An automated seed presentation device for use in machine vision identification of grain

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Jayas, D.S., Murray, C.E. and Bulley, N.R. 1999. **An automated seed presentation device for use in machine vision identification of grain.** Can. Agric. Eng. **41**:113-118. A kernel positioning system was designed and fabricated to automatically pick up and separate kernels of various grain types. The system was tested for its ability to separate kernels of four grain types: wheat (cv. 'Katepwa'), barley (cv. 'Manley'), canola (cv. 'Tobin'), and lentils (cv. 'Eston'). Wheat and barley were tested at three different moisture contents and canola was tested at two moisture contents. To determine if the system had any bias to the selecting of certain seeds, mixtures of different grain types were also used in the tests. The system successfully picked up and separated kernels of wheat, barley, canola, and lentils. The system's ability to pick up and separate kernels was not influenced by moisture content. In mixtures of grains (e.g., barley in wheat at 1, 3, and 5% levels by mass), there was no significant difference in the number of imageable wheat kernels. The system, however, had a bias to pick more kernels of the major grain component present in the mixtures of wheat and canola.

Un système automatique pour la séparation des grains a été conçu, fabriqué et testé sur quatre types de grains: le blé (cv. 'Katepwa'), l'orge (cv. 'Manley'), le canola (cv.'Tobin') et la lentille (cv. 'Eston'). Le blé et l'orge ont été testés avec trois différents taux d'humidité alors que seulement deux ont été utilisés avec le canola. Pour déterminer si le système avait une tendance à sélectionner certains grains au détriment des autres lorsque ces derniers étaient mélangés, différents mélanges ont été testés. Dans tous les cas, le système a réussi à séparer correctement les quatre types de grains malgré le fait qu'ils étaient mélangés dans différentes proportions. Le système n'a pas été influencé par le taux d'humidité des grains. Dans les mélanges d'orge contenant du blé dans des proportions de 1, 3 et 5% (de la masse), aucune différence significative dans le nombre visible de grains de blé n'a pu être démontrée. Le système avait cependant une tendance à sélectionner les grains majoritaires dans les mélanges de grain de blé et de canola.

INTRODUCTION

Morphological, optical, and textural features of various grain types have been measured using machine vision systems (MVSs) by many research groups (e.g., Neuman et al. 1987; Symons and Fulcher 1988a, 1988b; Zayas et al. 1989). The MVS is more precise and efficient in measuring dimensions of seeds than trained inspectors working with a microscope (Churchill et al. 1992). Paulsen et al. (1989) used an MVS to accurately determine the lengths, widths, and projected areas of maize kernels. The measured features have been used for seed identification. Sapirstein et al. (1987) obtained reasonably high levels of precision for classification of kernels of clean wheat, barley, oats, and rye. Hehn et al. (1991) were able to identify kernels of canola and mustard. Using morphological features, Shatadal et al. (1995) identified kernels of hard red spring wheat and barley from kernels of large seeds (buckwheat, pea beans, black beans, lentils, green peas) and small seeds (canola, mustard, flaxseed) found in typical grain samples. In 1993, Agro Vision, Lund, Sweden, announced a machine vision system for assessing the purity of grain samples (GrainCheck 310) (Egelberg et al. 1994).

In general, the use of MVS for grain identification has been limited to the closely controlled conditions of a laboratory. Most experiments were performed on seeds which were manually placed on some type of plate or tray and then moved into the field of view (FOV) of the imaging equipment. Such a procedure is tedious and labour intensive when a large number of seeds in a representative sample of the bulk grain are to be analyzed. For example, a representative 1 kg wheat sample, obtained from a railcar containing about 80 t of wheat, has about 30 000 kernels.

Therefore, the objectives of this study were: (i) to design and fabricate an automated kernel positioning system capable of mechanically picking up and separating kernels for presentation to a camera for imaging and (ii) to test the system for its ability to pick and separate kernels from bulk grain samples which differ in moisture content and composition.

