Development of a new crop lifter for direct cut harvesting dry bean

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Zyla, L.E., Kushwaha, R.L. and Vandenberg, A. 2002. **Development of a new crop lifter for direct cut harvesting dry bean**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**:2.9-2.14. The development of a new concept crop lifter for direct-cut harvesting narrow-row dry bean is reported. The crop lifter employs a series of bristles mounted to the cutterbar guard that is positioned perpendicular to the direction of harvester travel. The bristles lift and tilt low-hanging bean pods away from the plant stem preventing them from being cut, thereby reducing losses. To counter the higher resistance to plant flow through the bristle-guards, two reel bat designs were evaluated on a reduced diameter parallel-state pickup reel. Although the target loss of 10% of yield in 'Othello' pinto bean was not attained, losses were as low as 15% of yield. A combination of plant breeding and improved direct-cut harvest technology should ensure that an expanded dry bean industry in Saskatchewan is developed. **Keywords**: harvest, harvest loss, beans, edible beans, attachment, direct cut, cutterbars, guards.

Dans cet article, on rapporte le développement d'un nouveau modèle de releveur pour la récolte en coupe directe de haricots secs semés en rangs étroits. Le releveur est muni de poils montés sur le protecteur de la barre de coupe, et placés perpendiculaire à la direction de déplacement de la récolteuse. Les poils soulèvent et inclinent les gousses placées au bas des plants pour les éloigner de la tige, les empêchant ainsi d'être coupées. Les pertes à la récolte s'en trouvent réduites. Afin de contrer la résistance créée par le passage des plantes à travers les poils du protecteur, deux types de rabatteurs à lattes ont été évalués sur un tambour-ramasseur de diamètre réduit. Bien que le pourcentage de pertes de haricots pinto "Othello" visé de 10% n'ait pas été atteint, les pertes ont été aussi faibles que 15%. La sélection de cultivars et l'amélioration des technologies de récolte directe devraient permettre à l'industrie du haricot sec de la Saskatchewan de se développer. **Mots-clés**: récolte, pertes à la récolte, haricots comestibles, équipement, coupe directe, barre de coupe, protecteur.

INTRODUCTION

Dry bean, *Phaseolus vulgaris L.*, is an important pulse crop (edible legume) in many parts of the world. It is a nutritious and relatively inexpensive source of protein for people in Central America and parts of South America, Africa, Asia, and Europe. In North America, dry bean is typically sold as canned baked beans, refried beans, chilli, and in bags (dry) for soups. World area production was 24.7 million ha in 1997 (FAOSTAT 1997) with 0.7 million ha grown in the United States and 0.09 million ha grown in Canada. Of the more than fifteen market classes of dry bean listed by the United States Department of Agriculture (Hardman and Meronuck 1982), pinto is the most important commercial class. Other important classes include navy (pea or white bean), great northern, pink, kidney, small red, and black.

The row-crop production method described by McColly (1958), Pickett (1974), and Smith (1986) is used for a majority of the dry bean production in North America. Seed is planted in rows spaced 560 to 760 mm apart. Weed control is by inter-row cultivation and pesticides are applied to the rows with a band sprayer. At harvest, the plants are cut below, or pulled from, the soil surface by an undercutter that may be a blade-type cutter or rod-type puller. After undercutting, the plants are windrowed and harvested with a combined gathering and threshing unit called a combine. Alternatively, the undercut rows are gathered directly by a combine equipped with multiple windrow pickup units. The time between undercutting and combining varies and is dependent upon local weather conditions. Smith (1986) found that under-cut harvest losses varied from 1 to 13% for 20 growers of dry bean in Nebraska.

