

SMALL-SCALE MECHANICAL CARROT WASHER FOR RESEARCH SAMPLE PREPARATION

J. A. Moos, D. D. Steele, D. C. Kirkpatrick

ABSTRACT. Carrot samples from field research studies of irrigation, fertility, and variety trials must be cleaned prior to weighing and grading. Soil and other foreign materials must be removed, especially for medium- and heavy-textured soils in which a pre-harvest irrigation is used to loosen the soil prior to hand harvesting. The objective of this project was to develop a low-cost mechanical carrot washer to reduce the labor and time requirements for sample preparation. Design considerations and operating constraints included sample sizes ranging from 3 to 11 kg (6.6 to 24.5 lb), a low operating speed to prevent bruising and breakage, low water pressures and flow rates, retention of small pieces, ease of sample loading and unloading, time and cost savings compared with manual washing systems, and operator safety. Carrot plant tops (stems and leaves) were removed prior to washing in this system. Food-grade washing capabilities were not a requirement of the washer. A nonimmersion, rotary washing system was developed using a horizontal 208-L (55-gal) barrel supported by roller drive wheels and equipped with a low-pressure spray wand. For carrot samples taken from a Heimdahl loam soil in east-central North Dakota, the water requirement per sample was approximately 11 to 15 L (3 to 4 gal), the optimum operating speed was 10 to 12 rpm, and the sample washing time varied from 5 to 7 min per sample. The article provides construction procedures, a bill of materials, cost estimates, photographs, engineering drawings, suggestions for improvements in the design, and safety considerations. Compared with manual washing of carrots, the mechanical washer achieved considerable improvements in sample processing speed and reduced labor requirements with no reduction in carrot quality. The washer should be adaptable for other types of root crops.

Keywords. Vegetables, Root crops, Cleaning, Washing, Sample preparation, Processing.

Washing carrots is necessary to remove soil and other foreign material before sorting, grading, weighing, and counting the samples. The primary motivations for development of a mechanical carrot washer for small samples are improved carrot quality, time and labor savings, and improved speed and efficiency of sample handling. This article presents the need and design constraints for a small-scale mechanical carrot washer, the methods and materials used to construct the washer, the results obtained, suggestions for improvement, and safety considerations.

For a 1999–2000 field study of irrigation and fertilizer practices for carrots grown on loam soils, we hand-harvested a 1.00-m (3.28-ft) double-row length of carrot plants from each of 192 plots. Sample tops (leaves and stems) were

removed and the discussion in this article refers to carrot roots only. Sample sizes for the 2000 season averaged 7.3 kg (16.0 lb), with a range of approximately 3 to 11 kg (6.6 to 24.5 lb). The average number of carrots in the samples was 80.6, with a range from 31 to 171. Pre-harvest irrigations were necessary to loosen the soil prior to hand harvesting the carrots, but the irrigations resulted in significant amounts of soil adhering to the roots. For the 1999 season, a manual washing system consisting of a screened box and a high-pressure water spray that required one person to spend 15 to 20 min washing each sample, including sample loading and removal time. Tissue damage was noticed when the washer nozzle was too close to the carrots. The primary reason for the design and construction of a mechanical carrot washer was to reduce the time and labor required for sample processing compared with the manual system.

Relatively little information is available in the research literature on small-scale carrot washers for samples in the size range of 3 to 11 kg (6.6 to 24.5 lb). Le-Bohec (1993) stated that conventional washing methods for carrots, consisting of rotary washing systems in which carrots are not immersed, tend to damage carrots. Improvements developed by industry include washing on a horizontal plane or washing by immersion in a rotary system.

Mendenhall et al. (1988) discussed several approaches to vegetable washing, with concepts similar to the washing action of common machines such as household dishwashers, top and side loading clothes washers, an automobile washer, and ultrasonic methods. For a horizontal, rotating drum, in which the vegetables would be partially submerged, they

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expected incomplete cleaning for nonspherical vegetables such as carrots.

