}	39.7^{e}	4.9^{ef}	115.8^{a}	29.9^{c}
	Std Dev	16.2	23.5	18.7	13.3	17.1	0.8	18.6	4.7
9	Mean	55.7^{bc}	74.0^{bc}	47.1^{bcd}	45.2^{bc}	64.8^{abc}	5.5^{bc}	102.7^{c}	30.3^{c}
	Std Dev	9.8	20.8	16.3	11.8	15.9	1.1	13.3	6.3
10	Mean	31.9^{e}	36.2^{f}	24.1^{f}	24.7^{e}	37.5^{e}	4.6^{f}	97.0^{d}	32.7^{b}
	Std Dev	13.2	16.4	11.4	11.0	17.0	0.8	9.0	5.1

Tra – translucent area without corrections
Trb – translucent area with thickness corrections
Trc – translucent area with thickness and exposure corrections
Tr1% - Translucent area % formula 1(thickness and exposure corrections)
Tr2% - Translucent area % formula 2 (thickness and exposure corrections)
Samples 1 – 8, white cultivars
Samples 9 and 10, yellow cultivars

Formula 1: Translucency 1 = $\frac{\text{True translucent area } (mm^2)}{\text{Whole kernel area } (mm^2)} \times \frac{100}{1}$

Formula 2: Translucency 2 = $\frac{\text{True translucent area } (mm^2)}{\text{Endosperm area } (mm^2)} \times \frac{100}{1}$

* Damaged kernels were excluded from a total batch of 50 measurements, causing final sample size to vary
** Means with different letters are statistically significantly different ($p<0.05$) within a column

Statistically significant differences were found for Translucency 1 and 2 (Table 4.4) measurements between samples indicating that the data are suitable for further analysis by linear regression. Morphology data (thickness, total area and germ area) also showed statistically significant differences among the 10 samples.

4.5.2.2 Maize milling data

Experimental milling data are given in Table 4.5. Data include moisture contents after conditioning and before degerming, and yield of milled products (mass %) obtained during milling. The results represent mean values of 510 kg batches milled for each type of maize.

Table 4.5 Experimental milling data of 10 lots (22 sub-samples) of maize (eight white and two yellow) in a industrial 3 ton/hour Bühler dry maize mill

Sample no***		Whole kernel moisture before degermer (%)	Extraction at degermer (% overs, 5 mm sieve) ****	Break flour in thrus (%)*	Total maize meal extraction (%), as is	Total maize meal extraction (%), moisture free base
1	Mean	15.2	70.0^{a}	8.2^{bcde}	74.2^{c}	69.6^{bc}
	Std Dev	3.2	0.4	0.1	0.2	1.0
2	Mean	17.5	69.7^{ab}	7.9^{cde}	73.8^{c}	68.3^{c}
	Std Dev	0.6	3.6	0.5	0.6	0.8
3	Mean	17.3	72.1^{a}	7.5^{de}	76.0^{b}	71.0^{bc}
	Std dev	0.2	1.2	0.5	0.6	0.7
4	Mean	16.4	56.5^{cd}	10.2^{ab}	70.2^{d}	64.3^{d}
	Std Dev	1.8	3.3	1.4	1.2	2.2
5	Mean	15.6	69.7^{ab}	8.5^{bcd}	73.9^{c}	69.0^{bc}
	Std Dev	2.0	0.1	0.2	0.6	1.4
6	Mean	17.5	71.9^{a}	7.0^{de}	76.5^{b}	71.6^{b}
	Std Dev	0.8	2.4	0.7	0.4	0.7
7	Mean	15.5	59.5^{c}	9.8^{abc}	74.0^{c}	69.2^{bc}
	Std Dev	0.7	0.2	0.9	0.0	0.3
8	Mean	14.1	53.9^{d}	11.5^{a}	**	**
	Std Dev	0.7	3.6	1.9	**	**
9	Mean	16.9	64.6^{b}	6.3^{e}	80.0^{a}	76.1^{a}
	Std Dev	1.6	0.7	0.4	0.3	0.6
10	Mean	16.1	42.3^{e}	8.0^{cde}	68.7^{e}	62.2^{d}
	Std Dev	1.2	0.0	0.3	0.8	1.7

* Weight of fine flour (<500 μm) recovered after sieving the thru fraction obtained from the degermer
** Not determined due to mill breakdown
*** Samples 1 – 8, white maize, samples 9 – 10, yellow maize
**** Means with different letters are statistically significantly different ($p<0.05$) within a column

Statistically significant differences occurred among the yields of the various milled products for the 10 milled lots (Table 4.5). The different yields were in a narrow range for all the products except extraction at degermer, which showed a range of 29.8% for the mean of the yield between the highest and lowest values.

4.5.2.3 Correlations

Table 4.6 Product moment correlation coefficient (r) and R^2 matrixes for milled maize products and image analysis translucency measurements, with and without corrections for kernel thickness and light exposure, experiment 2 (n = 22, n includes all sub-samples of each lot, each sub-sample represents a separate milling trial)

Treatment	Tr1a	Tr2a	Tr1b	Tr2b	Tr1c	Tr2c
Extraction at degermer (weight %) r	0.91****	0.87****	0.91****	0.88****	0.93****	0.91****
Extraction at degermer (weight %) R^2	0.83	0.75	0.83	0.8	0.86	0.82
Total extraction of maize meal, no moisture corrections (weight %) r	0.61**	0.64**	0.75****	0.84****	0.68***	0.72****
Total extraction of maize meal, no moisture corrections (weight %) R^2	0.37	0.41	0.51	0.56	0.46	0.52
Total extraction of maize meal, 0% moisture (weight %) r	0.59**	0.64**	0.71****	0.75****	0.66***	0.72****
Total extraction of maize meal, 0% moisture (weight %) R^2	0.35	0.40	0.50	0.57	0.44	0.52
Break flour in the thrus (weight %) r	-0.46*	-0.48*	-0.50**	-0.52**	-0.50*	-0.50**
Break flour in the thrus (weight %) R^2	0.21	0.23	0.25	0.27	0.24	0.26

Tr1a – Translucency formula 1 without corrections
Tr1b – Translucency formula 2 without corrections
Tr2a – Translucency formula 1 with thickness corrections
Tr2b – Translucency formula 2 with thickness corrections
Tr1c – Translucency formula 1 with thickness and exposure corrections
Tr2c – Translucency formula 2 with thickness and exposure corrections

Formula 1: Translucency 1 = $\frac{\text{True translucent area (mm}^2\text{)}}{\text{Whole kernel area (mm}^2\text{)}} \times \frac{100}{1}$

Formula 2: Translucency 2 = $\frac{\text{True translucent area (mm}^2\text{)}}{\text{Endosperm area (mm}^2\text{)}} \times \frac{100}{1}$

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.0001$ for level of significance of the correlation coefficient

Correlation coefficients between extraction of milled maize products and maize kernel translucency (Table 4.6) were highly significant in general except for the break flour in the thrus, where the relationships were only significant at $p<0.05$. The values for extraction at degermer increased further after the application of thickness and exposure corrections. Although corrections for thickness significantly increased correlations for total extraction of maize meal and break flour in the thrus, corrections for exposure did not have the same effect (either stayed the same or decreased the correlations slightly.

Scatterplots and fitted regression lines of all correlations between translucency and product yield except extraction of total special maize meal at 0% moisture content are given in Figures 4.9 to 4.14. Scatterplots show the actual effect that correction factors had on the results such as changing slopes accompanied by changing correlation coefficients and levels of significance after corrections for thickness and exposure.

The placing of the translucency measurements within the middle of the scale range after corrections for exposure compared to having the uncorrected measurements at the higher end of the scale is clearly visible in all the Figures. Slopes did not always increase after corrections. In Figures 4.9 – 4.14, the slope decreased after corrections for thickness, but increased again after corrections for exposure. The slope always increased after exposure correction, while with thickness correction, the slopes decreased. Correlation coefficients either stayed the same or increased after thickness corrections, but either increased, stayed the same or decreased after corrections for exposure (Table 4.6). The combined effects of the slope and the r-value changes after applying the two correction factors produced stronger relationships in all cases.

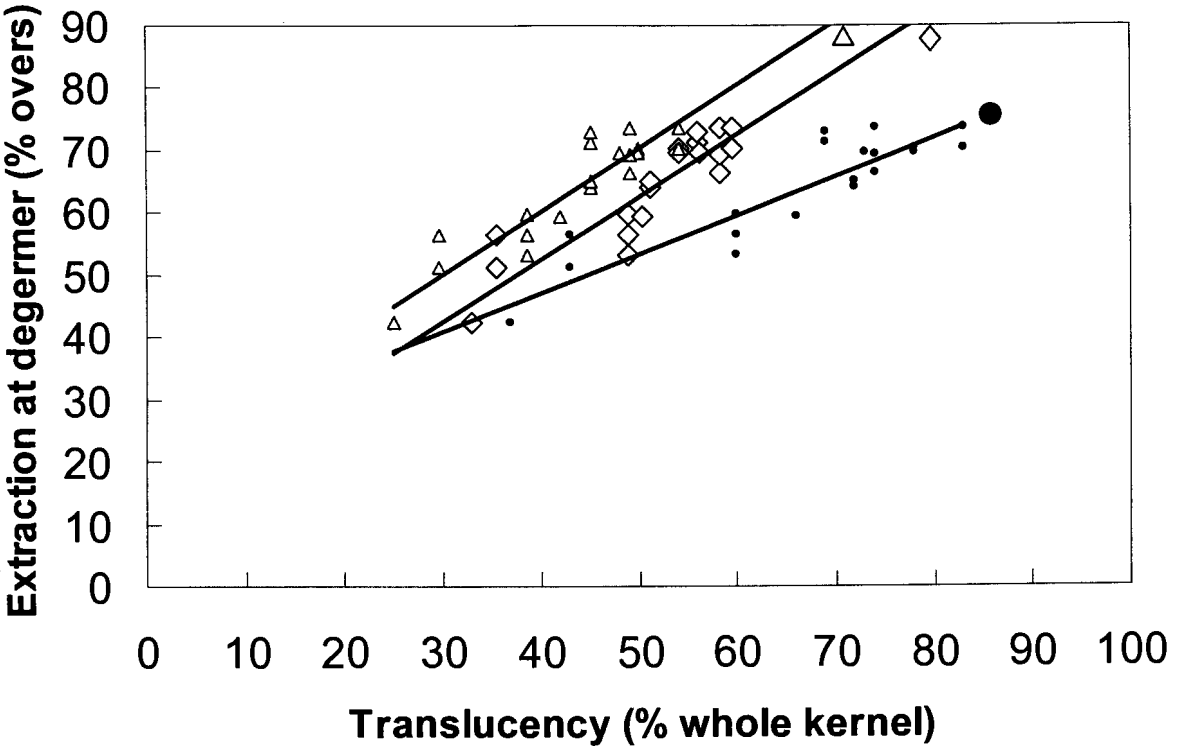

Figure 4.9 Effect of applying correction factors (CFs) on the relationship between extraction at degermer (mass %) and translucent area (% of whole kernel) of 8 industrial white maize batches and 2 industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = 1.0x + 12.4, r = 0.91); "●", after thickness CF (y = 0.62x + 22.3, r = 0.91); "△", after thickness and exposure CFs, (y = 1.0x + 19.7, r =0.93), n = 22. r-values were not significantly different from each other ($p \geq 0.05$) (Fisher test)

