

ENGINEERING & GINNING

Performance of a Cotton Gin Machine that Removes Plastic Contamination from Seed Cotton

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ABSTRACT

A commercial cotton contamination cleaner developed and used to combat the plastic contamination problem in Chinese cotton was tested to compare its performance at removing typical plastics found in U.S. cotton to that of conventional cotton gin seed cotton cleaners. Seed cotton “spiked” with pieces of shopping bags, single-layer non-tacky round module wrap (RMW), and three-layer RMW of various sizes was introduced into the machines. Overall, the contamination cleaner was more effective at removing plastic contamination than a conventional cotton gin stick machine and inclined cleaner. Increasing the airflow to the contamination cleaner improved plastic removal. Overall capture of plastic across all sizes and types increased from 16 to 48% when airflow was increased from 17,500 to 30,200 m³/hr (10,300 to 17,800 ft³/min). However, seed cotton captured with the plastic also increased from 1.4 to 34 kg (3 to 75 lb) per bale. Shopping bag material and one-layer non-tacky RMW (lighter, pliable) were more effectively removed than three-layer RMW (heavier, stiffer), and smaller plastic pieces were more effectively removed than larger pieces. All the machines tested removed about the same amount of cotton trash (about 13.6 kg or 30 lb per bale).

U.S. and international spinners have experienced serious contamination issues with U.S. cotton. Of particular concern are plastic contaminants – plastic trash that collects in cotton fields, black plastic film used as mulch in fields, plastic twine typically used for baling forage crops, and plastic film used for round module wrap (RMW). These

contaminants are typically introduced prior to ginning, but mechanical processes at the gin can tear and shred the plastics so that they become more challenging to detect and remove. The best solution is to keep plastic out of the cotton altogether but, when it does slip in, methods to remove the plastic at the gin are needed.

Byler et al. (2013) conducted research to understand the removal of sheet plastic by typical cotton ginning equipment. They added plastics to seed cotton, including RMW, irrigation tubing, shopping bag, agricultural mulch film, and typical consumer ice bags in several different sizes ranging from 2.5 cm x 2.5 cm (1 in x 1 in) to 7.6 cm x 15 cm (3 in x 6 in), and then processed the spiked seed cotton with a typical ginning equipment sequence for Upland cotton. They found that cylinder cleaners removed 10% of plastics and extractor-type cleaners removed 56% of the plastics, but 17% of the plastic material passed through the ginning processes to the ginned lint. They also found that larger plastic pieces and thinner plastics were less likely to be removed.

Hardin and Byler (2016) investigated how different operating conditions of a hot-air cylinder cleaner affected its removal of sheet plastic and fiber loss. They varied airflow rate through the cleaner, seed cotton processing rate, cylinder rotation speed, and plastic piece size. They found that plastic removal increased with increasing airflow rate, decreasing cylinder rotation speed, and decreasing plastic piece size. Shopping bag pieces were removed more effectively than RMW pieces. Fiber loss also increased with increased airflow rate but decreased with decreasing cylinder rotation speed.

A recently developed, vision-based technology was shown to be 90% effective at detecting and removing colored plastics at the gin stand (Rutherford and Sweers, 2020; Pelletier et al., 2021). This technology has limitations in that it detects and removes only colored plastics and is deployed late in the ginning system allowing plastics to be introduced into cotton gin machines upstream from the device. Alternative devices that extract plastics

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regardless of color or transparency and are designed for deployment at the beginning of the ginning process are needed.

