Semolina Speck Counting Using an Automated Imaging System[1]

S. J. SYMONS,[2] J. E. DEXTER, R. R. MATSUO, and B. A. MARCHYLO

Cereal Chem. 73(5):561–566

ABSTRACT

An objective instrumental method for counting specks in semolina has been developed. The method involves making pellets from semolina and detecting specks using a computerized image analysis (IA) system. The IA method for speck counting has been compared to visual counting of the pellets by three experienced technicians and to the visual counting of the original semolina using the standard Grain Research Laboratory (GRL) procedure. For a linear range of speck counts created by blending semolina samples, a linear response was obtained by the IA method. The robustness of the developed IA method was tested using semolina milled from a diverse range of plant breeders samples. Eight of these samples were used to test the influence of speck size and darkness on the count levels. The inclusion of smaller specks in the count method increased the count levels, while excluding lighter specks reduced the speck count. The IA method has proven reliable over a wide range of samples representing diverse genotypes and environments. It can be set for specific speck size and darkness, allowing calibration to relate directly to results by traditional visual counting. The semolina pellets may be stored for a long period, providing a permanent record of each sample, and allowing for standardization of speck counts over time.

The milling of semolina from durum wheat aims to fully separate the starchy endosperm from other components of the wheat kernel. In common with all milling processes, this is an imperfect process due to the complexity in structure of the wheat kernel itself, such that the semolina (starchy endosperm) product is contaminated by bran fragments. In addition, incomplete removal of contaminants from the grain during cleaning can ultimately provide a further source of impurities in the milled product. Bran fragments and ground impurities are visible as specks in semolina. The presence of specks has a negative impact on the value of the semolina because they cause brown or dark flecks in pasta, reducing consumer acceptability of the product. A count of the number of visible specks is usually conducted as part of the quality control process during semolina production, and often is a primary specification that the miller must meet. The exact nature of the counting process varies, but typically a semolina sample is spread on a table, the semolina surface is flattened, and a grid of known dimension is placed on top (Vasiljevic and Banasik 1980, Dexter and Matsuo 1982, El Bouziri and Posner 1988). The number of specks present is visually counted and expressed as the total number within a defined area.

Visual identification of specks is subjective; since it is based upon observer experience, it is influenced by factors such as fatigue and subject to observer bias in determining speck size and darkness for inclusion in the count. Visual counting is also tedious. Pouring the semolina sample gives an inconsistent and only temporary surface, providing no permanent record of the sample. It is difficult to generate consistent results, due to these constraints.

The limitations of visual speck counting make the development of a rapid objective instrumental procedure desirable for both laboratory and commercial applications. Imaging methods for detecting bran fragments in common wheat flours were reported using white light illumination (Evers 1993, Whitworth 1994) and commercialized using fluorescence methods (Harrigan 1995). The uneven surface of semolina, due to its coarser granulation, limits the use of common wheat flour imaging methods to count specks in semolina. The objective of the experiments reported here was to establish an objective method for counting specks in durum semolina that clearly defines speck size and darkness, and provides a permanent record of the sample.

METHODS AND MATERIALS

Semolina Samples

Wheat was cleaned and conditioned overnight at 16% moisture, the optimum conditions for durum wheat experimental milling as described by Dexter and Tipples (1987). Samples were milled with a four-stand Allis-Chalmers mill in conjunction with a laboratory purifier (Black 1966), according to the procedure of Dexter et al (1990).

For preliminary work, a series of semolina samples of variable speckiness was prepared by blending semolina from No. 1 (highest grade) and No. 5 (lowest grade) Canada Western Amber Durum (CWAD) cargoes in the following ratios: 7/0, 6/1, 5/2, 4/3, 3/4, 2/5, 1/6 and 0/7.

Samples used in subsequent experiments included semolina derived from composites of all CWAD grades from the 1992 Canadian Grain Commission harvest survey, breeding lines from the 1993 western Canadian CWAD cooperative program, and composites of CWAD cargoes shipped during the 1993-94 crop year.

Visual Speck Counting

A sample of semolina was spread on a table and flattened using a spatula to provide a flat surface for counting. A square grid divided into four quadrants with a total area of 25 cm^2 was laid onto the surface, and visible specks were counted according to the method of Dexter and Matsuo (1982). A 1.5× illuminated magnifier was used to aid identification of the specks. The semolina was poured and counted twice and the average number of specks reported per 50 cm^2.

