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Short Title: Seed Impact Mills in Soybean

Evaluating Weed Seed Kill Efficacy and Horsepower Draw of Two Impact Mills for Use in Soybean Production

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Abstract

Combine modifications for harvest weed seed control, like the Redekop Seed Control Unit (SCU) and the integrated Harrington Seed Destructor (iHSD), have been successfully used to kill problematic weed seeds in small grain production in Australia. These seed impact mills could have a fit in US soybean [Glycine max (L.) Merr.] production. Testing the seed kill rate of problematic weed species in soybean is important for confirming the efficacy of the mills. Additionally, the mills may be affected by changes in crop yield and harvest residue moisture as they can have an impact on chaff flow rate and chaff moisture, respectively. This research aimed to determine the seed kill percent for problematic weeds and how varying chaff flow rates and chaff moisture content in soybean chaff affect the seed kill rate and horsepower draw of two different impact mills, the Redekop SCU and the iHSD. All testing was conducted using stationary test stands. Chaff flow rate and chaff moisture levels tested ranged from 0.5x to 2x standard combine throughput and 11.7%-28.6% moisture, respectively. All tested species were killed at >98% by both mills. Increasing chaff flow rate resulted in a decrease in seed kill for all tested species with the iHSD and only common ragweed (*Ambrosia artemisiifolia* L.) with the Redekop SCU. Increasing chaff moisture only resulted in a decrease in seed kill for Palmer amaranth (*Amaranthus palmeri* S. Watson) with the iHSD. Data evaluating the horsepower needed to power the mills also indicated that chaff flow rate and chaff moisture resulted in a significant increase in horsepower draw. With generally high kill rates (>98%) and the ability to kill weed seeds at >98% in less-than-ideal harvest conditions (i.e. high moisture chaff), seed impact mills could be used in soybean production to reduce weed seed inputs into the soil seedbank during harvest.

Keywords: harvest weed seed control; HWSC; integrated Harrington Seed Destructor; iHSD; Redekop Seed Control Unit; Redekop SCU; seed impact mill

Introduction

Harvest weed seed control (HWSC) is a weed control method that focuses on concentrating, removing, or destroying weed seeds as they pass through the combine during harvest (Shergill et al. 2020). HWSC was originally developed in Australia to help combat herbicide resistance rigid ryegrass (*Lolium rigidum* Gaudin) populations in wheat (Walsh et al. 2013). *Lolium rigidum* is a problematic weed in Australian small grains cropping systems since it has developed resistance to twelve herbicide modes of action, which has reduced the herbicide options for controlling this problematic weed species (Boutsalis et al. 2012; Heap 2024). This resistance development necessitated the use of nonchemical control options, such as HWSC. HWSC allows farmers to reduce the number of weed seeds being returned to the soil seedbank, and this has led to the rapid adoption of HWSC techniques in Australian small grain cropping systems (Walsh et al. 2022).

Seed impact mills are modifications attached directly to the combine and process the chaff fraction during harvest and are one way to implement HWSC (Walsh et al. 2018). The weed seeds pass through the combine into the mill, where they are killed through multiple impacts delivered by the rotating and stationary bars or blades within the mill, and then the harvest residue is distributed back out into the field evenly (Walsh et al. 2018). Stationary testing units are commonly used to test seed impact mills for effectiveness. Using a stationary mill, researchers can test less chaff material and a wider range of chaff conditions that could be potentially encountered in the field. They allow researchers to test how different mill speeds, chaff flow rates, chaff moisture, and the amount of weed seeds used affect weed seed kill. For instance, Walsh et al. (2018) reported that the seed kill percentage changed significantly when the speed of the mill was changed. In this study, the kill rate for *L. rigidum* increased from 60% to 98% when the speed of the mill was increased from 1,000 RPM to 3,000 RPM (Walsh et al. 2018). Additionally, chaff moisture can also affect seed kill, with Walsh et al. (2018) reporting that seed kill of *L. rigidum* decreased from 92% to 88% when chaff moisture was increased from 10% to 16%. While most of these conditions could be found in a field, it would be time, labor, and cost-intensive to consistently find and replicate them. Stationary seed impact mills make testing these extremes easier and allow for more precise and consistent testing.

