Characterization of the Influence of Moisture Content on the Morphological Features of Single Wheat Kernels Using Machine Vision

G. Ramalingam, S. Neethirajan, D. S. Jayas, N. D. G. White

Abstract. *The objective of this study was to quantify changes in morphological features of kernels of western Canadian wheat classes caused by moisture increase using a machine vision system. One hundred single wheat kernels for each of eight western Canadian wheat classes were successively conditioned from 12% to 20% (wet basis) moisture contents using potassium hydroxide (KOH) concentrations which regulated relative humidity. A digital camera of 7.4 × 7.4-µm pixel resolution with an inter-line transfer charge-coupled device (CCD) image sensor was used to acquire images of single kernels. A machine vision algorithm developed at the Canadian Wheat Board Centre for Grain Storage Research, University of Manitoba, was implemented to extract seven morphological features (area, perimeter, major axis length, minor axis length, maximum radius, minimum radius, and mean radius) from the wheat kernel images. All the seven features of Canada Western Red Spring, Canada Western Amber Durum, Canada Prairie Spring White, Canada Prairie Spring Red, Canada Western Extra Strong, Canada Western Red Winter, Canada Western Hard White Spring, and Canada Western Soft White Spring wheat kernels were significantly (α = 0.05) different as the moisture content increased from 12% to 20%. All seven features showed a linearly increasing trend with an increase in moisture content.*

Keywords. *Machine vision, Moisture content, Single wheat kernels, Morphological features.*

Canada is one of the largest exporters of wheat in the world with annual exports of 18.6 Mt (million tonnes) in 2008-2009 (Agriculture and Agri-Food Canada, 2009). The Prairie Provinces produce 95% of total Canadian wheat (CGC, 1998). The physical properties of wheat kernels are used to design wheat cleaning, grading, or quality monitoring systems, as well as playing a role in efficiently operating the bulk handling systems to move grains from prairie farms to export terminals.

The influence of moisture content on the physical properties such as length, radius, and perimeter of sorghum and millet, rice, and red kidney bean kernels by Lazaro et al. (2005), Shimizu et al. (2008), Isik and Unal (2007), respectively, showed a general linearly increasing relationship between the physical properties and moisture content of the kernels. Being hygroscopic in nature, moisture content of grain kernels changes with environment and influences the physical properties of kernels. The manual methods of measuring the physical properties of grain kernels are tedious and time consuming, as well as only a limited number of morphological features can be characterized using these methods.

Machine vision technology has been explored as a modern tool for aiding humans in conducting operations such as grading, classification, and monitoring of the grain bulk. Zayas et al. (1989) used image analysis for discriminating wheat and non-wheat components in grain samples which emphasized the capability of machine vision systems in solving a variety of problems. Firatligil-Durmus et al. (2008) concluded that machine vision technology offers a simple and rapid methodology to estimate geometric features and engineering properties of lentil kernels. Igathinathane et al. (2009) developed a machine vision analysis system to determine orthogonal measurements of various food grains with more than 96.6% overall accuracy at a speed of 254 ± 125 particles/s. Using image processing, Urasa et al. (1999) demonstrated a third-order polynomial relationship between moisture content and the pixel ratio of soybean kernels extracted from image features. Tahir et al. (2007) evaluated the effect of moisture content on cereal grains using digital image analysis. They found that effect of moisture content on features of individual kernels was smaller than to the features of bulk kernels. They speculated that three-dimensional analysis using a high resolution camera will help to characterize the influence of moisture content on individual kernels. Generally the initial moisture content of wheat at harvest is around 20% which is reduced to around 13% for safe storage. The objective of this study was to characterize using machine vision the influence of moisture content on single kernels of different western Canadian wheat classes in the moisture range of 12% to 20% wet basis (w.b.).

Submitted for review in July 2010 as manuscript number FPE 8683; approved for publication by the Food & Process Engineering Institute Division of ASABE in February 2011.