The Handan Goldenlion Cotton Machinery Co. Ltd. Contamination Cleaner (Handan, Hebei, China) (GLCC; Fig. 1) was designed to remove plastic contamination from seed cotton entering the cotton gin with mechanical and pneumatic processes at 75% efficiency (MQYM10A Operation Manual, Handan Goldenlion Cotton Machinery Co. Ltd., Handan, Hebei, China). The company's online listing shows its contamination removal rate ranges between 50% for light trash and 80% for residual film (<http://hcmjs.ecer.com/sale-10596951-mqym10a-contamination-cleaner.html>). The GLCC has four cleaning areas that utilize mechanical and pneumatic methods. The first section ("A" in Fig. 1) contains rotating, horizontal, spiked cylinders in a pair of vertical flow chambers that remove strings and large pieces of plastic film. While one chamber is operated, the alternate chamber is cleaned by hand. The second section ("B" in Fig. 1) contains rotating, horizontal, spiked cylinders that move material horizontally over grid bars to remove small pieces of leaves and foreign matter. The third section ("C" in Fig. 1) contains round bars with gaps in between that also remove small pieces of leaves and foreign matter. The fourth section ("D" in Fig. 1) uses a blast of air to disperse the seed cotton and float fine foreign matter and small plastic pieces upward towards a rotating screen drum that removes and sends the plastic pieces (and some seed cotton) to a catchment. Cleaned seed cotton exits through the bottom of the cleaner and is conveyed to the next ginning process.

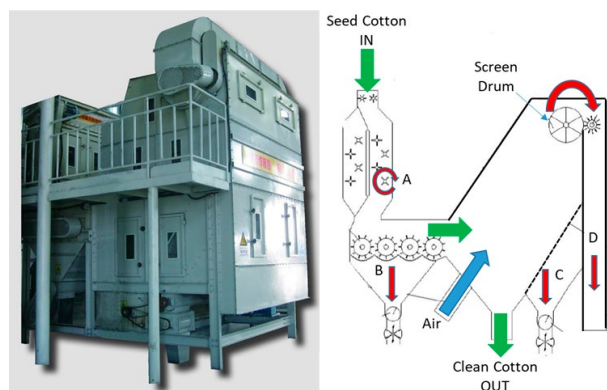


Figure 1. Handan Goldenlion Contamination Cleaner: A – removes strings and large pieces of plastic film; B – removes small pieces of leaves and foreign matter; C – also removes small pieces of leaves and foreign matter; and D – removes fine foreign matter and small plastic pieces.

Previous tests of the GLCC showed that the air-flow rate to the machine had a considerable impact on plastic removal performance (Whitelock et al., 2020). Overall, plastic capture increased from 12 to 50% when the airflow rate was increased from 14,100 to 30,200 m³/hr (8,300 to 17,800 ft³/min). Pieces of light weight RMW and shopping bags were captured within the range of the manufacturer's claims at the highest airflow, but thicker, stiffer RMW was not effectively removed. This elevated airflow also increased the amount of seed cotton captured with the plastic from 0.4 to 30 kg (0.8 to 67 lb) per bale. This work did not include baseline performance comparisons with conventional seed cotton cleaners.

The objective of this study was to compare the plastic capture performance of the GLCC to conventional cotton gin seed cotton cleaners (stick machine and cylinder cleaner). This will help cotton gins gauge whether the contamination cleaner could be an effective off-the-shelf tool to use in the fight against plastic contamination in U.S. cotton

MATERIALS AND METHODS

The gin test took place in 2020 at the USDA-ARS Southwestern Cotton Ginning Research Laboratory (SWCGRL) located in Las Cruces, NM. The seed cotton used was NexGen 4545 (Americot, Inc., Lubbock, TX). The GLCC was designed to be the first machine that seed cotton encounters when entering the gin system. In the U.S., seed cotton is opened slightly by the module feeder and pneumatically conveyance to the cleaning machinery. For this test, the seed cotton was prepared by opening a round module and dumping the seed cotton into a cotton trailer. To mimic opening up the cotton like a module feeder, the raw seed cotton was pneumatically conveyed from the trailer via a suction pipe to a three-cylinder separator located before a feed control hopper and then deposited in bins according to test lot weight.

Manufacturer rated capacity of the 2.5-m (8.2-ft) wide GLCC was 10,000 kg (22,046 lb) of seed cotton per hour. This is equivalent to about 6.6 bales/hr-m (2 bales/hr-ft) of width (assuming 612 kg [1,350 lb] seed cotton per bale). The stick machine used was a 1.8-m (6-ft) wide, two-saw model, and the inclined cleaner was also 1.8-m (6-ft) wide with six cylinders (Fig. 2).