There is tremendous potential for HWSC adoption in North America for cropping systems such as soybean, wheat, and rice, but the practice has little adoption to date (Shergill et al. 2020). These crops have the easiest path of adoption because of widespread herbicide-resistance, and they all are typically harvested with a platform header, which is necessary for adequate weed seed capture (Shergill et al. 2020). Seed impact mills are a form of HWSC that could be used in North American cropping systems, and testing in North America indicates a promising outlook. Schwartz-Lazaro et al. (2017) indicated that seed kill was >98% for all tested species with the iHSD when tested in both rice and soybean chaff. Palmer amaranth (*Amaranthus palmeri* S. Watson) and morningglory species (*Ipomoea* spp. L.) seeds were both reported to be killed 100% when present in soybean chaff, indicating further promise for use against problematic weeds (Schwartz-Lazaro et al. 2017). Additional tests revealed that even in adverse harvest conditions, such as higher chaff flow rate into the mill, *A. palmeri* and *Ipomoea* spp. did not have a significant decrease in seed kill as the chaff flow rate increased (Schwartz-Lazaro et al. 2017). Testing in Missouri indicated that using the Seed Terminator impact mill during soybean harvest resulted in >94% control for problematic weeds like waterhemp [*Amaranthus tuberculatus* (Moq.) J. D. Sauer], giant foxtail (*Setaria faberi* Herrm.), and *Ipomoea* spp. (Winans et al. 2023). Testing in Western Canada with a Harrington Seed Destructor (HSD) revealed that seed kill was >97% in all tested conditions which indicates promise in crops like canola, barley, and pea (Tidemann et al. 2017).

Testing of seed destruction equipment in North America could still be improved. Most of these tests only evaluated one seed impact mill brand and only a few weed species, leaving room for additional testing in soybeans with different seed impact mill brands and different weed species. Additionally, since these published results, design improvements have been made to these mills. Furthermore, in North America chaff moisture during harvest is often higher than in Australia, so higher chaff moisture rates should be tested that are more in line with typical rates for soybean harvest in North America (Walsh et al. 2022).

Increasing the chaff flow rate and chaff moisture has the potential to affect the horsepower draw of the seed impact mill. Since seed impact mills are integrated into the back of the combine, they are powered directly by the combine (Shergill et al. 2020). If the amount of chaff increases or the chaff moisture increases, the mill could require more power to process it. Farmers who have adopted seed impact mills have mentioned that the horsepower used by the combine increased with the mill (Shergill et al. 2020). This increase in horsepower and engine capacity ultimately results in increased fuel consumption by the combine (Flessner et al. 2021).

Additionally, if the combine does not have adequate engine capacity, harvest speed could be reduced, and this would not be desirable to farmers (Flessner et al. 2021). Therefore, it is important to understand how variable chaff moisture and flow rate conditions affect horsepower draw by the seed impact mill.

This research aimed to evaluate the effectiveness of two seed impact mills, the Redekop Seed Control Unit (SCU) and the integrated Harrington Seed Destructor (iHSD), using stationary test stands. Testing was divided into three objectives. The first objective was to test the seed kill of economically important weed species in soybean. The second objective was to determine how chaff flow rate into the seed impact mill affects weed seed kill and the amount of horsepower needed to power the mill. The third objective was to determine how chaff moisture percentage affects weed seed kill and the amount of horsepower needed to power the mill.

Materials and Methods

Stationary test stands for the Redekop Seed Control Unit (SCU) (Redekop Manufacturing, Saskatoon, SK Canada) and the integrated Harrington Seed Destructor (iHSD) (de Bruin Engineering, Mount Gambier SA, Australia) were provided by each manufacturer for testing (Figure 1). Both mills were powered by a John Deere 6140D tractor with a 115-horsepower rating at the power take-off (PTO) (Deere & Company, Moline, Illinois). Three objectives were conducted to evaluate the seed impact mill efficacy: seed kill (SK), chaff flow rate (CF), and chaff moisture (CM). Three thousand germinable seeds were used for each replicate in each objective. Five replicates were conducted for each objective, and the experiment was conducted twice. The weed seeds tested in the SK, CF, and CM objectives are in Table 1. Weed species were selected to represent a range of seed morphologies as well as common troublesome species in soybean.

Petri dish germination assays were conducted on the seed lots to determine the germination rate prior to seed impact mill testing. Prior to the germination assay, seeds were kept in cold storage at 3 ± 1 C. Five sets of 50 seeds were placed in between two pieces of dampened filter paper (VWR International, Radnor, Pennsylvania**)** and placed inside a Petri dish (VWR International, Radnor, Pennsylvania). The Petri dishes were sealed with parafilm (Bemis Company, Neenah, Wisconsin) and placed on the lab bench near a window under ambient lighting for two weeks at roughly 22 C. After two weeks, seeds with emerged radicles were

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counted, and an average germination rate was calculated for each species. Additionally, average 100 seed weights were calculated by weighing 10 sets of 100 seeds for each species. Using the germination rate and the average 100 seed weight, we calculated the weight of seed that was needed for each objective. Three thousand germinable seeds were tested for each replicate in all objectives. The number of seeds used was based on previous research that evaluated adequate seed sample size for seed impact mill testing (Tidemann et al. 2017; MJ Walsh, personal communication). The optimum chaff flow rate of a commercial combine is 3.0 kg sec^{-1}, which is normally processed by both mills from the twin mill system (Walsh et al. 2018). However, we only tested a single mill, so the optimum chaff flow rate was reduced to 1.5 kg sec^{-1}.