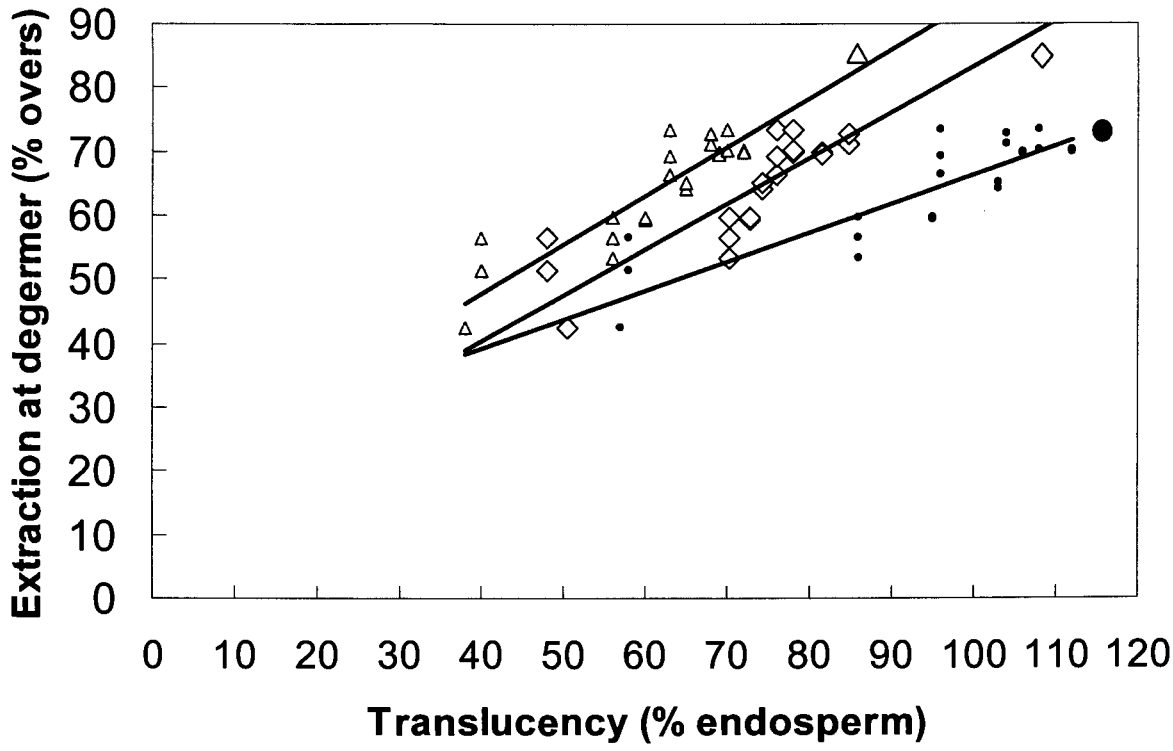

Figure 4.10 Effect of applying correction factors (CFs) on the relationship between extraction at degermer (mass %) and translucent area (% of endosperm) of eight industrial white and two industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = 0.72x + 11.8, r = 0.87); "●", after thickness CF (y = 0.45x + 21.1, r = 0.88); "△", after thickness and exposure CFs, (y = 0.76x + 17.1, r =0.91), n = 22. r-values were not significantly different from each other ($p \geq 0.05$) (Fisher test), but were all highly significant at $p < 0.0001$

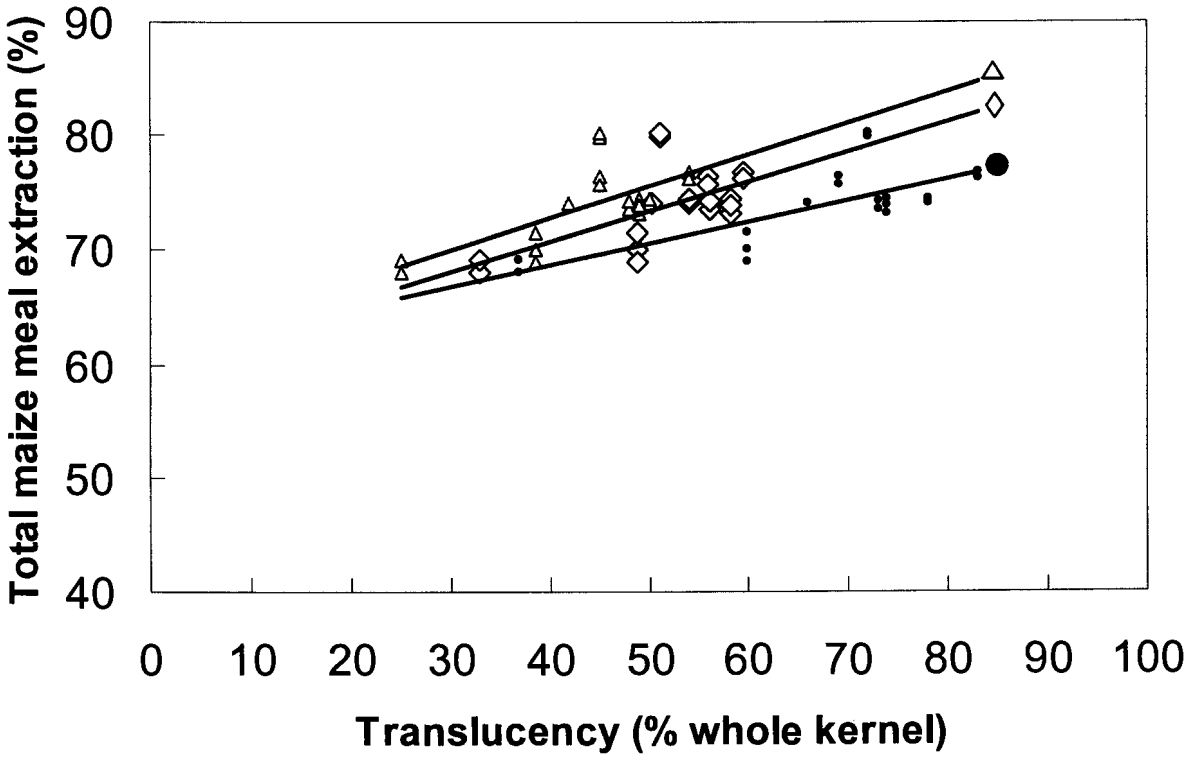

Figure 4.11 Effect of applying correction factors (CFs) on the relationship between total maize meal extraction (mass %) and translucent area (% of endosperm) of eight industrial white and two industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = 0.26x + 60.2, r = 0.61); "●", after thickness CF (y = 0.19x + 61.3, r = 0.72); "△", after thickness and exposure CFs, (y = 0.28x +61.8, r = 0.68), n = 22. r-values were not significantly different from each other ($p \geq 0.05$) (Fisher test)

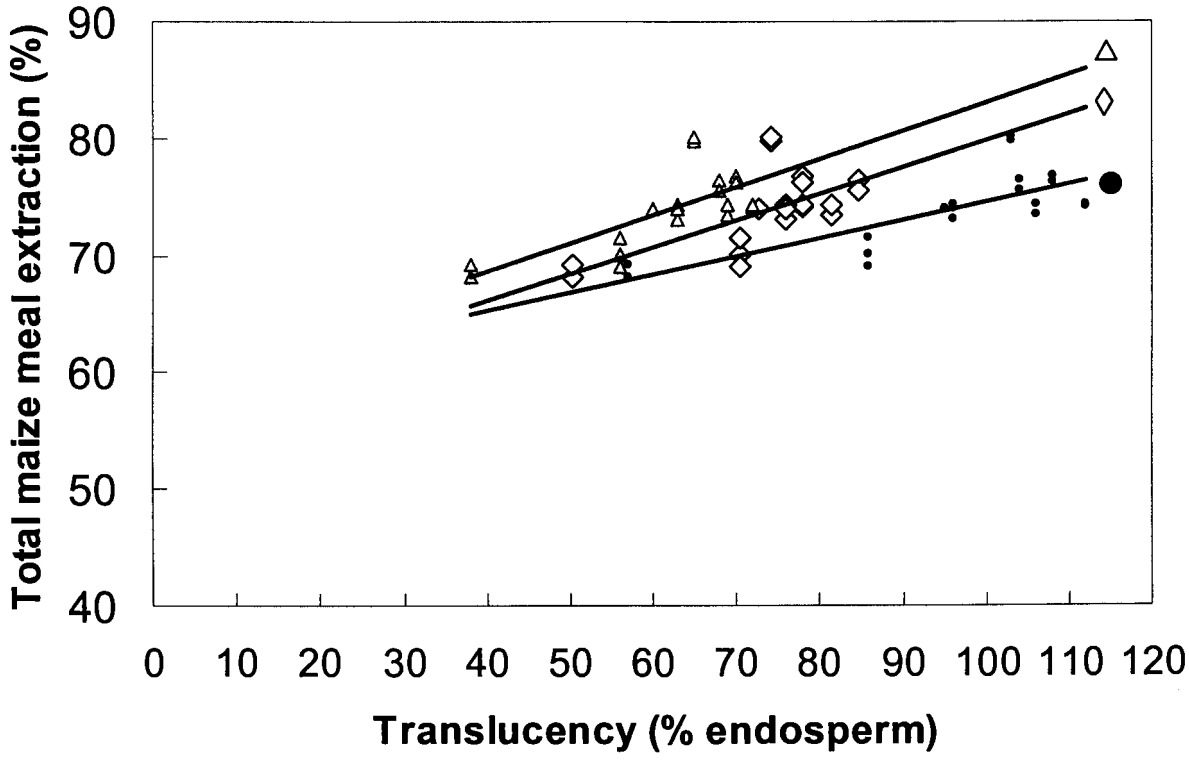

Figure 4.12 Effect of applying correction factors (CFs) on the relationship between total maize meal extraction (mass %) and translucent area (% of endosperm) of eight industrial white and two industrial yellow maize meal batches as determined by image analysis. "◊", before CFs (y = 0.23x + 57, r = 0.64); "●", after thickness CF (y = 0.16x + 59, r = 0.75);"△", after thickness and exposure CFs, (y = 0.24x + 59.1, r =0.72), n = 22. r-values were not significantly different from each other ($p \geq 0.05$) (Fisher test)

