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Summary of Findings

Date:	September 19, 2023	**Project No.**	A23013P
Client Name:	Redekop Manufacturing		
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SCU Devitalization Test

Introduction

Redekop Manufacturing (the Client) manufactures a harvest seed-control unit (SCU) designed to destroy harvestable weed seeds. The SCU attaches to the combine harvester and processes material coming from the cleaning system. The Client has tasked the Prairie Agricultural Machinery Institute (PAMI) to provide an independent, third-party evaluation of the SCU's effectiveness at devitalizing seeds in a controlled test environment, while following both the Walsh protocol and a second industry protocol (both of which are further discussed in the following section).

Background

Walsh et al. (2017) published a paper outlining a general procedure for testing harvester seed mills in Australia's cropping regions. Industry groups have also been striving to develop a more comprehensive protocol based the Walsh procedure to include variables such as chaff throughput, mill operating speed, mill condition, and a longer processing time; referred to as Protocol 2 throughout this report. Both procedures use similar experimental equipment, as depicted in **Figure 1**. A conveyor belt is loaded with a specific chaff and weed-seed ratio and then engaged at an equivalent mass throughput speed into the seed mill. The processed material is then collected and subsampled into smaller portions for the laboratory germination tests. The germination results are used to evaluate the seed mill devitalization efficacy.

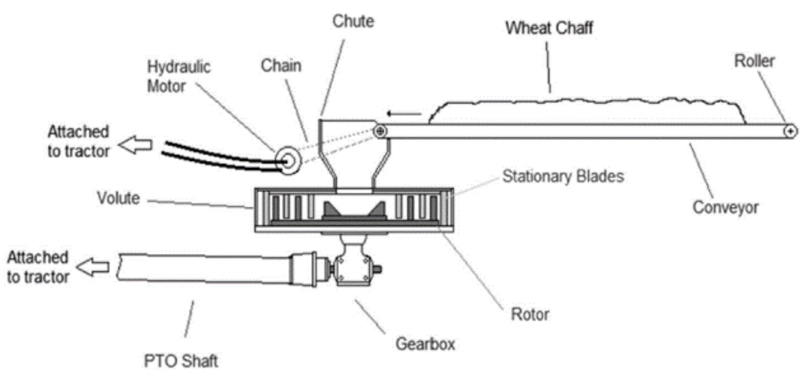

Figure 1. Schematic of iHSD test stand showing the mill and conveyor belt chaff delivery system. Modified from Guzzomi et al. 2017.

The differences between the Walsh protocol and Protocol 2 are itemized in **Table 1**. Minor changes were made to both procedures when benchmarking the Client's SCU. These changes reflect practical adaptations to streamline the testing process. Despite this, PAMI followed the true nature of both protocols.

Table 1. Test protocol comparison.

Test Parameter	Walsh Protocol	Protocol 2	PAMI Testing
Chaff/Seed Ratio	12 g of seed/kg of chaff[a]	2,000 germinable[b] seeds/kg of chaff	Followed both protocols
Weed Seed Type	Mixture of Ryegrass (Lolium rigidum) and others	Mixture of Ryegrass and Broadleaf Species	Ryegrass (Lolium rigidum)[c]
Chaff Mass Flow	1.5 kg/s[d]	1.0, 1.5, 2.0 kg/s[e]	0.75, 1.0, 1.5, 2.0 kg/s[f]
Test Time	1.33 s[g]	3.0 s	Followed both protocols[h]
Mill Speed	1,000, 2,000, 2,500, and 3,000 RPM	75% and 100% of manufacturer's recommended speed[i]	2,650 and 2,900 RPM[j]
Mill Configuration	Standard New	Standard New and Standard Worn	Standard New and Standard Worn
Collection System	Woven Mesh Bag (0.5 mm)	Indoor open area	Cyclone Dust Collector[k]

[a] Walsh et al. (2017) seed to chaff ratio was calculated based on **Table 1** (weed seed mixture) which had approximately 12 g of seeds/ kg of chaff. Seeds are thoroughly mixed throughout the entire chaff spread length.

