Jurnal Teknologi, 44(F) Jun 2006: 41–52

COMPARISON OF GRAIN PARTICLE SIZE DISTRIBUTION IN THE SINGLE KERNEL CHARACTERISATION SYSTEM AND DURING FIRST BREAK ROLLER MILLING

IDA I. MUHAMAD[1]*, CHAOYING FANG[2] & GRANT M. CAMPBELL[3]

Abstract. Flour milling has evolved into an efficient operation; however, process modelling, simulation, and optimisation can make significant improvements to the operation. A challenge of single kernel testing using an instrument such as the Perten Single Kernel Characterisation System (SKCS) is to relate the results to actual breakage achieved during roller milling. As a step toward this, wheat varieties covering a wide hardness range were broken in the SKCS and in the Satake STR-100 test roller mill (roll gaps of 0.3 – 0.8 mm; sharp-to-sharp and dull-to-dull roll dispositions) and the resulting breakage materials were studied for the two systems. The particle size distribution (psd) produced on breakage of wheat by the SKCS itself was measured using laboratory scale plansifting, and compared with the psd produced from first break milling at different roll gaps and under different roll dispositions. Under both sharp-to-sharp and dull-to-dull milling in the roller mill, the effect of increasing kernel hardness was due to the increase in the average size of the broken particles which showed that harder kernels do not break so readily. However, milling under dull-to-dull disposition at larger roll gaps showed the average psd decreased slightly with increasing kernel hardness. This unexpected result was also observed from the SKCS. Harder kernels resulted in smaller particles in the broken material which indicates a very positive crushing action within the SKCS. The psd from the SKCS was most similar to that produced from the roller mill at a roll gap of 0.8 mm under a dull-to-dull disposition.

Keywords: Particle breakage, size reduction, wheat milling behaviour, roller mill, single kernel testing

Abstrak. Proses pengilangan tepung semakin menitikberatkan keefisienan; walau bagaimanapun, pemodelan proses, simulasi, dan optimasi akan membawa kepada pembaikan operasi yang lebih signifikan. Aspek instrumentasi kini yang berasaskan pengujian satu-kernel, contohnya alatan *Perten Single Kernel Characterisation System* (SKCS) menghadapi cabaran dari segi keupayaan menghubung-kaitkan keputusan-keputusan yang diperoleh daripada pengujian tersebut dengan pengilangan gandum sebenar menggunakan alatan '*roller milling*'. Sebagai kajian permulaan, jenis-jenis gandum yang mempunyai julat kekerasan berbeza diuji pemecahannya di dalam SKCS dan di dalam alatan '*roller mill*' Satake STR-100 (julat bukaan '*roll*' pada 0.3 mm – 0.8 mm; disposisi '*sharp-to-sharp*' dan '*dull-to-dull*'). Hasilan gandum yang dihancurkan kemudian dikumpulkan dan dianalisa bagi kedua-dua sistem alatan. Taburan saiz partikel diukur menggunakan alatan pengayak skala makmal. Keputusan dibandingkan di antara hasilan kedua-dua sistem SKCS dan '*first break roller milling*' tersebut pada bukaan dan disposisi roll yang berlainan. Pada kedua-dua disposisi penggilingan '*sharp-to-sharp*' dan

[1] Faculty of Chemical & Natural Resources Engineering, Universiti Teknologi Malaysia, 81310 UTM, Skudai, Johor, Malaysia
[2&3] Satake Centre for Grain Process Engineering, Department of Chemical Engineering, UMIST, Manchester, UK
* Corresponding author: Tel: +607-5535541, Fax: +607-5581463, Email: idayu@fkkksa.utm.my

'*dull-to-dull*', didapati bahawa peningkatan nilai kekerasan kernel meningkatkan purata saiz partikel-partikel hasil penggilingan. Ia menunjukkan kernel-kernel yang lebih keras sukar untuk dipecahkan. Walau bagaimanapun, penggilingan pada disposisi '*dull-to-dull*' menggunakan bukaan *roll* yang lebih besar menghasilkan purata taburan saiz partikel yang lebih kecil dengan pertambahan kekerasan kernel gandum. Keputusan yang tidak dijangka ini turut diperoleh daripada alatan SKCS. Kernel yang lebih keras dipecahkan menjadi partikel-partikel tergiling yang lebih kecil menunjukkan tindakan pemecahan yang positif dalam alatan SKCS tersebut. Taburan saiz partikel daripada SKCS didapati paling hampir dengan partikel hasilan '*roller mill*' pada bukaan roll 0.8 mm dengan disposisi '*dull-to-dull*'.