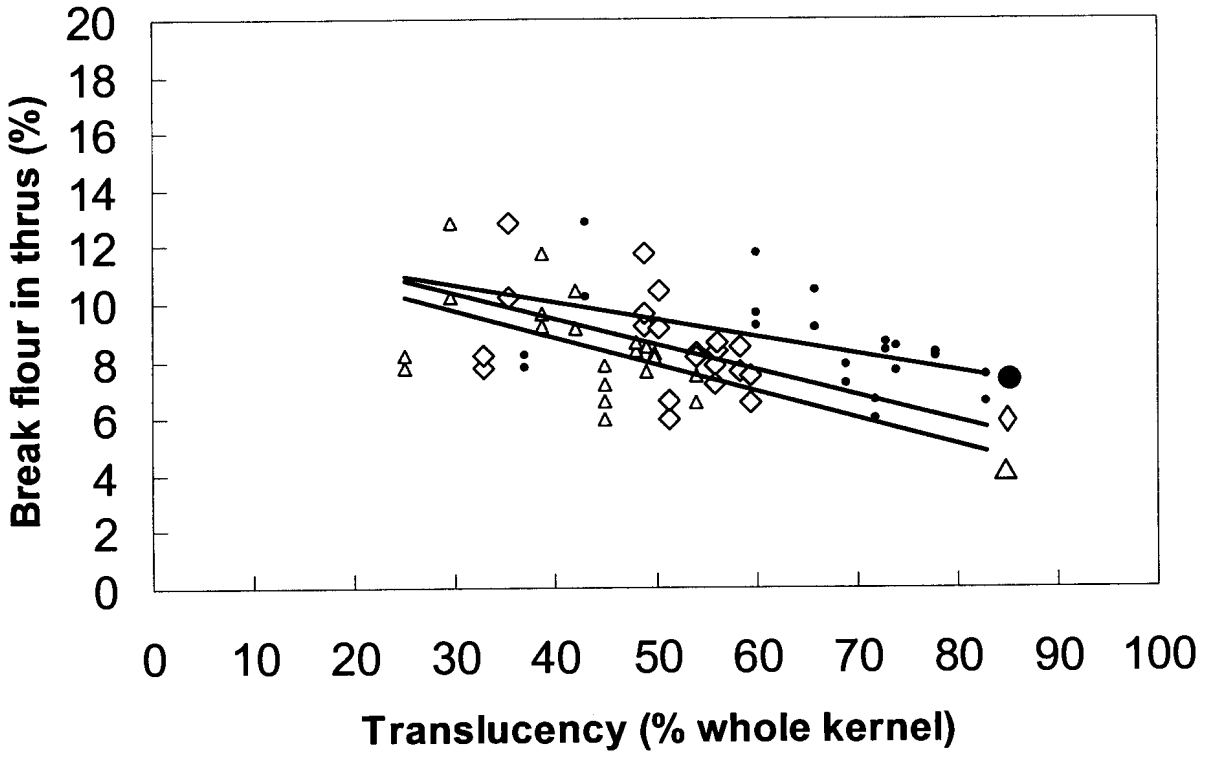

Figure 4.13 Effect of applying correction factors (CFs) on the relationship between break flour in thrus (mass %) and translucent area (% of whole kernel) of eight industrial white and two industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = -0.09x + 13, r = -0.46); "•", after thickness CF (y = -0.06x + 12.5, r = -0.50); "△", after thickness and exposure CFs, (y = -0.1x + 12.5, r = -0.50), n = 22. r-values were not significantly different from each other ($p \geq 0.05$) (Fisher test)

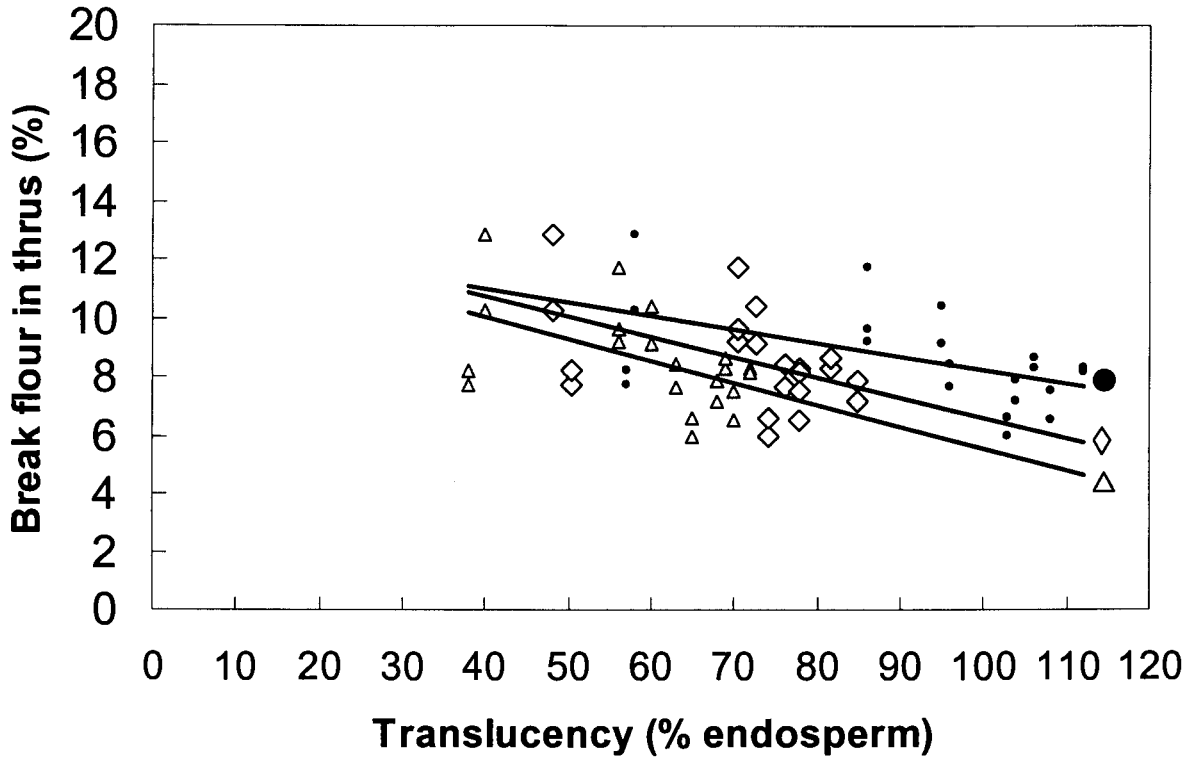

Figure 4.14 Effect of applying correction factors (CFs) on the relationship between the yield of break flour in thrus (mass %) and translucent area (% of endosperm) of eight industrial white and two industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = -0.07x + 13.5, r = -0.48); "•", after thickness CF (y = -0.05x + 12.8, r = -0.52);"△", after thickness and exposure CFs, (y = -0.0.7x + 13, r = -0.50), n = 22. r-values did not differ significantly from each other ($p \geq 0.05$) (Fisher test)

4.5.3 Experiment 3

4.5.3.1 Image Analysis

Table 4.7 Image analysis translucency and morphology measurements on 12 samples of yellow maize (45 – 50* kernels per sample)

Sample no		Tra (mm^2)	Trb (mm^2)	Trc (mm^2)	Tr1 (%)	Tr2 (%)	Thickness (mm)	Total area (mm^2)	Germ area (mm^2)
		**							
1	Mean	34.2^{a}	51.7^{a}	33.2^{a}	35.7^{a}	45.5^{ab}	4.5^{d}	88.5^{bcd}	24.2^{d}
	Std Dev	12.0	14.7	10.7	9.7	14.0	0.4	11.9	5.1
2	Mean	40.6^{c}	40.1^{cd}	24.4^{e}	28.2^{cd}	42.2^{cde}	4.7^{c}	93.7^{e}	24.0^{c}
	Std Dev	15.2	13.1	8.1	9.3	15.6	0.4	8.1	4.1
3	Mean	30.5^{a}	51.3^{a}	32.1^{ab}	35.7^{a}	49.8^{a}	4.4^{d}	79.9^{cde}	22.6^{d}
	Std dev	11.2	13.4	9.9	8.8	13.4	0.4	8.4	4.6
4	Mean	35.3^{b}	46.9^{ab}	29.3^{abcd}	32.7^{ab}	46.2^{abc}	4.5^{d}	87.2^{de}	27.7^{d}
	Std Dev	9.9	13.5	10.2	8.8	12.9	0.4	10.0	5.1
5	Mean	46.4^{ab}	46.3^{ab}	30.1^{abc}	31.8^{abc}	43.2^{bcde}	4.4^{d}	92.2^{ab}	25.3^{d}
	Std Dev	12.9	15.6	10.9	10.5	15.3	0.4	8.6	4.0
6	Mean	41.7^{c}	40.4^{bcd}	25.2^{de}	28.9^{cd}	39.2^{de}	4.8^{bc}	88.1^{de}	25.4^{d}
	Std Dev	10.9	15.0	10.6	10.2	14.8	0.5	10.6	4.5
7	Mean	32.8^{c}	40.9^{bcd}	26.5^{cde}	28.2^{cd}	43.6^{abcde}	5.1^{a}	94.4^{ab}	32.5^{a}
	Std Dev	9.9	12.4	8.4	8.6	14.1	0.3	9.1	3.8
8	Mean	31.9^{c}	43.3^{bc}	28.9^{bcd}	29.4^{bcd}	45.8^{abcd}	5.3^{a}	93.1^{a}	33.2^{a}
	Std Dev	10.2	12.3	9.4	8.0	13.0	0.3	8.5	4.6
9	Mean	32.1^{c}	40.8^{bcd}	25.9^{cde}	28.3^{cd}	44.5^{abcde}	5.2^{a}	92.0^{bcd}	32.9^{a}
	Std Dev	11.3	13.5	8.8	9.3	15.5	0.4	8.9	4.7
10	Mean	30.7^{c}	41.7^{bcd}	26.8^{cde}	28.8^{cd}	45.2^{abcd}	5.2^{a}	93.4^{ab}	30.0^{a}
	Std Dev	8.7	10.1	7.1	7.0	12.3	0.3	10.0	4.2
11	Mean	33.1^{c}	41.1^{bcd}	26.4^{cde}	28.3^{cd}	44.6^{abcde}	5.2^{a}	97.0^{bc}	34.4^{a}
	Std Dev	10.3	12.1	8.3	8.2	13.9	0.4	9.6	4.1
12	Mean	32.0^{c}	37.1^{d}	23.9^{e}	25.6^{d}	38.4^{e}	4.9^{b}	93.2^{ab}	32.8^{b}
	Std Dev	9.3	11.3	7.7	7.7	12.7	0.3	10.7	4.1

Tra – translucent area without corrections
Trb – translucent area with thickness corrections
Trc – translucent area with thickness and exposure corrections
Tr1% - Translucent area % formula 1(thickness and exposure corrections)
Tr2% - Translucent area % formula 2 (thickness and exposure corrections)

Formula 1: Translucency 1 = $\frac{\text{True translucent area } (mm^2)}{\text{Whole kernel area } (mm^2)} \times \frac{100}{1}$

Formula 2: Translucency 2 = $\frac{\text{True translucent area } (mm^2)}{\text{Endosperm area } (mm^2)} \times \frac{100}{1}$

* Damaged kernels were excluded from a total batch of 50 measurements, causing final sample size to vary
** Means with different letters are statistically significantly different ($p<0.05$) within a column

Statistically significant differences were found for Translucency 1 and 2 (Table 4.7) measurements between samples indicating that the data are suitable for further

analysis by linear regression. Morphology data (thickness, total area and germ area) also showed statistically significant differences among the 12 samples.

4.5.3.2 Degerming data

Experimental degerming data are given in Table 4.8. Results include the yield of milled products (weight %) obtained during milling. The results represent mean values of three batches milled for each type of maize. Maize was degermed, sieved and aspirated.

