AUTOMATIC CABBAGE FEEDING, PILING, AND UNLOADING SYSTEM FOR TRACTOR IMPLEMENTED CHINESE CABBAGE HARVESTER+

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ABSTRACT

Since Chinese cabbages weigh 3 to 5kgf and are big in size at the time of harvest, handling operations such as harvesting, loading and unloading including transportation require the highest labor demand among all other cultivation processes. Recently, though several cabbage harvesters were developed in Japan and Europe, those harvesters were not suitable for Chinese cabbages cultivated in Korea because of the size and shape. The cabbage harvester is almost meaningless without any proper cabbage piling and pallet unloading mechanism. Most harvesters developed so far adopted a sort of slide and free falling way in collecting cabbages into the pallet. Three or four labors are usually required for cleaning incoming cabbages and loading those in the pallet. Because of the required time for piling cabbages without severe damage and the required space capacity to carry empty and loaded pallets, harvesting speed should be adjusted in accordance with time required for consecutive operations. Up to now, any automatic or semi-automatic collecting device has not been developed in the world to pile cabbages on the layer one by one into the pallet in the ordered way with little damage and to unload pallet from the harvester continuously during the harvest process. To compromise system expenses and function, Semi-automatic cabbage piling and pallet unloading mechanism was devised and it required one labor. The foldable mesh pallet with a size of 1050㎜ × 1050㎜ × 1000㎜ and holding capacity of around 70 cabbages was utilized. The prototype for piling and unloading mechanism was composed of three parts such as feeding device, automatic piling device with retractable bellows, and pallet unloading device.

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Prior to developing the prototype, the geometric properties and the amount of the damage of the cabbage caused during the piling operation were investigated. Considering the height of the pallet, a series of cabbage carrying plates were mounted to the bracket chain to lift and to carry cabbages to the loading device. Indoor laboratory experiments showed that the cabbage carrying chain conveyor worked successfully. Considering the conveying speed 0.46m/sec of the pull up belt from the cabbages on the ground, the speed of cabbage carrying chain conveyor worked property in the range of 0.26m/sec to 0.36m/sec. The system allowed the operator to modify the position of cabbage slightly. Overall system worked successfully resulting into almost same capacity without severe damage to the cabbage as human did.

Keywords: Chinese Cabbage Harvester, Automatic Piling, Mesh Pallet, Tractor Implement

INTRODUCTION

In Korea, the total cultivation area of Chinese cabbage(C-cabbage) is the largest next to that of pepper. However, most processes in cultivating and harvesting C-cabbages depend on human labor. Recently, research on mechanization and automation of C-cabbage production has been started in Korea.

Since C-cabbages usually weigh 3kgf to 5kgf and are big in size at the time of harvest, handling operations such as harvesting, loading and unloading including transportation require the highest labor demand among all other production processes.

In Japan, experimental feeding and piling devices for the cabbage harvester were developed and tested from 1985 to 1988 at the BRAIN(Bio-oriented Technology Research Advancement Institution). A prototype feeding and piling device was composed of a steep cabbage feeding device, folding type two channel cabbage unloading guide, turning shouter with variable slope angle, and a burlap bag with elastic holding strip, whose position varies as amount of loaded cabbages increases. It was reported that further research should be done to reduce the damage on the cabbage and to improve the piling capacity and state. Recently several commercial cabbage harvesters are available in Japan and Europe. Those harvesters, however, are not suitable for C-cabbages. C-cabbages cultivated in Korea are bigger in size and have a cylindrical shape with spread leaves. And since they were not equipped with the proper mechanism for piling and unloading, three or four people should work to clean and pile the cabbages in a box or pallet.

In 1993 and 1994, Kanamitsu et al. developed a prototype of tractor implement type C-cabbage harvester. Research was focused on the development of the mechanism to

pull up and cut the C-cabbage root for harvesting. Here, it should be emphasized that the cabbage or C-cabbage harvester without the proper automatic piling and pallet unloading mechanism is almost meaningless in the viewpoint of labor reduction and job efficiency. In general, performance and efficiency of harvesting operation are determined from the function of the successive cabbage piling and pallet unloading processes. Since a pallet or box is usually used as truck transporting medium, mechanisms of cabbage piling into pallet with loading and unloading pallet are closely related to harvesting, transportation, and distribution.

In most cabbage harvesters, belt or chain conveyor is used to feed cabbages from the cabbage pull-up and cutting device. Most harvesters available so far adopted a sort of sliding device and free falling way in collecting cabbages into the pallet. And three or four labors are usually required for cleaning incoming cabbages, piling those into the pallet, unloading the filled pallet and reloading the empty one. Time required for piling cabbages into the pallet determines the ground speed of the harvester. And the carrying capacity of the empty and loaded pallets of the harvester determines the harvesting performance without intermission.