Image Analysis

Semolina was pelleted by pouring ≈4 g of semolina into a 38-mm diameter tube and compressing with a ring press (RIK, London, UK) for 4 min at a pressure of one metric ton per cm^2. The resulting pellets were 38 mm in diameter and 3 mm thick.

For image analysis (IA), the pellets were placed on a black background inside a cutout (mask) that was the exact dimensions of the pellet. The black surface eliminated light reflections from around the sample. The sample holder was on a 100-mm mechanical

[1]Contribution of the Canadian Grain Commission, Grain Research Laboratory, 1404-303 Main St., Winnipeg, Manitoba R3C 3G8.

[2]Corresponding author. Fax: 204/983-0724.

Publication no. C-1996-0805-03R.

stage mounted on a Wild Photomakroskope (Leitz, Canada). Magnification was adjusted so that a field of view for capture through the Apozoom lens was 10 × 10 mm. Epi-illumination was from a ring lamp affixed to the macroscope lens and powered by an Intralux 6000 illuminator (Volpi, Switzerland) color corrected to 5,000 K. Illumination levels were controlled by measuring the reflectance from a Kodak gray scale white patch of OD 0.05 and adjusting the lamp intensity to a constant reflectance relating to a gray value of 160 ± 2 on a scale of 0 (black) to 255 (white). The image was captured with a NC-70x (625/50) black and white camera (Dage MTI, Michigan City, IN) providing a PAL video signal and processed using an IBAS image processing system (Kontron Electronik, Eching, Germany). For each semolina pellet, nine images were captured, representing a total surface area of 9 cm^2. The scale factor used was 13.0 μm/pixel.

To identify the specks, the mean gray value of the field of view was determined. A gray value less than this mean was selected to identify the darker specks. The difference between the gray mean value and the speck selection level is referred to as delta gray. Speck size rejection thresholds were set using scrap values of 10, 20, and 40 pixels, which are equivalent to areas of 1,690, 3,380, and 6,760 μm^2. Specks were not counted below these sizes. The variables measured for each surface included the number of specks, speck size, shape, and brightness (gray value). These parameters were always collected, although not all are reported here.