In a study of dishwasher effectiveness in removing baked-on food soil from glass and aluminum substrates, Day (1975) noted that three types of energy inputs are required. The energy inputs are thermal (steam or high temperature water), mechanical (a concentrated jet of spray), and chemical (detergents). Since simplicity of design and relative ease of construction were important factors in this project, we did not consider thermal modifications such as heating the input stream of water or chemical additions such as detergents.

An example of a commercial carrot washer is reported by Stark (2000), whose cylindrical washer is 5 m (16.4 ft) long \times 0.9 m (2.95 ft) diameter, has a full-length spray bar, uses four rollers with 600-kg (1320-lb) capacity each, operates at 12 to 13 rpm, and has a 7.5-kW (10-hp) motor.

Because commercial-scale carrot washers are too large and expensive for our needs, the objective was to design and construct a small-scale carrot washer to clean samples for grading, counting, and weighing. Design considerations and operating constraints included the following factors. The carrots needed to be cleaned sufficiently so soil and foreign material would not significantly affect subsequent weighing and grading activities. The washer needed to handle samples smaller than 20 kg (44 lb). A low operating speed was necessary to prevent bruising and breakage. The water supply for the system was to be garden-hose compatible, with pressures and flow rates typical of indoor plumbing systems and not requiring additional pressurization. The washer needed to retain small carrot pieces, i.e., screens or openings should not be too large as to produce measurable sample loss. The washer needed to be easy to load and unload, as well as safe to operate. We needed to shorten the washing time compared with our previous method of batch washing in a screened box. Lastly, we needed to have a system costing less than a commercial washing system.

The carrot washer was not intended to clean the carrots sufficiently for human consumption. In addition, after the grading and weighing activities were completed for carrots washed in this system, subsamples were taken for laboratory testing of storability, sugar content, taste, etc. Such subsamples would need further hand washing in accordance with the criteria for those tests. We did not consider additional processes (Monroe and O'Brien, 1983) such as disinfection via the addition of chemicals, hydro cooling, and treatments for ripening, appearance, and preservation.

As design alternatives were considered, two approaches emerged. One approach was to adapt a potato washing system in which potatoes were conveyed on a rubber belt past a series of brushes and under several spray nozzles. This washing system was available from our potato research colleagues, but maintaining product flow and washing effectiveness was perceived as too difficult under the time and cost constraints of the carrot research project. Specifically, we expected the potato washer to turn the carrots sideways, thereby plugging the system or breaking the carrots. The second approach we considered was to use a nonimmersion, rotary washing system using a barrel and a low-pressure spray wand. The second design is the topic of this article.

The objective of this article is to chronicle the design, development, and performance of the mechanical carrot

washing system. We do not provide statistical comparisons of the mechanical versus manual washing systems, i.e., we do not present comparisons based on quantitative measurements of percentage soil removal or other measurements.

METHODS AND MATERIALS

The primary components of the washing system are a barrel, a spray wand assembly, and a chassis and drive mechanism (fig. 1). A bill of materials, prices, and possible sources of supply are given in table 1. We used materials on hand where possible to minimize purchases and the amount of time spent on the project. Suggestions for improvements in the washer and substitutions in materials are provided at the end of the article.

The barrel is a high-density polyethylene (HDPE) plastic 208-L (55-gal) drum approximately 0.58 m (23 in.) in diameter and 0.86 m (34 in.) long, with wall thickness of 4 mm (5/32 in.). Using a circular saw, four equally spaced, 3.2-mm (1/8-in.) wide slots were cut 0.66 m (26 in.) along the side of the barrel to provide drainage. To maintain barrel strength, each slot was cut so its ends were equidistant 0.1 m (4 in.) from the barrel ends. During operation, the unit was placed over a floor drain with a sediment trap. The outside of the barrel was wrapped with a ribbed rubber belt 0.46 m (18 in.) wide \times 1.85 m (73 in.) long to provide sufficient friction between the barrel and the drive rollers. The belt was anchored to the barrel with wire; string or cord may be preferred for added safety. The anchoring was accomplished by drilling four pairs of holes at 25-mm (1-in.) spacing through the belt and into the barrel near each corner of the belt piece. The belt was centered with respect to the slots; the belt cannot be the full width of the slots or drainage will not occur. A hinged door for loading and unloading samples was cut into the top (front) end of the barrel. The door size was 292 \times 165 mm (11 1/2 \times 6 1/2 in.). A hasp was used to keep the door closed during operation. Holes were drilled at the center of each end of the barrel to accommodate the bearings for the center pipe.