Up to now, any automatic or semi-automatic collecting and unloading device is not available in the world to pile cabbages by layers into the pallet with little damage and to unload pallet from the harvester continuously during the harvesting process.

In this paper, semi-automatic cabbage piling and pallet unloading system was developed based on the pre-specified functional requirements of harvesting process, physical properties of C-cabbage, and the overall harvesting efficiency. And the performance of the system including each component was tested and presented.

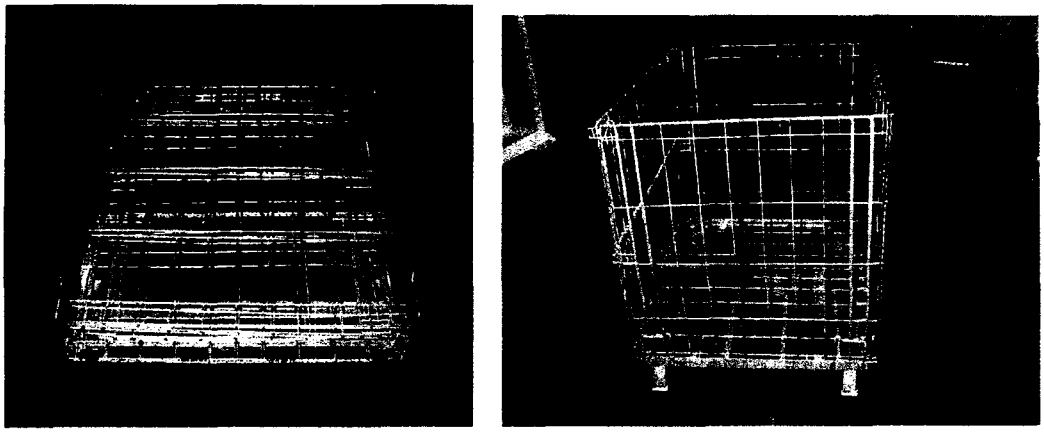
MATERIALS AND METHODS

Geometrical properties of C-cabbages are crucial in mechanizing harvesting process and are closely related to the design specification of the mechanism. And the amount of the damage, which could occur according to various ways of feeding and piling cabbages including free falling into the pallet were measured and analyzed. When cabbage falls down on the pallet floor, outer leaves can have damage. Damage caused by free fall was measured with the number of damaged(torn off) outer leaves and decrease of weight after removing leaves with damage.

Foldable mesh type pallet (1050㎜ × 1050㎜ × 1000㎜) made with 5mm diameter wire shown in Fig. 1 was chosen to reduce the space of harvester to carry the residual empty pallets. Pallet could hold around 70 cabbages of an average size. When a pallet was filled with cabbages and discharged to the ground, the pallet was unfolded and mounted. Bottom of the pallet the guide plate for wheel was attached.

Prior to specify the functional specification in designing semi-automatic cabbage piling and pallet unloading system, three prototype automatic piling system have been developed and tested. Those showed some deficiencies such as small piling capacity

because of improper piling methods and mechanism, moving interference of the piling guide inside the pallet during the piling process, high cost for the full automatic function, and too much weight of the system for the 30Hp tractor and etc. The final prototype was newly designed and built in compromising system cost and function.



(a) folded state (b) unfolded state

Fig. 1 Pallet used for the prototype.

Since it was economically meaningless and technically very difficult to fully automate loading and unloading the mesh pallet, the final prototype was developed in a semi-automatic manner with one operator. Functions of the prototype were selected to utilize operator's capability in a sense of the optimum collaboration and interface between man and system. This concept could reduce the system complexity and high cost caused by the sophisticated automatic mechanism to realize the desired handling job. Furthermore, it could improve the whole performance of the system with relatively low-level automatic devices due to the flexibility of human handling. Meanwhile, the low level automatic device could reduce simple but repetitive hard works.

Three major parts with functional specifications were set in developing semi-automatic cabbage piling and pallet unloading system.

a) Automatic feeding device
   - Secure and variable rate feeding of cabbage to the automatic piling device considering the speed of pull up belt
   - Compact and steep feeding mechanism to meet the spatial restriction