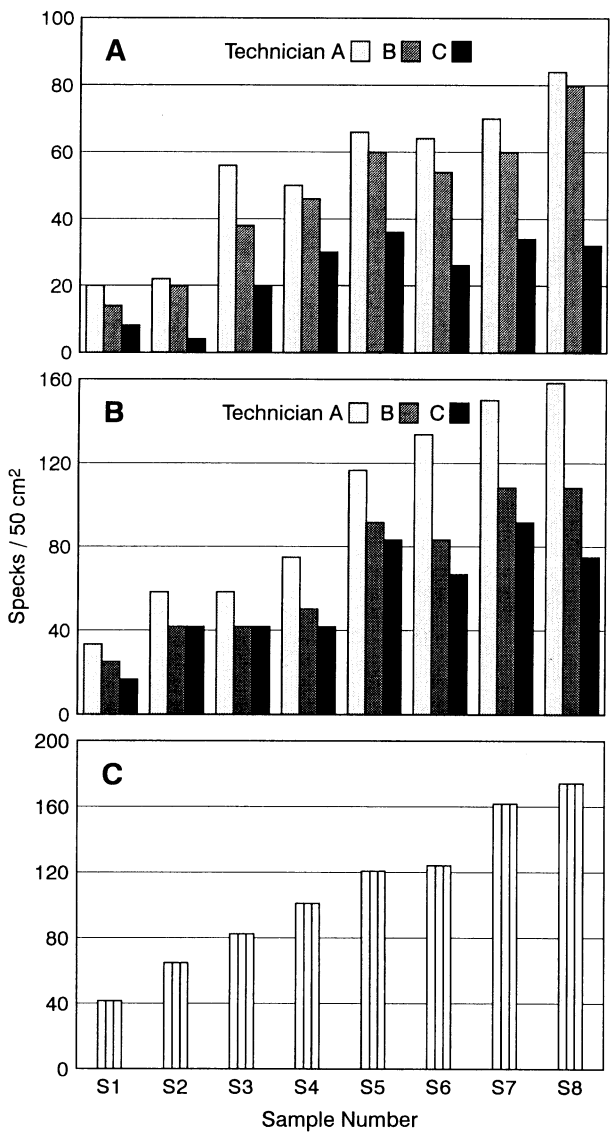

Fig. 1. Visual counts of specks determined independently by three technicians for eight semolina samples **(A)**; compressed pellets of semolina **(B)**; and speck counts by image analysis of the compressed pellets **(C)**. Semolina samples were prepared by blending a semolina from No. 1 and No. 5 Canada Western Amber Durum in varying proportions. Each observation for A is the mean of two replicated counts; for B is the mean of single counts of four pellets for each sample; for C is the mean of four repeated counts of eight pellets for each sample. Samples in order of anticipated increasing speck counts.

Experimental Design and Statistical Analysis

All IA experiments were performed in fully randomized complete block design. For each semolina pellet repeated measurements of random pellet orientations were made to estimate measurement error, and several pellets were measured to estimate sampling error. The number of repeated measures and numbers of pellets are reported for each experiment with the data.

All statistics were calculated using the procedures of the SAS (1988) software system v6.10 for Windows. Comparison for heterogeneity of regression slopes was by analysis of covariance type I errors (SAS 1986). Spearman's Rank Correlation is referred to as SRC.

RESULTS AND DISCUSSION

Preliminary Investigations: Semolina

The semolina series prepared by blending semolina from No. 1 and No. 5 CWAD was assessed by three experienced technicians using the Grain Research Laboratory (GRL) visual speck counting method. Relative to each other, the technicians were consistent in counting specks for each of the eight samples (Fig. 1a). Differences between the technicians were consistent, showing personal interpretations of specks suitable for counting. These results were highly correlated: Technician A to Technician B (SRC 0.97) or Technician C (SRC 0.81); Technician B to Technician C (SRC 0.87). A disadvantage of this procedure is that it does not produce a permanent record of the sample, making it difficult to standardize.

Preliminary Investigations: Image Analysis

We were unable to develop an IA method that gave satisfactory results for counting specks in semolina due to aberration effects caused by the large size of the endosperm particles during imaging. To provide a flat surface for imaging, semolina was compressed into solid pellets. These pellets initially were assessed visually for specks. Eight pellets were produced for each of the blended semolina samples. Only data from the first four pellets is presented here; the second set of four pellets was used as a replicate data set to confirm these results and counted eight to 10 months following pellet preparation. The combination of the two data sets into a single set of eight pellets showed homogenous results. Each of the three technicians counted each pellet for specks once (Fig. 1b). A black paper mask was laid over the pellet with a 3 × 2 cm window cutout, and visible specks were assessed using a protocol similar to that for the semolina. Visual assessment of pelleted semolina by the three technicians was more uniform than for semolina: Technician A to Technician B (SRC 0.97) or Technician C (SRC 0.86); Technician B to Technician C (SRC 0.94). The personal bias of each technician noted for speck counting in semolina was also noted for visual speck counting in the pellets. The use of pellets provides a permanent sample record that can be used to standardize counts among technicians, and over long time periods. The delay between counting of the first set of four pellets and the second set of four pellets indicates no apparent change in speck levels due to storage, although the pellets themselves become more friable during storage. Methods for stabilizing the pellets for long-term preservation are being investigated.

While it was noted that each technician has a slightly different perception of semolina speckiness, for all semolina and pelleted

samples, Technician A consistently reported the highest and Technician C the lowest counts. Each technician was consistent within his or her own perception, but absolute counts from one individual could not be compared directly to those from another individual. These differences are typical of subjective methods, such as visual speck counting, a test which is universal within the durum wheat processing industry. A more objective procedure is needed, and IA has the potential to satisfy this need.