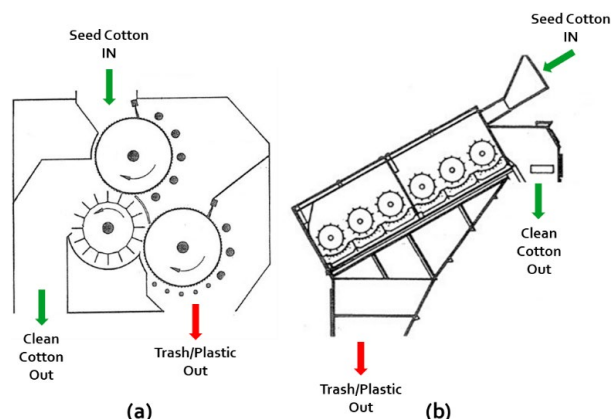


Figure 2: Schematic of a two-saw stick machine (a) and six-cylinder inclined cleaner (b).

A storage hopper that holds about 90 kg (200 lb) of seed cotton was fabricated and installed on the inlet to the GLCC (Fig. 3). The 90 kg (200 lb) test lot of seed cotton allowed about 30 seconds of run time for the GLCC. The hopper also incorporated a lid to block air from entering and ensured that airflow did not bypass the appropriate inlets. The seed cotton cleaners were fed 66 kg (145 lb) test lots of seed cotton for about 30 seconds to achieve the same capacity of 6.6 bales/hr-m (2 bales/hr-ft) of width.



Figure 3. The Handan Goldenlion Contamination Cleaner with seed cotton hopper installed.

The airflow rate to the GLCC is the variable that is readily adjustable. Three airflow rates to the contamination cleaner were used: 17,500, 23,786, and 30,242 m³/hr (10,300, 14,000, and 17,800 ft³/min).

These were obtained by setting a variable frequency drive on the fan, providing airflow to the contamination cleaner. The manufacturer's recommended maximum airflow rate ranged from 25,100 to 35,100 m³/hr (14,700 to 20,600 ft³/min). Airflow beyond 30,242 m³/hr (17,800 ft³/min) was not achievable due to the high-pressure losses through the GLCC at high airflow rates. Also, the earlier tests conducted by Whitelock et al. (2020) showed that high airflow rates resulted in excessive removal of clean seed cotton, so higher rates were deemed undesirable.

Three types and sizes of typical plastics found in U.S. ginning systems were used for the test (Fig. 4). The types ranged from thin, light, and pliable to thicker, stiffer, and heavier plastics and included shopping bags, single-layer (non-tacky inner) RMW (one-layer), and three-layer (tacky, tacky, non-tacky inner) RMW (three-layer). The sizes were small (5 cm x 5 cm [2 in. x 2 in]), medium (10 cm x 30 cm [4 in x 12 in]), and large (5 cm x 122 cm [2 in. x 48 in] RMW or whole shopping bag). Before each test run, 20-each pieces of the small and medium plastic samples and five of the large plastic samples for each plastic type were randomly distributed throughout the seed cotton lot.



Figure 4. Types and sizes of plastic pieces used for testing the Goldenlion Contamination Cleaner. Types were shopping bags (Red), single-layer round module wrap (RMW) (Light Yellow and Light Pink), and three-layer RMW (Dark Yellow and Dark Pink). Sizes were small, medium, and large RMW or whole shopping bag.

The GLCC was tested as follows (Fig. 5): 1) spiked seed cotton was placed in the hopper, 2) airflow rate was set according to the experiment design, 3) seed cotton was fed to the machine at the pre-determined feed rate (6.6 bales/hr-m [2 bales/hr-ft]), 4) cleaned seed cotton was collected under the machine, and foreign matter and plastic pieces were collected at the trash/plastic outlets, and 5) from each trash/plastic outlet, trash and seed cotton were collected and weighed, and the plastic pieces were separated, sorted by type and size, and counted.