Kata kunci: Pemecahan partikel, penurunan saiz, pengilangan gandum, corak penggilingan, '*roller mill*', pengujian satu-kernel

1.0 INTRODUCTION

Sugden and Osborne [1] described wheat milling process as breaking the kernel to release the endosperm and separate the bran using repeated size reduction and separation operations. Hence good milling performance means highly efficient separation of bran from the floury endosperm is achieved and good quality flour is produced for desirable end-use. The first break, the initial stage in wheat milling, opens the wheat kernels such that the bran particles tend to remain large while the endosperm particles are smaller, allowing ease of separation by size using plansifters. The first break roller mills comprise pairs of counter-rotating fluted rolls operating under a speed differential of up to 2.7:1 with a small gap between the rolls. First, break roller milling produces a wide range of particles from <200 μm to >2000 μm, and directly affects the subsequent system arrangement and succeeding operations [2]. The study of the first break, therefore, is an ideal starting point to understand and determine the effectiveness of the whole milling process. Campbell *et al.* [3] emphasized on the physicochemical properties of the wheat (size distribution, moisture content, kernel hardness) and the settings of the milling equipment which affect wheat breakage during first break roller milling.

The Perten Single Kernel Characterization System (SKCS 4100) is a sound and readily usable device which gives information on physicochemical properties of wheat hardness, weight, diameter, and moisture content prior to conditioning and milling [4]. Figure 1 shows the operating mechanisms of the SKCS 4100. The SKCS 4100 measures kernel hardness by crushing the kernels one at a time, recording the profile required to crush the kernel, and reporting the average force for crushing 300 kernels, in terms of a hardness index [5]. The force-deformation profile during the crushing of the kernel and the conductivity between the rotor and the electrically isolated crescent are measured against time. The information is algorithmically processed to provide the weight, size, moisture, and hardness of the kernel [6].

Previous studies on the application of SKCS data for wheat classification have shown potential for determining wheat quality parameters and desirable baking performance [5 - 8]. Gaines *et al.* [6] reported on the uniformity of SKCS hardness as the potential of

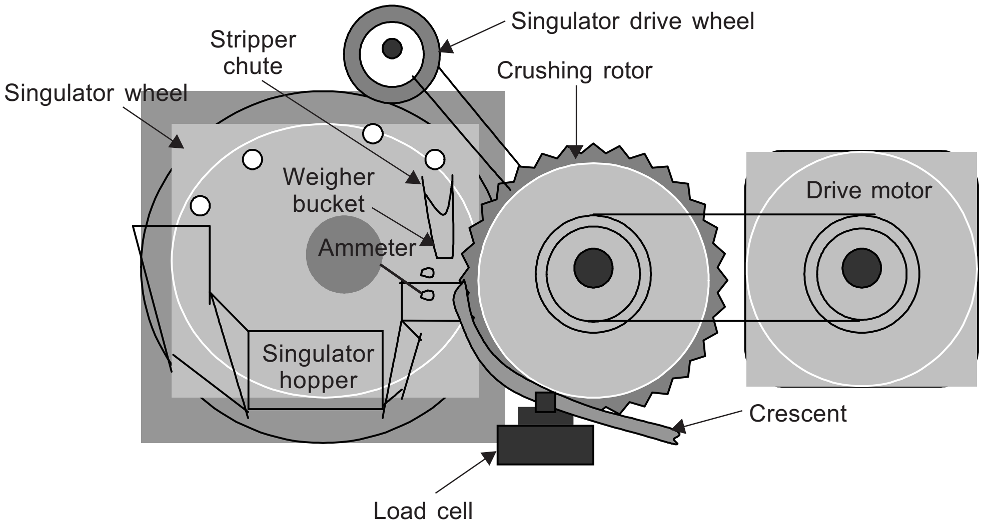

Figure 1 Single Kernel Characterisation System (SKCS 4100) operating mechanisms

the wheat to provide a consistent milling performance. Ohm *et al.* [9] reported that in relation to milling and baking quality, the SKCS characteristics were significantly correlated to conventional wheat quality parameters such as test weight, kernel density, and kernel sizing. Sissons *et al.* [10] demonstrated successful application of the SKCS data to the analysis of durum wheat in a breeding program. Some studies also indicated that useful equations might be derived from SKCS data to predict flour yield [7], milling quality characteristics [6], and a direct causal relationship between wheat kernel hardness and flour starch damage potential [8]. Campbell and Webb [11] noted that grains mill independently during first break milling and developed a breakage equation useful to predict the milling performance of a heterogenous mixture of grains from knowledge of their single kernel characteristics.