The authors are **Ganesan Ramalingam, ASABE Member,** Graduate Student, **Suresh Neethirajan, ASABE Member,** Research Engineer, Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada; **Digvir S. Jayas, ASABE and CSBE Fellow,** Vice-President (Research), Distinguished Professor, University of Manitoba, Winnipeg, MB, Canada; and **Noel D. G. White,** Senior Research Scientist, Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, MB, Canada. **Corresponding author:** Digvir S. Jayas, 207 Administration Building, University of Manitoba, Winnipeg, MB, Canada R3T 2N2; phone: 204-474-9404; e-mail: Digvir_Jayas@umanitoba.ca.

Materials and Methods

One hundred single kernels of each of the eight classes of wheat [Canada Western Red Spring (CWRS), Canada Western Amber Durum (CWAD), Canada Western Extra Strong (CWES), Canada Western Red Winter (CWRW), Canada Western Hard White Spring (CWHWS), Canada Western Soft White Spring (CWSWS), Canada Prairie Spring Red (CPSR), and Canada Prairie Spring White (CPSW)] were selected randomly from the composite mixture of various cultivars within each class. The samples were obtained from the Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg, Canada. Prior to selecting single kernels from the respective bulk sample, the entire wheat samples were treated with 2% sodium hypochlorite (NaOCl) aqueous solution to prevent fungal infection, then rinsed using distilled water and dried at room temperature to approximately 10% wet basis before starting to condition to 12% to 20% moisture content. Thus, changes in physical properties of kernels were characterized during sorption process.

Grain Conditioning

Five different concentrated potassium hydroxide (KOH) solutions (table 1), of 1 L each in volume, were used to create 60%, 70%, 80%, 85%, and 90% relative humidity environments at 25°C (Solomon, 1951), which approximately correspond to 12%, 14%, 16%, 18%, and 20% wet basis moisture content (MC) of wheat kernels, respectively. The wheat kernels were conditioned from the lowest to the highest moisture content to minimize the potential of mold growth on samples which may occur if they were exposed to higher moisture contents first. Equilibration period for attaining respective moisture contents was determined by measuring the mass, as well as moisture content (*ASAE Standards,* 2003), of 10-g samples on a daily basis. Based on these preliminary experiments and using a criterion that change in mass of sample as less than 0.01 g, seven days were chosen as period to attain equilibrated moisture contents at fixed relative humidity above KOH solutions.

The single wheat kernels were placed on respective numbered spaces without touching each other on a wire mesh holder, which was placed above the KOH solution stored in a plastic pail (5.5-L capacity) (fig.1). A fan (2.5×10^{-3} m^3/s airflow rate) was kept under the wire mesh inside the pail to circulate the air to hasten the equilibration. The placement of the kernels was in such a way that each kernel could absorb moisture from all sides due to the circulation of air inside the pail facilitated by the fan. After placing the sample kernels, the plastic pail was closed with a tight lid and wrapped using duct tape to prevent exchange of ambient air with wheat samples. A data logger (Model-HoboU10, Onset Computer Corporation, Pocasset, Mass.) was used to record and verify temperature and humidity inside pails at every hour. By using this experimental set up, the same 100 single kernels for each class were conditioned to next moisture level by moving kernels to the next higher relative humidity environment.

Table 1. Concentrations of the KOH solutions used and achieved humidity at nominal temperature of 25°C.

Weight % (g KOH/100 g of solution)	Density (g/mL) at 15°C	Achieved Mean Relative Humidity and Temperature Inside Pail (%,°C)
29.50	1.285	57.07 ±0.33 at 25.23 ±0.65
25.00	1.239	65.70 ±0.55 at 25.75 ±0.33
19.25	1.181	78.38 ±0.67 at 25.66 ±0.17
15.80	1.147	83.13 ±0.60 at 25 ±0.51
11.75	1.108	88.68 ±0.70 at 23.03 ±1.70