[b] Protocol 2 requires a prior germination test to determine the specific seed count when establishing the actual germinable seeds. Seeds are thoroughly mixed throughout the middle 75% of the chaff spread length.

[c] Gulf Annual variety was used. Closest available equivalent in the area.

[d] Based on maximum harvester capacity (wheat at 35,000 kg/h) each twin mill would process. Only a single throughput was tested as a worst-case scenario.

[e] 1.0 kg/s is considered the standard baseline throughput. The 1.5 and 2.0 kg/s rates are 1.5x and 2x overload conditions intended to simulate high yields and near plugging scenarios.

[f] Tested a full range of throughputs to capture the mill performance.

[g] Processed 2 kg of chaff at a rate of 1.5 kg/s - processed in 1.33 s.

[h] Using a constant conveyor speed, the mass of the material and length of the chaff spread was varied to attain all four target throughputs.

[i] The 75% speed is intended to simulate near plugging scenarios.

[j] The full effect of the mill speed was of less interest. The Client's mill typically operates at a single speed (2,900 RPM) and 75% (2,175 RPM) was deemed too low and unrealistic. 2,650 RPM was determined to be a reasonable lower speed for potentially higher chaff throughput (i.e., worst-case scenario).

[k] A cyclone dust collector was used to recover the processed material, as it was the most practical and least invasive. Static pressure drops of 0.3 inH_2O (74.7 Pa) and 0.5 inH_2O (124.4 Pa) were measured at 2,650 and 2,900 RPM, respectively.

The test matrix displayed in **Table 2** was based on the criteria from Protocol 2 and the Client's request. Each permutation had three repetitions for a total of 36 tests. Gulf Annual Ryegrass (Lot No. Y2219713 – Item 68955 [3.25 g/1,000 seeds]) was used, as it was the closest equivalent to the protocols that was available for testing.

Table 2. SCU experimental test matrix.

Protocol	SCU Configuration	Speed (RPM)	Mass Flow (kg/s)	Repetitions	Total Repetitions
Walsh & Protocol 2	Standard - New	2,900	0.75, 1.00, 1.50, 2.00	Three reps/trial/Protocol	24
Walsh & Protocol 2	Standard - New	2,650	2.00	Three reps/trial/Protocol	6
Walsh & Protocol 2	Standard - Worn	2,900	1.00	Three reps/trial/Protocol	6
TOTAL					**36**

The chaff-to-grain ratio can be varied based on numerous harvesting factors (yield, variety, location, growing conditions, etc.). Current literature suggests a range between 10% to 30% depending on the yield. Walsh et al. (2017) assume a ratio of 15%. Protocol 2 had referenced recent work from Walsh et al. (2022) showing a chaff-to-grain ratio closer to 10%. The standard baseline of 1.0 to 1.5 kg/s of equivalent chaff throughput may be subject to change depending on the accepted chaff-to-grain ratio.

To achieve all four material throughputs, the mass of the material and the length of the chaff spread was varied while maintaining a constant conveyor speed. The respective test parameter values for each throughput and protocol are outlined in **Table 3**. It should be noted that Protocol 2 requires a germination test to determine the germinable seed count and chaff ratio. Given the testing timeline and partially available data, PAMI assumed a 90% germination rate while determining the seed counts for Protocol 2. The Walsh protocol simply states a fixed mass of seed for the seed-to-chaff ratio (**Table 1**).

Table 3. Throughput test parameter values.

Mass Flow (kg/s)	0.75		1.00		1.50		2.00	
Test Protocol	**Walsh**	**P. 2**	**Walsh**	**P. 2**	**Walsh**	**P. 2**	**Walsh**	**P. 2**
Conveyor Speed (RPM)	100	100	100	100	100	100	100	100
Material Length on Conveyor (m)	1.13	2.55	1.13	2.55	1.13	2.55	1.13	2.55
Processing Time (s)	1.33	3.00	1.33	3.00	1.33	3.00	1.33	3.00
Mass on Conveyor (kg)	1.00	2.25	1.33	3.00	2.00	4.5	2.66	6.00
Seed Count [3.25 g/1000 seeds]	3,685	5,000	4,915	6,670	7,385	10,000	9,825	13,335

Test Set-up and Procedure

Figure 1 and **Figure 2** show the equipment layout used in the tests. The conveyor was positioned above the SCU and equipped with a transition chute to guide the chaff into the SCU opening. A cyclone dust collector was used to recover the processed material, as it was the most practical and least invasive. Static pressure drops of 0.3 inH2O (74.7 Pa) and 0.5 inH2O (124.4 Pa) were measured at 2,650 and 2,900 RPM, respectively, which was considered a minimal restriction.