The same pellets as visually evaluated were used for instrumental speck detection using a computer-based IA method. Detection parameters were set at delta gray 12 and scrap area at 20 pixels (12 gray values darker than the mean surface grayness; speck size greater than 3,380 μm^2), unless otherwise specified. Instrumental counts verified the known linear increase in speck count with each successive sample (Fig. 1c). There was good agreement between visual and IA speck counts of pellets: Technician A to IA (SRC 0.99); Technician B to IA (SRC 0.98); and Technician C to IA (SRC 0.88). Variability in the instrumental counting method was evaluated for each pellet using four repeated measures with a random orientation of the round pellet. The random positioning of the pellets reflects a practical application of the method, where operationally, it would not be desirable to have to orientate calibration samples with precision. For each repeated measure, the pellet surface evaluated was not exactly identical, although it was of the same area. These data are reported for eight pellets. For six of the eight samples, there was no significant heterogeneity between repeated measures ($Pr > F > 0.05$ for Type I [Table I] and Type III errors [not shown]). Generally, semolina pellets with lower speck counts showed higher variability than those with higher speck counts, demonstrating pellet to pellet variability for five of the samples ($Pr > F < 0.05$ for Type I [Table I] and Type III errors). Such a finding was not unexpected, because the number of specks is very low, indicating the need for evaluation of more than one pellet. The visual method is based on the assessment of a relatively large surface of semolina for this very reason. When a sufficiently large area is evaluated, IA is accurate, and reproducible (Fig. 1c).

The objectivity of the instrumental counting system compared to the visual system was strongly suggested due to the linear response of the instrumental system. For all three visual observers, there appears to be an underestimation of specks in the samples doped with higher speck quantities. In samples with few bran specks, the technical observer tends to count all dark specks visible, whereas in a sample with many specks, only the larger and darker specks tend to be counted. This phenomenon reflects human nature, and is not present in a computer-based measurement system.

Characterization of the Image Analysis System

To be of practical use, an automated system for counting semolina bran specks must be applicable to a wide range of samples. A set of 22 plant breeder lines representing a wide range in visual speck counts were selected to test the robustness of the IA system. Based on four pellets of each sample, there was generally good agreement between visual assessment of specks for the pellets and the automated machine count (SRC 0.87). The agreement between the visual assessment of semolina and visual counts of the pellets (SRC 0.51) and between the visual semolina and machine-counted pellets (SRC 0.56) was not as strong (Fig. 2). The four pellets were homogenous ($Pr > F$ 0.3282) at the 5% level when all samples were considered and when pellets were compared on a sample basis. Most samples showed high homogeneity between pel-

TABLE I
Heterogeneity of Repeated Measures and Replicated Measures for Eight Samples[a] of Semolina Compressed into Pellets

	$Pr > F$ (Type I Errors)[b]	
Sample	**Repeated Measure**	**Replicated Discs**
S1	0.0582	0.0005
S2	0.8771	0.0044
S3	0.0107	0.1210
S4	0.4202	0.0150
S5	0.3342	0.0540
S6	0.6097	0.0059
S7	0.0001	0.2017
S8	0.1845	0.0001

[a] Each sample consists of eight discs (replicates). Each measured four times.
[b] Value >0.05 indicates heterogeneity.