An alternative to row-crop production is the direct-cut or narrow-row production method commonly used for production of cereal and oilseed crops, where seed is planted in rows spaced 150 to 300 mm apart with pesticides applied to the entire field area. At harvest, the plants are cut and gathered with a combine, or cut and windrowed, allowed to dry, and then gathered with a combine. Advantages of direct-cut harvesting include lower equipment costs, reduced incidence of soil erosion and combine wear, and generally cleaner seed with less damage. A disadvantage of direct-cut harvesting is the excessive gathering losses that occur when the cutterbar cuts through pods positioned close to ground level.

In the 1970s, an attempt to establish a dry bean industry in South Saskatchewan Irrigation District #1 was unsuccessful when potential growers were unwilling to invest in the row crop equipment required (Vandenberg 1991). Successful development of lentil production in the 1980s prompted a renewed interest in dry bean and a breeding program was begun to develop a pinto bean variety with improved canopy structure, determinate growth habit, and non-shattering pod type. Whatley (1992) monitored production of 'Othello' pinto bean by Saskatchewan growers and found that gathering losses were typically greater than 40% of yield. This project was undertaken to develop an attachment for a combine or windrower that would reduce direct-cut gathering losses in 'Othello' pinto bean to 10% or less.

LITERATURE REVIEW

McColly (1958) reported gathering losses of 9.0% in navy bean, but the sickle had to be operated in the soil 40% of the time.

Fig. 1. Early bristle-guard attached to tabletop carriage.

Fig. 2. Single-bat design showing belting and bristle combination.

During dry conditions, losses of 23.2% were recorded. Gunkel and Anstee (1962) evaluated a modified row-crop head. Rubber fingers attached to v-belts were operated on an incline to comb through the vines and lift pods over a reciprocating cutterbar. Two conical, rotating brushes were later added to a similar device and positioned on each side of the row to sweep pods up vertically. The brushes clogged with plant material during testing.

Gunkel and Anstee (1962) evaluated a modified snap bean harvester. Preliminary results were encouraging, but the literature did not reveal a continuation of the work. A flat belt puller attachment, consisting of two 460 mm wide belts held together under spring tension, also was evaluated. The belts, positioned on each side of the row, captured bean plants and pulled them from the soil on an incline. Losses were 30% of conventional, but the device was not advanced to a commercial product.

The increasing importance of soybean to the United States cropping scenario provided impetus for improvements to direct-cut harvesting equipment. These included the flexible floating cutterbar (Neal 1978), the narrow-pitch combine cutterbar (Quick and Buchele 1974; Quick and Mills 1978), the integral flexible cutterbar (Bichel et al. 1976), and the row-crop soybean header (Bichel and Hengen 1978). Air-jet guards, consisting of nozzles positioned in front of the cutterbar to direct seed and pods into the harvester, were also evaluated (Nave et al. 1972, 1977; Tunnell et al. 1973; Wait et al. 1974; Nave and Yoerger 1975).

Researchers soon began investigating the potential of improved soybean harvesting equipment in dry bean. Smith and Biere (1985) compared the integral flexible floating cutterbar to undercutting and found gathering losses to be 25 and 9.0%, respectively. Harrigan et al. (1991) reported gathering losses of 8.3% in 'Mayflower' navy bean using an integral flexible floating cutterbar equipped with pickup reel and modified air reel. Comparable losses for rod and blade-type cutting were 3.9 and 4.6%, respectively. Zyla (1993) evaluated air-jet guards in 'Othello' pinto bean. Gathering losses were reduced from 50% of yield for the standard equipment to 39% for the air-jet guards.

MATERIALS and METHODS

Equipment design and laboratory evaluation

Bristle-guard A hand-operated, tabletop carriage was constructed to study plant characteristics and reduce the number of design parameters. It was noted that a vertical distance of approximately 100 mm existed between the tops of pods positioned within the cutting zone and ground level. Taking advantage of this distance, bristles were attached to a cutterbar guard to lift and tilt the lower pods forward, preventing them from being cut, and exposing the plant stem to the cutterbar. Individual bean plants were fastened to the floor of the carriage and bristle-guards employing bristles of different density, material, orientation, and length were visually evaluated (Fig. 1).