Table 4.8 Yield of products after experimental degerming of 12 samples of yellow maize in a pilot scale Beall-type degermer followed by sieving and aspiration

Sample no		Flaking grits > 3.9 mm (weight %)	Coarse grits > 3.3 mm (weight %)	Fines (break flour) (weight %)	Offal* (weight %)	Total grits > 1.01 mm (weight %)
		**				
1	Mean	51.0^{bc}	60.1^{ab}	14.3^{a}	12.1^{a}	73.7^{a}
	Std Dev	2.4	4.4	1.2	5.9	4.8
2	Mean	50.7^{bc}	60.9^{ab}	13.8^{ab}	11.5^{a}	74.6^{a}
	Std Dev	1.0	2.1	1.6	5.4	3.8
3	Mean	53.6^{a}	64.0^{a}	11.7^{ab}	10.4^{a}	77.9^{a}
	Std dev	0.7	2.1	0.2	3.6	3.4
4	Mean	51.8^{ab}	63.1^{a}	12.0^{ab}	10.9^{a}	77.1^{a}
	Std Dev	1.1	2.1	0.7	4.5	3.9
5	Mean	50.9^{bc}	60.5^{ab}	13.6^{ab}	12.4^{a}	73.9^{a}
	Std Dev	0.6	1.9	1.4	4.7	3.3
6	Mean	49.8^{bc}	61.9^{a}	13.0^{ab}	11.3^{a}	75.7^{a}
	Std Dev	2.1	3.7	0.5	5.3	4.9
7	Mean	45.5^{d}	56.9^{b}	14.0^{ab}	12.0^{a}	74.0^{a}
	Std Dev	1.9	3.4	2.1	6.9	4.9
8	Mean	49.0^{c}	60.1^{ab}	12.0^{ab}	13.6^{a}	74.4^{a}
	Std Dev	0.3	0.9	0.7	3.0	2.3
9	Mean	48.9^{c}	60.0^{ab}	11.9^{b}	12.2^{a}	73.5^{a}
	Std Dev	1.6	2.2	0.8	5.4	3.1
10	Mean	50.5^{bc}	62.4^{a}	11.7^{ab}	11.9^{a}	76.4^{a}
	Std Dev	2.4	2.9	1.3	5.3	4.0
11	Mean	49.6^{bc}	59.0^{ab}	12.9^{ab}	13.5^{a}	73.6^{a}
	Std Dev	1.1	2.3	2.3	6.6	4.4
12	Mean	43.3^{d}	56.2^{b}	13.6^{ab}	10.2^{a}	76.2^{a}
	Std Dev	1.7	2.4	2.0	5.7	3.8

* Offal consisted of total combined separated bran and germ fractions
** Means with different letters are statistically significantly different ($p<0.05$) within a column

Statistically significant differences occurred among the yields of degermed products for the 12 samples for flaking grits, coarse grits and fines (Table 4.8). However, the samples of coarse grits and fines could only be divided into three groups. No significant differences occurred among the yields of offal and total grits > 1.01 mm.

4.5.3.3 Correlations

Table 4.9 Product moment correlation coefficient (r) and R^2 matrixes for image analysis translucency measurements and yield (weight %) of products from yellow degermed maize, with and without corrections for kernel thickness and exposure, experiment 3 (n = 36)

Treatment	Tr1a	Tr2a	Tr1b	Tr2b	Tr1c	Tr2c
Flaking grits > 3.9 mm (weight %) r	0.68***	0.48*	0.73****	0.51*	0.67***	0.44*
Flaking grits > 3.9 mm (weight %) R^2	0.46	0.23	0.53	0.26	0.44	0.20
Coarse grits > 3.3 mm* (weight %) r	0.71****	0.49*	0.68***	0.45*	0.58**	0.34
Coarse grits > 3.3 mm (weight %) R^2	0.5	0.24	0.46	0.21	0.33	0.11
Yield of grits > 1.01 mm* (weight %) r	0.14	-0.02	0.10	0.05	-0.03	-0.04
Yield of grits > 1.01 mm (weight %) R^2	0.02	0.00	0.01	0.00	0.00	0.00

Tr1a – Translucency formula 1 without corrections
Tr1b – Translucency formula 2 without corrections
Tr2a – Translucency formula 1 with thickness corrections
Tr2b – Translucency formula 2 with thickness corrections
Tr1c – Translucency formula 1 with thickness and exposure corrections
Tr2c – Translucency formula 2 with thickness and exposure corrections

$$\text{Formula 1: Translucency 1} = \frac{\text{True translucent area (mm}^2\text{)}}{\text{Whole kernel area (mm}^2\text{)}} \times \frac{100}{1}$$

$$\text{Formula 2: Translucency 2} = \frac{\text{True translucent area (mm}^2\text{)}}{\text{Endosperm area (mm}^2\text{)}} \times \frac{100}{1}$$

* Cumulative yields (all grits above the target particle size)

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.0001$ for level of significance of the correlation coefficient

Correlation coefficients between extraction of milled maize products and maize kernel translucency (Table 4.9) were generally low indicating weak relationships, except for translucency 1 values against flaking grits and coarse grits, which were

slightly higher ($p<0.0001$). Correlations decreased after corrections for exposure in all cases.

Scatterplots and fitted regression lines of all correlations between translucency and product yield except the yield of grits larger than 1.01 mm are given in Figures 4.15 to 4.18.

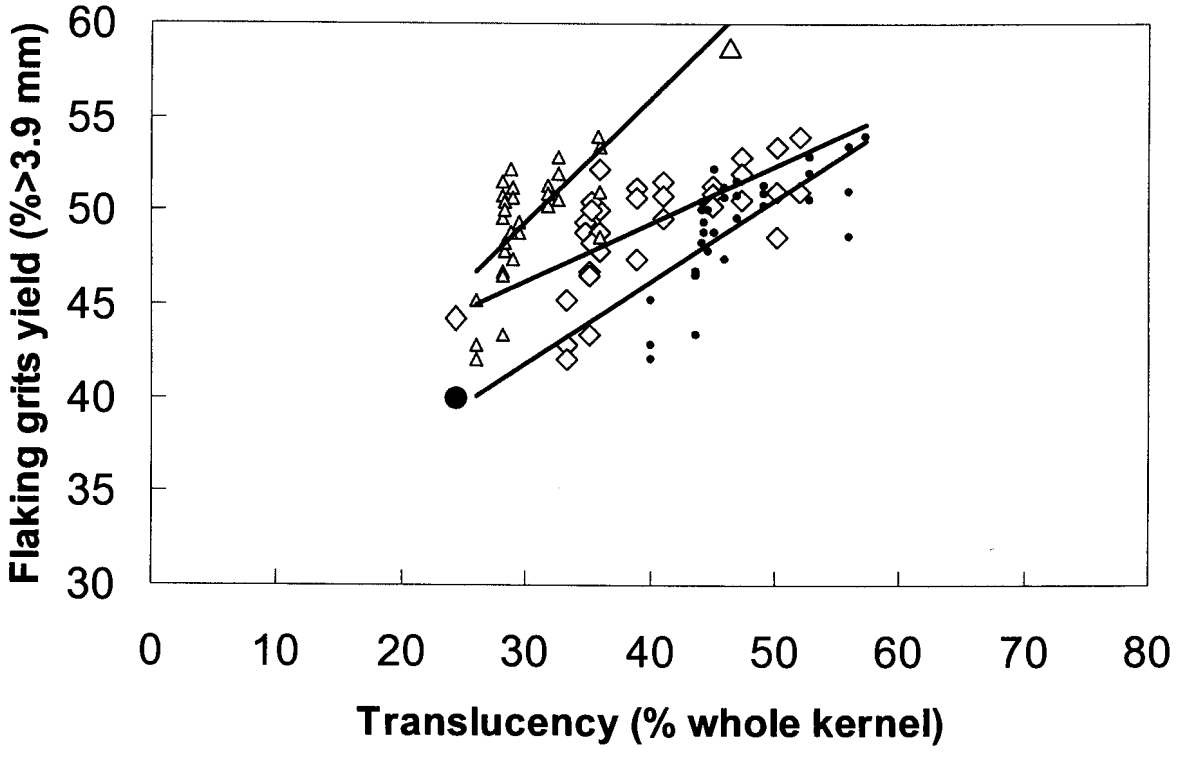

Figure 4.15 Effect of applying translucency correction factors (CFs) on the relationship between the yield of grits larger than 3.9 mm (mass %) and translucent area (% of whole kernel) of twelve industrial yellow maize samples as determined by image analysis. "◊", before CFs ($y = 0.31x + 39.9$, $r = 0.68$); "●", after thickness CF ($y = 0.44x + 28.7$, $r = 0.73$); "△", after thickness and exposure CFs, ($y = 0.66x + 29.6$, $r = 0.67$), $n = 36$. r-values did not differ significantly from each other ($p \geq 0.05$) (Fisher test)

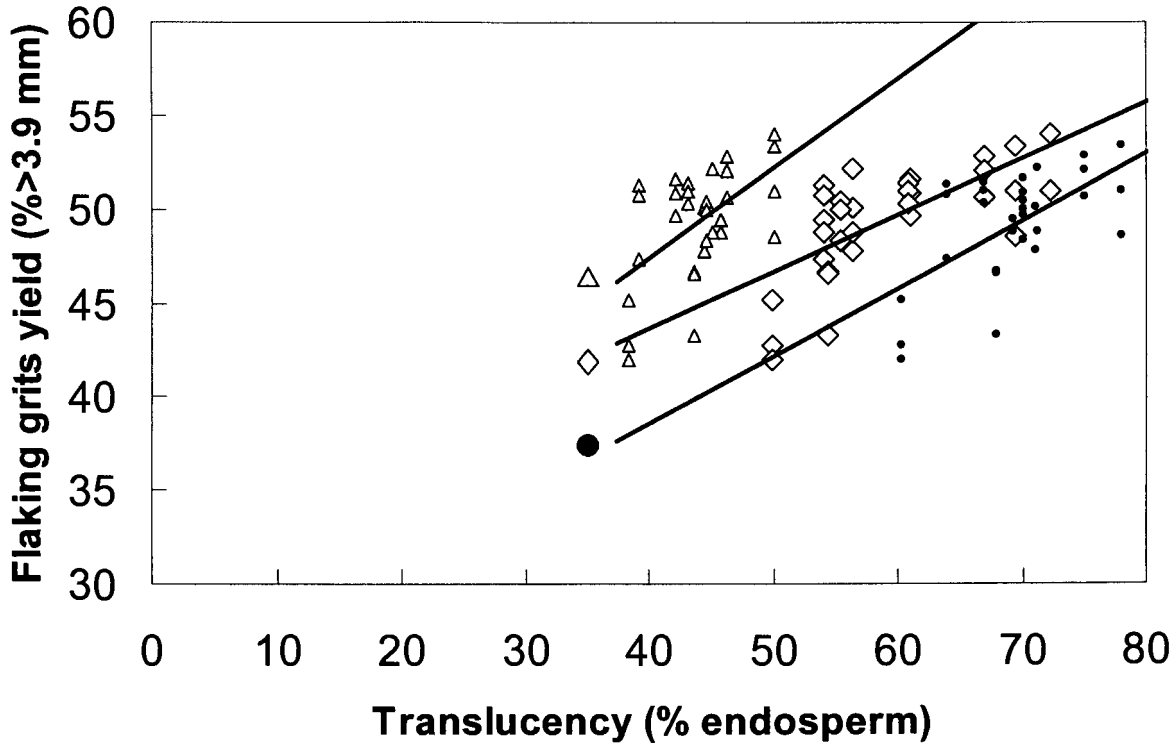

Figure 4.16 Effect of applying translucency correction factors (CFs) on the relationship between the yield of flaking grits larger than 3.9mm (mass %) and translucent area (% of endosperm) of twelve industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = 0.24x + 50.5, r = 0.48); "●", after thickness CF (y = 0.33x + 44.8, r = 0.51); "△", after thickness and exposure CFs, (y = 0.47x + 46.2, r =0.44), n = 36. r –values did not differ significantly ($p \geq 0.05$) (Fisher test)