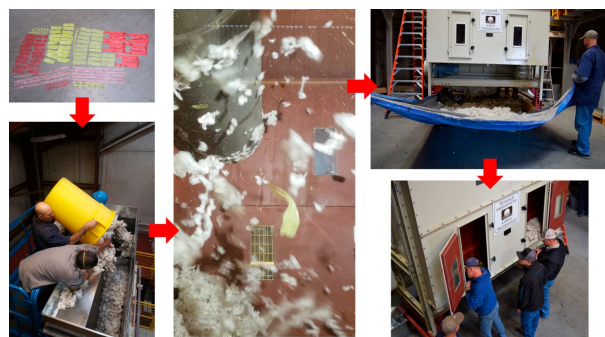


Figure 5. Phases of testing the Goldenlion Contamination Cleaner.

The seed cotton cleaners were tested as follows (Fig. 6): 1) spiked seed cotton was placed on the floor at the entrance to a conveying pipe that ran to a seed cotton separator above the seed cotton cleaners, 2) seed cotton was manually introduced into the pipe entrance at the pre-determined feed rate (6.6 bales/hr-m [2 bales/hr-ft]), 3) cleaned seed cotton was collected under the machine, and the foreign matter and plastic pieces were collected at the trash/plastic outlets, and 4) from the trash/plastic outlet, the trash and seed cotton were collected and weighed, and the plastic pieces were separated, sorted by type and size, and counted. Before each test run, two subsamples of seed cotton were collected to determine foreign matter and moisture content using standard SWCGRL procedures based on Shepherd (1972) and Funk et al. (2018), respectively.



Figure 6. Process of "spiking" the seed cotton with plastic contamination pieces and feeding the conveyance pipe to the stick machine and cylinder cleaner.

The experimental design was a randomized complete block with replication serving as blocks. Cleaner treatment was randomized within replicate. Statistical analyses were conducted using JMP version 12.2.0 (SAS Institute, Inc., Cary, N.C.). The Fit Model platform with the standard least squares option was used to fit a mixed model with cleaner treatment, plastic type, plastic size, and their two-way and three-way interactions as the main effects and replication as a random effect. Multiple-pairwise

comparisons of the least square means were performed using Tukey HSD. A significance level of 5% was used to identify differences.

RESULTS

Seed cotton foreign matter content and moisture content before processing averaged 6.34% and 5.59% (w.b.), respectively. Processing rate across all lots averaged 3,778 kg/hr-m (2,539 lb/hr-ft), which was very near the GLCC manufacturer recommended capacity of 4,000 kg/hr-m (2,688 lb/hr-ft). There were no significant differences in seed cotton foreign matter content (p value = 0.38), seed cotton moisture content (p value = 0.30), and processing rate (p value = 0.52) among cleaner treatments. This was desired to reduce variability in the results due to differences in the seed cotton conditioning or processing rate.

Statistical analysis of the amount of plastic removed by the cleaners showed that there were significant differences (p value < 0.01) among cleaner treatments, among plastic types, and among plastic sizes (Table 1). The number of plastic pieces (type and size) removed by the cleaners ranged from 2.2 to 48.1%. The GLCC with High and Med airflow removed a larger percentage of plastic pieces than the conventional seed cotton cleaners, but the number of plastic pieces removed by the GLCC with Low airflow was not different from the stick machine. The cylinder cleaner removed the lowest percentage of plastic pieces while processing the seed cotton.

Continuing with Table 1, the amount of plastic removed among plastic types ranged from 11.0 to 34.7%. Of the three plastic types, more of the shopping bag was removed than either of the RMW types; the three-layer RMW was the least amount of plastic removed. This is likely due to the shopping bag being lighter and more flexible, and more easily lifted by the air currents and conforming to the separation cylinder in the air chamber of the GLCC, while the three-layer RMW was the heaviest and least flexible plastic type. The amount of plastic removed among sizes ranged from 19.7 to 29.3%. More of the small size plastic pieces were removed by the cleaners than the larger sizes. The two-way interactions (cleaner*plastic and cleaner*size) and the three-way interaction (cleaner*plastic*size) were significant (Table 1); a discussion of the interactions follows.

Table 1. Statistical analysis of plastic removed by cleaner type, plastic type, plastic size, and their interactions.