An International Harvester Model 93 combine (International Harvester Co., Chicago, IL), equipped with a 3 m direct-cut header and a six-bat parallel-state pickup reel (H. D. Hume Co., Mendota, IL), was subsequently used for preliminary laboratory tests. Drives to all parts of the combine except the header were disconnected. Mature 'Othello' pinto bean plants, collected from a site near Saskatoon, Saskatchewan were fastened to a conveyance platform that was pulled under the header to simulate forward motion of the combine. Gathering losses were determined by collecting the seed from each test and expressing the mass of lost seed as a percentage of the total mass of seed.

Reel Laboratory tests revealed that the bristle-guards offered greater resistance to plant flow through the cutterbar than standard guards. To counter this resistance, additional reel support for the plants was needed and three design changes were proposed. Firstly, the conventional reel fingers were replaced with a belting and bristle combination to improve support by preventing plants from passing between the fingers (Fig. 2). The bristles (1.4 mm diameter polypropylene, 20 mm depth) served to sweep loose seed into the header. The belting, (5 mm, 2 ply semi-rough polyvinyl chloride), trimmed 25 mm above the bottom of the bristles, prevented the bristles from being cut when the reel was operated close to the cutterbar.

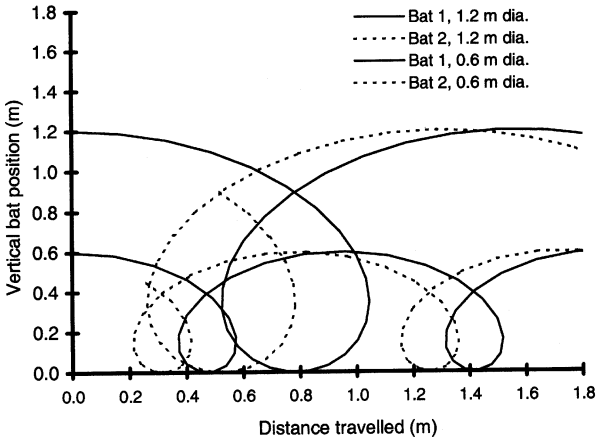

Fig. 3. Travel path for reel bats of 1200 mm and 600 mm diameter reels; reel speed index of 2.0. For clarity, only two bats for each reel are shown.

A second design change arose after evaluation of the effect of reel diameter on plant support. The travel path of a reel bat traces an extended cycloid in profile for reel speed indexes greater than 1.0. Reel speed index is defined as the ratio of reel peripheral speed to forward travel speed and is typically 1.25 to 1.5 under most conditions in upright crops (Kepner et al. 1978). While increasing reel speed index decreases the distance between bat contact, the risk of plant damage from higher reel bat velocities is increased. To overcome this difficulty, a 600 mm diameter reel was constructed. Figure 3 shows the travel path for a standard 1200 mm diameter reel and for a modified 600 mm diameter reel on a right hand Cartesian co-ordinate system with the positive X axis horizontal to the right and the positive Y axis directed vertically upward. At a reel index of 2.0, the distance between bat contacts for the 1200 mm diameter reel is 315 mm and for the 600 mm diameter reel it is 157 mm. The reel index of 2.0 was chosen, by experience, to be a maximum value for the 1200 mm diameter reel before plant damage occurs.

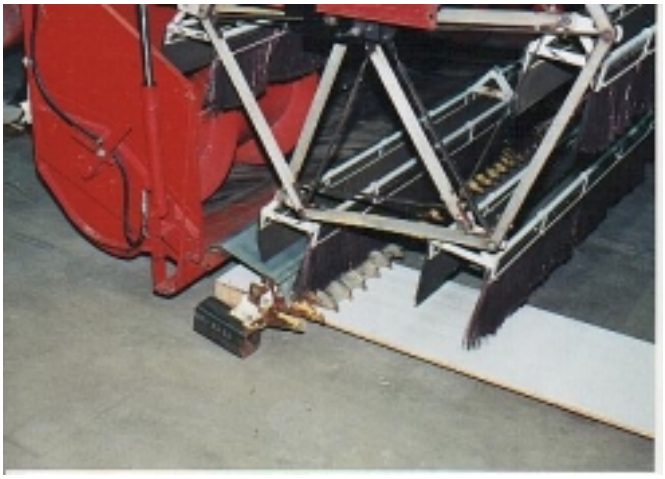

Fig. 4. Double-bat installed on modified 600 mm diameter reel.