Image Acquisition

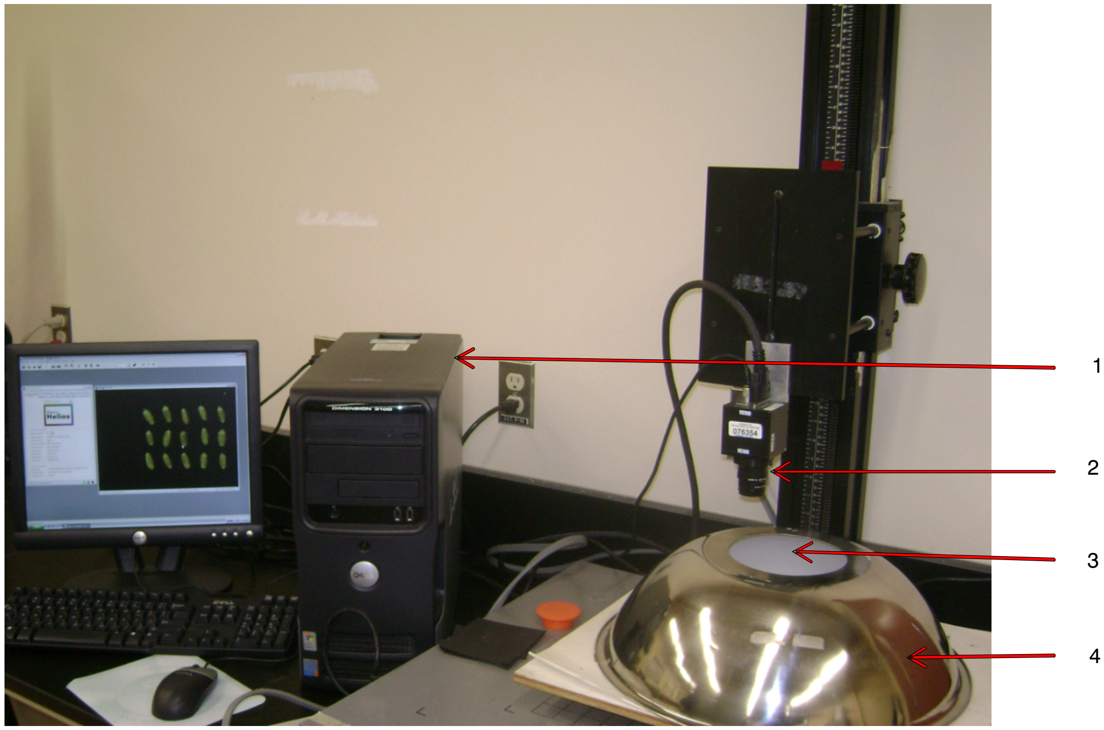
Images of single kernels, at each moisture content, were acquired (fig.1) using a color camera with 7.4- × 7.4-µm pixel resolution (Dalsa, Model- DS-22-02M30, ON, Canada). The camera had an inter-line transfer charge-coupled device (CCD) image sensor. A vertical copy stand (Bencher Inc., Chicago, Ill.) was used to mount the camera over the illumination chamber to fix a constant camera height from the kernels being imaged. Images were stored using Helios/CL dual interface, Matrox Intellicam 8.0 (Matrox Electronic Systems Ltd., Dorval, QC, Canada) on a computer (Pentium IV 3.0 GHz processor). Illumination for the images was provided by a 32 W fluorescent lamp (FC12T9, Philips Electronics Ltd., ON, Canada), and a light diffuser.

The light diffuser was a dome made of steel, inside of which was painted and smoked with magnesium oxide, to uniformly illuminate the sample kernels (Majumdar and Jayas 2000). The power supply to the light source was controlled by a fluorescent lamp controller (Mercron Inc., Richardson, Tex.) to ensure constant supply of voltage as well as light intensity throughout the imaging session. The lamp was switched on 30 min before imaging to ensure stable lighting, as the lamp controller could stabilize the light within 0.25% of the selected light intensity in this time. Before imaging every sample (25 kernels/image; 4 images/sample) of wheat kernels, the camera was calibrated for constant illumination settings using a grey card. This procedure confirmed that the images of different wheat kernels were acquired under the same illumination conditions.

