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소농을 위한 밤 수확기의 개발

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Development of Chestnut Harvesters for Small Farms

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Abstract

Three prototype chestnut harvesters were constructed and evaluated their chestnut collection ability and field efficiency. Air-lock paddle system successfully picked up all loose material, and pick up efficiency was about 56 kg/h. Power required to operate this system was evaluated to be 8.7 kW with an air flow rate of 32.6 m^3/min. A radial blade type blower with 0.41 m impeller diameter was considered to be a minimum size for this system. For the auger system, air was sucked into the cylinder as the hinged flat cover began to be opened by the material pushed by the auger, and the empty burrs flew back to the container through the space between auger flights and collected in the bottom of the container. It was considered to add a device to prevent air from flowing back or to use the back flowing air for separation of burrs and nuts inside the container. The venturi system could not pick up chestnuts, as they only carried part way up to the suction hose. Consideration was given to an idea that the venturi could be used as a cleaning and separation mechanism for containers filled with both empty burrs and good nuts. A minimum vacuum of 129 mm wg was required to pick up chestnuts, and the corresponding inlet air velocity was 19.3 m/s. 104 mm of vacuum, which was about 81 % of that required for nuts, was enough to pick up burrs with nuts inside. Also, empty burrs with higher moisture content recorded the same pressure as for the burrs with nuts.

Keywords : Chestnut harvester, Air-lock paddle, Auger system, Venturi tube system

1. INTRODUCTION

Chestnuts, produced by trees in the genus *Castanea*, are common in the diets of European, Middle-eastern, and Asian peoples. Chestnuts have not played a major role in food production in North America since the accidental importation of the chestnut blight fungus which killed billions of chestnut trees in North America in the early 1900's. Today, chestnuts are making a comeback as an orchard-grown tree. Chestnut growers are primarily growing chestnut blight tolerant trees (Chinese chestnut) or avoiding the blight, by growing in areas with reduced blight due to naturally occurring biological controls. Chestnuts have a sweet and nutty flavor and can be eaten raw but are more commonly consumed boiled or roasted to enhance the sweet, nutty flavor. Their distinctive flavor and texture can give an unique taste to a range of dishes from appetizers, to main dishes and desserts. As chestnuts become commonly grown in North America, more Americans will be introduced to this "new" food.

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A team of researchers at Michigan State University, in close collaboration with chestnut producers, are helping develop the production, processing, and marketing aspects of the evolving chestnut industry. The status of the industry is such that growers now have well established trees producing significant quantities of chestnuts; more than can simply be picked up by family members or a few laborers. Thus, the growers are at, or are nearing, where they are in need of automation assistance in harvesting the nuts. One of the challenges related to harvesting chestnuts is the differences in orchard floor cover (soil, grass, etc). While commercially available harvesters do exist, the current and expected size of orchards or level of production for many growers is relatively small and can not support the purchase of such equipments. A consideration might be to distribute the cost of a harvester among a group of sharing growers, however, with the challenge of needing to remove the nuts almost continuously over the several days the nuts mature and drop due to wildlife foraging, this is not a viable option. Therefore, there appears to be a current and future need for a small to medium-sized cost effective automated harvest assist system. Farm size of two hectares or less with less than 600 chestnut trees were considered to be small farms.

The purpose of this study was to construct and evaluate the suction capabilities of three different suction based prototype chestnut harvesters to develop a cost efficient harvester. Three concept prototypes are: 1. suction container with air-lock paddle discharge, 2. suction container with auger discharge, and 3. Venturi tube.

2. MATERIALS AND METHODS

A. Design and Construction of Suction Mechanism

A radial blade type high pressure blower with a 0.457 m (18 inch) fan diameter (Model HP-8D, Cincinnati Fan) was used to generate vacuum to a suction hose connected to suction containers. A 17.7 kW (24 HP) gasoline engine (GX 670, Honda) was used as a prime power source of the system to run the blower, air-lock paddle shaft, and auger shaft. Two V-belt tension clutches were installed for the blower and collector shafts. All the equipments were installed on a 1.85 m × 1.35 m flat-bed trailer.