Figure 2. SCU test stand configuration

A New Holland T7.230 (165 kW/225 hp) tractor unit was coupled to the SCU with the power take-off (PTO). A data acquisition system (eDAQ) was used to record the SCU RPM during testing.

Figure 3. SCU test stand data acquisition and tractor unit (New Holland T7.230).

Figure 4 shows an example of chaff placement on the conveyor for both the Walsh protocol and Protocol 2. The Walsh protocol required less material and had a shorter duration than Protocol 2.

Figure 4. Walsh and Protocol 2 chaff spreads on conveyor.

A specific chaff-and-seed ratio (**Table 3**) was prepared on the conveyor before each run. The chaff was first placed in the centre of the conveyor and then the correct number of Ryegrass seeds were mixed in. It is worth reiterating that the Walsh protocol requires a thorough mixing of seeds throughout the entire length of the spread. However, Protocol 2 requires only the middle 75% of the spread be mixed with seeds. After loading the chaff and seeds onto the conveyor, the SCU was brought to speed before engaging the conveyor. The material was then collected from the cyclone after processing in the SCU. Each repetition was subdivided into approximately 100 g using a rotary sampler (**Figure 5**). These samples were then given to an independent seed testing laboratory for seed germination testing. Baseline samples of processed and unprocessed chaff (with and without seeds) were also sent for germination testing. This was meant to identify any pre-existing seeds in the chaff material.

Figure 5. Rotary sampler with 12-Bin drum.

Test Results

Discovery Seed Labs Ltd. (DSL) in Saskatoon conducted the independent germination testing for all the trials (June to August 2023) by following the protocol outlined in the Canadian Methods and Procedures for Testing Seed (2013, CFIA).

Each processed subsample was mixed with an equal mass of soil and set to germinate in a lab-controlled environment for 28 days. The subsamples were also divided into five smaller samples to promote germination. Germination results were recorded weekly; the total amount of germinated seeds was shared with PAMI.

Before processing the data, the controlled germination test (T3; processed chaff and soil with 500 seeds) was used as a baseline for adjusting the kill rate. As such, a baseline germination rate of 66.8% was recorded and used to establish the new total seed count in the samples when calculating the kill rate (**Table 4**).

Table 4. Control samples – germination tests.

Control Samples	Germination Rate (%)
Control T0- Seeds in Soil	77.4
Control T1 -Unprocessed Chaff and Soil - No Seeds	0.0
Control T2 -Unprocessed Chaff and Soil – with Seeds	75.0
Control T3 -Processed Chaff and Soil – with Seeds	66.8
Control T4 -Processed Chaff and Soil – No Seeds	0.0

General Results

Table 5 compares both protocols in the standard configuration for a 1.0 kg/s throughput (considered the standard baseline). As previously identified in **Table 3**, Protocol 2 utilizes more chaff and seed throughout a test to create a longer test duration when compared to the Walsh protocol. The calculated coefficient of variation (CV) and Standard Errors are slightly higher with Protocol 2. This is likely due to the greater amount of material being processed. The increase in variability also appears to be proportional to the decrease in SCU speeds highlighted in **Figure 6** and **Figure 7**.

Table 5. Kill rate for average chaff throughput (1.0 kg/s).