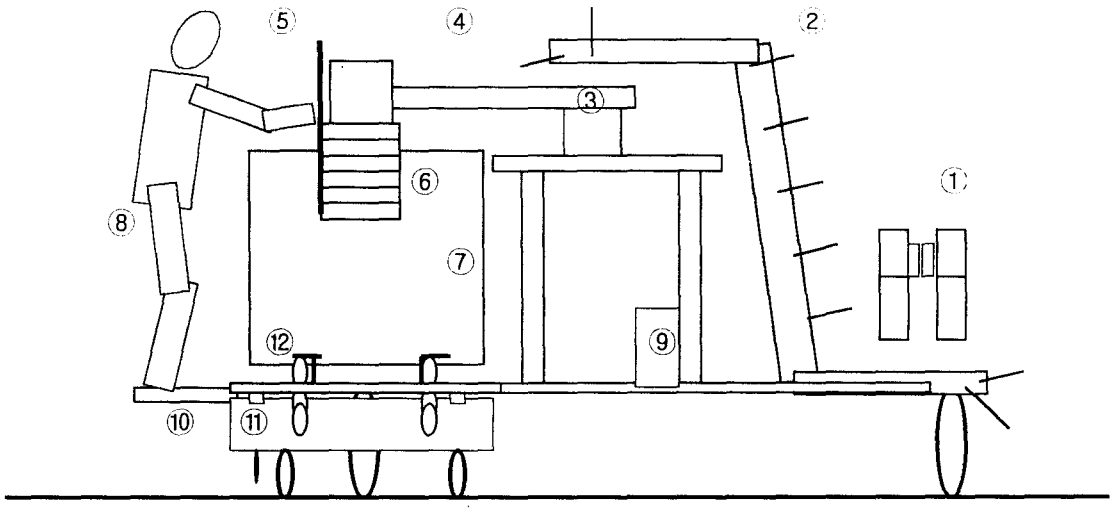
b) Semi-automatic piling device
   - Automatic sequential positioning of the end of the piling belt conveyor
   - Speed control of piling belt to feed cabbage securely
   - Sensor to check incoming cabbage
   - Secure feed and guide into the pallet with flexible positioning

c) Pallet loading and unloading device
   - Folding and unfolding type mesh pallet with guide plate

- Roller attached floor with hook joint
- Pallet holder and release pedal

The prototype was composed of three parts such as feeding device, automatic piling device with retractable bellows, and pallet unloading device. Fig. 2 shows the overall schematic figure of the prototype.

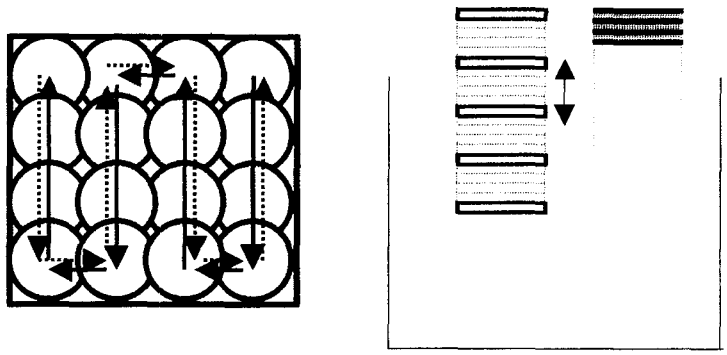
A series of cabbage carrying plates made of stainless steel were attached to the chain conveyor to carry cabbages to the piling device. Carrying plates were devised to be folded and unfolded using roller and guide attachment. Speeds of the chain belt and piling belt conveyor were adjusted to ensure the proper attitude of cabbage while being fed to the bellows mounted at the end of piling belt conveyor. Piling belt conveyor was controlled sequentially using PLC to automatically position the bellows within the pallet. Piling positions were pre-specified in RΘ direction as shown in Fig. 3a. Circular brush plates were mounted inside the bellows to reduce the passing speed of cabbages through the bellows. The role of the brush is reducing speed when cabbage fell down through the bellows. Outside the bellows, two sets of springs were mounted to adjust the extraction force of the bellows. The operator could extract and contract the spring-mounted bellows by moving the attached handle (Fig. 3b). Two hydraulic cylinders with rotary encoders were used for activating belt conveyor. Belt conveyors were controlled to position sequentially and manual and automatic operations with functions of reset and emergency stop were implemented.



① Pull up and cutting device and feeder
② Steep feeding conveyor
③ r-Θ positioning device
④ Piling feeder
⑤ Handling rod with switch box

6 Retractable bellows
7 Mesh type pallet
8 Operator
9 System controller
10 Foot plate with pallet fixing device
11 Detachable discharging plate with hook
12 Roller guide of pallet

Fig. 2 Overall schematic diagram of the prototype.



(a) (b)

Fig. 3 A pre-specified sequence of path of bellows(a) and extraction and contraction of bellows(b).

The overall system performance of the prototype was evaluated through testing each unit such as collecting unit from pull-up-device, feeding unit, piling unit and unloading unit. One hundred cabbages harvested at Hwasung, Korea were used without being treated for the experiment(Fig. 4).

Fig. 4 Cabbages used for the experiment.

RESULTS AND DISCUSSION

Geometric properties of six varieties of C-cabbage were measured. The overall width and height ranged from 460mm to 760mm and from 330mm to 440mm respectively. Width and height of the head ranged from 190mm to 240mm and from 260mm to 360mm respectively. Weight ranged from 2.5kgf to 4.5kgf. The number of outer leaves was 10 to 15.