Previous researchers linked the wheat physical properties data obtained from the SKCS to first break grinding and evaluated the performance of the first break roll by the particle size characteristics of the milled wheat and the energy consumed [12, 13]. However, Scanlon and Dexter [14] noted that the energy consumption during milling depends heavily on the mill adjustments. Fang and Campbell [15, 16] studied the nature of the stresses and strains occurring during first break roller milling and reported on the effect of roll disposition on the breakage patterns of wheat kernels and the resultant size distributions. During milling, the breakage of wheat kernels during first break roller milling depends on many factors, including the disposition of the fluted rolls. Dull-to-dull gives slippage between the flutes and the kernel, and thus imparts less shear strain than sharp-to-sharp. The planes with principal strain are shown in Figure 2.

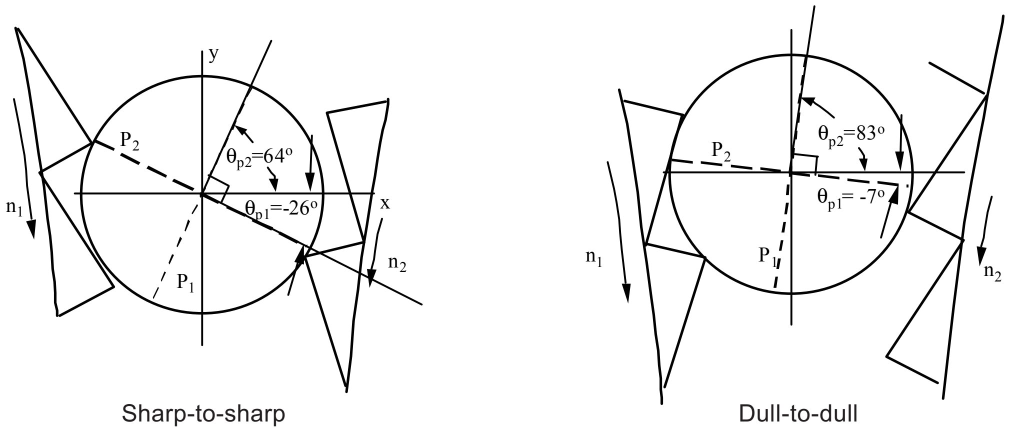

Figure 2 Forces experienced by kernels during sharp-to-sharp and dull-to-dull roller milling

Studies on the design and application of both roller milling equipment and SKCS have long been reported. However, relatively little work has been done to link breakage in the SKCS to the actual breakage in the roller milling.

The objective of this study is to investigate the breakage of wheat kernels in the SKCS and roller mill and to compare the resultant particle size distribution (psd) from both systems. As the test in the SKCS is a destructive type, it results in milled fractions of the test wheat which are usually discarded. This work aims at broadening the use of the SKCS from different point of view by measuring the psd of the milled fractions and comparing them to the psd from the actual mill operation using the roller mill.

2.0 MATERIALS AND METHODS

Nineteen samples of wheat of different hardnesses were used in this study. Table 1 shows the average physical properties of the samples as measured by the Single Kernel Characterization System (SKCS model 4100, Perten Instruments AB, Sweden).

Before milling, 100 grams of each dry wheat sample was conditioned overnight to reach 16% (optimum) moisture content, wet basis; this toughens the bran and germ and softens the endosperm, making the separation of endosperm from germ and bran easier. Then, the moist wheat was allowed to temper for at least 16 hours to give an even distribution of moisture.

Sample breakage: All samples were milled in both the SKCS and Satake STR-100 roller mill (Satake Corporation, Japan).

SKCS: Conditioned samples were loaded into the SKCS (Perten Instrument SKCS 4100) to be broken using the procedure according to the operating manual [17].