Chaff was collected from a soybean field in Virginia that was in commercial production. The field selected for chaff collection was weed-free at the time of harvest to eliminate weed seed contamination in the chaff. A chaff cart was connected to the back of the combine, and it was used to collect the chaff as it exited the combine during harvest. Large residues that exited the combine through the straw chopper were not collected. Once the chaff was collected, it was transferred into tote bags and stored in ambient conditions until it was needed for testing. Soybean chaff was stored for 18-24 months, and wheat chaff was stored for 6-12 months. At the time of testing, ambient chaff moisture was determined by oven-drying three chaff samples for four days. Chaff moisture was 6.1% and 4.2% during Redekop SCU and iHSD testing, respectively.

Seed Kill

For the SK objective, 1.5 kilograms (kg) of chaff was evenly fed into the mill via a conveyor belt in a one-second increment to achieve the 1.5 kg sec^{-1} flow rate used by Walsh et al (2018). The chaff was loaded up on the conveyor belt and then evenly spread out. The weed seeds were added on top of the chaff, within the middle 80%, and lightly mixed. The mill was powered and brought to the correct speed. A photo tachometer (CEN-TECH, China) was used to ensure the mill was operating within +/- 2% of proper operating speed as indicated by the mills' manufacturers. Once the mill was up to speed, the conveyor belt was engaged, and the chaff was fed into the mill. The chaff was caught using a 500-micron mesh bag as it exited the mill, which allowed for the collection of processed residues without restricting airflow (Figure 1). This collected processed material was weighed and taken to the greenhouse for additional testing, as described below.

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Chaff Flow Rate

For the CF objective, four different rates of chaff were tested. The flow rates were 0.5x, 1x, 1.5x, and 2x, based on the standard flow rate for a commercial combine as described by Walsh et al. (2018). The corresponding chaff rates for testing a single mill were 0.75, 1.5, 2.25, and 3.0 kg sec^{-1}.

The mill was brought up to speed for testing, and the conveyor belt was loaded and operated as mentioned above. For all rates, the testing interval was one second, and the amount of chaff on the conveyor belt varied as appropriate. Once the mill was up to speed, a log of the horsepower required to power the mill was recorded using a Tractor PTO Shaft Monitoring System (Datum Electronics LTD., United Kingdom) that generated 90-100 data points per second. After the mill had achieved optimum operating speed, the horsepower was logged for 5-10 seconds, then the conveyor belt was turned on, and the chaff was fed into the mill. After the chaff was processed, the PTO monitor continued to log data for another 5-10 seconds. Processed residues were collected and processed as previously described.

Chaff Moisture

For the CM objective, four different rates of chaff moisture, 11.7%, 17.4%, 23.0%, and 28.6%, by weight were tested. These values span and exceed moisture values that are typically found during soybean harvest. The chaff flow rate was the standard flow rate of 1.5 kg sec^{-1} with only the percent moisture varying. To achieve the correct moisture content, 1.5 kg of chaff was weighed and placed in a plastic bag (Uline, Pleasant Prairie, Wisconsin). Water was added to the bag to raise the chaff moisture to the desired test value. These bags were sealed, mixed, and allowed to sit for 24 hours so that the chaff had ample time to absorb the water and homogenize. Mill operation and horsepower monitoring were conducted as previously described.

Greenhouse Testing

After processing, SK, CF, and CM samples were brought back to the greenhouse, and exhaustive germination studies were conducted on them. Processed chaff was added in a 1:1 ratio with Miracle-Gro moisture control potting mix (Scotts Miracle-Gro, Marysville, Ohio) in 25.4 cm x 50.8 cm trays (Greenhouse Megastore, Danville, Illinois) (Schwartz-Lazaro et al. 2017). For each replicate, the processed chaff and weed seeds were homogenized and equal amounts were added to four trays to ensure an adequate amount of chaff was tested. Depending on the objective, the total percent of residue sampled ranged from 25% - 100%. Three check

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trays were also established for each objective. Check trays consisted of a 1:1 ratio of potting mix and seed-free chaff that had been processed by the mill (Schwartz-Lazaro et al. 2017). The check trays were spiked with 100 seeds of each tested species from the same seed lot. All trays were placed randomly in the greenhouse and mixed to ensure good seed-to-soil contact. Trays were watered once daily by hand. Seedlings were counted, recorded, and removed from the trays once per week. Every third week, trays were mixed to ensure that seeds at the bottom were brought to the surface. The trays remained in the greenhouse for twelve weeks. After twelve weeks, data collection ceased, and the counts were compiled.

Statistical Analysis

Seed kill data from SK, CF, and CM objectives were recorded and compiled with each seed impact mill being analyzed separately. Equation 1 was used to determine the number of germinable seeds sampled. Emergence from the check trays was used to determine the germination percent.