Fig. 5. Bristle-guards installed on floating cutter bar. Some bristles have been removed for illustration purposes.

The third design change proposed for improved plant support was construction and evaluation of a double-bat (Fig. 4). The double-bat consisted of a belting and bristle combination similar to that used in the single-bat design, along with a second bat of belting only. Since the distance from the centre of rotation to the bat position for this reel is unchanged, the net horizontal impact velocity was unchanged from that of the single-bat.

Field evaluation

Equipment A floating cutterbar (Hart Carter Co., Peoria, IL) and rear discharge collection system were installed on the test combine to obtain a consistently low cutting height and to prevent contamination of threshing losses with gathering losses. Bristle diameter (0.31 mm) and density (3.2 bristles per mm, or 800 bristles over two layers) were selected to balance ease of crop feed with pod lift effectiveness. Figure 5 shows the bristle guards installed on the floating cutter bar of the combine, and Fig. 6 shows the completed header.

Fig. 6. Combine header with double-bats and 600 mm diameter reel installed.

Table 1. Test parameters for Saskatoon site.*

Class	Levels	Values
Guard	2	bristle-guard, standard guard
Reel bat	2	single-bat, double-bat
Travel speed (km/h)	2	2.5, 4.0
Reel speed index	3	1.6, 2.0, 2.4

*Number of replicates = 3

Bristle-guards (modified) were compared with standard guards (control). The single-bat and double-bat designs were interchanged on the modified 600 mm diameter reel during field evaluations. Optimal reel and header heights were obtained during preliminary trials and subsequently used for field evaluations.

Site data The experiment was conducted on a 0.6 ha plot of 'Othello' pinto bean at Saskatoon, Saskatchewan. Estimates of pre-harvest loss were obtained by collecting the shattered seed from six randomly chosen, 1.0 m^2 areas. Whole plants were then collected from the same sample areas to obtain an estimate of yield.

The collected plants were threshed and the seed separated from the plant material. The seed collected for pre-harvest loss and yield estimates was then dried according to ASAE Standard S352.2 (ASAE 1991) and adjusted to 16% moisture content wet basis (wb).

Pod clearance, defined as the percentage of pods hanging entirely above 40 mm from ground level, was estimated to be 50% for the 1994 growing season. A cutting height of 40 mm is considered a typical minimum for a direct-cut harvester.

Field testing began when approximately 75% of the pods were mature and was completed over a two-day period to minimise variability in crop maturity and moisture content. The site was free of weeds and had an estimated yield of 2800 kg/ha, with negligible pre-harvest loss.

Gathering losses were sampled by randomly tossing a 1.0 m^2 measuring frame into the sample area. Lost seed was then collected from within the frame and separated according to shatter, stalk, and stubble loss. Shatter loss is defined as loose seed on the ground; stalk loss is defined as seed attached to broken stems, but lying on the ground; stubble loss is defined as seed still attached to standing stubble (Quick and Buchele 1974). The collected seed was then dried and adjusted to 16% moisture content (wb).

Pod moisture content, an important indicator of susceptibility to shatter loss during harvest, was obtained by collecting samples of threshed pods and determining moisture content according to ASAE Standard S352.2 (ASAE 1991). Mean pod moisture content during testing was 12.3% with a standard deviation of 1.4%.