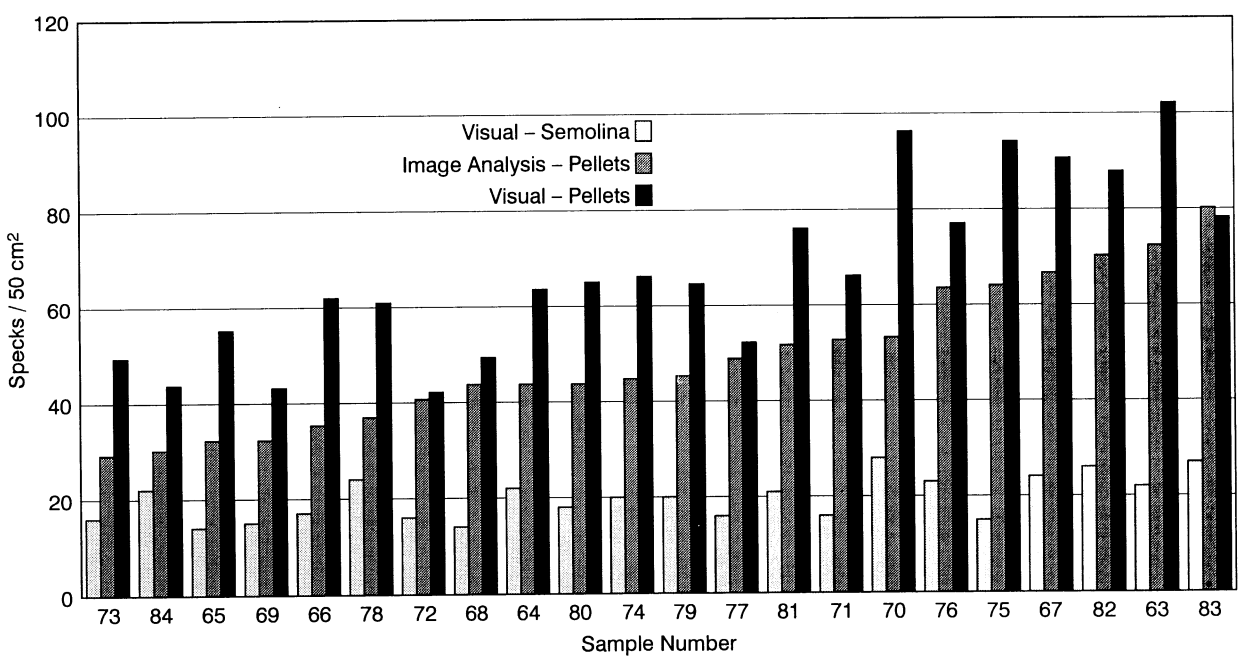

Fig. 2. Visual counts of specks in semolina and compressed pellets and image analysis counts of bran specks in compressed pellets from 22 Canada Western Amber Durum plant breeder samples. Visual semolina counts are the mean of two replicates. Pellet visual observation is the mean of four pellets for each sample. Computer-based counts are the mean of four repeated counts of four pellets for each sample. Samples in order of increasing speck counts content by image analysis.

lets, with only three of the 22 samples showing pellet-to-pellet variability (Table II). Such variability could be attributed to poor blending of the samples.

In contrast to visual assessment, the IA system was set to count only specks greater than a specific size (scrap = 20 pixels) and darker than a specific darkness (delta gray = 12). These absolute parameters would account partly for the variability between the manual and instrumental methods. To further determine how speck particle size and darkness influenced the IA system, eight of the plant breeders samples, representing a range of speckiness, were further used to investigate speck size and darkness effects on machine counting.

The magnification of the pellet surface due to instrumental optics enabled detection of very small specks. Practically, the smallest and lightest specks are not visually detected in semolina or in pasta products. By moderating particle size cut-off and particle darkness, it should be possible to calibrate the IA system to relate directly to a visual system. Three preset sizes were selected to investigate how particle size scrap levels affected IA speck counts. As expected, when the particle size cut-off was adjusted for 10, 20, or 40 pixels (1,690, 3,380, and 6,700 μm^2), there was a decrease in the number of particles counted (Fig. 3a). The particle size limits selected had no effect on the ranking of the samples. Similar speck counts at scrap = 10 and scrap = 20 were noted for sample 70. This indicates that no specks of <3380 μm^2 were detected and counted in this sample.

Darkness of the specks counted is another factor that can be measured by an IA system. The delta gray value was varied for the subset of eight plant breeders samples to set a cut-off value below the gray level (brightness) of the pellet surface. With selection for increasing darkness of specks (increasing delta gray), the number of specks counted decreased (Fig. 3b). This was anticipated, because the larger the value of delta gray, the darker the specks must be to be counted. The number of particles counted at

TABLE II
Heterogeneity of Repeated Measures and Replicated Measures for 22 Samples[a] of Semolina from Breeders Cooperative Tests Compressed into Pellets

Sample	Pr > *F* (Type I Errors)[b]	
	Repeated Measure	Replicated Discs
63	0.8426	0.6354
64	0.7584	0.6466
65	0.3588	0.2580
66	0.1814	0.1340
67	0.8224	0.1395
68	0.6770	0.1346
69	0.9851	0.3332
70	0.1816	0.0229[c]
71	0.5829	0.0373[c]
72	0.1788	0.1788
73	0.1084	0.0819
74	0.9121	0.2598
75	0.1181	0.2004
76	0.6703	0.1107
77	0.9423	0.7048
78	0.1281	0.1661
79	0.7406	0.0102[c]
80	0.5698	0.1305
81	0.9529	0.0816
82	0.8530	0.3192
83	0.8002	0.3237

[a] Each sample consists of four discs (replicates). Each measured four times.
[b] Value <0.05 indicates heterogeneity.
[c] Value showing heterogeneity.