(1) Germinable seeds sampled = Total # seeds tested * % germination * % chaff sampled

Equation 2 was then used to determine the seed kill percentage.

$$(2)\ \text{Seed kill} = 100 - \left(\frac{\text{\# of emerged weeds}}{\text{\# of germinable seeds sampled}} * 100\right)$$

Replications were treated as random effects. Compiled counts for each replicate were analyzed using JMP 16.2 (SAS Institute, Cary, North Carolina) and were subjected to ANOVA. Means and standard errors of seed kill percentages for all objectives, and all species tested were generated using JMP 16.2. Means separation was conducted with Tukey's $HSD_{(0.05)}$ using JMP 16.2. Seed kill data were presented using graphs generated by GraphPad Prism (Dotmatics, Boston, Massachusetts). For CF and CM objectives, linear regressions with one fixed factor were conducted on seed kill data using GraphPad Prism.

Horsepower data were plotted using GraphPad Prism. To account for any variability at a given data point for horsepower draw, the data were smoothed within GraphPad Prism, which used 20 data points surrounding each point (Savitzky and Golay 1964). The highest point was used to determine the horsepower draw required for each replicate at the tested chaff flow rate or chaff moisture percentage. Empty mill tests were also conducted to establish a baseline horsepower draw. Using the empty mill horsepower requirements, a percent increase was calculated for each chaff flow rate and chaff moisture percentage tested. Replications were treated as random effects. The data were analyzed using JMP 16.2 and subjected to one-way

ANOVA to determine differences in chaff flow rate or chaff moisture. Means and standard errors were generated using JMP 16.2 for each tested value within CF and CM objectives. Horsepower means were subjected to a linear regression with one fixed factor using GraphPad Prism.

Results and Discussion

Seed Kill

Both iHSD and Redekop SCU test stands generated high seed kill (>98%) for all tested species (Table 1). For the iHSD, giant ragweed (*Ambrosia trifida* L.) (100%) and *A. palmeri* (99.93%) had the highest kill rates, while redroot pigweed (*Amaranthus retroflexus* L.) (99.30%) and *S. faberi* (98.29%) had the lowest. For the Redekop SCU, johnsongrass [*Sorghum halepense* (L.) Pers.] (99.93%) had the highest, while barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] 99.31%) and *S. faberi* (98.61%) had the lowest. Across both mills, seed kill was similar for all *Amaranthus* spp. with *A. palmeri*, *A. tuberculatus*, and *A. retroflexus* having seed kill rates of 99.93%, 99.78%, and 99.30%, respectively, for the iHSD and 99.57%, 99.78%, and 99.43%, respectively, for the Redekop SCU. Despite species covering a range of seed shapes and sizes, and including both broadleaves and grasses, both mills were able to generate high seed kill rates (>98%) for all tested species. This indicates that the mills were effective, regardless of seed size and shape, on a variety of weed species (Table 1).

Despite subtle differences in seed kill, both seed impact mills generated high kill rates. General seed kill data were comparable to previously reported cases. Schwartz-Lazaro et al. (2017) reported kill rates for iHSD at 99.8%, 100%, 99.9%, 100%, 100%, and 100% for *E. crus-galli, A. trifida, S. halepense, Ipomoea* spp.*, A. palmeri,* and velvetleaf (*Abutilon theophrasti* Medik.), respectively, in soybean chaff. Additionally, seed kill for *A. tuberculatus*, *Ipomoea* spp., and *S. faberi* were reported at 94%, 96.5%, and 98%, respectively, when processed by the Seed Terminator in soybean (Winans et al. 2023). Tidemann et al. (2020) reported that the Redekop SCU killed an average of 99.5% of volunteer canola (*Brassica napus* L.) seed, which was similar to our tested broadleaf species. Other research that tested multiple species also concluded that the iHSD was similarly effective despite differences in seed shape and seed size (Schwartz-Lazaro et al. 2017; Walsh et al. 2018). While there were slight differences between specific species between the two mills, the overall seed kill between the two mills was similar both internally and with previously reported data.