Treatment group	Significance level	Treatments ^z	Plastic pieces removed ^y
	----- <i>p</i> value -----		----- % -----
Cleaner	< 0.0001	GLCC High	48.1 a
		GLCC Med	35.4 b
		GLCC Low	15.9 c
		Stick Machine	13.0 c
		Cylinder Cleaner	2.22 d
Plastic Type	< 0.0001	Shopping Bag	34.7 a
		1-layer RMW	23.1 b
		3-layer RMW	11.0 c
Plastic Size	< 0.0001	Small	29.3 a
		Medium	19.7 b
		Large	19.7 b
Cleaner*Type	< 0.0001	see Figure 7	
Cleaner*Size	< 0.0001	see Figure 8	
Type*Size	0.23		
Cleaner*Type*Size	< 0.0001	see Figure 9	

^z GLCC = Goldenlion Contamination Cleaner; High, Med, Low = level of airflow through the GLCC; RMW = round module wrap

^y Means followed by the same letter within a treatment group are not significantly different at the 0.05 level.

Figure 7 shows the amount of plastic removed for the interaction between cleaner and plastic type; the 95% confidence intervals are included on each interaction. The amount of plastic removed by the GLCC treatments was greater for the lighter, more flexible shopping bag and lesser for the heavier, stiffer three-layer RMW. For the GLCC High and Med treatments, the shopping bag was removed at a significantly higher rate than the one-layer RMW, which in turn was removed at a significantly higher rate than the three-layer RMW. This could be attributed to lighter plastics being more easily lifted by the airflow in the GLCC and adhering better to the screen drum due to their flexibility. It can also be seen that reducing airflow in the GLCC reduced plastic removal. Based on the overlap of the confidence intervals, the GLCC High and Med had significantly higher removal amounts than the GLCC Low for shopping bags, the GLCC High removal amount was significantly higher than the GLCC Low for one-layer RMW, and the GLCC High had a significantly higher removal amount than the GLCC Med and Low for three-layer RMW. Plastic type had little impact on the stick machine, and cylinder cleaner as the amount of plastic removed was the same regardless of plastic type.

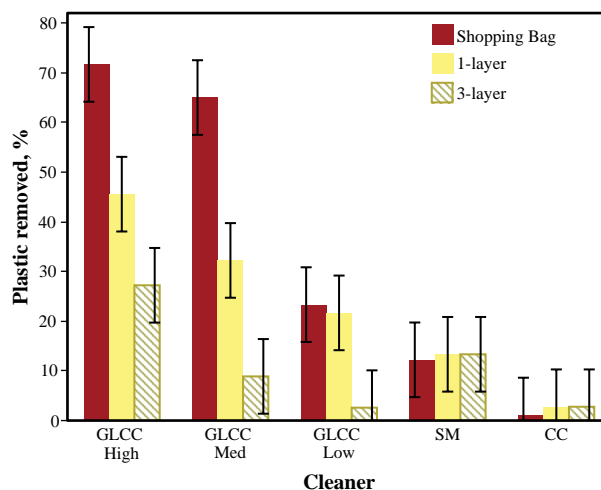


Figure 7. Amount of plastic removed for the cleaner type*plastic type interaction with 95% confidence intervals. GLCC High, Med, and Low = Goldenlion Contamination Cleaner at high, medium, and low airflow; SM = stick machine; CC = cylinder cleaner.

Figure 8 shows the amount of plastic removed for the interaction between cleaner and plastic size; 95% confidence intervals are included on each interaction. For the small and medium size pieces, the removal rate increased with airflow rate in the GLCC (Low to Med to High), but this trend did not hold for the large pieces, as evi-

denced by the overlapping confidence intervals. The trend for plastic removal decreased with plastic size for the GLCC High, was mixed for the GLCC Med, and plastic removal increased with size for the GLCC Low. The stick machine removed about 40% of the small pieces (similar to that removed by the GLCC cleaner treatments), but only 1% or less medium and large pieces. The cylinder cleaner removed less than 5% of the small, medium, or large pieces.