Table 1 The SKCS properties of nineteen varieties of wheat used in the study

Wheat variety	Weight (mg)	Diameter (mm)	Hardness index	Moisture content (%)
Consort	48.35	3.01	11.2	15.80
Claire	40.80	2.66	24.6	16.20
Riband	51.36	3.11	27.6	15.87
Drake	46.36	2.83	29.2	15.72
Crofter	51.06	2.98	42.0	15.89
Soissons	44.12	2.91	52.2	15.94
Raleigh	48.57	2.99	58.5	15.65
Charger	45.90	2.89	59.3	15.66
Abbot	45.32	2.95	61.1	15.65
Buster	52.01	3.33	62.7	15.65
Avalon	53.51	3.05	62.8	15.86
Malacca6	44.02	2.93	63.2	16.17
Hereward	43.54	2.92	65.3	15.56
Rialto	50.58	3.08	65.7	15.82
Brigadier	51.03	3.02	67.1	15.51
CWRS	31.11	2.39	71.5	15.91
Mercia	44.28	2.90	73.6	15.54
Cadenza	56.32	3.35	76.9	15.80
Spanish	45.19	2.81	80.4	16.72

Roller mill: Each sample was milled in a random order on the Satake STR-100 test roller mill under sharp-to-sharp (S-S) and dull-to-dull (D-D) dispositions and at six roll gaps (0.3, 0.4, 0.5, 0.6, 0.7, and 0.8 mm). The roll gaps were set using a feeler gauge. The entire mill stocks from each trial were collected for sieve analysis. After each sample breakage was completed, broken samples were collected and kept in individual sealed polyethylene bags for further analysis.

Sieving: Samples were sieved for 5 min on a Simon sifter oscillated at 190 rpm with a throw of 7.5 cm, using 200 mm diameter wire mesh sieves of 2000, 1700, 1400, 1180, 850, 500, and 212 μm along with a bottom pan. The mass fraction of particles staying on each sieve in the stack divided by the difference between the aperture size of the sieve and that of the adjacent larger sieve gives the probability density function. The cumulative percentage of particles undersize was calculated to obtain the cumulative psd. Cumulative psd's from the SKCS and from the roller mill were compared for all nineteen varieties.

3.0 RESULTS AND DISCUSSION

3.1 Comparing SKCS with Roller Miling

Figure 3 shows the example of the cumulative psd's for soft wheat, Consort obtained from the SKCS and the roller mill under different roll dispositions dull-to-dull and sharp-to-sharp at roll gap 0.3 mm. Milling under a dull-to-dull disposition gave a distribution with more larger and smaller particles, and fewer in the middle size range.

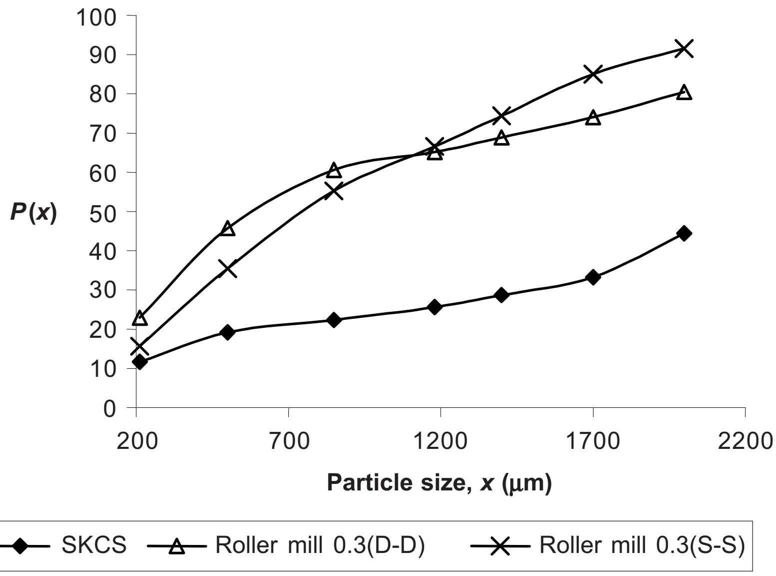

Figure 3 Cumulative size distribution of Consort wheat from different milling operations

By contrast, a sharp-to-sharp disposition gave a relatively uniform size distribution over the particle size range of 212 – 2000 μm. Clearly, the degree of breakage that occurred in the SKCS was much lower compared to both from the roller mill.