Chaff Flow Rate

Linear regression analysis indicated that all weeds for the iHSD experienced a significant decrease in seed kill across the tested chaff flow rates. Seed kill decreased by 0.32, 0.16, 0.27, and 0.74% for *A. palmeri*, common ragweed (*Ambrosia artemisiifolia* L.), *E. crus-galli*, and *Ipomoea* spp., respectively, when chaff flow rate increased from 0.75 to 3.0 kg sec^{-1}, which spans 0.5- to 2-fold chaff flow rate in a normal operation (Figure 2). With the Redekop SCU, linear regression analysis indicated that only *A. artemisiifolia* experienced a significant decrease in seed kill by 0.36% across the same range (Figure 2). Despite statistically significant regression trends in some cases, seed kill was still high (>98%) at the highest chaff flow rates, indicating these trends are not likely agronomically relevant. In previous research, Schwartz-Lazaro et al. (2017) reported that there was no effect on seed kill for *A. palmeri* and *Ipomoea* spp. with increasing chaff flow rate when testing the iHSD. The differences we saw could be due to the high number of seeds we tested for each species. Our testing utilized 3,000 germinable seeds per test, while 500 seeds were utilized by Schwartz-Lazaro et al. (2017). This higher number of seeds potentially allowed us to observe better details in seed kill. Tidemann et al. (2017), however, did see an effect on seed kill and increasing levels of chaff flow. They reported an increase in seed kill for the Harrington Seed Destructor (HSD) from no chaff to moderate rates of chaff, followed by a decrease in seed kill from moderate rates to high rates of chaff. Since our testing did not include a no-chaff test, we cannot confirm if our data follows the same quadratic trend that they reported. However, Tidemann et al. (2020) reported that the chaff flow rate did not have an effect on *B. napus* seed kill with the Redekop SCU. However, despite the differing trends in seed kill reduction in our results, the rates remained high (>98%) at the highest tested flow rate for all species and across both mills. This suggests that growers can still achieve high seed kill in variable chaff flow situations without the combine operator having to make instantaneous changes during harvest.

When looking at horsepower, chaff flow rate had a significant effect on horsepower draw by both mills (Figure 3). At the standard 1x flow rate, peak horsepower usage increased by 156% and 189% for the iHSD and Redekop SCU, respectively, when compared to an empty mill. At the 2x chaff flow rate, peak horsepower usage increased by 245% and 323% for the iHSD and Redekop SCU, respectively, when compared to an empty mill. Linear regression indicated that horsepower draw increased as chaff flow rate increased. In the field, however, adjusting the

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combine's harvest speed as yield changes should minimize changes in crop throughput, which will reduce variability in chaff output. To the best of our knowledge, there is a lack of prior studies to directly compare horsepower use of seed impact mills.

Chaff Moisture

Based on a linear regression analysis, only *A. palmeri* with the iHSD experienced a significant decrease in seed kill across the tested chaff moisture rates (Figure 4). *Amaranthus palmeri* experienced a 0.058% decrease in seed kill from 11.7% to 28.6% chaff moisture. Based on linear regression analysis, there were no decreases in seed kill for all tested species for the Redekop SCU (Figure 4). When comparing visible decreases in seed kill, all changes were <0.6%, from 11.7% to 28.6% chaff moisture. Schwartz-Lazaro et al. (2017) reported no effect on seed kill from chaff moisture content. Our data are similar except for *A. palmeri* and *E. crus-galli*. The differences that we saw could be because of our wider testing range. We tested from ~12% to ~30% chaff moisture, while Schwartz-Lazaro et al. (2017) only tested to 24% moisture. However, similar to previous research, our kill rates remained >98.5% for all species and both mills at the highest tested moisture content. Unlike chaff flow rate, combine operators cannot make adjustments to account for chaff moisture. Therefore, these data are important because they indicate that chaff moisture does not greatly influence seed kill, and it does not limit the conditions that growers are willing to harvest in.

When looking at horsepower draw by both mills, chaff moisture had a significant effect on the percent change in horsepower used when compared to an empty mill (Figure 5). While the iHSD horsepower draw was affected by chaff moisture, there was not a linear relationship between chaff moisture and percent change in horsepower. For the Redekop SCU, there was a significant linear relationship between chaff moisture and percent change in horsepower. Horsepower percent change increased by 0.67% for every 1% increase in chaff moisture for the Redekop SCU. In reviewing the available literature, no studies were found that directly address the horsepower usage in seed impact mills.

In conclusion, seed impact mills like the Redekop SCU and the iHSD show potential as a new integrated weed management tool in soybean production. The high kill rates for many problematic species indicate that seed impact mills could be useful in reducing soil seedbank additions at harvest. Also, the linear relationship between horsepower draw and variable harvest conditions provides a model for assessing potential costs associated with running the mill. The

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high seed kills even in poor harvest conditions, such as high chaff moisture and flow rates, indicate the potential utility of these mills in commercial production. While these data show promise for these mills, there are still areas that need further research to confirm the utility of these mills in North American soybean production, such as understanding how seed moisture affects seed kill and preventing moist residue from building up in the mill.

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Competing Interests

The authors declare none.

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Table 1. Species evaluated in the seed kill, chaff flow, and chaff moisture objectives and mean seed kill (± SE) of tested species by the Redekop Seed Control Unit (SCU) and integrated Harrington Seed Destructor (iHSD) from the seed kill experiment. Letters indicate differences between species within tested mill according to means separation with Tukey's $HSD_{(0.05)}$. Only bolded species were tested in chaff flow rate and chaff moisture experiments.