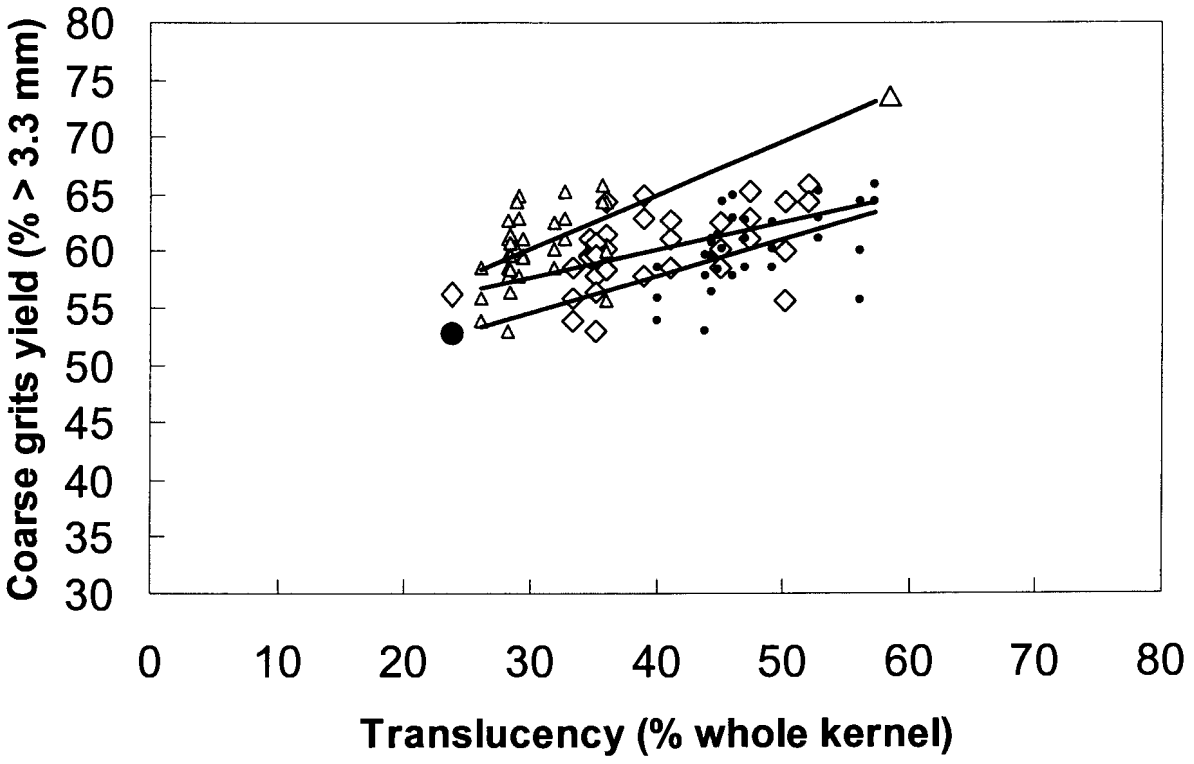

Figure 4.17 The effect of applying translucency correction factors (CFs) on the relationship between the yield of coarse grits larger than 3.3 mm (mass %) and translucent area (% of whole kernel) of twelve industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = 0.3x + 31.6, r = 0.71); "●", after thickness CF (y = 0.36x + 24.1, r = 0.69); "△", after thickness and exposure CFs, (y = 0.48x + 28.2, r =0.58), n = 36. r-values were not significantly different from each other ($p \geq 0.05$) (Fisher test)

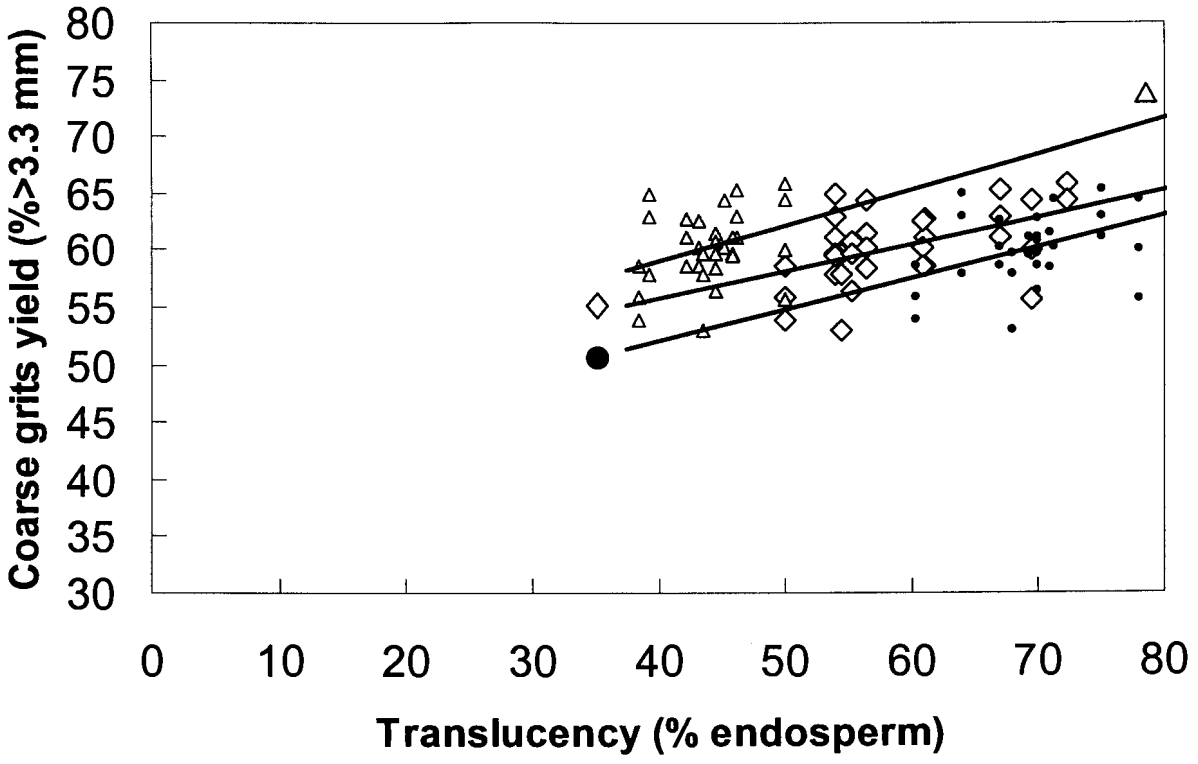

Figure 4.18 The effect of applying translucency correction factors (CFs) on the relationship between the yield of coarse grits larger than 3.3mm (mass %) and translucent area (% of whole kernel) of twelve industrial yellow maize batches as determined by image analysis. "◊", before CFs (y = 0.24x + 46.4, r = 0.49); "●", after thickness CF (y = 0.27x + 41.1, r = 0.45); "△", after thickness and exposure CFs, (y = 0.31x + 46.5, r =0.34), n = 36. r-values were not significantly different from each other ($p \geq 0.05$) (Fisher test)

No useful correlations were found between image analysis translucency measurements and the yield of grits larger than 1.01 mm and therefore graphs were not constructed. Slopes increased in all cases after thickness as well as after exposure corrections. Translucency values were also adjusted to the correct ranges after corrections for exposure (Figures 4.15 to 4.18). Corrections had a more consistent effect on slope (increased in all cases), than on the correlation coefficients (which increased, stayed the same or decreased in the various tests).

4.6 DISCUSSION

Experiment 1

Percent Translucency measured by image analysis correlated negatively with floating number at a very high significance level -0.84 and –0.88 for translucency 1 and 2, respectively, after both corrections for thickness and exposure were applied. Therefore, floating number may be an indication of kernel opaqueness. Translucency (expressed in terms of opaqueness which is the inverse value) could possibly be used as an indication of the floating number, depending on the consistency of other factors such as the occurrence of stress cracks (Watson 1987a). Floating number (also known as the flotation test) is a density-related property (Watson 1987a).

The density of maize kernels is the sum of the densities of the different components such as starch, protein, oil and water. Vitreous endosperm is very dense, while floury endosperm is full of void spaces in the cells trapping air and is less dense (Watson 1987a, Hoseney, 1994). This is illustrated clearly in Figure 2.2 where the loosely packed starch granules of the opaque (floury) endosperm are shown. The floating number (also known as percentage floaters) is widely used as an indication of the levels of vitreous endosperm (which is also translucent) (Gerstenkorn, 1991). The accuracy of the floating number test can be influenced detrimentally by kernel damage, allowing liquid to be absorbed into the voids of the opaque endosperm and therefore increasing the density of the maize kernels overall. The floating number value is also influenced by moisture content generally and accurate measurements can only be made if all samples are at the same moisture content (Watson 1987a). The 20 maize samples tested in this study were all produced under South African rain fed conditions with no artificial drying and therefore, stress crack levels and the development of large void spaces typically found in artificially dried maize were negligible and of no significance. In spite of general concerns around the accuracy of percent floaters, it is still widely used as a screening method for the selection of floury maize for the wet industry (Fox, Johnson, Hurburgh, Dorsey-Redding and Bailey 1992).

Experimental milling produced products from the different maize samples with a narrow range, for example a minimum of 33% and a maximum of 38% of semolina 1 yield (Table 4.2). The range for total semolina yield was even less, even after corrections were made for fat content. The primary difference between semolina 1 and total semolina was in the origin of the products. Semolina 1 only consisted of the reduced size grits obtained from large clean vitreous endosperm grits (larger than 1 mm) obtained after the first break (Figure 4.1). The large vitreous endosperm products obtained from the first break (rolls I and II, Figure 4.1) needed fewer steps to be cleaned and separated from contaminants such as bran and fat (maize germ particles). Smaller grits are more difficult to separate cleanly (Kent 1984) and more steps such as sieving and aspiration are needed. The reason for this is that the particle sizes of smaller grits and the small pieces of bran and germ in these fractions are similar and sieving does not separate them. Larger grits are heavier than the pieces of bran and germ, allowing for separation by aspiration where sieving did not produce the desired result. However, if the pieces of endosperm become too small, the weight differences are too small for separation by aspiration which results in fractions that are still contaminated with tiny pieces of germ and bran (Kent 1984). The semolina 2 and 3 fractions consisted of grits derived from smaller sized vitreous endosperm grits and were therefore more contaminated with fat and bran and more difficult to clean.

Differences in vitreous endosperm yield were expected to be more pronounced when comparing clean fractions than comparing fractions having a certain amount of bran and fat that could not be separated. The expected differences were clearly demonstrated with a wider range of yields for semolina 1 when compared to total semolina yield (the total of the three semolina fractions), as well as higher levels of statistical significance for semolina 1 when semolina yield and translucency were correlated. Semolina 1 was used as an indication of milling resistance (see section 4.3.1.2.4) as the fraction was obtained after the milling of cleaned endosperm pieces larger than 1 mm obtained after the initial milling stages (I and II followed by sieving) (Figure 4.1).