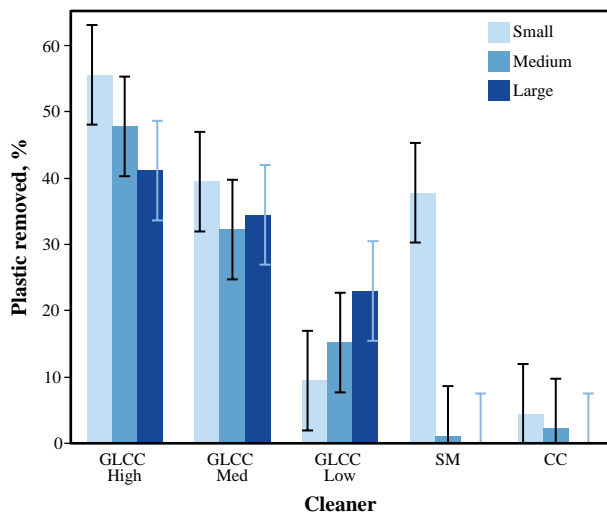


Figure 8. Amount of plastic removed for the cleaner type*plastic size interaction with 95% confidence intervals. GLCC High, Med, and Low = Goldenlion Contamination Cleaner at high, medium, and low airflow; SM = stick machine; CC = cylinder cleaner.

Figure 9 shows the amount of plastic removed for all combinations of cleaner*plastic type*plastic size with 95% confidence intervals included on each interaction. A review of the figure confirms the overall results shown in Table 1 that, in general, the GLCC removed the most plastic pieces and the cylinder cleaner removed the least, 2) more plastic pieces were removed with increased airflow to the GLCC, 3) the capture of plastic pieces increased from heavier, stiffer plastic (three-layer RMW) to lighter, flexible plastic (shopping bag), and 4) as plastic piece size increased from small to large, fewer plastic pieces were removed.

Further inspection of Figure 9 revealed several other findings. Overall, the plastic removal rate was highest in the top left corner with small size and shopping bag plastic (lightest and most flexible) and decreased as one moves to the right (increasing plastic size) and downward (increas-

ing plastic weight and stiffness) with the lowest removal rate in the bottom right corner with large size and three-layer RMW plastic (heaviest and least flexible). The number of plastic pieces removed by the GLCC High was not significantly different from that of the GLCC Med for any of the type x size combinations. The GLCC with high airflow removed more of the small shopping bag and one-layer RMW plastic pieces than the other cleaner treatments (80% and 58%, respectively) except for the GLCC Med. The stick machine removed the small size of all three types of plastic at about the same rate (38%) and removed more three-layer RMW than the other cleaner treatments apart from the GLCC High. The GLCC with high airflow removed the most medium size plastic pieces (68, 52, and 23% of shopping bag, one-layer RMW, and three-layer RMW, respectively), but again, not significantly more than the GLCC Med. The other cleaner treatments (GLCC Low, stick machine, and cylinder cleaner) removed less than 3% of the medium size three-layer RMW, less than 15% of the medium size one-layer RMW, and 30% or less of the medium size shopping bag. The results for large plastic pieces were mixed among plastic types. The GLCC with high airflow removed the most large-size three-layer RMW pieces (30%), the GLCC Low removed the most large-size one-layer RMW pieces (40%), and the GLCC Med removed the most whole shopping bags (83%). The stick machine and cylinder cleaner did not remove any of the large plastic pieces.

Figure 10 shows the amount of cotton trash removed, the overall percentage of all plastic types and sizes removed (repeated from Table 1), and the amount of seed cotton captured with the plastic pieces by the different cleaners. All the cleaners removed about 14 kg (30 lb) of gin trash per bale. Overall, the GLCC with high and medium airflow removed about 48% and 35%, respectively, of all plastic pieces, more than twice as much as the other machines. However, the GLCC with high airflow also captured more than three times the amount of seed cotton with the plastic (34 kg [75 lb] per bale) than the other machines (11 kg [23.5 lb] for GLCC with medium airflow and 1.4 kg [3.0 lb] for GLCC with low airflow). This mixture of cotton and plastic could pose a new challenge for the cotton gin to deal with.