	Redekop SCU	**iHSD**
Species	**Seed Kill**	**Seed Kill**
	-----------------%-----------------	
Amaranthus palmeri[1]	99.57 ± 0.10 ABC	99.93 ± 0.02 a
Ambrosia artemisiifolia[2]	99.72 ± 0.03 ABC	99.83 ± 0.02 ab
Echinochloa crus-galli[1]	99.31 ± 0.07 C	99.78 ± 0.01 ab
***Ipomoea* spp.**[1, 3]	99.77 ± 0.06 AB	99.66 ± 0.04 abc
Setaria faberi[1]	98.61 ± 0.17 D	98.29 ± 0.25 d
Ambrosia trifida[1]	99.79 ± 0.16 AB	100.0 ± 0 a
Amaranthus tuberculatus[1]	99.78 ± 0.09 AB	99.78 ± 0.04 ab
Sorghum halepense [1]	99.93 ± 0.03 A	99.84 ± 0.03 ab
Abutilon theophrasti[1]	99.54 ± 0.08 ABC	99.53 ± 0.06 bc
Amaranthus retroflexus[2]	99.43 ± 0.04 BC	99.30 ± 0.08 c

[1] Seeds obtained from Azlin Seed Service (Leland, MS).

[2] Seeds collected from weedy populations in Virginia.

[3] Mixture of *Ipomoea lacunosa* and *Ipomoea hederacea*.

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Figure 1. Setup for the integrated Harrington Seed Destructor (iHSD) (left) and Redekop Seed Control Unit (SCU) (right) test stands. Chaff was loaded on the conveyor belt and fed into the mill that was powered by the tractor PTO.