Figure 1. Assembled carrot washer (guard box and pulley guards not shown). Barrel rotation is clockwise to prevent movement of the stabilizer arm.

Table 1. Bill of materials, cost estimates, and material sources for the carrot washer.

Item	Quantity	Price (\$) ^[a]	Total (\$)	Source
Garden hose	3–6 m (10–20 ft)	8.00	8.00	Local ^[b]
Garden hose quick connect coupler	1	4.89	4.89	Local
Brass pipe to hose connector	2	2.29	4.58	Local
Garden hose shutoff valve	1	2.29	2.29	Local
Galvanized threaded water pipe 13 mm (1/2 in.)	1.52 m (60 in.)	7.66	7.66	Local
Pipe Tee 13 mm (1/2 in.)	1	0.85	0.85	Local
Galvanized end cap 13 mm (1/2 in.)	1	0.65	0.65	Local
Rain Drop Ultra #2 spray nozzle	3	10.00	30.00	Delavan–Delta Inc., Lexington, Tenn.
Quick Tee Jet clamp	3	3.22	9.66	
Quick Tee Jet caps	3	0.82	2.46	
Used plastic drum 208 L (55 gal)	1	15.00	15.00	Local
Safety hasp	1	2.29	2.29	Local
Piano hinge	0.61 m (24 in.)	6.29	6.29	Local
Door handle	1	2.49	2.49	Local
Miscellaneous bolts, nuts, washers, and screws	NA	10.00	10.00	Local
Lumber, 19 × 25 × 686 mm (3/4 × 1 × 27 in.)	2	0.10	0.20	Local
Small pulley	1	8.50	8.50	Grainger Industrial Supply
Medium pulley	1	47.95	47.95	
3/4-hp electric motor	1	432.75	432.75	
Bearing 5/8 in.	1	23.37	23.37	Local
Channel iron, 76 × 35 × 5 × 1194 mm (3 × 1–3/8 × 3/16 × 47 in.)	2	5.92	11.84	Local
Tubing, 51 × 51 × 76 mm (2 × 2 × 3 in.)	8	0.475	3.80	Local
Roller drums and bearings	2	250.00	500.00	Bearings & Drives, Fargo, N. Dak.
Expanded metal for shield box, 13 mm (1/2 in.) #16 flattened	Two sheets 1.2 × 2.4 m (4 × 8 ft) each	32.00	64.00	Local
Angle iron, 25 × 25 × 3 mm (1 × 1 × 1/8 in.)	30 ft	0.25	7.50	Local
Hinges for shield box, 76 × 76 mm (3 × 3 in.)	2	5.73	11.46	Local
Rubber belting	8 ft × 24 in	14.44	14.44	Local
Total			1,232.92	

^[a] Based on 2000 US\$ prices.

^[b] Components generally available from local hardware or lumber retailers.

By supporting the barrel on rollers, the center pipe of the spray wand assembly is not required to support the barrel and its load. That is, the only requirements for the holes in the barrel and their supporting bearings are that they should rotate freely and be able to support the weight of the spray wand and its accessories. An additional benefit of using rollers to support the barrel is that the barrel is easily tilted or removed for sample loading and removal, barrel cleaning, etc. These operations would be more complicated and likely more dangerous if the drive mechanism was attached directly to the barrel.

The bearing on the door end of the barrel is a 51-mm (2-in.) length of PVC pipe, with ID 23.8 mm (15/16 in.) and OD 33.3 mm (1 5/16 in.). The bearing on the bottom (rear) end of the barrel is a metal flange mount bearing (mounted on the outside of the barrel) with a setscrew lock to hold the shaft end of the spray wand assembly.