DESIGN PROCESS

Development of design criteria

The developed seed-separation system (Fig .1) works basically on the principle that seeds are attracted and held onto the surface of a perforated plate due to a vacuum. The plate is moved and the seeds are released when the vacuum is broken.

To design a working prototype, it was first necessary to determine some of the design criteria. Experiments were conducted for the determination of design parameters using a simple vacuum drum device similar in principle to a system developed by Nyborg et al. (1972). The following design criteria for the final design (Fig. 1) were developed from these experiments.

1. The peripheral velocity of the drum should be about 9.6 m/s in order for seeds of various shapes to be adequately held on to orifices.
2. The slope of the hopper for presentation of bulk seeds to the drum should be approximately equal to the angle of repose.

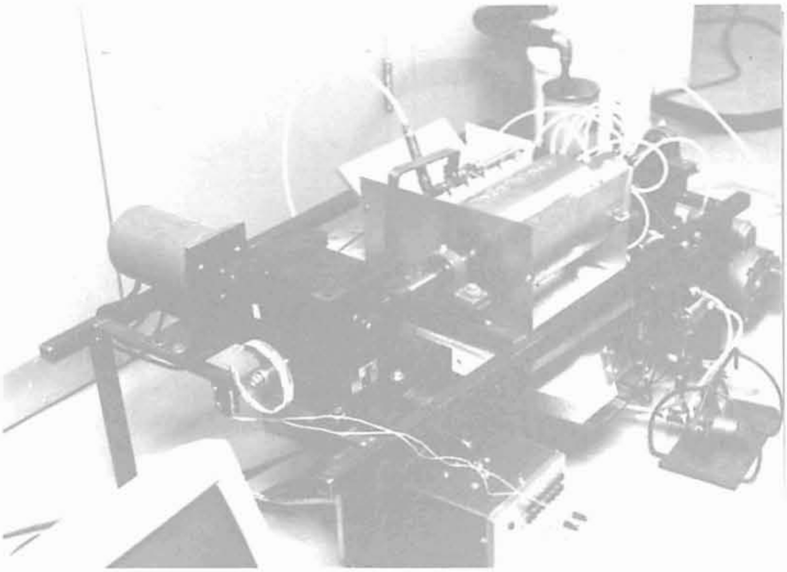

Fig. 1. Assembled components of a seed singulation and presentation device.

3. The hopper should be filled so that a minimum of the bottom third of the drum face is in contact with the seeds. Seeds should be distributed evenly across the face of the drum.
4. The orifices drilled with a No. 59 drill (1.04 mm diameter) proved effective in holding seeds of various shapes and sizes (wheat, barley, oats, canola, soybeans, and lentils). Machining a 60° indent on the backside of the orifices caused no noticeable effect on the effectiveness of the orifices but facilitated easier cleaning of the plate.
5. The orifice plates required indents machined around each orifice to keep round seeds from rolling off the plates when the vacuum was cut. A minimum indent diameter of 19.1 mm and a depth of 0.25 mm were found suitable.
6. A 60° diverging air brush, drilled with a No. 62 root hole (0.97 mm diameter), mounted a maximum of 25.4 mm from the vacuum drum face and pressurized to 130 to 150 kPa (abs) was found to work effectively to reduce the multiple kernels picked up at the orifices. Testing revealed that barley was the most sensitive to air brush positioning.
7. A vacuum of 40 to 50 kPa (abs) was necessary to ensure that at least one seed was held per orifice.
8. A scavenging pressure of 120 to 140 kPa (abs) was required to clean the orifices.