TABLE III
Spearmans Correlation Coefficient ($\alpha = 0.5$) for Speck Counts from Eight Plant Breeders Samples at Three Delta Gray Values and a Visual Count of the Pellets

	12	15	Visual
9	0.79	0.91	0.74
12		0.94	0.88
15			0.85

TABLE IV
Coefficient of Variation (CV) of Mean Grey Value for Bran Specks Determined at Three Delta Grey Values for Eight Plant Breeder Samples

Sample	9	12	15
69	2.67	3.30	5.05
70	1.74	2.48	2.83
72	1.89	2.04	2.10
73	0.90	2.18	2.74
76	1.36	1.94	2.25
77	0.78	2.15	4.12
80	1.67	1.84	2.70
82	1.65	1.84	1.56

[a] CV based upon measurement of four replicate pellets.

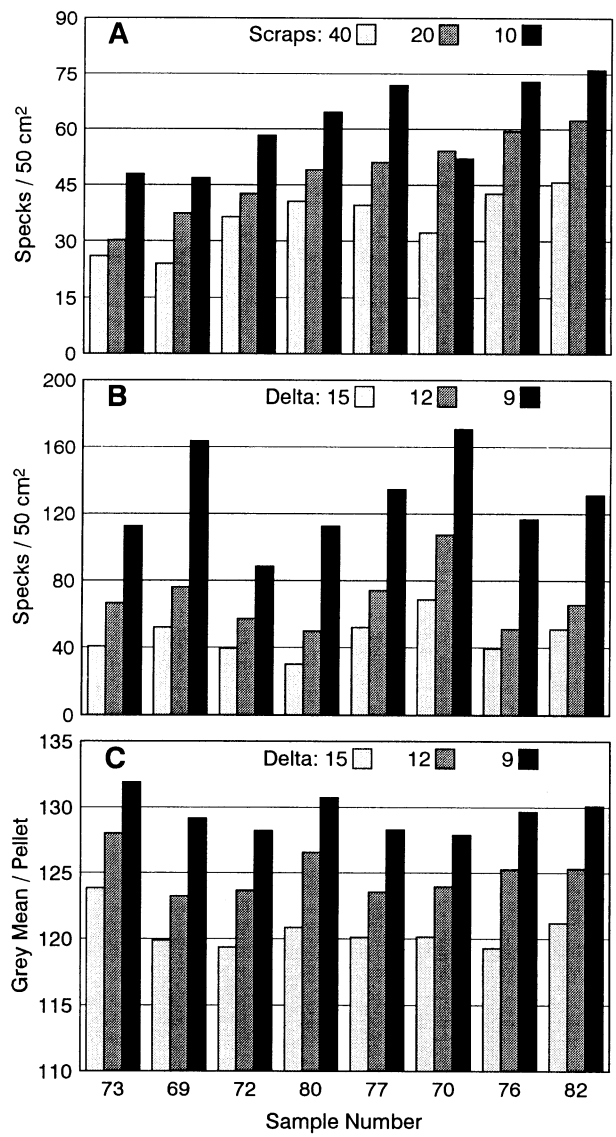

Fig. 3. Visual and image analysis counts of specks in compressed pellets from a subset of eight western Canadian plant breeder samples. **A,** Counts based on speck size of areas >1,690, 3,380, and 6,760 μm^2 (10, 20, 40 pixels); **B,** speck counts at delta gray levels of 9, 12, and 15; **C,** speck darkness (mean gray value) delta levels of 9, 12, and 15. Pellet visual observation is the mean of four pellets for each sample. Image analysis counts are the mean of four repeated counts of four pellets for each sample.

each of three delta gray values (9, 12, 15) were highly correlated (Table III). Visual counts were highly correlated to IA speck counts at higher delta gray levels (Table III) indicating that the darker particles are preferentially counted visually.