To prevent moisture loss from kernels during each imaging session, samples were moved swiftly between the pail and the image acquisition system. Approximately 20 min was required for each sample to be imaged. In addition, each kernel of the samples was imaged in such a way that the maximum exposure time to illumination was maintained around 2-3 min. Because moisture change from wheat is a slow process, its exposure to cool light of fluorescent lamp for such a short duration will have negligible effect on its moisture content. The kernels were placed in 'crease-down' position under the field of view of camera to make the position of kernels consistent throughout the study.

Feature Extraction

Seven morphological features (area, perimeter, maximum radius, minimum radius, mean radius, major axis length, and minor axis length) of 100 single kernels, at five moisture levels, of all eight wheat classes were extracted using an algorithm developed at The Canadian Wheat Board Centre for Grain Storage Research, Department of Biosystems Engineering, University of Manitoba (Paliwal, 2002; Visen, 2002). Detailed information on the development of the algorithm and the method of extracting seven morphological



1 – Processor; 2 – Digital camera; 3 – Illumination chamber; 4 – Light diffuser

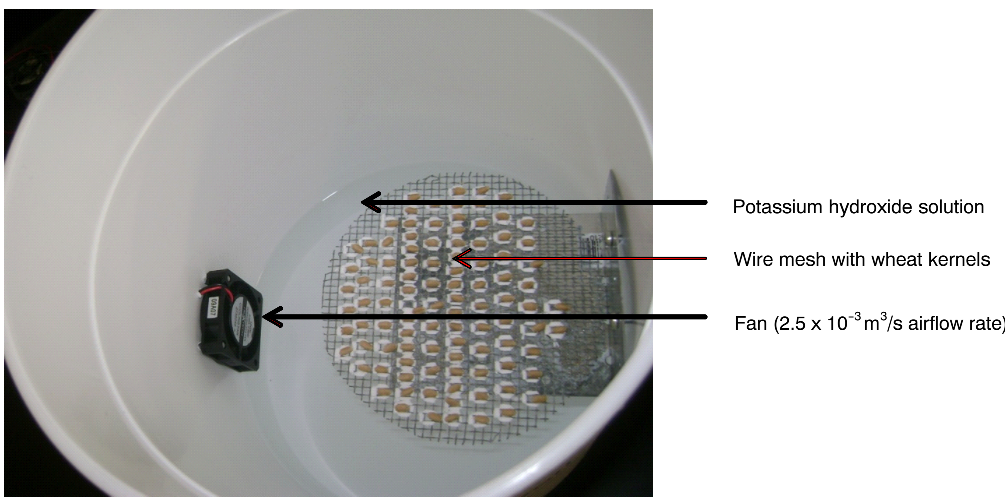


Figure 1. Machine vision system and grain conditioning set up.

features are given in Majumdar and Jayas (2000), Paliwal (2002), Visen (2002), and Paliwal et al. (2003).

The algorithm determined kernel boundary using a 4-connect technique where the values of pixels were used to distinguish the object pixels from background and other noise. Once it found the boundary, the perimeter of a kernel was calculated using Euclidean distance between adjacent boundary pixels. Distance between each boundary pixel and the center of mass was used to compute maximum, minimum, and mean radius values of the kernels. The maximum distance between two points on boundary that were diametrically opposite with respect to center of mass was determined as major axis length and minor axis length was calculated as maximum distance between opposing pixels that formed a line perpendicular to the major axis (Majumdar and Jayas, 2000; Paliwal, 2002; Visen, 2002; Paliwal et al., 2003).

Calibration of Spatial Resolution

The algorithm extracted all the features in pixels. The diameter/major axis length of a Canadian 25¢ coin was measured (25 measurements) using a Vernier caliper as well as the machine vision algorithm. The average of both measurements was used to compute the equivalent millimeter (mm) value of a pixel. It was found that one pixel was equal to 0.0619 mm or 62 μm.