B. Air-lock Paddle System

A 0.60 m long by 0.36 m diameter air-lock paddle wheel with six paddles was constructed and installed in the lower part of a chestnut collecting container, 0.61 m long, 0.61 m wide, and 0.98 m high. The container was sealed to maintain vacuum except for the bottom when the paddle wheel system operates. The bottom of the container was opened 0.15 m wide for the continuous discharge of vacuumed materials, including chestnuts, empty burrs, dirt, leaves, etc. as the paddle wheel rotates. Rubber sheeting was fixed on the end of each paddle so the flexible material pressed against the round container bottom walls to ensure vacuum inside. The paddle wheel was set to turn at 8.45 rpm when the blower speed was 3000 rpm. At the inlet a 9 m long, 0.1 m diameter flexible hose was connected to a flange on the circular upper part of the container. The air outlet of the container was connected to a cyclone which in turn connected to the inlet of the blower (Fig. 1). This cyclone was installed in this system to evaluate the amount of foreign materials that passed through the container. The diameter of the cyclone was 0.47 m and overall height was 1.07 m. The height of cone was 0.71 m. Inlet and outlet diameter of the cyclone was 0.15 m and 0.18 m, respectively. A slide dust valve was installed under the 0.15 m diameter dust discharge outlet of the cyclone. Air outlet of the cyclone was connected to the inlet of the 0.20 m inlet of the blower by using a reducer. After several indoor tests, the blower speed was set to be 3300 rpm for effective nut suction. At this blower speed, static pressure at the discharge outlet was monitored by a manometer and air volume was measured by

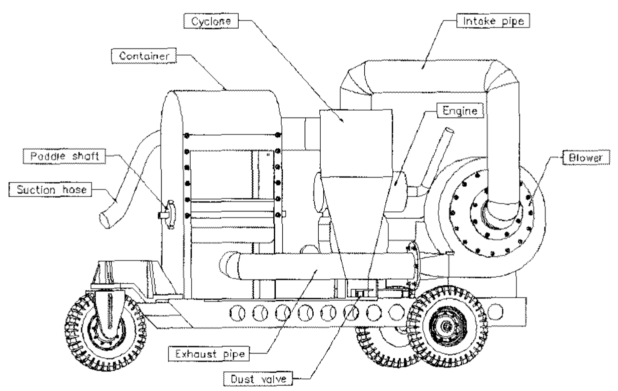

Fig. 1 Air-lock paddle system.

a Velometer by using Alnor series 6000-p Velometer (Alnor Instrument Company) for the estimation of the power requirement of the system.

C. Auger System

An independent cyclone-shaped container with an auger on the bottom replaced the air-lock paddle container and the cyclone of the air-lock paddle system noted in the previous section (Fig. 2). The diameter of the container was 0.48 m and height was 0.77 m. One end of the container was tapered to fit to the auger. The length of the auger was 0.45 m. The collection container was constructed from a small barrel with one end cut and tapered to fit and feed into the cross auger with diameter of 0.2 m and pitch of 0.1 m. The auger was cantilever mounted in two bearings from the closed end of the auger housing to keep the opposing end free for material discharge. The auger was positioned in a close-clearance cylindrical metal housing attached to the bottom of the collection container. The air inlet flange was mounted in a tangential manner near the top of the container.

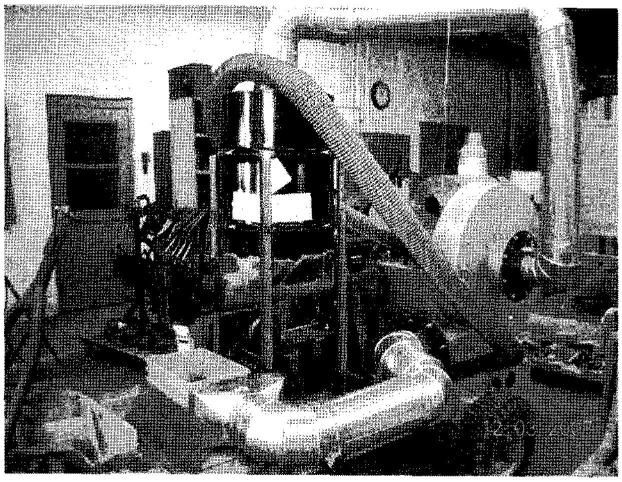

Fig. 2 Auger system.