Two flights (tumbler bars) at 180° spacing and midway between drainage slots were added to mix the samples and ensure that the water spray contacted all carrot surfaces (fig. 2). The flights consist of 19-mm (3/4-in.) × 25-mm (1-in.) wood pieces, length 0.69 m (27 in.), fastened with screws to the inside of the barrel. The 19-mm (3/4-in.) side was attached to the barrel surface. Without the flights, the carrots tended to slide down the side of the barrel as it rotated, resulting in incomplete washing. Larger flights, extending further toward the center of the barrel, were not used because

they would increase the drop distance for the carrots, thereby increasing breakage. Larger flights would also require more torque on the drive unit, since a greater percentage of the total sample would be lifted with each pass of a tumbler bar.

A handle was attached to the rear (bottom) end of the barrel to facilitate tipping and sample removal. The handle was oriented 180° from the door so when the door was down (6 o'clock position) for sample removal, the handle was on the top (12 o'clock position) of the rear end of the barrel.

The main components of the spray wand assembly are a center pipe and a stabilizer arm (fig. 3). The pipes are 13-mm (1/2-in.) nominal galvanized water pipes. The downstream end of the center pipe was not capped; rather, a 16-mm (5/8 in.) diameter × 108-mm (4 1/4-in.) long shaft was turned down as needed to fit into the end of the pipe. The shaft was inserted 57 mm (2 1/4 in.) into the end of the center pipe and welded in place. The exposed end of the shaft was inserted into the flange mount bearing on the bottom of the barrel and anchored with a setscrew. Three fan-type spray nozzles, each with 0.0126 L s⁻¹ (0.2-gpm) capacity (Delavan–Delta Inc., Lexington, Tenn.) were spaced at 0.20– to 0.23-m (8– to 9-in.) intervals inside the barrel. The stabilizer arm kept the nozzles pointed vertically downward. Note that the stabilizer arm is inclined approximately 45° (fig. 1) from the vertical orientation of the nozzles. To preserve the downward orientation of the nozzles, the holes for the nozzles in the center pipe should be aligned and drilled after,

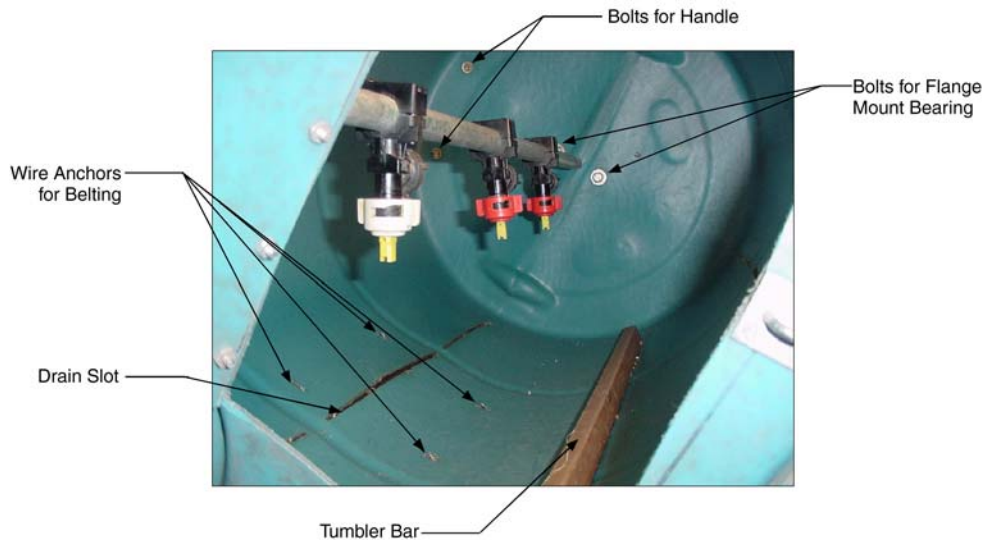


Figure 2. Interior of barrel.

not before, attaching and tightening the stabilizer arm. A close nipple, a pipe-to-garden-hose adapter, a quick-connect coupler, and a shut-off valve were used to route the water supply to the washing system and provide disconnection capabilities while loading and unloading samples.