Prior to actual imaging, the variability produced by the machine vision system on the measurements of wheat kernel features was determined by imaging 100 single CWRS kernels of the same moisture content. One hundred images of the same kernel were taken repeatedly for all the 100 kernels using the actual set up. The same algorithm was implemented to extract the morphological features to measure the variability of the system.

Data Analysis

The data of seven morphological features of 100 single wheat kernels at five different moisture levels were compiled for each wheat class. Significance of influence of moisture was analyzed using 'Proc Mixed' and 'Proc GLM' models (SAS Institute Inc., 2008) and paired t-test results were produced by considering every kernel as a block in a randomized block design. The effects of five moisture treatments on the morphological features of every single kernel were quantified.

Results and Discussion

System Calibration

The results from the calibration for system variability showed that the error from the repetitive imaging was smaller than the original size variation of the kernels of the sample class and moisture content (table 2). It resulted in an insignificant variability caused by the machine vision system on the wheat kernel features. Molds will normally develop above 75% relative humidity on grain kernels during storage (Pixton and Warburton, 1971). The pre-treatment of wheat kernels with NaOCl solution helped to keep wheat samples mold-free.

Table 2. Feature variability due to kernel and system.

Feature[a]	Original Kernel Variability Mean - Standard Deviation (CV[b], %) of 100 Kernels	System Variability Mean - Standard Deviation (CV[b], %) of Each Kernel
Area	2031.53 ±177.43 (8.73)	2032.72 ±112.95 (5.55)
Perimeter	189.52 ±8.65 (4.65)	189.57 ±6.30 (3.32)
Mean radius	25.75 ±1.10 (4.2)	25.76 ±0.71 (2.76)
Major axis length	74.55 ±3.41 (4.58)	74.56 ±2.52 (3.39)

[a] All feature values are in pixels (1 pixel = 0.0038 mm^2 for area and 0.062 mm for other features),
[b] Coefficient of Variation.

Effect on Morphological Features

The analysis of the morphological features by general linear models (GLM) and the mixed procedures (SAS Institute Inc., 2008) showed that all seven morphological features were significantly ($\alpha = 0.05$) affected by the increase in moisture content from 12% to 20% wet basis.

Area

Area of kernels of all eight wheat classes increased with an increase in moisture content (table 3). When increasing moisture content of kernels from 12% to 14% and at 20% moisture content, the area values were significantly different, within each class, for CWRS, CWAD, CPSW, and CWHWS kernels (fig. 2). However, the area of CWSWS, CPSR, CWRW, and CWES wheat kernels were not significantly different between 12% to 14% moisture increase but were significantly higher at 20% MC. By and large there was no significant increase in area values between 16 and 18% moisture treatments except for CPSW and CWHWS wheat kernels. Regression curves were drawn to explain the relationship between moisture content and kernel area values of the eight western Canadian wheat classes. In general, the area of wheat kernels showed a linearly increasing trend with increasing moisture content (R^2 ranging from 0.6 to 0.8 for the eight classes.

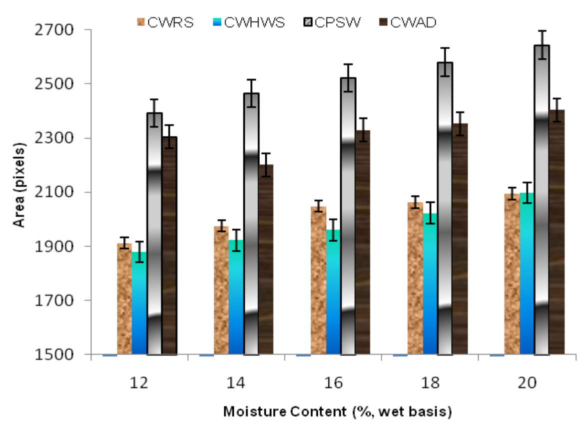


Figure 2. Area values of CWRS, CWAD, CWHWS, and CPSW wheat class kernels at five different moisture contents where the bars indicate the lease significant difference used for statistical grouping.

Table 3. Statistical grouping of mean area (mm^2) values of 100 kernels of each of eight western Canadian wheat samples at five different moisture contents.