Experimental design. A completely randomised split-plot design was chosen with 2 x 2 main plot factors of guard type and reel bat type and 3 x 2 sub-plot factors of reel speed index and travel speed. There were three replications for each trial. Table 1 lists the levels and values of each factor in the experiment. Three loss samples were collected from each replication.

RESULTS and DISCUSSION

The preliminary laboratory evaluations revealed that effectiveness of pod lift by the bristle-guards was dependent upon pod orientation relative to the plant stem and harvester travel direction. Pods in the cutting zone that were positioned in front of or immediately behind the central stem were not reliably tilted, thereby increasing the number of pods cut by the cutterbar. However, an examination of the plants after completion of the laboratory trials revealed that the stem was often cut above the lowest pod indicating that the bristles were effectively lifting pods at the side of the stem. A plant with pods positioned away from the central stem was recommended to reduce the number of pods directly in front of and immediately behind the stem. This characteristic was targeted for incorporation into a new bean variety (Vandenberg et al. 1997).

For the field test data, a significant difference between the single-bat and double-bat designs was not detected at the 5% significance level (Table 2). Therefore, subsequent discussion focuses on the single-bat design only. Furthermore, for reasons of efficiency during commercial production, the single-bat design would be chosen over the double-bat design.

Table 2. Analysis of variance for test parameters at Saskatoon.

Source of variation[a]	Degrees of freedom	Sum of squares	Mean square	Computed F[b]	Pr >F
Guard (GRD)	1	1773	1773	6.43*	0.0350
Reel bat (BAT)	1	66	66	0.24	0.6385
GRD x BAT	1	20	20	0.07	0.7955
Error (M)	8	2207	276		
Travel speed (SPD)	1	95	95	1.84	0.1825
Reel speed index (IND	2	193	97	1.87	0.1675
SPD x IND)	2	182	91	1.76	0.1851
M x S	15	688	46	0.89	0.1115
Error (S)	40	2069	52		

[a] M,S = main plot and subplot, respectively
[b] * = significant at 5% probablity level

Gathering losses for the bristle-guards varied from 15 – 24%, with a mean of 18% (S.D. = 4.3%) (Figs. 7 and 8), while gathering losses for the standard guards varied from 26 – 33%, with a mean of 29% (S.D. = 2.6%). It was apparent from the plotted data that shatter losses comprised the largest portion of the gathering losses, and there did not appear to be a difference between the stubble and stalk

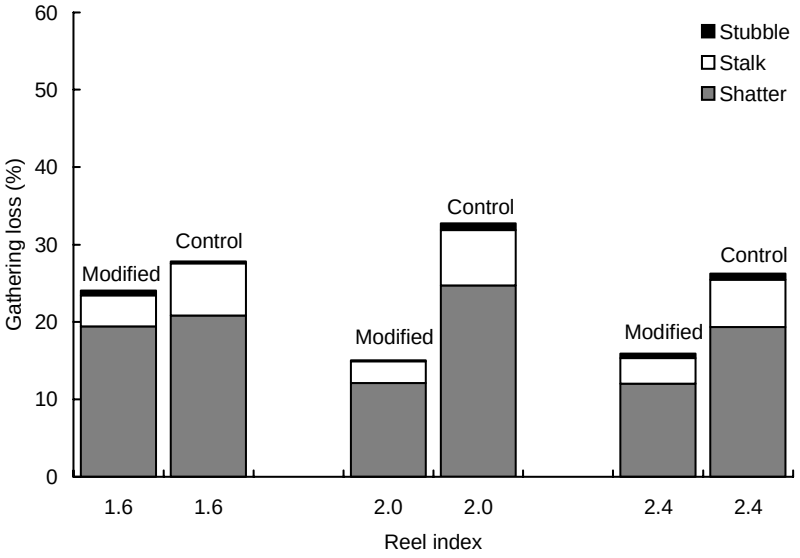

Fig. 7. Gathering losses at Saskatoon, single-bat, 2.5 km/h travel speed.

losses. Therefore, the analysis of variance considered the total of these components or gathering losses only.