The chassis and drive mechanism consists of two 0.146-m (5 3/4-in.) diameter metal rollers on a metal frame (fig. 4). The frame was raised only enough to provide floor clearance for the rotating barrel. One roller was powered, while the other was not. Rubber belting was attached to the driven roller to provide additional friction. Power was supplied to the washer with a hydraulic power unit available in our laboratory (not pictured). A 0.75-kW (1-hp) electric

motor powered a hydraulic pump, which in turn powered a hydraulic motor attached to the chassis of the carrot washer. A V-belt transferred power from the hydraulic motor to the pulley on one of the rollers. A variable flow control valve was used on the hydraulic motor to vary and find the optimum operating speed of the system. As an alternative, an electric motor could be used directly on the drive pulley, with different pulley sizes available for different speeds.

The time required for construction of the carrot washer was estimated at 9 hours for two people, i.e., 18 man-hours. This estimate does not include time to purchase supplies.

RESULTS AND DISCUSSION

The optimum operating speed for the barrel was approximately 10 to 12 rpm. Based on a barrel-to-roller diameter ratio of 4:1, this operating speed requires a roller speed of 40 to 48 rpm. Slower speeds tended to make it difficult for the unit to start and keep rotating, while faster speeds were not used because we wanted to avoid carrot breakage. We did not have carrot breakage problems and statistical studies to optimize the washing efficiency and/or minimize breakage as a function of operating speed were beyond the scope of this project.

The carrot washer removed soil and foreign material sufficiently to allow grading and sorting to proceed (fig. 5). The system can accommodate samples up to 16 kg (35 lb). The water requirement per sample is approximately 11 to 15 L (3 to 4 gal). An operator needs to be present only for sample loading and unloading and is free for other tasks during the wash cycle.

Washing time was 5 to 7 min per sample, a reduction of over 50% from the 15 to 20 min per sample for the manual washing system. The 5 to 7 min washing time estimate was obtained as follows. After loading a sample, a timer was set for 5 min and the wash cycle started. Most samples were sufficiently clean after 5 min of washing. If the sample was not clean after 5 min, the sample was washed for another 2 min. All samples were sufficiently cleaned after 7 min of

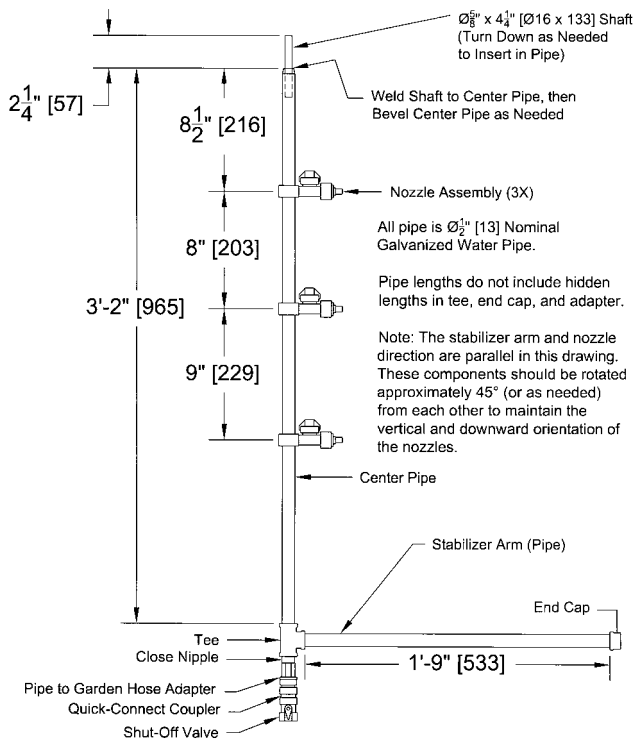


Figure 3. Spray wand assembly drawing. Primary units are feet (') and inches ("); alternate units in brackets [] are millimeters (mm).