Test	Throughput (kg/s)	Mill Speed (RPM)	Protocol	Avg. Kill Rate (%)	CV (%)	Std. Error (%)
Average Harvest Rate – Std. New	1.0	2,900	Walsh	92.1	1.09	0.58
Average Harvest Rate – Std. New	1.0	2,900	Protocol 2	94.6	1.65	0.90

Figure 6 and **Figure 7** shows sample runs of the measured SCU speed for both protocols at each chaff throughput. When material is introduced into the SCU, a slight decrease in speed occurs. In normal operations with a harvester, the SCU operates in steady-state conditions with a pre-set speed of 2,900 RPM when processing material. The test methodologies differ from typical operating conditions by having a pre-set speed when unloaded (no material). **Figure 6** and **Figure 7** highlight the sudden surge of material with the decrease in speed. The Walsh protocol and Protocol 2 had similar decreases in speed with respect to chaff throughput as identified in **Figure 9**. Walsh had a slightly larger peak drop in speed but quickly recovered compared to the Protocol 2 tests. With larger amounts of chaff being processed, Protocol 2 decreased in speed for a longer duration.

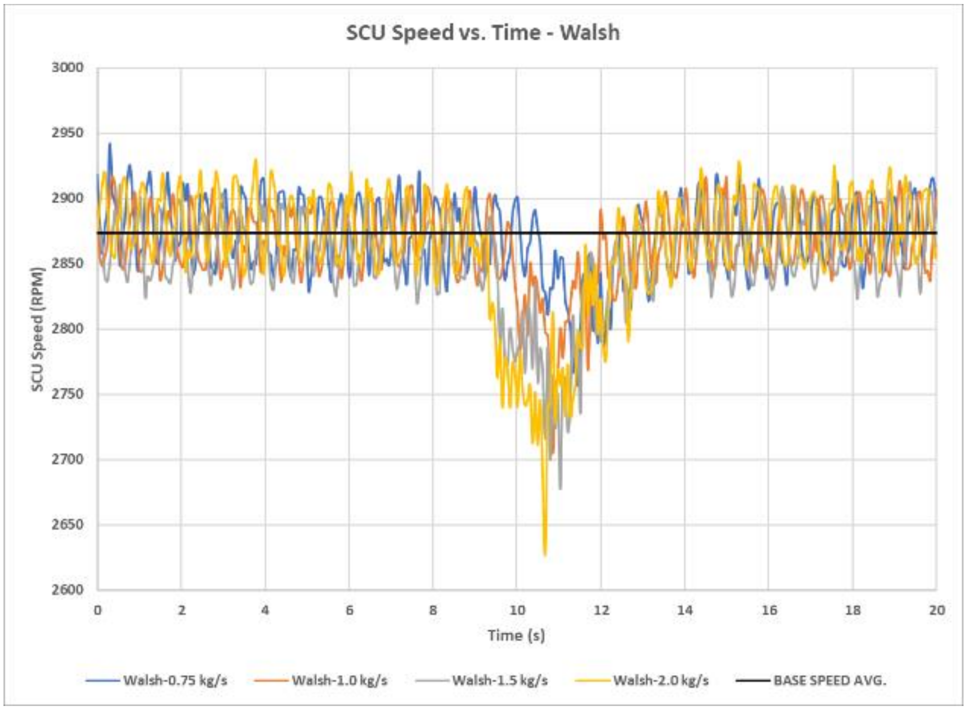

Figure 6. Sample runs of recorded SCU speed at all throughputs – standard setting for Walsh Protocol – (Black Line: average target speed).