Feature	Wheat Class	Moisture Content[a] 12%	14%	16%	18%	20%	Least Significant Difference (LSD)[b]
Area	CWHWS	7.14_a	7.31_b	7.45_b	7.69_c	7.97_d	0.15
	CPSW	9.09_a	9.37_b	9.58_c	9.80_d	10.04_e	0.19
	CWRS	7.27_a	7.51_b	7.79_c	7.84_c	7.96_d	0.08
	CWAD	8.76_a	8.36_b	8.85_{ac}	8.94_c	9.14_d	0.16
	CWRW	7.03_a	7.13_{ab}	7.27_b	7.28_b	7.30_b	0.18
	CWES	8.79_a	8.97_{ab}	9.15_{bc}	9.36_{cd}	9.46_d	0.22
	CPSR	8.52_a	8.47_a	8.91_b	8.98_b	9.13_b	0.23
	CWSWS	7.82_a	7.97_a	7.95_a	7.91_a	8.42_b	0.24

[a] Values with same letter, within each wheat class, indicate that they were not significantly different at $\alpha = 0.05$ using t-test;
[b] LSD values are in mm^2 and were calculated using standard error and critical t-value.

Table 4. Statistical grouping of mean perimeter (mm) values of 100 kernels of each of eight western Canadian wheat samples at five different moisture contents.

Feature	Wheat Class	Moisture Content[a] 12%	14%	16%	18%	20%	Least Significant Difference (LSD)[b]
Perimeter	CWHWS	10.84_a	10.97_b	11.07_b	11.28_c	11.50_d	0.12
	CPSW	12.85_a	13.03_b	13.15_b	13.30_c	13.55_d	0.14
	CWRS	11.37_a	11.55_b	11.71_c	11.73_c	11.88_d	0.08
	CWAD	12.91_a	12.61_b	12.94_a	12.98_a	13.21_c	0.15
	CWRW	11.04_a	11.10_{ab}	11.20_{bc}	11.22_{bc}	11.28_c	0.15
	CWES	12.87_a	12.98_{ab}	13.11_{bc}	13.26_{cd}	13.31_d	0.17
	CPSR	12.49_a	12.46_a	12.70_b	12.81_{bc}	12.91_c	0.17
	CWSWS	11.34_a	11.48_a	11.43_a	11.40_a	11.86_b	0.17

[a] Values with same letter, within each wheat class, indicate that they were not significantly different at $\alpha = 0.05$ using t-test;
[b] LSD values are in mm and were calculated using standard error and critical t-value.

Perimeter

The perimeter of all eight western Canadian wheat classes also increased with an increase in moisture content of kernels (table 4). Increase in moisture content from 12% to 14% resulted in significant increase in perimeter values of CPSW, CWAD, CWRS, and CWHWS wheat samples but there was no significant difference for CPSR, CWRW, CWES, and CWSWS at these two moisture levels. At 20% moisture content, the perimeter values of CWHWS, CPSW, CWAD, and CWSWS significantly increased from other lower moisture levels. During mid-range moisture treatments, the perimeter had a similar trend as area values of the respective wheat samples because area and perimeter are inter-related features.

Radius and Length

The extracted axial and radial features of eight western Canadian wheat class kernels such as maximum radius, minimum radius, mean radius, major axis length, and minor axis length increased with an increase in moisture content from 12% to 20% (tables 5 and 6). Generally, there was a significant increase in the radial feature values of CWHWS, CWRW, CWAD, and CPSW wheat kernels while increasing moisture content from 12% to 14%, followed by a statistically constant feature values at 14%, 16%, and 18%

Table 5. Statistical grouping of mean radius (mm) values of 100 kernels of all eight wheat samples at five different moisture contents.