Figures 4(a) and (b) show an example of the comparison of psd's from the SKCS and the roller mill at different roll gaps and dispositions for Consort wheat. The percentage of breakage occurred in the SKCS was much lower compared to the roller mill. Milling under a sharp-to-sharp disposition (Figure 4(b)) consistently produced uniform size distribution relative to the psd from milling under a dull-to-dull disposition (Figure 4(a)). Clearly, larger roll gaps produced less breakage of wheat kernels. The effect of roll gap was to change the balance between large and small particles [16]. Comparing both figures, it was observed that the dull-to-dull disposition result was much closer to the line of equivalence than that from sharp-to-sharp. The closest agreement was obtained at the largest roll gap, 0.8 mm, under dull-to-dull milling. This indicates that the psd produced from breakage in the roller mill at a roll gap of 0.8 mm under a dull-to-dull disposition is the closest to the psd resulting from breakage in the SKCS.

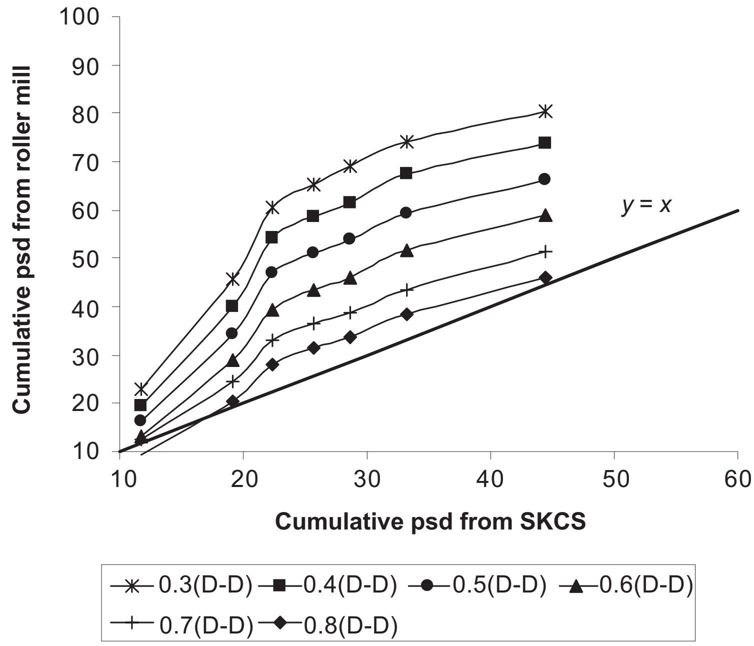

Figure 4(a) Comparison of psd from roller milling Consort at different roll gaps under a dull-to-dull disposition with the psd obtained from the SKCS

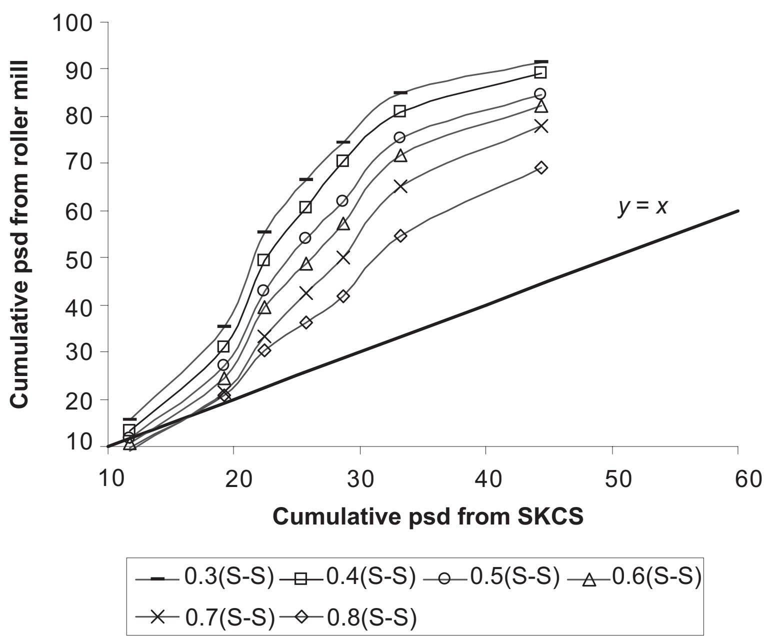

Figure 4(b) Comparison of psd from roller milling Consort at different roll gaps under a sharp-to-sharp disposition with the psd obtained from the SKCS