Final design

The above design criteria were incorporated into the final design of the device (Fig. 1). The device consisted of a vacuum drum, a vacuum and pressure unit, a rotary air valve, a positioning unit, a controlling unit, and a seed hopper. In the vacuum drum, 6 brass plates were used with five equally spaced orifices in each plate. A 19.1-mm diameter and 0.25-mm deep indentation was machined around each orifice to prevent the seeds from rolling off the plate when the vacuum was cut. These plates were attached longitudinally on the cylinder drum surface over the circumference. A channel was machined beneath each seed plate. These channels exited one end of the drum via drilled holes to plastic hoses. The device utilized both compressed air and vacuum during each cycle. The compressed air was supplied by a commercial air compressor unit. The vacuum was supplied by an Edwards E1M18 (Edwards High Vacuum, Burlington, ON) single stage direct drive vacuum pump which had an ultimate pressure of 2 Pa vacuum and a displacement of 415 L/min. To reduce the potential for an oil film to build up on the equipment, a 20-L pail filled with fibreglass insulation was attached to the outlet port of the vacuum pump to catch the oil mist and a fan was connected to the pail to remove the exhaust fumes. A series of solenoids was used to control the differential pressure across the orifices of each individual seed plate. The rotary air valve consisted of a brass cylinder with 6 holes, drilled in through an end, which were used for connecting the channels beneath the seed plates to the air sources. The vacuum drum was mounted on a shaft running at the central axis of the cylinder through the brass insert. The shaft had bearings on either side fixed to a frame. Therefore, when the shaft was turned, the drum and connecting valve sleeve rotated while the brass insert remained fixed. The shaft was connected to an output shaft of a 10:1 reducer gearbox with a Lovejoy coupler. The input shaft of the gearbox was in turn connected by a Lovejoy coupler to a high-torque 72-rpm Slo-syn synchronous motor. This motor was capable of stopping within 5° of shaft rotation (reduced to 0.5° by the gearbox) when power was interrupted. This allowed the motor to be used for accurately positioning the drum. A personal computer was used to control the solenoids and the AC motor.

MATERIALS and METHODS

Experimental design

The testing of the system was performed using four types of seeds, differing in size, shape, and surface roughness at various moisture contents and for mixtures of seed types. Certified seeds were obtained in 45 kg and 25 kg bags from Proven Seed, Winnipeg, MB. The selected seed types were: wheat (cv. 'Katepwa'), barley (cv. 'Manley'), canola (cv. 'Tobin'), and lentils (cv. 'Eston') at moisture contents of 13.5, 12.8, 8.7, and 9.1% wet mass basis (wb), respectively. To determine the effects of moisture content on the system's ability to pick up and separate kernels, additional tests were done for wheat at 15.6 and 17.3%, for barley at 14.2 and 16%, and for canola at 10.3% moisture content. Five repetitions were done for each test. In each test, the objective was to determine the number of single or multiple seeds picked per test and the frequency of zero seeds or foreign material picked per test.

In the second group of tests, wheat was mixed with three different levels of barley (wheat-barley combination), barley with three different levels of wheat (barley-wheat combination), canola with three different levels of wheat (canola-wheat combination), and wheat with one level of canola (wheat-canola combination). In each mixture, the secondary grain was 1, 3, and 5% of the sample by mass except for the wheat-canola combination when only 5% canola level

Table I. Seed separation results for wheat, barley, canola, and lentils at various moisture contents.

Crop and 'cultivar'**	Moisture content (% wb)	Expected number of seeds	Mean ± SD* of occurrence				
			Single kernels***	Double kernel	Three or more kernels	Zero kernels	Foreign material
Wheat 'Katepwa'	13.5	115	108.0 ± 3.2 a	1.8 ± 0.4 a	0.6 ± 0.9 a	4.4 ± 2.1 a	0.2 ± 0.4 a
	15.6	115	104.2 ± 4.2 a	4.2 ± 1.9 b	0.6 ± 0.9 a	5.0 ± 2.5 a	1.0 ± 0.7 b
	17.3	115	103.8 ± 1.3 a	4.6 ± 0.9 b	0.4 ± 0.9 a	3.8 ± 1.1 a	2.4 ± 0.9 c
Barley 'Manley'	12.8	115	89.8 ± 8.3 a	2.6 ± 1.1 a	0	22.0 ± 7.7 a	0.8 ± 0.8 a
	14.2	115	89.0 ± 8.5 a	6.0 ± 1.7 b	0.2 ± 0.4	17.8 ± 7.3 a	2.0 ± 2.0 a
	16.0	115	93.6 ± 2.9 a	6.2 ± 1.9 b	0	13.4 ± 4.2 a	1.8 ± 2.9 a
Canola 'Tobin'	8.7	115	112.8 ± 1.8 a	0.6 ± 0.9 b	0.6 ± 0.5 a	1.0 ± 2.2	0
	10.3	120	115.4 ± 1.1 b	1.8 ± 0.8 a	2.8 ± 1.3 b	0	0
Lentils 'Eston'	9.1	115	102.8 ± 3.5	3.4 ± 1.5	0	7.8 ± 5.7	1.0 ± 1.0