The grits (semolina) obtained were fine grits as all grits were reduced to have a particle size of less than 1000 microns. The final products resembled semolina (from

the wheat milling process) in appearance and consisted of clean vitreous endosperm particles with no visible break flour. Generally, the yield of such cleaned products is low (60%) when compared to other industrial milling yields of endosperm products (75%) (Fowler 1993). Floating number was in the range 58 to 87%.

Despite the narrow ranges for the milling yield data, significant correlations were found between translucency and the yield of some of the milled products (Table 4.3). Significant correlations were found between yield of semolina 1 and % translucency. The relationship between semolina 1 and % translucency both as a percentage of the whole kernel and the percentage of the endosperm was significant even before any corrections were made.

Levels of significance increased for both translucency 1 (translucent area as a percentage of whole kernel area) and translucency 2 (translucent area as a percentage of endosperm area) after corrections for thickness and exposure for all cases. The levels of significance for both translucency 1 and 2 increased in the same way. Correlation coefficients between translucency 1 and 2 were not significantly different from each other. The order of the correction applications did not have an affect on the final results and did not change the final values whether thickness or exposure corrections were done first.

A significant correlation was obtained at the 95% significance level for total semolina yield against % translucency only after all corrections were applied. The extremely narrow ranges of the data of the total yield of semolina influenced the overall significance level of the results. Narrow ranges of vitreousness in maize samples are a practical reality as the profitability of maize milling would have been seriously compromised if maize of variable quality is used. Millers search for maize of a consistent milling performance, even if up until now it has been primarily a matter of using the history of previously milled batches and linking it with factors such as cultivar, area, farmer and climatic condition. Over a number of years, cultivars tended to become similar in their performance purely by the continuous reactive selection by millers (personal communication, Viljoen, A., Research and Development Manager, Tiger Milling and Baking).

Providing that the dry milling fraction used for correlating yield is clearly defined, it is clear from these results that significant predictions are possible using % translucency as measured by image analyses according to the developed method. The definition of the fraction of choice for predicting milling yield is highly important. This is shown clearly in these results by the fact that the semolina 1 fraction gave significantly better correlations than the combined fractions did. This finding can be related to the action of the milling process. The milling process consists of gradual steps aimed at extracting a clean morphological fraction such as vitreous endosperm. The first fractions are easily separated, while successive fractions become more and more difficult to clean, causing a significant amount of other components (or contaminants) to be included and thereby reducing the accuracy of the final measurements. These components or contaminants include pieces of bran and germ fractured during the first stages of milling. If these contaminants have the same particle size or density as the endosperm particles, separation systems such as aspirators or gravitational systems cannot totally separate the contaminants from the endosperm (Kent 1984; Gerstenkorn 1991).

The correction factors increased the slope of the fitted curves and generally increased the level of significance of the correlation coefficients (Table 4.3). Although all correlation coefficients increased after corrections, the coefficients did not differ significantly from each other after comparing them using a z-transformation test. This can be attributed to the relatively low number of degrees of freedom available in the models. Only 20 different samples could be done due to time and cost constraints.

Experiment 2

Statistically significant differences by analysis of variance were found for all image analysis measurements on the 10 samples used for industrial milling (Table 4.4). Statistically significant differences were also found for all the milled products (Table 4.5). All these differences occurred at the $p<0.05$ level and indicated that despite large standard deviations in the image analysis data (Table 4.4), regression models could be developed. If no differences existed, regression modelling would have been impossible.

It is clear that there were excellent correlations between translucency 1 and 2 and the various products obtained from the mill (Table 4.6). Highly significant correlations ($p<0.0001$) were obtained between translucency and extraction at degermer, total extraction of special maize meal without moisture corrections and total extraction of maize meal on a dry basis. Generally, correlations were significant before corrections. It can be concluded that it is possible to predict the yield of specified milled products derived from vitreous endosperm by using % translucency as a predictor. Corrections for kernel thickness increased the level of significance of the correlation coefficients in all cases. Corrections for exposure had a limited effect on the correlation coefficients and slightly reduced the correlation coefficients between translucencies 1 and 2 and the total extraction of maize meal with and without moisture. However, the important effect of corrections for exposure were that they adjusted the translucency values into the correct range, i.e. the corrections took out overexposure. Slopes of the linear regression lines also increased in all cases after corrections for exposure and if correlation coefficients stayed the same, but the slope increased, it still indicated an overall improvement in the strength of the relationship. Overexposure have led to calculated translucency values (%) of more than 100. After correcting for thickness followed by correcting for overexposure, values were adjusted to within a realistic range. This was true for both positive and negative correlations. Significant negative correlations were found between break flour in the thrus and translucency. Break flour is mainly derived from opaque endosperm (Alexander 1987) and a negative correlation between translucency and break flour yield was expected, as break flour is not translucent. Although the corrections increased the levels of significance of the fitted regression curves, the r-values for each set of corrections did not differ significantly from each other following a z-transformation test. Again, the inability to show significant differences was the result of the low number of degrees of freedom due to practical problems limiting the actual number of samples that could be milled. In general, the slope of all the lines also increased with the application of correction factors. Translucency 2 (% of endosperm) apparently gave better correlations with total special maize meal extraction and than translucency 1, while translucency 1 and 2 had similar correlations with extraction at degermer and break flour in the thrus (also obtained directly after the first degerming step). These differences between translucency 1

and 2 were, however, not significant according to the z-transformation test for differences between r-values.

Experiment 3

Yellow maize samples showed statistically significant differences in translucency by analysis of variance at the $p<0.05$ confidence level (Table 4.7). However, after degerming, statistically significant differences were only found for flaking grits, coarse grits and fines (Table 4.8). The yields of offal and total grits were not significantly different from each other making it impossible to determine correlations between yields of these products and translucency (Table 4.9). Significant correlations were only obtained between % translucency and the yields of flaking grits and coarse grits. The yield of fines was not significantly correlated with translucency. Corrections for thickness and exposure did not increase the level of significance or the strength of the correlations. They either remained the same or were slightly reduced. The slopes of all lines increased after the application of the correction factors (Figures 4.15 – 4.18). Again, r-values were not significantly different from each other after the application of z-transformations and comparative analysis according to the Fisher test. The correlations became weaker as more of the grits at smaller particle sizes were added to the yield. This can be ascribed mainly to the fact that grits at smaller particle sizes could not be cleaned efficiently from contaminants such as pieces of opaque endosperm, bran and other particles using only sieving and aspiration after degerming. In order for these fractions to be separated completely, a series of further gradual steps of milling with rollers followed by sieving and aspiration must be used (Kent 1984). Roller milling flattens the small pieces of germ which can then be sieved out as their particle size will then differ from the reduced-size grits. After degerming only, small germ particles are produced that are similar in size to certain pieces of endosperm, making it impossible to separate out by sieving.

Particular problems were encountered with the degerming method. It was found during preliminary tests when the pilot-scale degermer was built and commissioned, that the standard error of measurements changed significantly with increased repetition of the process starting very high for three repetitions and reducing significantly with each additional repetition. Using the Fisher test (Diem and Seldrup

1982) to determine significant differences between standard deviations, it was found that the ideal number of repetitions for the degermer was 9 repetitions per cultivar or maize sample. From a practical perspective, this is undesirable especially when only limited sized samples are available from seed breeders. Yellow maize samples were grown specially for experiment 3 and only enough material for 4 repetitions per sample was available. This indicated that a high variability existed between repetitions and it was ascribed to variability induced by the degermer itself. When the degermer was studied to find a possible source of the induced variation, it was found that the motor tended to run at lower speeds due to the resistance of the kernels created during degerming. The average revolutions per minute (rpm) of the pilot-scale degermer running free without kernels was 1500 rpm. When running full of maize, the speed was significantly reduced and if the flowing speed into the degermer was too high, the machine came to a complete stop. The pilot-scale degermer was an experimental unit and it was found that the torque exerted from the motor was not sufficient to cope with the grinding resistance caused by the kernels when running full. By using a vibratory feeder to pour the kernels into the degermer at a fixed flow, it was possible to control the degermer speed between 200 and 600 rpm. Finer control was not possible and the variation in speed within the 200 to 600 rpm range would influence the torque on the kernels resulting in differences in the shattering of the vitreous endosperm. These problems with the pilot-scale degermer could have accounted for the fractions with no significant differences (Table 4.9), and unfortunately, it probably was also responsible for rendering the effect of the thickness and exposure correction factors on the data inconclusive, except in the case of translucency 1 and flaking grits, where the correlation coefficient and level of significance was increased.

4.7 CONCLUSIONS

In general, correlations of high significance were obtained using both methods of translucency calculation and the various products derived from the maize dry milling process. In all cases, better correlations were found between translucency and vitreous endosperm fractions obtained from the first break process (semolina 1 in experiment 1, extraction at degermer in experiment 2 and yield of large flaking grits > 3.9 mm in experiment 3) than with for fractions obtained from further milling steps.

The former fractions are usually easy to clean with only small quantities of opaque endosperm still attached to them. It was also easier to remove germ and bran from these fractions as the size of the coarse endosperm particles is still large and differ sufficiently in weight from germ and bran materials. As the separation of the fractions became more difficult, correlations with translucency became less significant, although still highly useful, for example the total extraction of maize meal in experiment 2, where r-values were 0.68 and 0.72 ($p<0.001$) after corrections.

Experiment 2 was done in an industrial mill with a degerming and full separation facility. This could therefore account for the better correlations obtained in this milling trial. Both the smaller-scale tests (experiments 1 and 3) gave smaller ranges of product yields, which can be attributed to the fact that small scale systems do not contain all the steps required to fully simulate the separation processes in a modern industrial mill.

CHAPTER 5: GENERAL DISCUSSION

Hoseney (1994) stated that vitreousness of maize is related to the translucency. Vitreousness, in turn, has been shown to be generally related to milling yield (Mestres, Louis-Alexandré, Matencio and Lahlou 1991; Paulsen and Hill 1985) and even with concerns about precision (Chandeshekar and Mazhar 1991), it was therefore expected to find a correlation in the work reported here of some description between translucency and milling yield, although the nature of these correlations were not known.