Wheat Class	Feature	Moisture Content[a] 12%	14%	16%	18%	20%	Least Significant Difference (LSD)[b]
CWHWS	Maximum radius	2.10_a	2.13_b	2.14_b	2.18_c	2.21_d	0.024
	Mean radius	1.51_e	1.53_f	1.54_f	1.57_g	1.60_h	0.015
	Minimum radius	1.02_i	1.03_{ij}	1.04_j	1.07_k	1.09_l	0.014
CPSW	Maximum radius	2.64_a	2.68_b	2.71_c	2.74_d	2.78_e	0.022
	Mean radius	1.74_e	1.77_f	1.79_f	1.82_g	1.84_h	0.018
	Minimum radius	1.03_i	1.04_i	1.06_j	1.08_{jk}	1.09_k	0.017
CWRS	Maximum radius	2.30_a	2.32_b	2.34_c	2.35_c	2.36_c	0.017
	Mean radius	1.55_e	1.58_f	1.60_g	1.60_g	1.62_h	0.009
	Minimum radius	0.93_i	0.96_j	0.99_{jk}	1.00_{kl}	1.01_l	0.011
CWAD	Maximum radius	2.65_a	2.61_b	2.65_a	2.66_a	2.70_c	0.034
	Mean radius	1.73_e	1.70_f	1.74_e	1.75_e	1.77_g	0.017
	Minimum radius	0.96_i	0.94_j	0.97_{ik}	0.98_{kl}	0.99_l	0.015
CWES	Maximum radius	2.67_a	2.69_{ab}	2.72_{bc}	2.74_c	2.75_c	0.037
	Mean radius	1.73_e	1.74_{ef}	1.76_{fg}	1.78_{gh}	1.79_h	0.021
	Minimum radius	0.99_i	1.01_j	1.02_{jk}	1.04_{kl}	1.05_l	0.017
CPSR	Maximum radius	2.56_{ab}	2.55a	2.59_{bc}	2.62_c	2.63_c	0.038
	Mean radius	1.69_e	1.68_e	1.72_f	1.74_f	1.75_f	0.022
	Minimum radius	0.98_i	0.98_i	1.01_j	1.02_j	1.03_j	0.018
CWSWS	Maximum radius	2.25_a	2.27_a	2.27_a	2.27_a	2.33_b	0.030
	Mean radius	1.58_e	1.60_e	1.60_e	1.60_e	1.65_f	0.022
	Minimum radius	1.05_i	1.07_i	1.07_i	1.07_i	1.10_j	0.023
CWRW	Maximum radius	2.19_a	2.21_{ab}	2.23_{bc}	2.24_{bc}	2.25_c	0.032
	Mean radius	1.51_e	1.53_{ef}	1.54_{fg}	1.55_{fg}	1.56_g	0.020

[a] Values with same letter, within each wheat class, indicate that they were not significantly different at $\alpha = 0.05$ using t-test;
[b] LSD values are in mm and were calculated using standard error and critical t-value.

Table 6. Statistical grouping of mean length (mm) values of 100 kernels of all eight wheat samples at five different moisture contents.