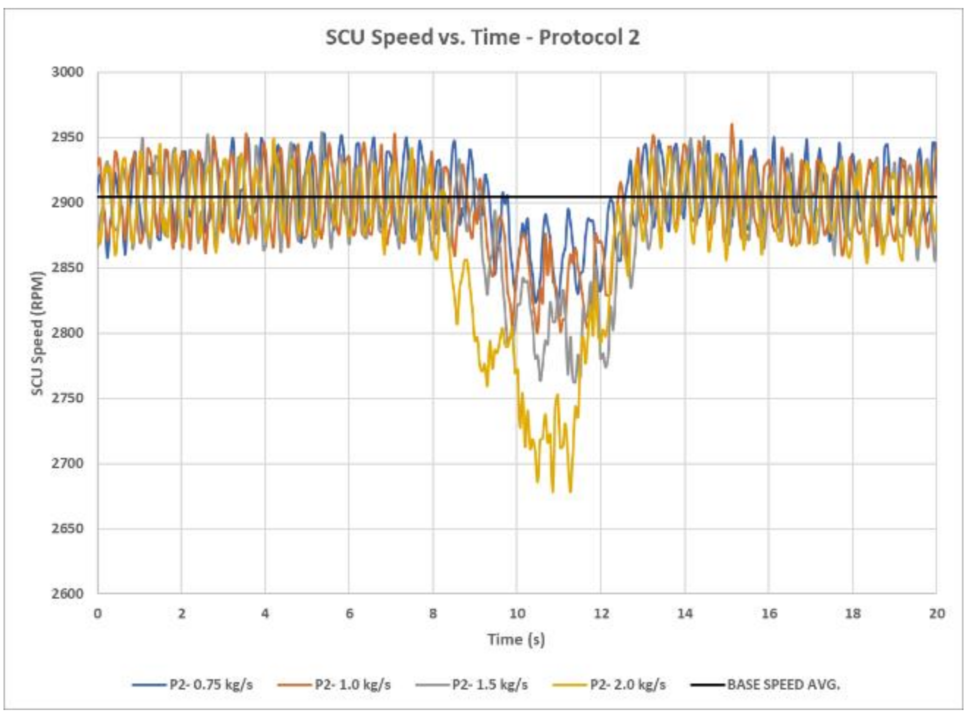

Figure 7. Sample runs of recorded SCU speed at all throughputs – standard setting for Protocol 2 (Black Line: average target speed).

In general, as the chaff rate increased, so did the drop in SCU speed (**Figure 8**). Both protocols are designed to process equivalent amounts of chaff on a mass flow basis (kg/s) but for different durations. Despite this, the protocols encountered varying degrees of speed fluctuations at the respective throughputs. The seed placement within the chaff spreads also differed as per the protocol requirements (**Table 1**). The combination of the test duration, speed drop, and seed locations within the chaff may have impacted the variability observed in the kill rates.

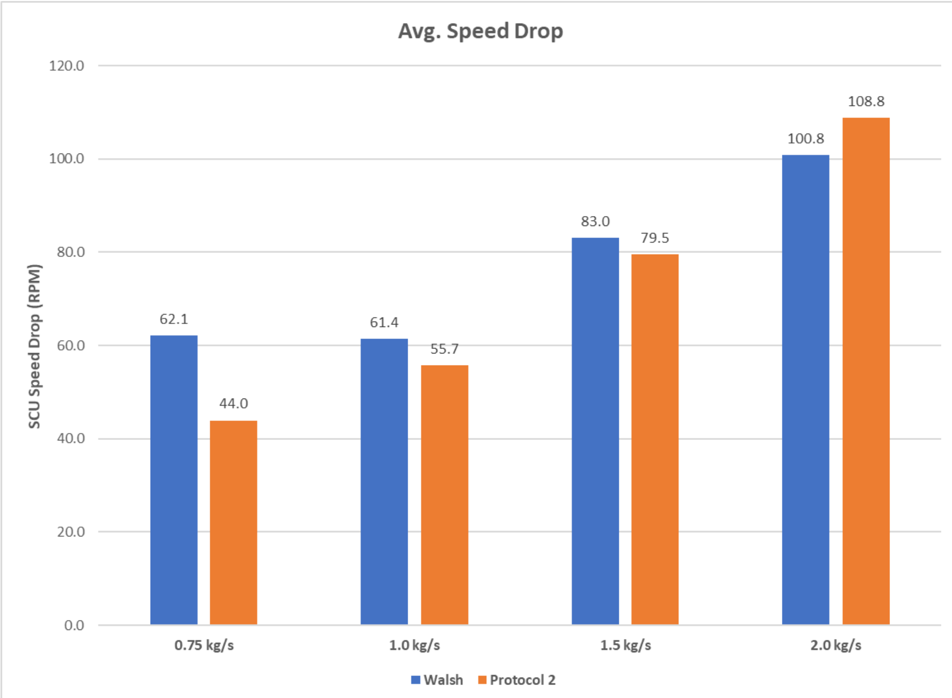

Figure 8. Average speed drop for sample runs of recorded SCU speed at all throughputs – standard setting for the Walsh protocol and Protocol 2.