Vitreousness has been shown to be linked to the yield of certain product fractions during dry maize milling (Paulsen and Hill 1985; Watson 1987a, Louis-Alexandré, Mestres and Faure 1991). Vitreousness has been measured on single kernels based on the measurement of the vitreous and total endosperm areas by viewing sectioned kernels and these measurements were correlated with milling test data (Louis-Alexandré, Mestres and Faure 1991). Inevitably, there will be considerable variation between measurements made on single maize kernels due to the biological nature of the samples. Therefore, standard deviations of individual measurements tend to be quite large when compared with standard deviations obtained for other measurements such as moisture or fat contents of samples, where a selection of kernels is homogenised first by grinding and the analysis done on a sample taken from this mixture. In the work of Louis-Alexandré, Mestres and Faure (1991) it was found that standard deviations of kernels with smaller vitreous endosperm areas tended to be larger than those with large vitreous endosperm areas. This phenomenon was also found in the work of Kirleis, Crosby and Hously (1984) who used a similar technique to measure the amount of vitreous endosperm in sorghum. It was clear in their work that the standard deviations of samples with smaller amounts of vitreous endosperm were larger. In Tables 4.1, 4.4 and 4.7, standard deviations of the translucency measurements showed that in contrast with the published values (Louis-Alexandré, Mestres and Faure, 1991) for vitreousness indexes, the translucency values had similar standard deviations for samples with larger or smaller translucent areas. Standard deviations for translucency measurements as a percentage of the whole kernel (translucency 1) were similar in

comparison to those for vitreousness measurement on cut kernel surfaces published by Louis-Alexandré, Mestres and Faure (1991), but the standard deviations for translucency measured as a percentage of the endosperm (germ area removed, translucency 2) were higher. Both standard deviations (SDs) for the measured translucencies were generally lower than the SDs for translucency measurements in terms of grayscale indexes as published by Felker and Paulis (1993), except for the SD's of translucency 2 values in experiment 2 (Chapter 4), which were similar to those of Felker and Paulis. In the work published by Felker and Paulis, standard deviations varied between 20 and 50% from the measurement of only 10 individual kernels, while in this study standard deviations varied between 20 and 30% obtained from a minimum of 45 measurements per cultivar. Reasons for this difference is most probably linked to the selection of the samples at the initial stages of the experiment. Maize for dry milling purposes has been selected in South Africa for a number of years and individual kernels tend to be homogenous providing that damaged kernels are not included in the analysis. As only industrial samples were used in the milling experiments, it was expected that the homogeneity of the kernels would have been higher especially if produced under controlled industrial farming practices. Samples evaluated in Chapter 3 (method development) were selected from single cultivars produced under experimental farm conditions and a high level of homogeneity was also expected. Standard deviations were similar to the work described in Chapter 4.

It is interesting to note that in the work of Felker and Paulis (1993), standard deviations of grayscale indexes also increased after the area of the germ was removed, similar to the general increase in the variability found with the translucency 2 values (germ area removed) as shown in Tables 4.1, 4.4 and 4.7. Reasons for this are probably either errors in the translucency measurements due to the occurrence of partial translucency of the germ, or the difficulty in exactly measuring the germ area on the image analyser. Germ area had to be detected by marking of the boundaries by hand as the contrast between germ and the rest of the kernel was too small for automatic detection. In the work of Felker and Paulis, a fixed sized area including the germ was excluded and it also resulted in increased standard deviations of measurements. Similar trends were found in Tables 3.11 and 3.12, Chapter 3.

Felker and Paulis (1993) did not attempt to correlate their image analysis measurements of maize translucency with any milling test and therefore, no such correlation data exists for comparison with the work reported here. The closest data found were data on correlations between maize vitreousness as measured by detection of vitreous endosperm area on cut kernel surfaces with a selection of laboratory estimations of dry milling properties (Mestres, Louis-Alexandre, Matencio and Lahlou 1991). A correlation coefficient of 0.92 between vitreousness and kernel density was reported. In the work reported here, a correlation of –0.88 was found between the Floating Number and translucency (experiment 1, Chapter 4). This good correlation was obtained after applying kernel thickness and exposure correction factors (Table 4.3). Kernel density and floaters are inversely related (Chandrashekar and Mazhar 1991), providing that the influence of factors such as environmental conditions are taken into account and therefore, a significant negative correlation between translucency and % floaters was expected.

Percent floaters have been correlated with milling yields. Wu and Bergquist (1991) obtained correlation coefficients of as high as 0.89 ($p<0.01$) between corrected density values and total grits yield after milling maize according to a degermer/roller milling process described by Peplinski, Anderson and Eckhoff (1984). Peplinski, Anderson and Eckhoff (1984) obtained significant negative correlations between corrected (for moisture) maize kernel densities and % floaters. In the results of experiment 1, Chapter 4, the significant negative correlations obtained between % translucency and % floaters could indicate that % translucency can be a good indication of maize kernel density. The excellent correlation of 0.89 between corrected density and total grit yield obtained by Peplinski, Anderson and Eckhoff (1984), could be partially ascribed to a large range of samples in terms of differences in density and % floaters. Their samples varied between 19 and 100% for percent floaters with 100% floaters for "cornnuts 88" which was a cultivar with no vitreous endosperm. The samples analysed in experiment 1, Chapter 4 varied only from 58 to 87% floaters which gave a narrower range and therefore smaller r-values (Table 4.4).

In an industrial-scale milling trial by Paulsen and Hill (1985), 1780 ton samples of maize were milled for the production of large clean grits for cornflake manufacture. These grits contained less than 0.5% fat and less than 4% attached "hull" after degerming. Paulsen and Hill (1985) found a correlation coefficient of -0.98 between Floating Number and the yield of clean grits obtained after separation of the overtail stock at the degermer. As previously described, Floating Number and % translucency were significantly negatively correlated in Experiment 1, Chapter 4. It is possible to compare the r-value of Paulsen and Hill (1985) with the r-values obtained between extraction at degermer (an indication of flaking grits yield) and % translucency (an indication of % floaters) obtained in experiment 2, Table 4.6, which was an industrial milling trial. These r-values were obtained after application of both correction factors. Very high r-values were also obtained in experiment 2, Table 4.6 ($r = 0.93$) for extraction at degermer and % translucency (whole kernel). A trend in this study was observed, namely that larger milling trials using larger samples and more separation steps tended to produce better correlations between % translucency and kernel density and the yield of clean vitreous endosperm products. A similar trend was observed when comparing results of correlations between % floaters and the yield of dry-milled products in the published literature with values obtained by Paulsen and Hill (1985). These authors specifically mentioned that in order to produce high yields of flaking grits, it is preferable to use maize with high ratios of vitreous endosperm relative to floury endosperm, and that it is desirable to have complete separation of the endosperm fractions with the germ and bran. This emphasised the use of a larger, more complex milling system and this trend was clearly demonstrated in the results reported here. An interesting observation about the results of Paulsen and Hill (1985) is that the high correlations were found between % floaters and flaking grits, but the yields of so-called "white products" were similar regardless of the quality of the maize milled. "White products" represented all grits, flour and meal obtained by the addition of all the fractions after separation of the germ and "hull" portions. These results were similar to results obtained in all three experiments (Chapter 4) where correlation coefficients decreased significantly when finer fractions of clean products were added, for example the total maize meal extracted versus extraction at degermer (overtail flaking grits) in experiment 2, Chapter 4. A similar trend regarding correlations between % floaters and the yield of semolina was observed by Manoharkumar, Gerstenkorn, Zwingelberg and Bolling

(1978) where a higher correlation coefficient (r = 0.72) was found between % floaters and coarser semolina (>500 microns) than with finer semolina plus flour (r = 0.35).

Correlations between % vitreousness (as determined by measuring the percentage of vitreous endosperm on cut kernel surfaces) and the yield of vitreous endosperm following a micromilling process (similar to hand dissection) were determined by Louis-Alexandré, Mestres and Faure (1991). Correlation coefficients were similar to the values obtained in the work reported here, with better r-values obtained in experiment 2 (Chapter 4). However, Louis-Alexandré, Mestres and Faure (1991) did not do any further milling tests where the yields of products from milling were compared to the results obtained from the hand dissections. Li, Hardacre, Campanella and Kirkpatrick (1996) also measured the ratio of vitreous to opaque endosperm on cut kernel surfaces, but used vernier callipers and only measured 10 kernels per sample. They obtained correlation coefficients between vitreous/opaque endosperm ratio measurements and some milling properties obtained from the Stenvert Hardness Test. They found a r-value of 0.74 between vitreous/opaque ratio (as a percentage of the whole kernel surface) and milling energy and a r-value of 0.62 for resistance time using 38 cultivars of maize. They suggested that low to average correlations may have been due to inaccuracies during the measurement of the vitreous endosperm. They also suggested that the proportion of the vitreous endosperm at the measured section of the kernel was not an accurate estimation of the true volumes of vitreous and opaque endosperm which could have given rise to poor r-values. Their r-values were very similar to the values obtained in experiment 1 and experiment 3 (Chapter 4), but the r-values for experiment 2 (Chapter 4) were significantly better. Experiments 1 and 3 (Chapter 4) and also the trials done by Li, Hardacre, Campanella and Kirkpatrick (1996) were laboratory-scale milling assays, while experiment 2 (Chapter 4) was an industrial-scale experiment. It is not possible to simulate all the different milling, sieving, aspiration and cleaning steps possible in an industrial-scale test and better separations of the endosperm fractions are possible in a fully-operated mill. As no data on the correlation between the ratio of vitreous to opaque endosperm measured by cut kernel surface area ratios and the yield of dry-milled products obtained from an industrial mill exist, it is not possible to further compare the results of experiment 2 with any relevant data in the literature.

Mestres, Louis-Alexandré, Matencio and Lahlou (1991) also determined r-values between vitreousness (ratio of vitreous/opaque endosperm determined as area ratios on cut kernel surfaces) and the yield of semolina (maize grits) produced on a roller mill using 4–5 kg samples. Their samples were significantly smaller than those used in experiment 2 (510 kg each). They found a correlation of only 0.44 which was not statistically significant, but did indicate that there were problems during the sieving stages of the milling process. Unfortunately, no further comparisons can be made with this data due to the experimental problem mentioned.

Yuan and Flores (1996) estimated the ratio of vitreous to opaque endosperm by using hand dissection and weighing the fractions. They correlated the ratios with experimental milling data obtained from milling 500 g samples on a small laboratory-type horizontal drum degermer, followed by separating the germ and bran firstly by sieving and aspiration and then a further separation by flotation. During the flotation step, remaining germ and bran was removed by suspending the sieved maize grits in a $NaNO_3$ solution with a specific gravity of 1.22. They obtained a r-value of 0.44 between vitreous/opaque endosperm ratio and flaking grits (large grits), 0.58 between endosperm ratio and total grits (cleaned grits) and 0.61 between endosperm ratio and prime products. Only the mesh size of the prime products were given (3.5–25 mesh or 5.6–0.7 mm) with no further detail other than mentioning that this process was only a degerming process, but with an additional cleaning process using flotation. The results of Yuan and Flores (1996) can be compared to the results of experiment 3 (Chapter 4) based on the fact that translucency was correlated with hand dissection as previously described in Chapter 3. The correlations shown in Table 4.9 were similar to those found by Yuan and Flores (1996). It can thus be concluded that by using translucency measurements to estimate vitreous/opaque endosperm ratios, similar results can be obtained to results from using vitreous/opaque ratios from the hand dissection method when estimating the yield of maize grits from the degerming process on a laboratory scale. It also seems as if small-scale degerming of maize poses many problems as correlation coefficients are generally low due to the crudeness of the process. The samples in experiment 3 (Chapter 4) could not be completely cleaned as laboratory aspiration and sieving alone could not remove all the germ and endosperm particles left in the grits after degerming, resulting into experimental errors during weighing of the fractions.

Kirleis and Stroshine (1990) also used the ratio of vitreous/opaque endosperm determined as areas on cut kernel surfaces, but evaluated only three types of maize. They suggested a relationship between the ratio of vitreous/opaque endosperm and Stenvert Grinding time with the sample with the longest time having the highest vitreous/opaque ratio. Unfortunately, no comparisons can be made due to only three samples being tested with the result that r-values could not be determined statistically. However, it should be pointed out that their work focused on the effect of drying conditions on changes in dry milling properties and the correlation between milling properties and endosperm ratios was not the main focus of their work.