The air outlet was a 0.18 m wire mesh tube protruding 0.38 m down from the top and terminating near the center of the container. The mesh tube was connected to a cylindrical ducting which was attached to the blower inlet. At the material discharge outlet cylinder a space of 0.15 m was provided so the materials sucked and pushed by the auger toward the outlet could be packed. A flat cover was installed at the discharge outlet to prevent the air from flowing into the container at the early stage of operation before the auger cylinder is full of collected materials. It was expected that the cover valve would be kept closed by inside vacuum and eventually be opened by the expelled material pressure as the suction continued. The auger speed was set to be 15.1 rpm at blower speed of 3000 rpm.

D. Venturi Tube System

The discharge outlet, 0.2 m in diameter, of the blower, was connected to the inlet of a venturi tube. The dimensional specifications of the venturi tube were based on ASME, 1989. This arrangement produced a 1 to 4 air speed ratio (inlet or discharge to throat). The venturi tube was installed 45 degrees from horizontal level, and the vertical height from ground to the center of the tube throat was 1.58 m (Fig. 3). A suction hose, 0.1 m in diameter, was connected to the perpendicular flange at the throat of the tube. This suction hose was expected to take in the chestnuts and burrs together from the ground and discharge through the outlet of the tube. Chestnuts and empty burrs were expected to travel different distances when discharged in the air for potential separation of the harvested chestnuts from unwanted materials such as burrs and leaves.

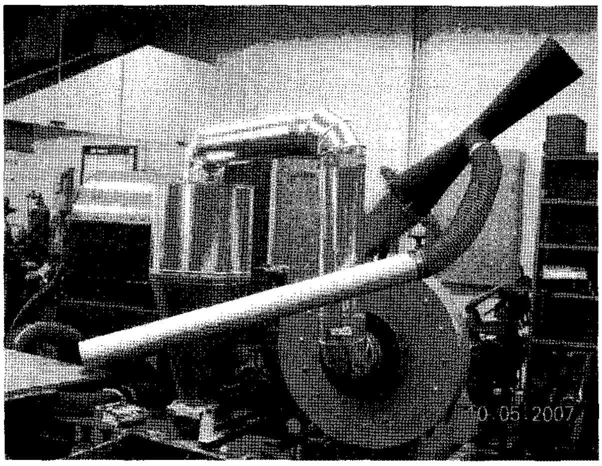

Fig. 3 Venturi tube system.

E. Static Pressure Measurement for Materials Suction

Static pressure in the suction hose was monitored from a manometer installed at a 0.165 m distance from the inlet to evaluate the minimum vacuum to suck the nuts, empty burrs, and burrs with nuts which are the major materials the harvester should take into the containers or into the venturi throat. The suction height between the hose inlet and container was 1.51 m. The paddle wheel system was used for this measurement. Weights, lengths, widths, heights, and moisture contents (wet basis) of respective small, medium, and large samples were measured after the tests.

F. Field Evaluation

The air-lock paddle harvester was operated at the MSU chestnut farm during harvesting season, September, 2007. The experimental area of about 75 m^2 was fenced to prevent deer from entering in the area. Blower speed was set to 3300 rpm. For comparison three men collected nuts with the harvesters for given areas, 9.1, 11.7, and 9.8 m^2, respectively, and the time required was measured. These data were converted into the efficiency of the machine in m^2/h. Nuts in the machine collected materials were separated by hand, and were converted into the machine efficiency of nut harvest in kg/h. The weights of foreign materials collected at the slide valve of the cyclone were measured at the end of each test run. Separate field tests for the venturi and auger system were not carried out as the results would be very similar to that of air-lock system if the two systems work as intended. After the field tests, static pressure and air velocity were measured at the blower discharge outlet to evaluate the power requirement of the air-lock paddle system by using a Velometer.

3. RESULTS AND DISCUSSION

A. Air-lock Paddle System

This system successfully picked up all loose material on the ground. Out of an average of 169.3 kg/h of collected materials, average chestnut pick-up was evaluated to be 56 kg/h when harvesting at a corresponding rate of 208 m^2/h. This throughput is about 1/3 that of three prototype chestnut harvesters which had two suction inlets, 160 kg/h, tested by Berutto et al. (1996). However, it was only slightly less than that of 62.5 kg/h reported by Park et al. (1998). The weight of collected foreign materials on the cyclone slide valve was less than 0.5 percent of materials collected through the paddle. This result indicated that the cyclone in this system could be removed and the collecting container itself was successful for both chestnut and dust collection. The power requirement for this system was evaluated to be 8.7 kW (11.8 HP) with a static pressure of 546 mm wg, and an air flow rate of 32.6 m^3/min. Air density of 1.1805 kg/m^3 at 25.6℃ and relative humidity of 72 %, and a safety factor of 1.5 and fan efficiency of 50 % were considered in this evaluation. Based on the information provided by the blower manufacturer, it was evaluated that same type of blower with smaller impeller diameter of 0.41 m would be good enough for successful chestnut pick up.