The IA method chosen for speck counting, identifies particles that are darker than the base semolina gray level for each sample, allowing for a change in brightness or color of the base semolina without the need for manually recalibrating the instrument. By determining the brightness (gray value) of the particles selected as the delta gray value was changed, the effect of the semolina base color upon the number of specks counted can be determined. For the subset of eight plant breeders samples, the mean gray values of the particles selected at three delta values was reasonably uniform, with one sample (73) showing lighter (higher gray value) specks (Fig. 3c). The coefficient of variability for the gray means at each of the three selected delta gray values was typically ≈2% (Table IV), strongly suggesting that particles could be classified according to blackness. Commercially, speck counts frequently are expressed as total specks and black specks. Black specks are more undesirable as they are highly visible in the pasta product.

Application of Image Analysis to Routine Quality Monitoring

Further verification of the IA method was achieved by examining two independent series representing all of the CWAD grades from the 1992 Canadian Grain Commission harvest survey. Increasing tolerances for physical damage due to frost and surface discoloration causes semolina speckiness to increase with lowering grades (Fig. 4a and b). For each series of samples, there was a very high correlation between the visual counts of semolina (mean results from Technicians A and B), pellets, and automated counting (SRC > 0.95, SRC > 0.97; Fig. 4a and b, respectively). The high correlation for each of the independent sample sets gave a high SRC for both sample sets combined (SRC > 0.92). Four pellets of each sample were used for automated speck counting. For both data sets, there was excellent agreement between the replicated pellets ($Pr > F > 0.8$).

Composites of Canadian export cargo samples collected during the 1993-94 shipping period were chosen to test the IA method with commercial CWAD wheat samples. Thirteen cargo samples were analyzed by visually counting specks in the semolina and pellets (mean results from Technicians A and B), and by IA of the pellets. There was general agreement between all three methods. The highest correlation was between visual and machine counts of the pellets (SRC 0.83) (Fig. 5). Correlation of semolina counts to visual pellet counts (SRC 0.65) and to machine counts of the pellets (SRC 0.70) were weaker, but still highly significant. While the ranking of samples between the three methods was not as strong as those reported in the previous data sets, these cargo samples represent a narrower range of quality compared to samples used in other experiments. Nevertheless, differences in speck counts were evident (Fig. 5).

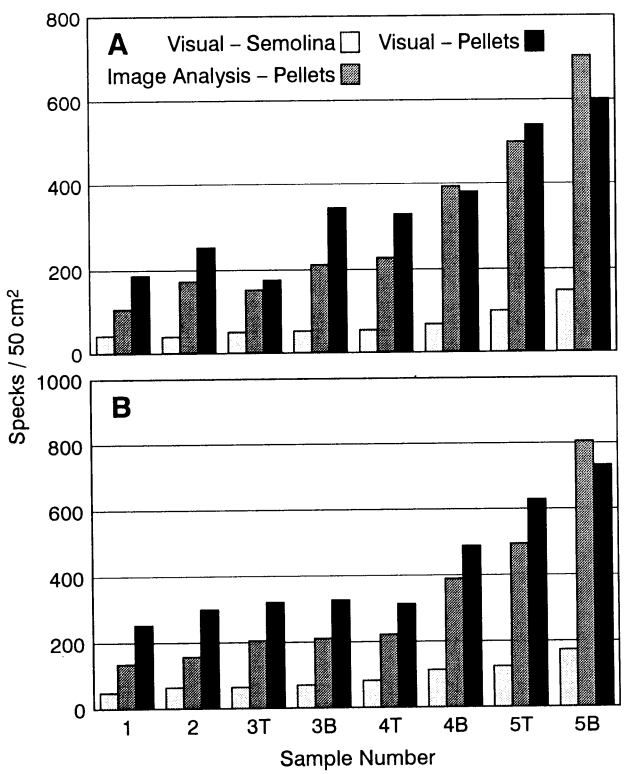

Fig. 4. Visual counts (mean of count by two technicians) of specks in semolina and compressed pellets and image analysis counts of bran specks in compressed pellets from two independent sets (**A** and **B**) of Canada Western Amber Durum (CWAD) from the 1992 harvest. Sample number represents the grade of Canada Western Amber Durum. No. 3, No. 4, and No. 5 CWAD grades are subdivided into two samples representing the top (T) and bottom (B) visual appearance. Visual semolina counts are the mean of two replicates. Pellet visual observation is the mean of four pellets for each sample. Image analysis counts are the mean of four repeated counts of four pellets for each sample. Samples in order of increasing specks by image analysis.