With respect to the work reported here, it can be said that good correlations between translucency and the yield of milled products were possible in all cases, providing that the end products were properly defined as being clean from contaminating fractions. Corrections for moisture and fat contents in end products did not seem to have significant effects on the correlation coefficients in general. For example correction for fat in experiment 1 (Chapter 4) and correction for moisture in experiment 2 (Chapter 4). The main reason for this is that all samples were treated exactly the same in each experiment, for example all samples being conditioned similarly. Therefore, the small differences in fat or moisture content as a result of individual differences between kernels did not seem to influence correlation coefficients to any significant extent (Tables 4.3 and 4.6). It can thus be concluded that the moisture and fat contents of cleaned vitreous endosperm products will not have a significant influence on the correlations between translucency and yield, as long as samples are prepared under the same conditions.

The correction factors developed using the hand dissection method described in Chapter 3 was applied to the results of the milling tests described in Chapter 4. In general, the correction factors had a similar effect on the measured translucency values both for hand dissection data (yields of vitreous and opaque endosperm) and the yields of milled products. In both cases, the correction factors improved the relationships between the calculated translucencies and the determined mass fractions of vitreous endosperm products.

Corrections for exposure generally caused the translucency values to become lower, and also to move into the correct ranges. Before corrections, % translucency could in some cases be more than 100%. This was due to overexposure, especially from maize kernels with a high percentage of translucent endosperm resulting in the germ area also being sensed by the computer as translucent. Corrections for exposure resulted in correcting the actual values of the translucency. It did not, however, always increase the significance levels of the r-values (for example experiment 2, Table 4.6). In some cases r-values remained unchanged, while in other cases they decreased or increased slightly. In the yellow maize samples, r-values decreased quite dramatically after corrections for exposure, while although small decreases in some of the white maize samples were observed, the decreases were so slight that they can be regarded as insignificant (Table 4.9). A possible explanation for the large effect with yellow maize is that the yellow colour of maize differs in intensity depending on the cultivar's genetic make-up (Zuber and Darrah 1987). These authors defined three distinct yellow intensity classes namely light, moderate and intense yellow based on the number of alleles for yellow obtained from the parents of the type of maize. Although an exposure correction factor was developed using three cultivars of yellow maize, it is possible that differences in the intensity of the yellow colour could have resulted in an incorrectly determined correction factor. Although all image analysis was done on the grayscale images, further work will be necessary to determine the effect of the different yellow intensity classes as described by Zuber and Darrah (1987) on the grayscale.

A possible solution for future application could be to investigate the use of a monochromatic light source in order to exclude the spectrum of light absorbed by the yellow colour in maize. In this research, the light source had a full visible wavelength spectrum. Although the white maize results were influenced to a lesser extent, it was also clear that there are visible colour differences between white maize cultivars as well and the extent of these differences on the measured gray levels is unknown. Further work is needed to find a wavelength that will not be absorbed by colour pigments in any of the white or yellow maize samples.

In most cases, thickness corrections increased the level of significance of the r-values. However, in experiment 2 (Table 4.6), thickness corrections had no

significant effect on the r-value obtained between % translucency and extraction at degermer, but did have a significant important effect on the r-value for the extraction of maize meal. The r-value between % translucency and extraction at degermer was very high before applying the correcton factors and the thickness effect could have been too small to be significant. In experiment 1 (Table 4.3), thickness corrections were very important resulting in significant increases in r-values. In experiment 3 (Table 4.9), thickness corrections resulted in significant increases in the correlation between % translucency and flaking grits > 3.9 mm. It had no effect on the other correlations. As stated, due to problems encountered with the degermer itself during operation, the sensitivity of the results could have been negatively influenced and although thickness may have had an affect on correlations between % translucency and all the fractions, it is possible that the data did not show it due to experimental errors. The significance of thickness corrections seems to be influenced by the range of the measurements of the dry milled products. For example, extraction at degermer (experiment 2) had a yield range of 29.8% and thickness correction did not increase the r-value significantly, but in the same experiment, it did have a significant effect on the r-value for the extraction of maize meal, where the yield range was only 11.3%. In experiment 1, thickness corrections had a major influence on the r-values for products such as the yield of semolina 1 (yield range of 5%) and total semolina yield (yield range of 3.9%). A similar trend was found in experiment 3 for the correlations between translucency and yield of flaking grits > 3.9 mm (yield range of 10.3%). This observation needs further investigation, but it is important from a practical viewpoint as there will definitely be a need to design an image analyser system capable of measuring kernel thickness as well as kernel area and kernel translucency.

In general, no statistically significant differences for r-values existed between the two ways of measuring translucency. Translucency 1, where translucency was measured as a percentage of the whole kernel, gave results almost identical to Translucency 2, where the translucency was measured as a percentage of the endosperm. However, as the germ size had to be drawn in by hand on the images for determining Translucency 2, errors could have occured as the distinctions between germ, tip cap and endosperm were not always clear on the images due to interferences from

adhering pieces of pedicel (remnants of the maize cob attached to the tip cap of a kernel).

The lack of significant differences (Fisher test) between r-values of Translucency 1 and Translucency 2 correlations with various milling properties in all experiments is an important finding, as it will lead to a reduction of the time needed for analysing the kernels. It will eliminate the need to measure the size of the germ and the tip cap of each kernel, which probably cannot be done automatically due to contrast problems and was prone to errors when estimated manually, as described.

By installing two cameras capable of detecting the top and side surfaces of each kernel, all required measurements are possible using the Translucency 1 calculation, simply by changing only the lighting set-up, followed by detecting appropriate images (including thickness). This can be programmed into the computer sequences including the sequence for changing of the lights. No manual calculation of data will be necessary and eliminates the use of the human eye which is subjective. A system with this type of design also has potential for use as an on-line measurement system. Autosampling is used for analysing specks of bran in wheat flour samples (Branscan, 2003), where on-line measurements of the desired property in the mill was found to be impractical. An autosampling system for maize kernels to be measured for translucency is a commercially viable option (as shown by the Branscan system for wheat flour), otherwise a custom-made conveyor system allowing kernels to be placed in specially designed slots for analysis can be designed.

The differences in the detected translucent areas when kernels are measured with the germ facing towards or away from the camera were not measured in this study and will need further investigation. Once known, the effect of germ position could be added to the calculations based on probability values for maize kernels sampled automatically with the germ facing towards or away from the camera.

The developed Image Analysis assay may have wide application in the field of seed breeding where non-destructive analyses of genetic material is advantageous. Additionally, it should have wide applications in maize processing quality control laboratories, ranging from analyzing incoming maize at silos to selecting preferred

batches of maize suitable for specific process applications such as the manufacture of corn flakes where large sized maize grits are desirable.

The use of this type of system could also find wide application in fields where the determination of vitreousness will lead to the prediction of a specific quality trait. For example, the use of Image Analysis to measure vitreousness in durum wheat was investigated by Novaro, Colucci, Venora and D'Egidio (2001) and Mahler, Beckmann and Ludewig, (2002), as non-destructive analytical techniques. In both these investigations, the percentage of vitreous kernels out of a total amount of randomly selected kernels was calculated by computer classification and counting in order to replace the visual classification tests. Although the actual formulas for measuring translucency differed from the work described in this study, they were based on similar principles demonstrating the potential usefulness of the assay for other cereals as well.

One of the potential applications for the developed image analysis technique is to measure the amount of opaque endosperm in maize used for wet milling. During wet milling, maize kernels are soaked in a mixture of sulphur dioxide and lactic acid in order to break disulphide bonds in the protein, as the main objective of wet milling is the extraction of pure starch. Better yields of starch are obtained during wet milling when kernels with higher percentages of opaque endosperm are used, which is usually measured by the percentage floaters (or Floating Number) test (Watson 1987a). As wet maize milling is a major industry world-wide, the new technique will have commercial potential in this area.

CHAPTER 6: GENERAL CONCLUSIONS AND RECOMMENDATIONS

Maize kernel translucency as determined by Image Analysis (IA) correlates significantly with laboratory and industrial dry milling yields of vitreous/primary products.

The IA method developed is rapid and non-destructive. Correction factors are applied to allow for constant illumination for each individual kernel taking into account kernel size variation as well as kernel thickness for white as well as yellow dent maize.

Maize kernel translucency as determined by IA is significantly correlated with Floating Number. It is suggested that translucency can potentially be used as a prediction method for the dry milling industry to replace the floating number test as an intake quality control screening method.

As very little sample preparation is necessary (only initial cleaning of kernels by removing damaged kernels or other foreign material), large numbers of individual kernels can be analysed quickly. Analysis rate will depend on the size and speed of the camera, computer software and the selected sampling technique.

The thickness measurement method developed will require some refining to confirm or adjust the current thickness correction factors. Suggested refining should include the effects of cultivar, relative size of germ, kernel shape and colour (for example different classes of yellow) and refinement of the preparation of samples for measuring the thickness effect. It is suggested to evaluate the thickness effect using specially-grown cultivars consisting of translucent endosperm only, and to evaluate the effect of light scattering caused by the distribution of opaque endosperm inside the kernels systematically.

The effect of the correction factors on the strength of the linear relationships is better demonstrated with the white maize cultivars than with the yellow cultivars. Differences in the intensity of the yellow colour in the yellow maize have an additional

influence on the measured translucency values. For future work, it is suggested to use different light sources such as monochromatic light at a wavelength that is not absorbed by the pigments in the maize kernels in order to reduce the effect of different endosperm colours.

The correction factor for exposure successfully addresses the problem of reduced contrast caused by excess light shining around the kernels by allowing the use of light areas of a fixed size smaller than the size of the kernels. This will successfully replace the use of modelling clay that was used previously for embedding of the kernels to exclude excess light.

The use of the correction factors can easily be programmed into computer software and therefore, the developed method has potential to be developed further as an on-line maize translucency detection method.

The differences between the correlations achieved when the translucency was measured as a percentage of the whole kernel and when it was measured as a percentage of endosperm only, are very small and not significant. To calculate translucency as a percentage of endosperm, the area of the germ and tip cap on the kernels is measured separately using a manual step (by hand with a computer mouse), while the calculation of translucency as a percentage of the whole kernel is done automatically using only computer software. As both methods produce similar results, the use of translucency as a percentage of endosperm can safely be discarded.

For the system to be successful as an on-line detection system, it is proposed to develop a future system consisting of two cameras at a 90° angle to each other. One camera will detect the features from the top or bottom of the kernel including the translucency measurements, while the second camera will detect the thickness of the same kernel. As the unique requirements of the lighting system will make direct detection on a conveyor belt not feasible, an autosampler system is proposed as the solution. In such a system, a specially adapted unit will have to be installed allowing for automatic sampling and spreading of kernels on a specially designed illumination

mask, possibly with indents or another device to allow for the kernels to be positioned on top of the holes. Further development work will be necessary in this area.
The developed method is also suitable for other applications. The most important potential application is for the prediction of the yield of starch with maize wet milling. Opacity of maize is linked to starch yield and the method can potentially easily be adapted for this purpose.

The measurement of translucency on other cereals is another potential application. Translucency in cereals such as wheat, rice and sorghum is a known phenomenon, but the precise use of it as a tool for predicting processing performance is only partially understood, mainly as it is not easily analysed. The newly developed method will allow for easier analysis of these samples leading to a better understanding of the translucency relationships.