B. Auger System

All materials were successfully picked up into the container and conveyed and packed in the auger cylinder in the initial operating stage. However, as the hinged flat cover began to be opened by the material pushed by the auger, air was sucked into the cylinder and the empty burrs flew back to the container through the space between auger flights and collected in the bottom of the container. Chestnuts were only able to come out of the outlet as the space between auger flights were completely packed. It was considered to add a device to prevent air from flowing back or to use the back flowing air for separation of burrs and nuts inside the container.

C. Venturi Tube System

This system was only able to effectively suck empty burrs into the tube neck and discharge them through the tube outlet. It could not pick up chestnuts, as they only carried part way up the suction hose, even at a recommended maximum blower speed of 5000 rpm. Reducing the tube neck and inlet hose diameters might result in the ability to pick up the chestnuts by increasing the air velocity in the neck. This was not attempted because of limitation of the outside diameters of burrs. Consideration was given to the idea the venturi could be used as the cleaning and separation mechanism for containers filled with both empty burrs and good nuts.

Table 1 Weight, size, and moisture content of individual samples used for suction tests, and suction pressure(Ps) and inlet air velocity required for corresponding samples

Materials	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)	M.C. (%, w.b.)	Ps (mm, wg)	Air vel. (m/s)
Empty burrs	6.06	78.56	48.76	34.10	10.73	82	12.2
	8.86	77.91	79.17	54.64	10.61	82	12.2
	21.16	73.68	71.86	33.31	63.56	104	13.1
	46.24	82.26	79.76	59.96	73.68	104	13.1
	49.49	91.17	84.42	74.84	68.11	104	13.1
Burrs with nuts	13.30	64.37	63.73	51.53	32.11	104	13.1
	25.23	66.34	59.67	47.70	66.71	104	13.1
	39.46	65.54	64.21	59.80	57.20	104	13.1
Nuts	7.24	33.83	32.39	18.93	15.88	129	19.3
	8.49	33.95	30.59	17.07	42.29	129	19.3
	13.54	35.20	33.47	23.68	46.60	129	19.3

D. Static Pressure for Materials Suction

Weight, size, and moisture content of major materials, that could be suctioned by the harvester, empty burrs, burrs with nuts, and nuts were measured and are shown in Table 1. Five empty burr samples, three burrs containing nuts, and three nut samples were evaluated. Minimum vacuum pressure and air inlet velocity to suction them are also shown. Different weights and sizes with an emphasis on the moisture variability were selected and tested. A minimum vacuum of 129 mm wg was required to pick up chestnuts, and the corresponding inlet air velocity was 19.3 m/s. 104 mm of vacuum, which was about 81 % of that required for nuts, was enough to pick up burrs with nuts inside. Also, empty burrs with higher moisture content recorded the same pressure as for the burrs with nuts. Dried empty burrs were suctioned easily compared to the wet ones.

SUMMARY

Three prototype chestnut harvesters were constructed and evaluated their chestnut collection ability and field efficiency. Air-lock paddle system successfully picked up all loose material, and pick up efficiency was about 56 kg/h. The cyclone in this system was considered to be removed as the weight of collected material in the cyclone bottom was less than 0.5 % of all the collected materials through the air-lock paddle. Power required to operate this system was evaluated to be 8.7 kW (11.8 HP) with an air flow rate of 32.6 m^3/min (1151 cfm). A radial blade type blower with 0.41 m (16 inch) impeller was considered to be the minimum size for chestnut pick up.

For the auger system, all materials were successfully picked-up into the container and conveyed and packed in the auger cylinder in the initial operating stage. However, as the hinged flat cover began to be opened by the material pushed by the auger, air was sucked into the cylinder and the empty burrs flew back to the container through the space between auger flights and collected in the bottom of the container. Chestnuts were only able to come out of the outlet as the space between auger flights were completely packed. It was considered to add a device to prevent air from flowing back or to use the back flowing air for separation of burrs and nuts inside the container.

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