3.2 Comparing Breakage of Wheats of Different Hardnesses

To investigate this observation further, psd's from four representative varieties of varying hardness values (Consort (11.2), Drake (29.2), Buster (62.7), and CWRS (71.5)) were plotted against the SKCS data. Figure 5 shows the comparison at roll gaps 0.3, 0.6, and 0.8 mm under dull-to-dull and sharp-to-sharp roll dispositions. Clearly, under

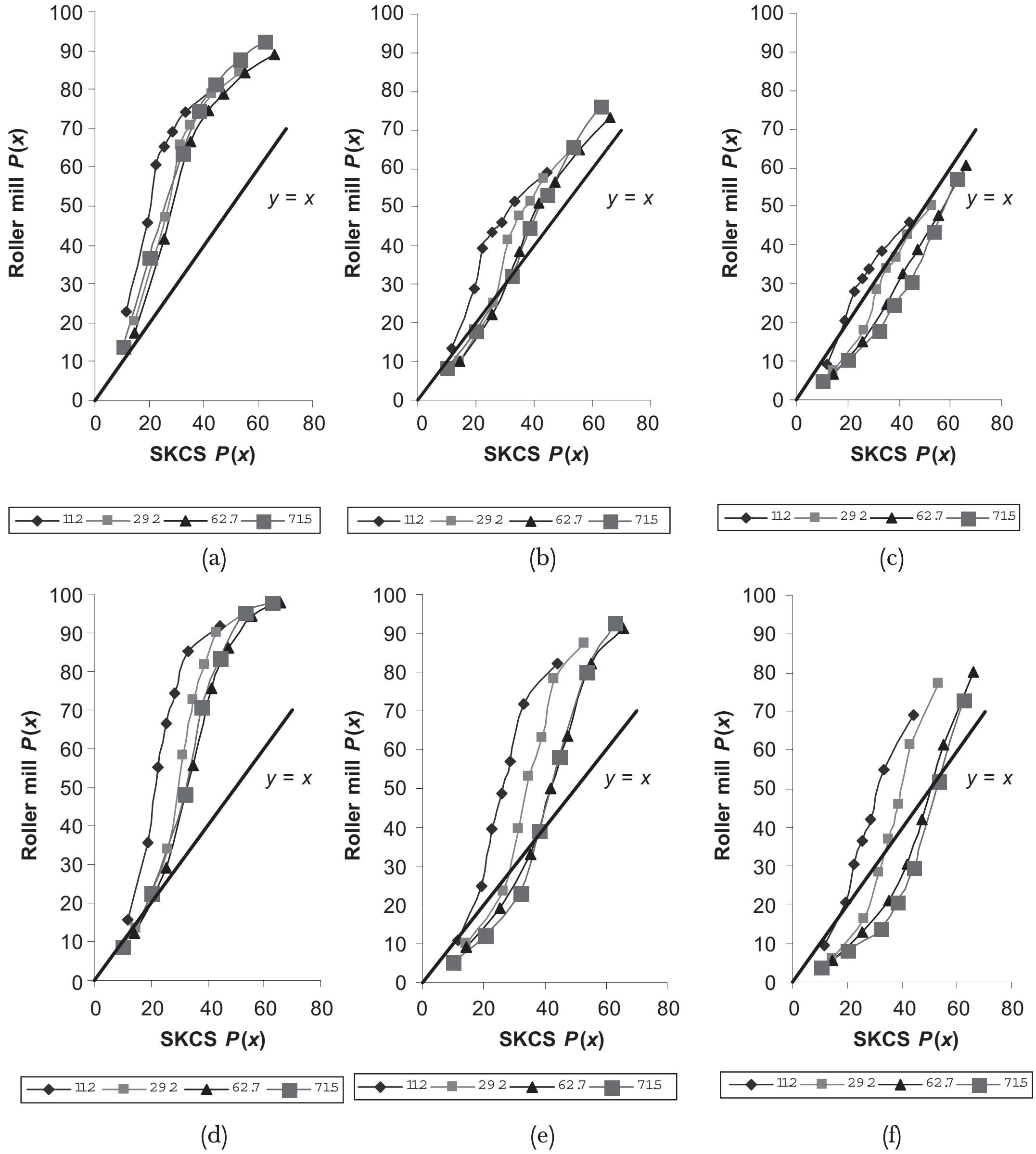

Figure 5 Comparison of cumulative particle size distributions from SKCS and roller mill at roll gaps: (a) 0.3, D-D; (b) 0.6, D-D; (c) 0.8, D-D; (d) 0.3, S-S; (e) 0.6, S-S; (f) 0.8, S-S