*SD = standard deviation based on n=5

**Masses of 1000 kernels (mean ± SD, based on three replicates) were 31.260 ±0.264, 42.697 ±1.614, 2.078 ±0.041, and 34.386 ±0.536 g for wheat (13.0% mc), barley (12.8% mc), canola (8.7% mc), and lentils (9.1% mc), respectively.

***Means in a column group followed by the same letter (a,b,c) do not differ significantly from each other at the 5% level of significance.

was used. These combinations were formed by manually mixing the desired amounts of seeds.

The evaluation of the developed system on mixtures was done based on the numbers of the kernels picked and separated for each seed type from bulk mixtures. To convert the number percentages in the mixtures of seed types to percentages based on mass, masses of 1000 randomly selected kernels were determined for each seed type using an electronic balance with 0.001 g resolution. Three replicates were performed for each seed type and average masses and standard deviations were determined.

Conditioning of samples

To increase the moisture content of the samples to higher selected levels, predetermined amounts of water were lightly sprayed over the seeds spread out on a plastic sheet. The samples were then thoroughly mixed and sealed in plastic bags. The samples were stored at approximately 16°C for 48 h to ensure uniform distribution of the moisture in the seeds. Moisture contents of the samples were measured using ASAE Standard S352.2 (ASAE 1993). For lentils, the standard for edible beans given in ASAE Standard S352.2 was used.

Test procedure

For each experimental test, a grain sample to be analyzed was removed from storage and thoroughly mixed. Approximately 1500 mL of grain were taken from the sample container and poured into the hopper using a slow side to side motion parallel to the drum face. The desired number of drum revolutions were entered at the computer prompt and the system was activated. As each seed plate passed through the vertical position, the drum was stopped and vacuum was released. The number of single, double, and triple (or more) kernels retained per orifice, the number of empty orifices, and the number of orifices retaining foreign material were counted and recorded. For the second group of tests, the number of "imageable" kernels (multiple kernels that were separated in the indentation when vacuum was released) and frequency of grain type picked were also counted and recorded. Once a replicate was completed, the grain was returned to the sample container. The grain for a second and subsequent replicates was then mixed and placed in the hopper in the same manner.

RESULTS and DISCUSSION

Effect of grain class and moisture content

The mean (based on five replicates) number of single, double, and three (or more) kernels retained on the orifices per test and the mean number of empty orifices and orifices retaining foreign material are given in Table I. Means were compared using a t-test with α=0.05 to determine if any significant differences existed between the various moisture contents for each seed type. No significant difference in the number of single kernels picked per test occurred as the moisture content of wheat was increased from 13.5% to 17.3% (Table I). The occurrence of single kernels picked per test varied from 90.3% to 93.9%. No significant difference was found in the number of single kernels picked for barley at three moisture contents (12.8, 14.2%, and 16.0%). The frequency of single kernels retained was in the range of 77.4% to 81.4% (Table I), which was lower than that of wheat. It was noticed that barley was more prone to being blown off as it passed the airbrush. This

Table II. Seed separation results for mixtures of seeds.