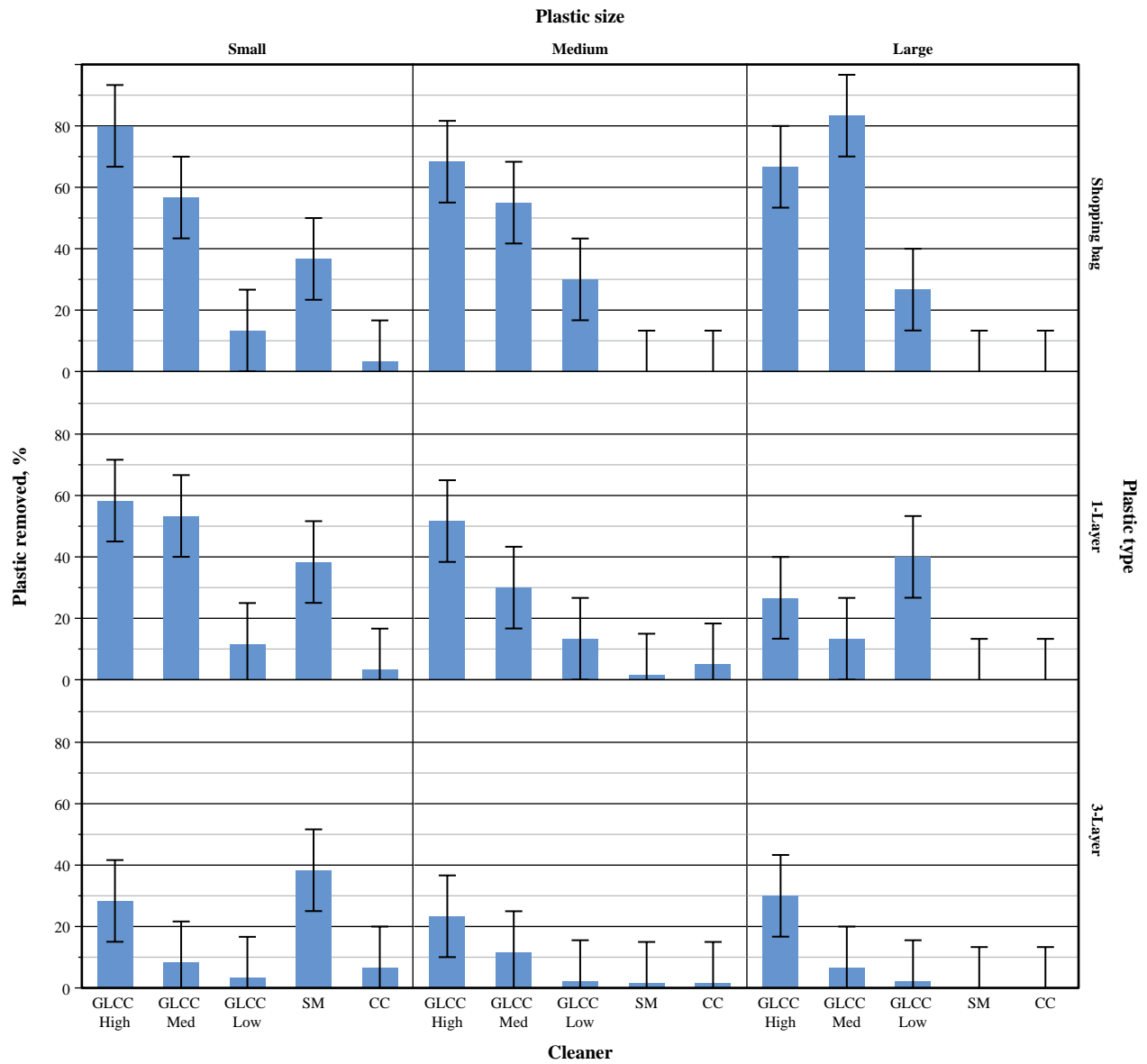


Figure 9. Amount of plastic removed for the cleaner type*plastic type*plastic size interaction with 95% confidence intervals. GLCC High, Med, and Low = Goldenlion Contamination Cleaner at high, medium, and low airflow; SM = stick machine; CC = cylinder cleaner.