disposition sharp-to-sharp in the roller milling, the average size of the broken particles increased with the increase in kernel hardness. The same result was observed from dull-to-dull milling except at larger roll gaps, for which the average psd decreased slightly with increasing kernel hardness. This unexpected result was also observed from the SKCS, that harder kernels resulted in smaller particles in the broken material. This indicates a very positive crushing action within the SKCS.

The particle size below which 50% of the particles fall is defined as x_{50}. Similarly, the particle size below which 25% of the particles fall is defined as x_{25}. Figure 6 shows the values of x_{50} and x_{25} for all 19 wheat varieties, for the output from both the SKCS and the roller mill at 0.8 mm, dull-to-dull. Clearly the values of x_{50} and x_{25} were very similar for both systems across a range of hardness values. Interestingly, there is only a very slight effect of hardness on the resulting particle size, indicating that the actual breakage in the SKCS, or in dull-to-dull milling at a large roll gap, is relatively insensitive to wheat hardness. In the case of the SKCS, this indicates a design that gives a very positive and consistent crushing action to all wheat varieties.

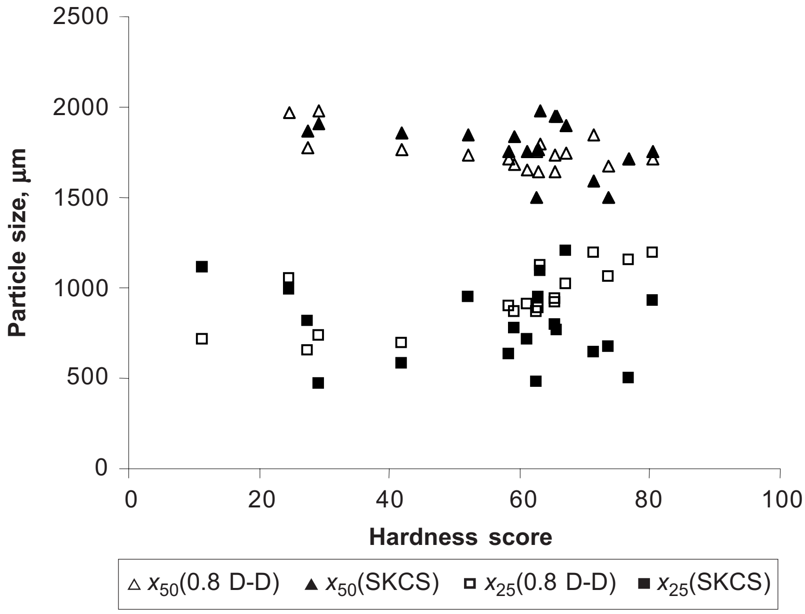

Figure 6 Comparison of x_{50} and x_{25} from the SKCS and the roller mill (0.8 mm, D-D) for a range of values of wheat hardness

This new approach in studying and utilizing the information from the SKCS, opens an alternative way of relating single kernel parameters to actual milling in the roller mill. The findings will add to the use of SKCS information as a tool for millers or researchers aiming to understand and control the first break roller milling operation.

4.0 CONCLUSIONS

Wheat was milled into a more uniform psd under a sharp-to-sharp roller disposition over the particle size range of 212 – 2000 μm than that was produced from milling under a dull-to-dull disposition. However, milling under dull-to-dull disposition gave a distribution with more larger and smaller particles, and fewer in the middle size range.

The particle size distribution from the SKCS was most similar to that produced from the roller mill at the largest roll gap of 0.8 mm under a dull-to-dull disposition.

The effect of increasing kernel hardness in the roller milling, under disposition sharp-to-sharp was to increase the average size of the broken particles. The same effect was true for dull-to-dull milling. However, at larger roll gaps, the average psd decreased slightly with increasing kernel hardness. This unexpected result was also observed from the SKCS, that harder kernels resulted in smaller particles in the broken material. This indicates a very positive crushing action within the SKCS.