Table 6 outlines the measured wheat chaff moisture contents during the testing period. The moisture remained relatively constant throughout the tests (varied 1% to 5%). No analysis was conducted to identify the potential effect of moisture on the kill rate. Walsh et al. (2017) had previously conducted such tests where they found a decrease in kill-rate efficacy when increasing the moisture content in some instances. Efforts were made throughout testing to ensure a consistent chaff moisture content by storing indoors and occasionally mixing the material.

Table 6. Wheat chaff moisture sample tests.

Chaff Sample	Starting Weight (g)	End Weight (g)	M.C. Wet Basis (%)
June 12 - 1:35 pm	100	87.64	12.4
June 12 - 4:52 pm	109.6	93.2	15.0
June 13 - 12:48 pm	100.73	89.29	11.4
June 14 - 8:30 am	141.78	121.28	14.5
June 14 - 1:08 pm	126.42	107.79	14.7

DSL Samples were weighed, placed in 60°C incubator for 48 hours, then reweighed.

Statistical Analysis

The R-Stats package (version 4.3.1) was used to conduct an Analysis of Variance (ANOVA), and variable correlation.

To appropriately identify any potential effects on the seed kill rate, three sub-datasets were generated to isolate the variables of interest when conducting the ANOVA. For each test, the P-Values and analysis are included in the **Appendix**.

Based on the statistical analysis, the kill rate was found to be correlated to the throughput and the SCU speed. The kill rate data at the varying throughputs and speeds were significantly different from each other. Comparing the SCU conditions (new vs. worn), no significant difference was observed with respect to the kill rate. Similarly with the Walsh and Protocol 2 test methods, the kill rates were not significantly different.

Figure 9 displays the average kill rate with respect to the chaff throughput. In all conditions, a decreasing kill rate trend is observed as the throughput increases. It is also apparent that the CV increases with the chaff throughput.

Figure 9. Average kill rate versus throughput at 2,900 rev/min, standard setting, and both protocols (Walsh and Protocol 2) – CV% ± bars.

Despite only having two SCU speeds for comparison, the visible trend in **Figure 10** confirms the results from the statistical analysis. As the speed increases, so does the resulting kill rate. It should be noted that the speed settings were set without product within the SCU. As the chaff and seed were introduced into the system, the speed would drop 2% to 4% below the set speed depending on the throughput (**Figure 8**).

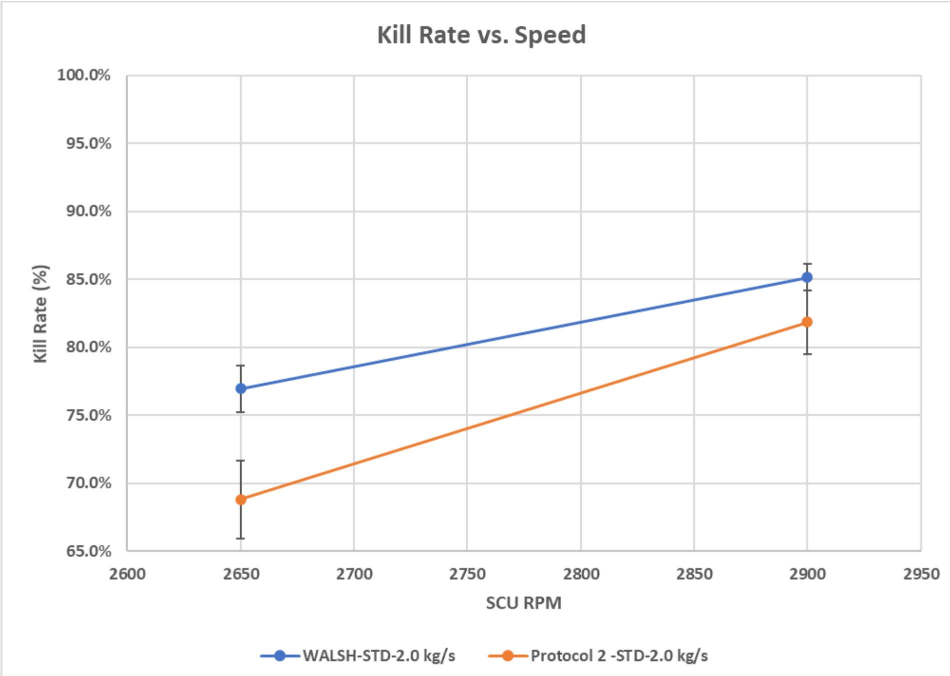

Figure 10. Average kill rate versus speed at 2.0 kg/s, both protocols (Walsh and Protocol 2) – CV% ± bars.