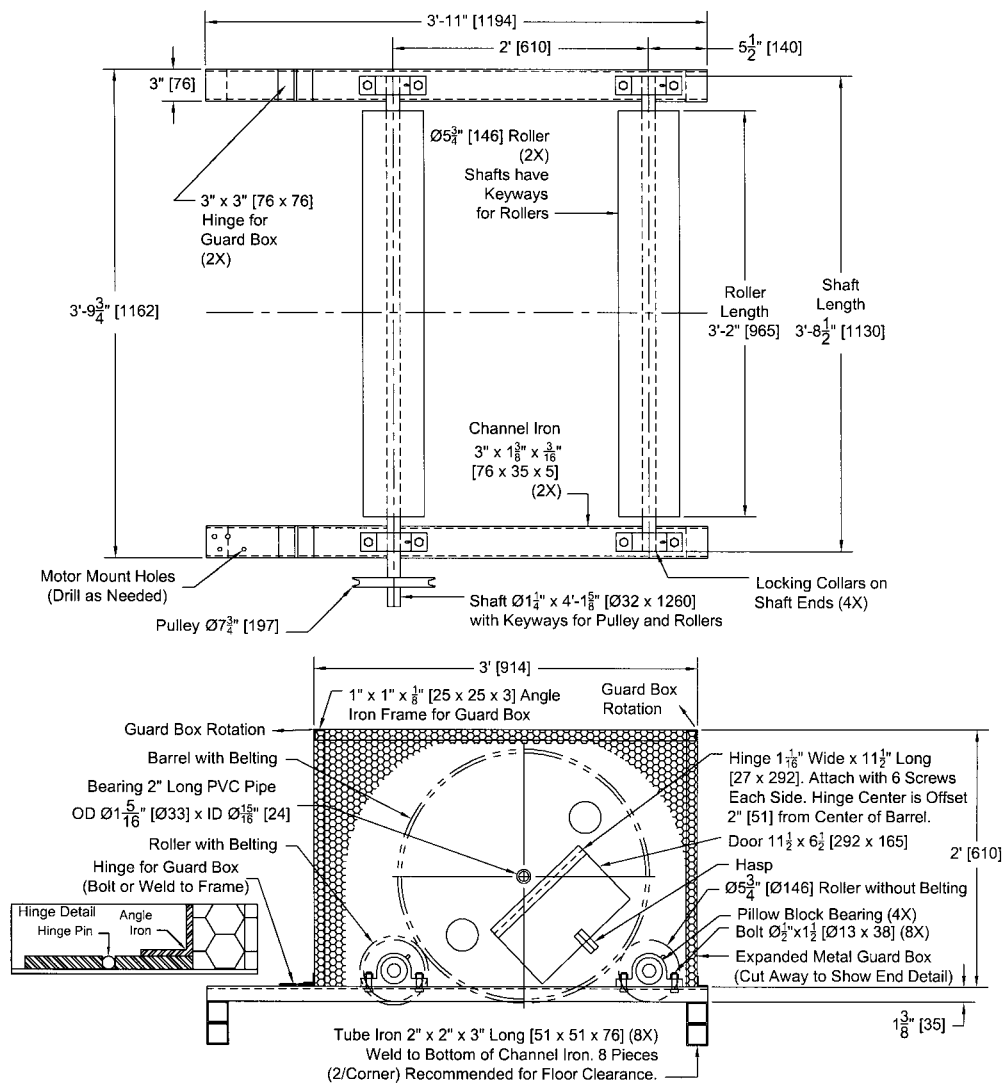


Figure 4. Chassis and drive mechanism drawing. Primary units are feet (') and inches ("); alternate units in brackets [] are millimeters (mm).

washing. Note that we are not reporting results from a statistical, randomized, side-by-side comparison of the mechanical versus manual washing systems for carrots



Figure 5. Carrot samples before (right) and after (left) washing.

grown during a single year. Other factors may have affected the difference in average washing times between 1999 and 2000, e.g., the longer pre-wash sample storage times in 1999 could have caused stronger soil adhesion to the carrots. Similarly, differences in soil moisture conditions at harvest time for each year could have affected the subsequent ease or difficulty of washing.