Wheat Class	Feature	Moisture Content[a] 12%	14%	16%	18%	20%	Least Significant Difference (LSD)[b]
CWHWS	Major axis length	4.12_{a}	4.17_{b}	4.21_{b}	4.28_{c}	4.34_{d}	0.045
	Minor axis length	2.15_{e}	2.18_{f}	2.21_{g}	2.24_{h}	2.30_{i}	0.026
CPSW	Major axis length	5.14_{a}	5.21_{b}	5.26_{bc}	5.32_{c}	5.40_{d}	0.066
	Minor axis length	2.16_{e}	2.20_{f}	2.24_{g}	2.27_{gh}	2.28_{h}	0.032
CWRS	Major axis length	4.51_{a}	4.54_{b}	4.59_{c}	4.59_{c}	4.63_{d}	0.031
	Minor axis length	1.96_{e}	2.01_{f}	2.08_{g}	2.10_{gh}	2.11_{h}	0.022
CWAD	Major axis length	5.20_{a}	5.12_{b}	5.22_{a}	5.23_{a}	5.32_{c}	0.065
	Minor axis length	2.05_{e}	1.99_{f}	2.07_{eg}	2.09_{gh}	2.01_{h}	0.030
CWES	Major axis length	5.21_{a}	5.24_{ab}	5.29_{bc}	5.33_{c}	5.35_{c}	0.068
	Minor axis length	2.09_{e}	2.13_{f}	2.15_{f}	2.19_{g}	2.21_{g}	0.034
CPSR	Major axis length	4.97_{ab}	4.96_{a}	5.04_{bc}	5.08_{c}	5.10_{c}	0.072
	Minor axis length	2.08_{e}	2.08_{e}	2.15_{f}	2.15_{f}	2.19_{g}	0.037
CWSWS	Major axis length	4.41_{a}	4.46_{a}	4.43_{a}	4.43_{a}	4.56_{b}	0.058
	Minor axis length	2.23_{e}	2.25_{e}	2.25_{e}	2.24_{e}	2.32_{f}	0.046
CWRW	Major axis length	4.28_{a}	4.30_{ab}	4.35_{bc}	4.36_{bc}	4.38_{c}	0.060
	Minor axis length	1.98_{e}	2.01_{ef}	2.02_{f}	2.03_{f}	2.04_{f}	0.034

[a] Values with same letter, within each wheat class, indicate that they were not significantly different at $\alpha = 0.05$ using t-test;
[b] LSD values are in mm and were calculated using standard error and critical t-value.

MC, and a final significant increase at 20% MC. Minimum radius of CWRW wheat class was not significantly affected due to moisture increase where the value remained almost constant across the range of tested moisture contents.

For CWSWS, CPSR, CWES, and CWRW wheat kernels, the radial features were not significantly different at 12% and 14% moisture treatment but were significantly different at the lowest and the highest moisture treatments. The major and minor axes lengths of all wheat kernels increased with increasing moisture levels. The statistical grouping for length feature was similar to radial features of the respective wheat class kernels. A similar increase was attained in area, radius, and length dimensions of three popular varieties of Iranian wheat when Karimi et al. (2009) mechanically measured the effect of moisture content. A linear relationship was also proven between mechanical measurements of various properties of green wheat and moisture content (Al-Mahasneh and Rababah, 2007).

All the basic morphological feature values were, in general, significantly different during initial increment of moisture content (12% to 14%) which was followed by almost statistically constant value during intermediate moisture treatments (16% and 18%) for all eight western Canadian wheat samples. This could be because moisture-holding forces of a grain kernel decrease as moisture content increases (Pixton and Warburton, 1968) which in turn produced statistically insignificant changes during intermediate moisture treatments on the basic morphological features such as area, perimeter, radial and axial dimensions of wheat kernels. However, further increase in moisture content to 20% established significant increment on the basic morphological features for almost all eight western Canadian wheat class samples.

This single kernel study demonstrated significant difference on area and perimeter features of CWRS and CWAD wheat kernels when the same kernels were conditioned to increasing moisture contents. However the effects of moisture content on area and perimeter of single CWRS and CWAD kernels were not significantly different in a study by Tahir et al. (2007) when they randomly picked kernels from different grain bulks conditioned to 12%, 14%, 16%, 18%, and 20% MC. It is possible that bulk samples (Tahir et al., 2007) mask the variability which is noticed in this study with individual kernels. Future work is essential to study the influence of moisture content on the textural and color features of single wheat kernels. The variability of kernel features with moisture contents must be considered while developing algorithms for classifying grains or admixtures in grains.

Conclusions

The influence of moisture content on the morphological features of eight classes of western Canadian wheat kernels was characterized using the machine vision algorithm. The statistical analysis showed that the seven morphological features were significantly ($\alpha = 0.05$) different as the moisture content increased from 12% to 20%. Generally the basic morphological features such as area, perimeter, major axis length, minor axis length, maximum radius, minimum radius, and mean radius showed a linearly increasing trend with an increase in moisture content.

Acknowledgements

The authors thank the Canada Research Chairs Program and the Natural Sciences and Engineering Research Council of Canada for funding this study.

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