Composition		Expected number of seeds	Mean ± SD* of occurrence				
Primary (% mc) (Secondary % mc)	Percent of secondary by mass		Single kernels**	Double kernel	Three or more kernels	Zero kernels	Foreign material
Wheat (12.5 - 13.0) (Barley 12.8)	1	120	109.2 ± 2.7 a	5.6 ± 1.5 a	0.8 ± 0.8 a	3.4 ± 2.4 a	1.0 ± 1.0 a
	3	120	109.0 ± 3.4 a	5.8 ± 1.3 a	0.6 ± 0.9 a	3.0 ± 2.5 a	1.6 ± 1.1 a
	5	120	112.2 ± 2.3 a	4.2 ± 2.9 a	0.6 ± 1.3 a	2.4 ± 0.4 a	0.6 ± 0.9 a
Barley (12.8) (Wheat 13.5)	1	120	95.8 ± 5.8 a	5.4 ± 3.0 a	0.2 ± 0.4 a	16.4 ± 4.7 a	2.0 ± 1.9 a
	3	120	97.8 ± 5.8 a	6.2 ± 2.7 a	0.2 ± 0.4 a	14.0 ± 4.6 a	1.8 ± 1.6 a
	5	120	97.6 ± 8.8 a	6.8 ± 1.8 a	0.4 ± 0.5 a	18.0 ± 6.0 a	5.2 ± 5.4 a
Canola (8.7) (Wheat 13.5)	1	120	115.2 ± 2.2 a	1.6 ± 0.9 a	3.2 ± 1.5 a	0	0
	3	120	115.4 ± 1.8 a	1.6 ± 0.5 a	3.0 ± 1.6 b	0	0
	5	120	115.0 ± 2.0 a	1.6 ± 1.5 a	3.4 ± 1.8 a	0	0
Wheat (13.5) (Canola 8.7)	5	120	113.0± 3.0	4.2 ± 1.9	0.8 ± 0.8	1.6 ± 1.8	0.4 ± 0.9

*SD = standard deviation based on n=5

**Means in a column group followed by the same letter (a,b,c) do not differ significantly from each other at the 5% level of significance.

was reflected in the higher number of empty orifices during a test (zero kernels) (Table I).

In the context of using the system for singulating kernels for viewing with a camera, a zero kernel response is not a major problem because it results in one less kernel viewed in the image. The system can be operated until a desired number of kernels is viewed. In contrast, double or triple kernels may result in touching kernels necessitating further separation.

For canola, it was found that the number of single kernels retained per test did differ significantly as the moisture content was increased from 8.7% to 10.3%. The percentage of canola picked at 8.7% moisture content was 98.1%. This dropped to 96.2% as the moisture content was increased to 10.3%. With such a high level of separation in each case, it is reasonable to assume that the difference can be neglected. The percentage of single kernels of lentils (9.1% moisture content) being retained was 89.4%.

Effects of combining seeds at various levels of mixture

Table II summarizes the separation results for mixtures of seeds. It was observed that no difference existed between the number of single kernels retained during a test when wheat was the primary grain and barley was mixed at 1, 3, and 5% by mass (Table II). The mean percentages of single kernels retained for the three mixture levels varied between 90.8% and 93.5% similar to the percentages obtained for wheat with no addition of barley (Table I).

When barley was the primary constituent, the percentage of single kernels picked varied from 79.8 to 81.9% (Table II) similar to the percentages obtained for barley with no addition of wheat (Table I). There was no difference in the number of single kernels picked per test with an increase in the amount of wheat.

The combination of canola with increasing levels of wheat showed no change in the number of single kernels retained (Table II). The number of single kernels retained (between 95.8% and 96.2%) was similar to the number retained when no wheat was added to canola (Table I). In the mixture of wheat with 5% canola by mass 94.2% single kernels were retained.