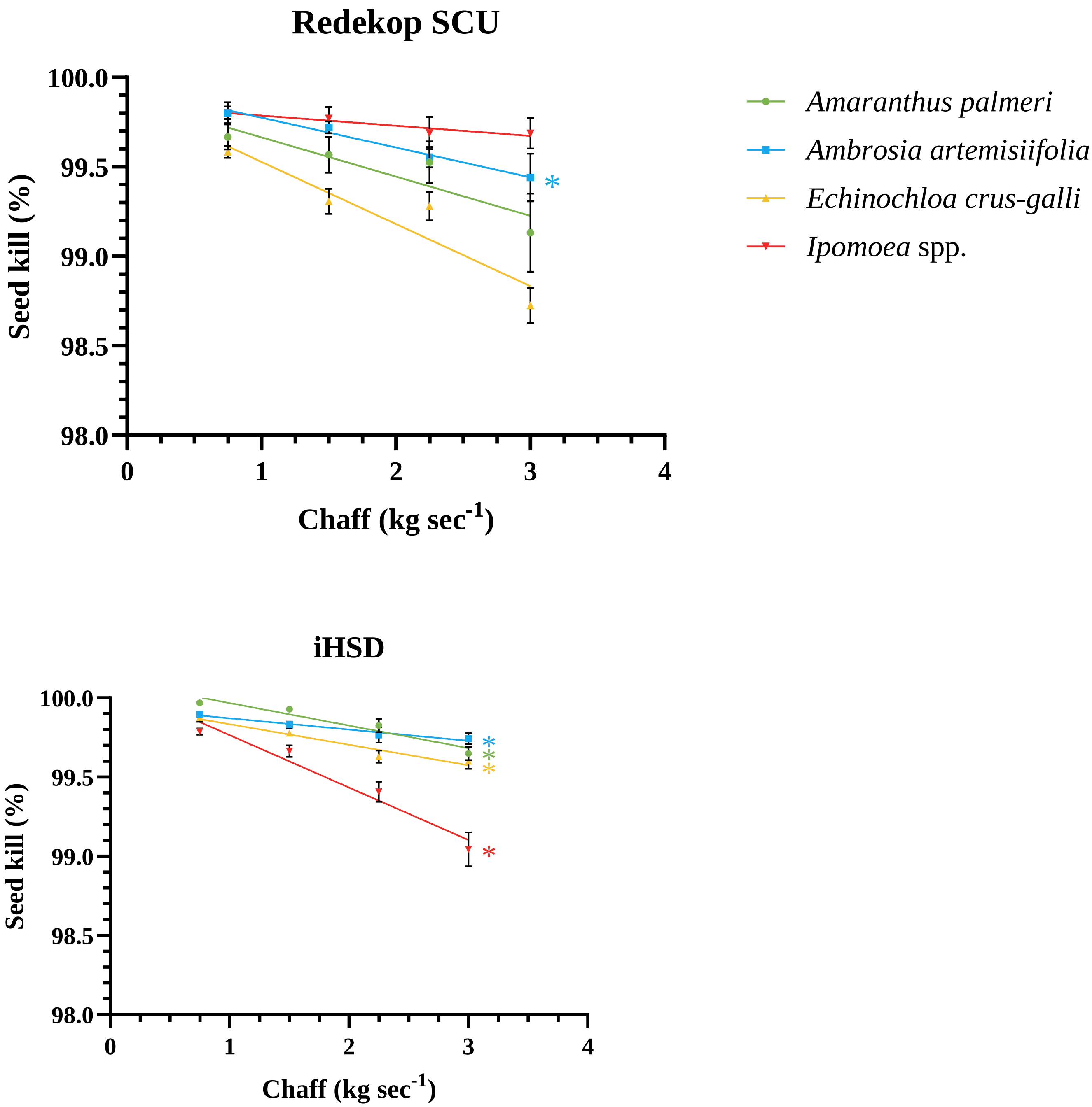

Figure 2. Seed kill of problematic weed seeds by the Redekop Seed Control Unit (SCU) (top) and integrated Harrington Seed Destructor (iHSD) (bottom) as chaff flow rate increases. Standard 1x throughput is equal to 1.5 kg sec^{-1}. Points represent the mean, bars represent the standard error, and lines with * represent significant linear regressions ($P < 0.05$).

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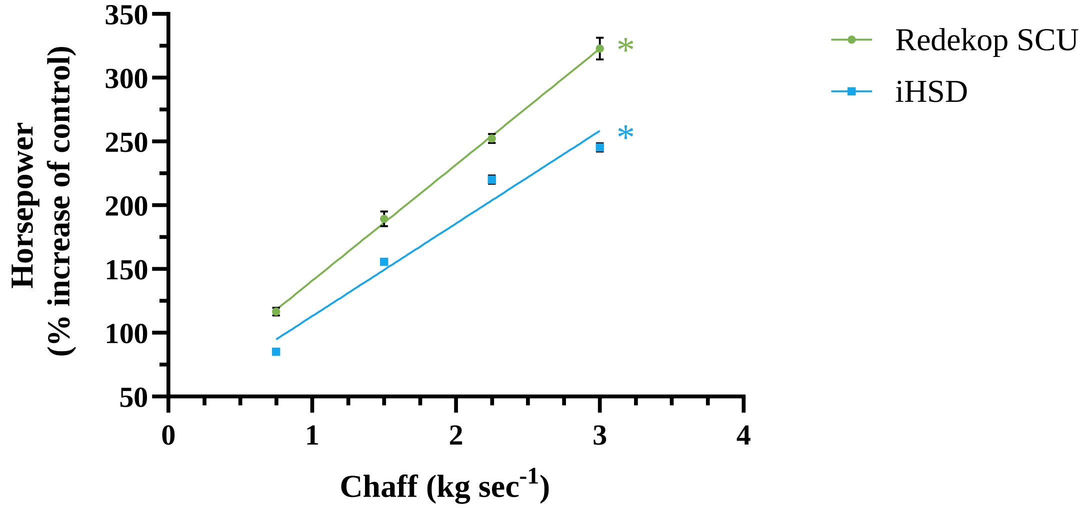

Figure 3. Horsepower required to power the Redekop Seed Control Unit (SCU) and integrated Harrington Seed Destructor (iHSD) as chaff flow rate increases. Standard 1x throughput is equal to 1.5 kg sec^{-1}. The data presented represents a percent increase from the horsepower required to power an empty mill. Points represent the mean, bars represent the standard error, and lines with * represent significant linear regressions ($P < 0.05$).