As also identified within the statistical analysis, the kill rate was not significantly affected by the condition of the SCU unit. The worn and new stators had varying trends between the test protocols, as seen below in **Figure 11**. The Walsh protocol displayed a slight increase in kill rate while Protocol 2 showed a decrease when changing to the worn stator.

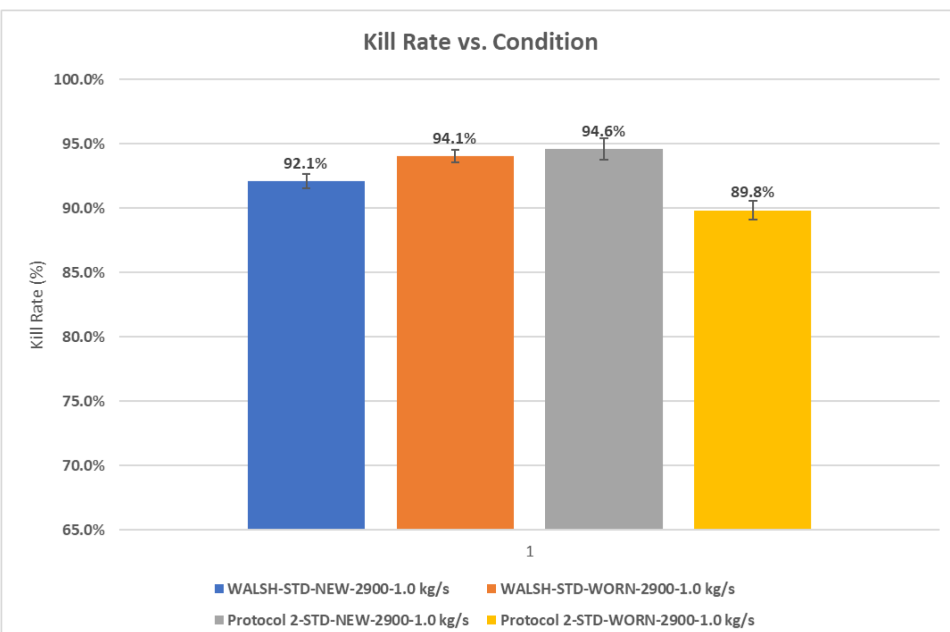

Figure 11. Average kill rate versus condition at 1.0 kg/s, standard setting, and both protocols (Walsh and Protocol 2) – CV% ± bars.

Conclusion and Observations

Both the Walsh protocol and Protocol 2 attempt to establish a consistent and repeatable methodology for testing the effectiveness of a harvester weed-seed mill. Walsh established the initial template, which was further developed in Protocol 2. Walsh et al. (2017) used a single worst-case throughput of 1.5 kg/s and varied mill speeds to evaluate the seed kill rate. Protocol 2 had three levels of throughput (1.0, 1.5, and 2.0 kg/s), two speeds (75% and 100%), and accounted for the condition of the mill (new versus used). The interpreted intention of Protocol 2 was to create longer and more consistent trial runs at varying operating conditions. The Walsh and Protocol 2 runs have equivalent durations of 1.33 s and 3.00 s, respectively.

PAMI adopted both methodologies by testing four throughputs (0.75, 1.0, 1.5, and 2.0 kg/s), two speeds (2,650 and 2,900 RPM), and two stator conditions (new and worn). Except for the catch system (cyclone dust collector), both methodologies were followed. A cyclone dust collector was used to recover the processed material, as it was the most practical and least invasive.