Timeliness of sample processing and improved carrot quality were the primary benefits of the mechanical carrot washer compared with the manual washing system. In both 1999 and 2000, soiled carrot samples were transported from the field in black plastic bags. Several holes were made in each bag to provide air circulation and the samples were temporarily stored in a walk-in cooler. To avoid mold and spoilage problems in 1999, we chose to wash all samples manually, rebag them in clean, perforated black plastic bags, and re-refrigerate the samples prior to grading. The entire set of 192 samples was washed before the grading process was started and sample bags were each handled and transported to and from the cooler twice in 1999. Knowing that a mechanical system would reduce sample washing time in 2000, we modified the sequence of washing, storage,

handling, and grading activities for the carrots. For the 2000 season, samples were removed from temporary storage, washed, and *immediately* graded. The reduced time and labor requirements of the washing process allowed workers to simultaneously wash and grade carrots, thereby reducing the overall time and labor requirements of the project. In 1999, workers labeled 15 of 192 samples as moldy at the time of grading, while the number of mold-affected samples in 2000 was zero. The reduction in the incidence of mold in 2000 was attributed primarily to a reduction in the amount of time samples were held in temporary storage, i.e., earlier cleaning made possible by the mechanical washer.

The mechanical washing system offers additional benefits compared with manual washing. First, if harvest dates are staggered (ours were 7 and 21 October 1999 and 10 and 23 October 2000) and labor is available immediately, faster sample throughput reduces the amount of refrigerated storage space and time required by large projects. Second, a mechanical system offers a more consistent and gentle handling of carrot samples. In a manual system, a person naturally tends to move a spray wand closer to a carrot with tightly-adhered soil, increasing the incidence of tissue damage. Such tissue damage was observed in 1999, but not quantified. With a mechanical system, a user noting tightly adhered soil can only wash the sample for a longer period of time — the mechanical system maintains the same water pressure and spray distance. The mechanical system thus has the potential to reduce the amount and variability of tissue damage among samples compared with the manual system.

An economic comparison of manual and mechanical washing systems can be made based on fixed wage rates and best- or worst-case sample processing speeds for each washing system. Using a wage of $\$7.00 \text{ h}^{-1}$ and a best-case washing time of 15 min per sample for the manual washing system, the labor cost for the manual system was $\$336$ for 192 samples or $\$1.75$ per sample. The corresponding labor cost for the mechanical washing system was $\$157$ for a worst-case washing time of 7 min per sample, a per-sample equivalent of $\$0.82$. Assuming the labor savings of $\$0.93$ per sample must equal the construction cost of $\$1,233$ (table 1), the mechanical system would need to process 1,326 samples to realize monetary savings. This analysis does not include electric energy costs and assumes the payback period is within the same year, i.e., interest rates and the present value of a capital investment are not factored into the analysis. We note that the materials used in this design were chosen on the basis of their availability for the project, not because they represented the lowest-cost construction materials.

After using the system to wash 192 carrot samples, several areas for improvement became apparent. Improvements include changes in the design and construction of the washer, as well as substitution of more appropriate materials. Following is a summary of our observations and the suggestions made by the users of the washer:

Frame. For sturdiness and rigidity, the frame for the drive mechanism should include cross members in addition to the rollers. That is, the rollers should not serve as the primary support members parallel to the barrel axis. The frame should be equipped with wheels to improve mobility for tasks such as moving the system to clean out the drain or sediment trap. A raised frame would make sample loading and unloading easier; if the frame is raised, additional shielding will be required. As an alternative to a metal frame, wood could be

used for the frame. However, we caution that the rollers should be bolted, rather than nailed or glued, to the structural material.

Drive Mechanism. Guides or stops should be placed on each end of the barrel to keep it from creeping off the rollers. We did not have this problem, but suggest the use of guides as a precaution.

For simplicity, powering a single roller is preferred. If slippage is a problem, belting can be added to the second roller or power can be applied to both rollers. Applying power to the second roller will require a double pulley on the first roller, a single pulley on the second roller, and a rubber belt on both rollers. In addition, the barrel would need to be turned around so its door is on the opposite end of the pulleys.