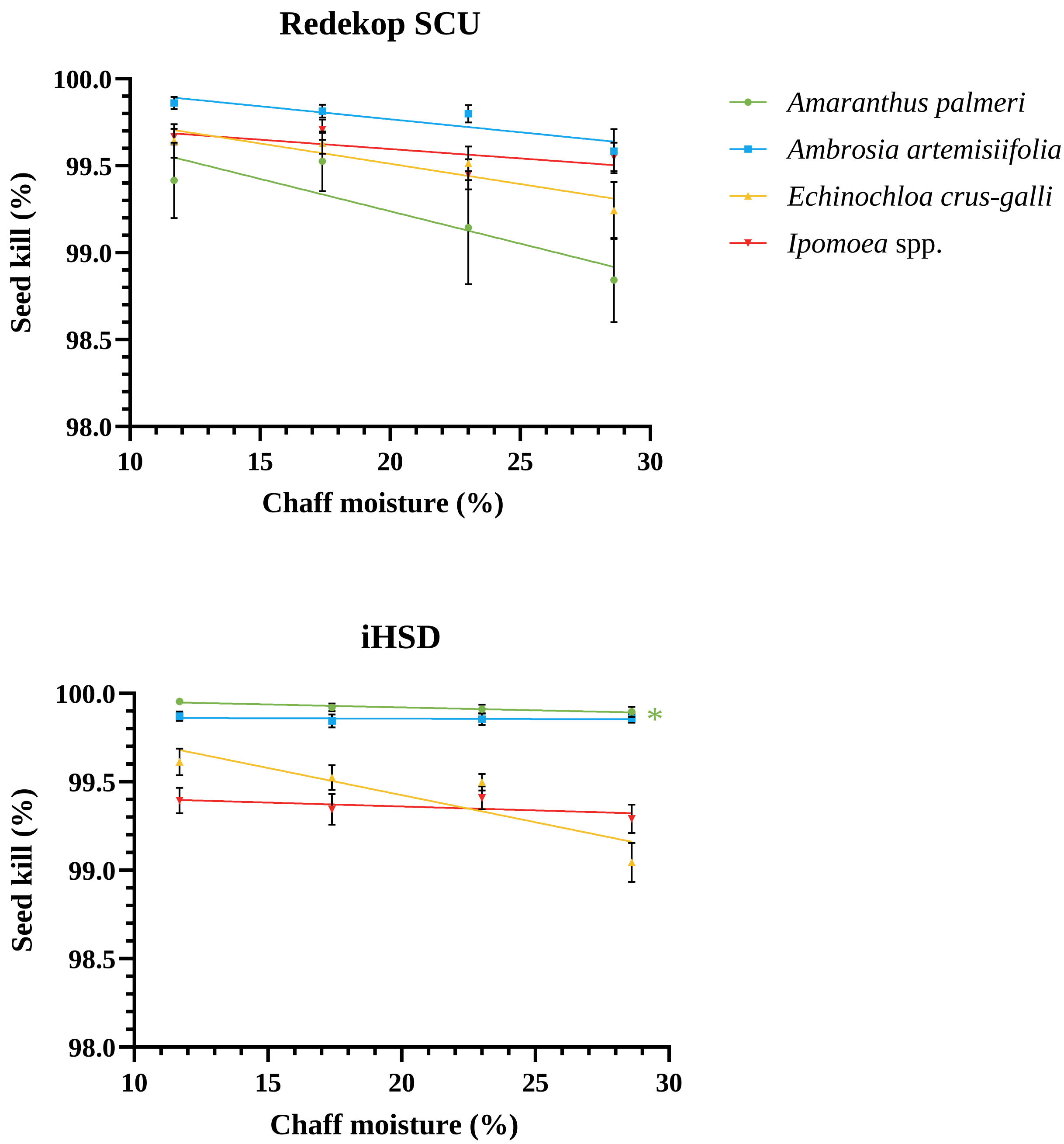

Figure 4. Seed kill of problematic weed seeds by the Redekop Seed Control Unit (SCU) (top) and integrated Harrington Seed Destructor (iHSD) (bottom) as chaff moisture increases. Points represent the mean, bars represent the standard error, and lines with * represent significant linear regressions ($P < 0.05$).

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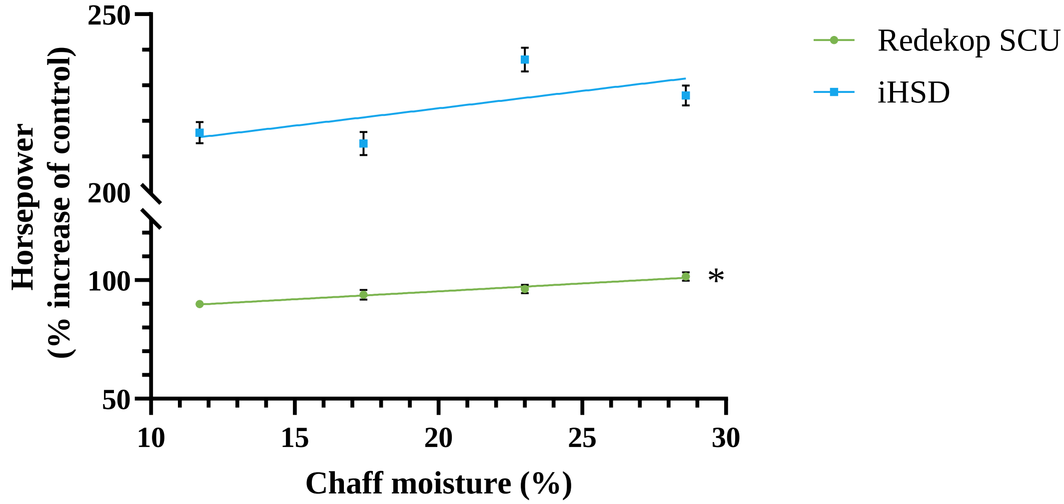

Figure 5. Horsepower required to power the Redekop Seed Control Unit (SCU) and integrated Harrington Seed Destructor (iHSD) as chaff moisture increases. The data represents a percent increase from the horsepower required to power an empty mill. Points represent the mean, bars represent the standard error, and lines with * represent significant linear regressions ($P < 0.05$).

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