The results on the distribution of grain types are given in Table III. The numbers of imageable kernels (Table III) were higher than the number of single kernels (Table II) in each case. For wheat-barley combinations, there was no significant difference in the number of imageable wheat kernels as the level of barley in the sample was varied (Table III). From a practical point of view, a sample of wheat from a railcar will be identified as a wheat sample if it contains up to 5% barley. The number of barley kernels picked was greater than the number in the prepared mixture. For example, when the mixture had 0.73% barley kernels on number basis, the system picked 1.36% barley kernels.

In the barley-wheat combinations, the number of imageable barley kernels decreased when the amount of wheat was 5%. However, considering the high levels of barley kernels picked, this difference is not of practical importance because a sample from a railcar would still be identified as containing barley.

Canola was picked almost exclusively when combined with small levels of wheat. Between 97.3 and 98.8% of the kernels

Table III. Seed separation results for mixtures of seeds in terms of class distribution and imageable kernels.

Composition		Expected number of seeds	Mean ± SD* of occurrence				
Primary (% mc) (Secondary % mc)	Percent of secondary by mass **		Kernels suitable to image***	Wheat kernels	Barley kernels	Canola kernels	Foreign material
Wheat (12.5 - 13.0) (Barley 12.8)	1 (0.73)	120	118.0 ± 1.6 a	115.2 ± 2.8 a	1.6 ± 1.7 a	-	1.2 ± 1.1 a
	3 (2.21)	120	120.6 ± 1.8 b	112.4 ± 3.0 a	6.6 ± 1.1 b	-	1.6 ± 1.1 a
	5 (3.71)	120	117.6 ± 1.9 a	109.0 ± 2.3 a	7.8 ± 1.6 a	-	0.8 ± 1.3 a
Barley (12.8) (Wheat 13.5)	1 (1.36)	120	105.2 ± 5.6 a	2.0 ± 2.0 a	101.2 ± 4.1 a	-	2.0 ± 1.9 a
	3 (4.06)	120	107.6 ± 3.5 a	2.2 ± 1.3 a	103.6 ± 3.3 a	-	1.8 ± 1.6 a
	5 (6.71)	120	102.6 ± 7.3 a	6.2 ± 2.6 b	91.0 ± 11.1 b	-	5.4 ± 5.4 a
Canola (8.7) (Wheat 13.5)	1 (0.071)	120	118.6 ± 2.4 a	0	-	118.6 ± 2.4 a	0
	3 (0.205)	120	118.0 ± 2.5 a	0	-	118.0 ± 2.5 a	0
	5 (0.349)	120	117.0 ± 2.6 a	0.2 ± 0.4	-	116.8 ± 2.6 a	0
Wheat (13.5) (Canola 8.7)	5 (44.2)	120	120.4 ± 3.4	92.4 ± 4.8	-	27.6 ± 8.2	0.4 ± 0.9

*SD = standard deviation based on n=5

**Numbers in parentheses are the percent of secondary grain based on the number of kernels calculated from the 1000 kernel mass for each seed type

***Means in a column group followed by the same letter (a,b,c) do not differ significantly from each other at the 5% level of significance.

picked were canola with no significant difference resulting as wheat levels increased from 1% to 5%. Since the number of wheat kernels picked is small, it can be concluded that the device is biased in favour of picking small kernels. In wheat-canola (95% wheat and 5% canola by mass) combination, only 23% canola kernels were picked from the expected 44%. Based on canola-wheat or wheat-canola mixture results, it can be concluded that the system has a bias to pick more kernels from the larger component of the mixture when it contains seeds from widely separated sizes.

CONCLUSIONS

The following conclusions were drawn from this study.

1. The automated kernel positioning system successfully singulated kernels of the four types of seeds tested: wheat, barley, canola, and lentils.
2. Moisture content had negligible effect on the number of single kernels picked.
3. There was no difference in the number of single kernels retained per test as the level of secondary grain in the mixtures varied from 1% to 5%.
4. In general, there was no difference between the number of kernels of primary grain picked as the secondary levels of grain varied from 1% to 5%.
5. For mixtures containing seeds of widely separated sizes, the system had a bias to pick more kernels from the larger component of the mixture.

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