The analysis of variance (SAS Institute Inc. 1985) revealed a significant reduction in gathering losses for the bristle-guard over the standard guard ($\alpha = 0.05$). Increasing travel speed from 2.5 to 4.0 km/h did not increase losses ($\alpha = 0.05$). No other treatment or interaction effects were significant at the 5% significance level. An irregular soil surface may have contributed to higher gathering losses. It was noted that plants were growing within drill runs that were at times 40 mm deep.

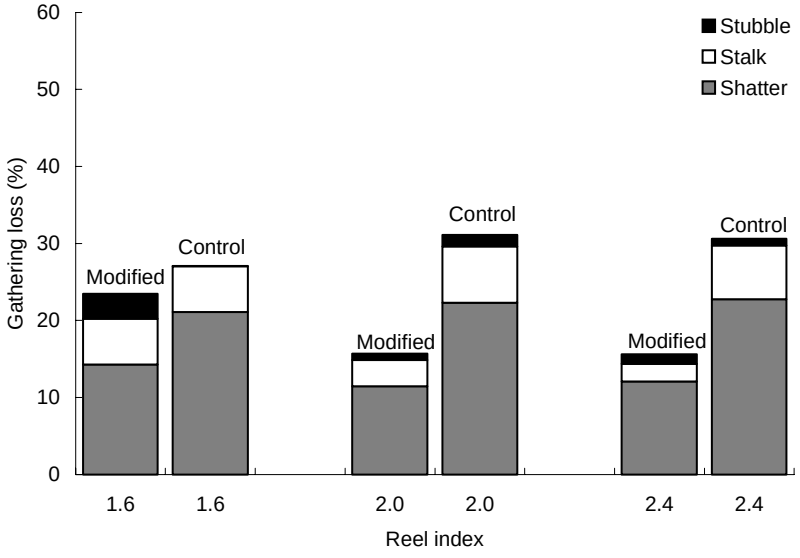

Fig. 8. Gathering losses at Saskatoon, single-bat, 4.0 km/h travel speed.

SUMMARY

Replicated field trials of a new crop lifter for dry bean were conducted in 1994. A series of bristles was mounted laterally to the top of the guard point to lift and tilt lower pods away from the cutterbar. Mean losses in 'Othello' pinto bean were 18% for the crop lifter, identified as a bristle-guard, and 29% for the standard guard. A majority of the gathering loss was comprised of shattered seed.

The increased resistance to material flow through the bristle-guard necessitated evaluation of two different bat types with a reduced diameter reel. Replacement of the standard reel fingers with a belting and bristle combination improved contact with the bean plants. A double-bat design, chosen to offer more support for the plants, was evaluated but showed no improvement over the single-bat design. A theoretical analysis showed that the reduced diameter reel offers additional support for bean plants in the bristle-guard system with less opportunity for plant damage.

A subjective evaluation of the bristle-guards during preliminary laboratory trials has shown that their effectiveness may be reduced during harvest of plants with pods that are positioned in front of or behind the stem relative to the direction of harvester travel. In varieties with pods positioned away from the stem and higher in the canopy losses would likely be lower. New varieties, being developed at the University of Saskatchewan, will have both an improved architecture for direct-cut harvest and improved pod structure for reduced shatter. The combination of bristle-guard technology and plant breeding improvements should ensure the development of an expanded dry bean industry in Saskatchewan.

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AUTHORS' NOTE

Bristle-guards were installed on a John Deere Model 216 integral flexible header (Deere & Company, East Moline, IL) in 1995. Field tests were conducted on 50 ha of pinto and black beans in Saskatchewan and Alberta to evaluate durability of the bristle-guards and a standard diameter, parallel state pickup reel. Both performed acceptably

and the technology has recently been patented in Canada (Zyla et al. 1997), the United States, France, and Germany. A farm equipment manufacturer (Keho Alto Products Ltd, Barons, AB) began production and marketing in 1998.

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