The initial data displayed higher levels of variance (CV: 2% to 6%) among the kill rates conducted at 2.0 kg/s throughput with Protocol 2. The other kill rates had CV values of 1% to 3%. A decrease in mill speed (2% to 4%) was observed during these higher throughputs. With the larger overall quantity of chaff used with Protocol 2 (1.5 and 2.0 kg/s), the kill rate efficacy varied significantly.

The statistical analysis identified the throughput and mill speed as the variables that significantly affected the kill rate. The condition of the mill and the test protocol (Walsh and Protocol 2) had no significant impact on the kill rate.

Recommendations

The following are PAMI's recommendations after completing testing on the Client's SCU:

- Consider increasing the number of baseline germination tests to reduce potential variability when adjusting the potential kill rate.
- Consider increasing the number of sub-samples for the germination tests.
  - A better representation of the seed devitalization efficacy could be observed.
- Consider further investigation when establishing the chaff throughput values.
  - Varying accounts and recorded datasets may suggest higher or lower ranges depending on several harvesting conditions (i.e., crop type, yield, moisture content, etc.).
  - The principal objective of these methodologies is to establish consistent and repeatable results. Conditions in lab-controlled experiments may not always align with evolving crop varieties and operating scenarios.
- Consider replacing the high 2.0 kg/s throughput with an intermediate value. (i.e., between 0.75 and 1.5 kg/s)
  - The higher CV value created more scatter among data.
  - The 2.0 kg/s throughput may not be very representative of any realistic harvesting conditions.

- Consider setting the SCU speed while processing material instead of unloaded.
    - This would align the speed with actual harvester field conditions.
- Consider increasing the mill speed range for future testing (three to four points).
    - Speed optimization could lead to energy savings for a given acceptable kill rate.

References

Canadian Food Inspection Agency. 2012 Version. Canadian Methods and Procedures for Testing Seed. Section: 4.0 Germination

South Australian Grains Industry Trust (SAGIT) Project. 2022. Trengove Consulting & University of Adelaide Weeds Research.

Walsh, M. J., Broster, J. C., Powles, S. B. 2017. iHSD Mill Efficacy on the Seeds of Australian Cropping System Weeds. Weed Science Society of America.

Walsh, M. J., Broster, J. C., Tayner, A. K., Sturt, C. 2022. Seed destruction when using a stripper front – does it work. Australian Government – Grains Research Development Corporation (GRDC).

Appendix

TableA-1. Correlation analysis.

Interaction	COR Coef.	COR P-Value	Correlation	Dataset
Kill Rate: Throughput	0.863	5.98E-08	YES	Data_1
Kill Rate: Speed	0.768	3.53E-03	YES	Data_2

Correlation is considered strong with coefficient above 0.5 and significant with P-Value below 0.05.

Table A-2. ANOVA results.

Interaction	ANOVA P-Value	Sig. Different	Dataset
Kill Rate: Throughput	5.97E-08	YES	Data_1
Kill Rate: Method	0.961	NO	Data_1
Kill Rate: Speed	3.53E-03	YES	Data_2
Kill Rate: Method	0.183	NO	Data_2
Kill Rate: Condition	0.318	NO	Data_3
Kill Rate: Method	0.542	NO	Data_3

Significantly different with P-Values smaller than 0.05.

Table A-3. Trial average summary for each test configuration.

METHOD	Speed (RPM)	SETTING	Throughput (kg/s)	CONDITION	KILL Rate (%)	CV (%)
WALSH	2,900	STD	0.75	NEW	93.0	1.8
WALSH	2,900	STD	1.00	NEW	92.1	1.1
WALSH	2,900	STD	1.50	NEW	87.3	1.1
WALSH	2,900	STD	2.00	NEW	85.1	2.0
Protocol 2	2,900	STD	0.75	NEW	94.4	2.1
Protocol 2	2,900	STD	1.00	NEW	94.6	1.6
Protocol 2	2,900	STD	1.50	NEW	87.2	3.0
Protocol 2	2,900	STD	2.00	NEW	81.9	4.7
WALSH	2,650	STD	2.00	NEW	76.9	3.4
Protocol 2	2,650	STD	2.00	NEW	68.8	5.7
WALSH	2,900	STD	1.00	WORN	94.1	1.0
Protocol 2	2,900	STD	1.00	WORN	89.8	1.5