ACKNOWLEDGEMENTS

The authors are grateful to the Engineering and Physical Sciences Research Council UK (EPSRC grant no. GR/M49939), Universiti Teknologi Malaysia, Skudai and Satake Corporation of Japan for the support in this study.

REFERENCES

[1] Sugden, T. D., and B. G. Osborne. 2001. Wheat Flour Milling. In *Cereals and Cereal Products: Chemistry and Technology*. Edited by D. A. V. Dendy, and B. J. Dobraszczyk. Maryland: Aspen Publ. Inc. 140-181.

[2] Smith, L. 1994. *Flour Milling Technology*. 3rd Ed. Northern Liverpool, England.

[3] Campbell, G. M., P. J. Bunn, C. Webb, and S. C. W. Hook. 2001. On Predicting Roller Milling Performance, Part II: The Breakage Function. *Powder Technology.* 115(3): 243-255.

[4] Williams, P. C., D. Sobering, J. Knight, and J. Psotka. 1998. Application of the Perten SKCS-4100 Single Kernel Characterisation System to Predict Kernel Texture on the Basis of the Particle Size Index. *Cereal Foods World* (Abstract). 43(7): 550.

[5] Martin, C. R., R. Rousser, and D. L. Brabec. 1993. Development of a Single-kernel Wheat Characterization System. *Trans. ASAE.* 36: 1399-1404.

[6] Gaines, C. S., P. F. Finney, L. M. Fleege, and L. C. Andrews. 1996. Predicting a Hardness Measurement Using the Single-Kernel Characterization System. *Cereal Chemistry.* 73(2): 278-283.

[7] Satumbaga, R., C. Martin, D. Eustace, and C. W. Deyoe. 1995. Relationship of Physical and Milling Properties of Hard Red Winter Wheat Using the Single-kernel Wheat Characterization System. *Assoc. Operative Tech. Bull.* January: 6487-6496.

[8] Osborne, B. G., R. Jackson, and S. R. Delwiche. 2001. Rapid Prediction of Wheat Endosperm Compressive Strength Properties Using the Single-Kernel Characterisation System. *Cereal Chemistry.* 78(2): 142-143.

[9] Ohm, J. B., O. K. Chung, and C. W. Deyoe. 1998. Single-Kernel Characteristics of Hard Winter Wheats in Relation to Milling and Baking Quality. *Cereal Chemistry.* 75(1): 156-161.

[10] Sissons, M. J., B. G. Osborne, R. A. Hare, S. A. Sissons, and R. Jackson. 2000. Application of the Single-kernel Characterization System to Durum Wheat Testing and Quality Prediction. *Cereal Chemistry.* 77(1): 4-10.

[11] Campbell, G. M., and C. Webb. 2001. On Predicting Roller Milling Performance, Part 1: The Breakage Equation. *Powder Technology.* 115(3): 234-242.

[12] Pasikatan, M. C., E. Haque, Keller-McNutty, J. L. Steele, Q. Fang, C. K. Spillman, and W. Gao. 1998. Single Kernel Wheat Physical Properties and First-Break Grinding. ASAE Mid-Central Conference. April 24-25, 1998, Missouri.

[13] Pujol, R., C. Letang, I. Lempereur, M. Chaurand, F. Mabille, and J. Abecassis. 2000. Description of a Micromill with Instrumentation for Measuring Grinding Characterisation of Wheat Grain. *Cereal Chemistry.* 77(44): 421-427.

[14] Scanlon, M. G., and J. E. Dexter. 1986. Effect of Smooth Roll Grinding Conditions on Reduction of Hard Red Spring Wheat Farina. *Cereal Chemistry.* 63(5): 431-435.

[15] Fang, C., and G. M. Campbell. 2002a. Stress-strain Analysis and Visual Observation of Wheat Kernel Breakage During Roller Milling Using Fluted Rolls. *Cereal Chemistry.* 79(4): 511-517.

[16] Fang, C., and G. M. Campbell. 2002b. Effect of Roll Fluting Disposition and Roll Gap on Breakage of Wheat Kernels During First-break Roller Milling. *Cereal Chemistry.* 79(4): 518-522.

[17] Perten Instruments. 1995. *SKCS 4100 Single Kernel Characterization System*. Perten Instruments Instruction Manual. North Am., Reno, NV: Perten.