Barrel. The following changes should be made in the drain slots in the barrel: a) the slots should be cut perpendicularly to the barrel axis, rather than parallel to it; b) the slots should be shorter; c) the number of slots should be increased, for example by using a staggered pattern of slots; and d) the slots should not cross or cut through any ribbing in the barrel. These changes will provide the following advantages: a) the drainage or outlet capacity will be increased, which will allow the use of nozzles with larger flow rates, the latter reducing the washing time; b) the barrel will be stronger; c) the barrel will maintain its circular shape, reducing slippage and uneven rotational speed; and d) the system will require a smaller amount of belt, such as two narrow strips rather than one large one.

A larger door should be provided to make it easier to unload the barrel. A door could be cut into the bottom end of the barrel. Alternatively, a door could be cut in the top of the barrel (as in the present design), but the shape of the door could be changed to a curved bottom, following the rim of the barrel. The second option would allow the barrel to be tipped so the carrots would fall out by themselves rather than requiring hand removal.

Users may want to attach the belt with glue rather than wire, although glue would preclude removal of the belt for cleaning or replacement. Another alternative is to use a heavy cloth material to provide friction between the barrel and the rollers. Instead of using cloth or rubber belting on the rollers, the user may want to purchase a roller with a rough surface.

Interior. Low-cost nozzles should be used, rather than the more expensive dripless type used in this design. A set of brushes could be added to the tumbler bars for improved cleaning action. In cases where carrot bruising must be minimized, such as for long-term storage tests, the design should include carpeting, rubberized matting, or similar material as a lining on the inside of the barrel. Le-Bohec (1993) tested designs involving carpeting as a way to reduce carrot breakage and improve the storage characteristics of carrots. Note that interior padding must be perforated so it drains at least as quickly as the slots in the barrel.

SAFETY CONSIDERATIONS

Design, construction, and operation of a mechanical carrot washing system pose inherent hazards of entanglement of bodily parts, electrical shock hazards, and possibly other risks not mentioned in this article. Those involved in design, construction, operation, and other aspects of use of the mechanical carrot washing system are hereby advised to

follow applicable safety codes and considerations, to construct and use the system at your own risk. THIS SYSTEM IS EXPERIMENTAL, AND THE AUTHORS MAKE NO WARRANTY, EXPRESS OR IMPLIED, AS TO THE OPERATION OR SAFETY OF THE SYSTEM.

For safety, guarding should be used for all pulleys, belts, motors, rollers, etc. in accordance with applicable standards (ASAE Standards, 1998). To keep limbs and extremities out of the roller–barrel interface, an expanded metal guard box or similar structure should be used. The expanded metal should be welded to the outside of an angle iron frame, the latter covering the barrel and rollers. The end view of the chassis and drive mechanism in figure 4 shows a cut–away view of the guard box. The dimensions of the guard box are 0.61 m (2 ft) high \times 0.91 m (3 ft) wide \times 1.162 m (45 3/4 in.) long. Expanded metal is specified for the top and all sides of the guard box; shielding for the bottom should be provided if necessary for the particular application of the washing system. A slot in the expanded metal is needed to accommodate the shaft on the driven pulley. The hinges for the guard box can be attached to the channel iron frame with bolts or by welding. An expanded metal covering is preferred, rather than a sheet metal covering, because the former will provide visibility of the operation of the washer. The frame of the guard box is hinged on the channel iron frame to provide access to the barrel after moving parts have stopped.

A readily accessible and easily operated power disconnect switch should be provided for operator safety. Proper grounding procedures for electrical components and isolation from shock hazards, such as from short–circuiting to the water supply and/or floor drains, must be followed.

Safety alert and warning signs should be placed on the carrot washer to indicate hazards of finger, hand, or leg entanglement caused by the rotating rollers and drum; entanglement hazards caused by pulleys and belts; electrical hazards; and other hazards as appropriate (ASAE Standards, 1999; 2000).

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