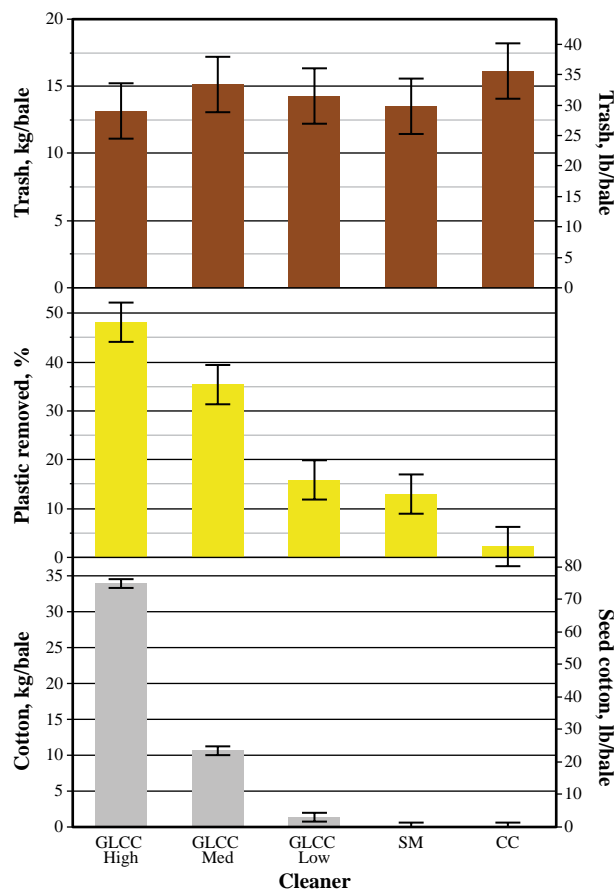


Figure 10. Amount of cotton trash removed, amount of all plastic types and sizes removed, and amount of seed cotton captured with the plastic pieces with 95% confidence intervals. GLCC High, Med, and Low = Goldenlion Contamination Cleaner at high, medium, and low airflow; SM = stick machine; CC = cylinder cleaner.

CONCLUSIONS

Overall, the GLCC was more effective at removing plastic contamination than the stick machine and cylinder cleaner. Lighter and more pliable shopping bag material and one-layer non-tacky RMW were removed better than heavier and stiffer three-layer RMW. Smaller size pieces were more effectively removed from seed cotton than medium and large RMW or whole shopping bag size pieces. Increasing airflow to the GLCC improved plastic removal, but seed cotton captured with the plastic also increased. For small and medium pieces and lighter shopping bags and one-layer RMW plastics, the GLCC with medium and high airflow captured plastics within the range stated in the manufacturer’s literature (50% to 80%). The stick machine removed small size pieces of plastic consistently at a 38% removal rate. The cylinder cleaner did not effectively remove any of

the plastic. All the machines tested removed about the same amount of cotton trash. For cotton ginneries, capturing plastic pieces will need to be balanced with also removing seed cotton with the plastics.

FUTURE WORK

Video captured during testing revealed an issue that may be limiting the machine’s performance. Images in Figure 11 show that often pieces of plastic adhered to the screen drum for separation as designed (a). However, as the screen drum rotated (b) and the plastic piece reached the vertical position (c), the air circulating inside the machine stripped the plastic piece from the screen drum (d). It is unknown if those pieces of plastic were later collected on the screen drum again or if they recombined with the seed cotton flow. Further work is needed to investigate this issue and determine if it can be mitigated through minor modifications without increasing the amount of seed cotton captured with the plastic.

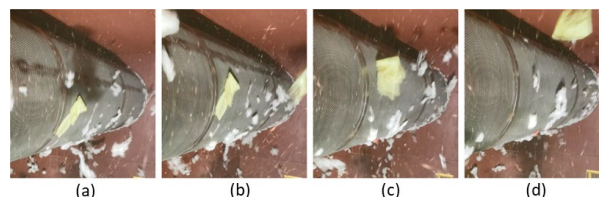


Figure 11. Video images of plastic pieces attached to, and then stripped from, the Goldenlion Contamination Cleaner screen drum by air currents.

DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

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