CONCLUSIONS

We have reported here an IA method for counting specks in semolina milled from CWAD wheats with a wide range of genotypes and growing environments. The method is robust and applicable, not only to laboratory test samples with a wide range in quality, but to CWAD cargo samples with a much narrower range of quality. The IA method can be set for a specific speck size range and darkness. Generally, changes to these two parameters affect only the number of specks counted, not the relative ranking of the samples. This method is now in use at the GRL for the routine quality monitoring of harvest survey, cargo monitoring, and plant breeder lines.

The objective parameters used by IA for counting semolina specks will facilitate direct replacement of the subjective visual methods currently used by the milling industry. Adjustment of speck size and darkness parameters will allow the IA system to reflect speck counts consistent with current visual counting systems. A computer-based IA method would provide consistent

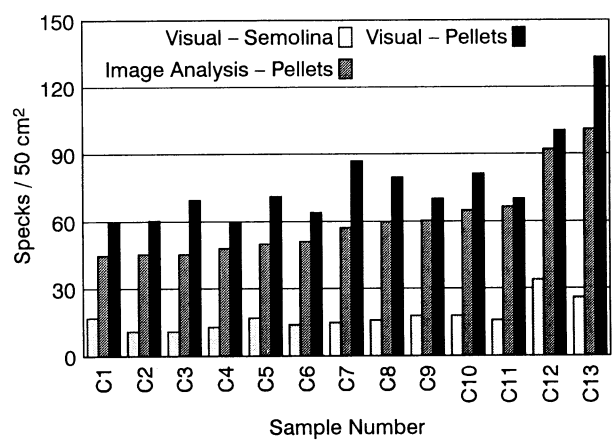

Fig. 5. Visual counts (mean of count by two technicians) of specks in semolina and compressed pellets and image analysis counts of bran specks in compressed pellets from 1993-94 Canada Western Amber Durum export composites. Visual semolina counts are the mean of two replicates. Pellet visual observation is the mean of four pellets for each sample. Computer-based counts are the mean of four repeated counts of four pellets for each sample. Samples in order of increasing specks by image analysis.

speck counts between on-site laboratories, central processing and quality control laboratories for multisite commercial companies, and different processors.

We are currently extending the IA method to classify not only total specks, but also to identify black or other colored particles in the semolina, and to extend the method to pasta and noodle speck counting.

ACKNOWLEDGMENTS

We gratefully acknowledge the expert technical assistance of R. G. Desjardins, L. C. M. Van Schepdael, J. N. Burrows, R. Daniel, M. Lymych, and C. M. Panting.

LITERATURE CITED

BLACK, H. C. 1966. Laboratory purifier for durum wheat semolina. Cereal Sci. Today 11:553.

DEXTER, J. E., and MATSUO, R. R. 1982. Effect of smudge and black-point, mildewed kernels, and ergot on durum wheat quality. Cereal Chem. 59:63.

DEXTER, J. E., and MATSUO, R. R. 1990. The spaghetti-making quality of commercial durum wheat samples with variable α-amylase activity. Cereal Chem. 67:405.

DEXTER, J. E., and TIPPLES, K. H. 1987. Wheat milling at the Grain Research Laboratory. 2. Equipment and procedures. Milling 180(7):16.

EL BOUZIRI, M., and POSNER, E. S. 1988. Farina milling: Development of an experimental flow sheet and a speck counting method. Assoc. Operative Millers Bull. 2:5393.

EVERS, T. 1993. On line quantification of bran particles in white flour. Food Sci. Technol. Today 7: 23.

HARRIGAN, K. 1995. Flour power: Microscope image analysis in the food industry. Cereal Foods World 1:11.

SAS. 1986. Linear Models. The Institute: Cary, NC.

SAS. 1988. User's Guide: Statistics, Ver 6.03. The Institute: Cary, NC.

VASILJEVIC, S., and BANASIK, O. J. 1980. Quality testing methods for durum wheat and its products. North Dakota State University: Fargo, ND.

WHITWORTH, M. 1994. Under the spotlight. International Milling Flour and Feed 188(5):10.

[Received November 27, 1995. Accepted June 12, 1996.]