Table 1 shows the damage of C-cabbage from free falling. Damage caused by free fall was measured with the number of damaged(torn off) outer leaves and weight decrease after removing damaged leaves. Free falling at the height of 500mm caused little damage to the outer leaves. If cabbage falls down at the height over 1000mm, some kind of buffer device to reduce the impact is necessary. When the pallet is used for piling, the bottom layer is the one, which needs the buffer. Once bottom layer is filled with cabbages, bottom layer works as a buffer. From the second layer, impact damage caused by free fall is not that serious. However, piling in an order increases the holing capacity of the pallet and reduces damage caused by contact friction among cabbages.

Fig. 5 showed the overall view of the developed prototype, which was composed of three parts such as feeding device, automatic piling device with retractable bellows, and pallet unloading device. Indoor laboratory experiments showed that the cabbage carrying chain conveyor worked successfully in the range of 0.185m/s to 0.36m/s. Considering the conveying speed 0.46m/sec of the pull up belt from the cabbages on the ground, the speed of cabbage carrying chain conveyor worked properly in the range of 0.26m/sec to 0.36m/sec.

Table 1 Damage of cabbage caused by free falling

Weight (kgf)		Height(mm)			
		1000		1300	
		WD(kgf)	LR	WD(kgf)	LR
2.5-3.0	Range	0.00-0.13	0-2	0.00-0.27	1-6
	Avg	0.06	0.8	0.11	2.8
3.0-3.5	Range	0.00-0.04	0-1	0.10-0.34	2-4
	Avg	0.03	0.2	0.19	3.6

Avg: average WD: weight decrease LR: number of leaves removed

Piling device was also tested in the laboratory. Piling conveyor worked successfully in the speed range of 0.39m/sec to 2.38m/sec. The piling conveyor worked properly in the range of 0.91m/sec to 2.38m/sec with cabbage carrying chain conveyor. Considering the conveying speed of the pull up belt from the cabbages on the ground, the speed of the piling conveyor should be over 0.34m/sec and proper speed range was

2m/sec to 2.38m/sec.

Piling test showed that cabbages were piled in order at the 1st, 2nd and 3rd layers without any serious damage because of the bellows. Without bellows operator should bent his body a lot to pile cabbage at the bottom(1st) floor of the pallet, 2nd and 3rd layer piling. For piling at the 4th and 5th layer, bellows was fully contracted to the reset position and operator did not control the bellows. At the 4th and 5th layer controlling bellows is difficult because of the small space and bellows worked as an obstacle to the path of cabbage. Since the piling conveyor automatically moved along specified positions sequentially and the height of falling was less than 500mm at the 4th layer, cabbage fed from the piling conveyor did not move much after falling.

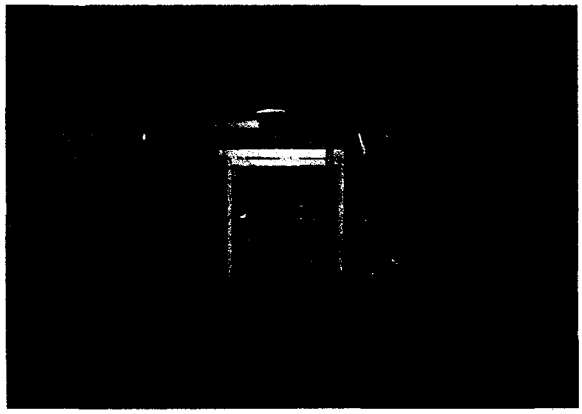


Fig. 5 Developed prototype.

Moreover, since, operator did not need to bent his body seriously at the 4th and 5th layer, he could work easily without bellows. Operator only modified the attitude and position of the cabbage slightly without concerning the bellows control. Piling capacity of the proposed system showed about 95.6% of the capacity by manual piling.

CONCLUSIONS

Since Chinese cabbages weigh 3 to 5kgf and are big in size at the time of harvest, handling operations such as harvesting, loading and unloading including transportation require the highest labor demand among all other cultivation processes. Most harvesters developed so far adopted a sort of slide and free falling way in collecting cabbages into the pallet. Three or four labors are usually required for cleaning incoming cabbages and loading those in the pallet. Because of the required time for piling cabbages without severe damage and the required space capacity to carry empty and loaded pallets, harvesting speed should be adjusted in accordance with time required for consecutive operations.

In this paper, semi-automatic cabbage piling and pallet unloading system, which

required one labor, was developed based on the pre-specified functional requirements of harvesting process. The system allowed the operator to modify the position of cabbage slightly to ensure piling in order without serious damage. Overall system worked successfully resulting into almost same capacity without severe damage to the cabbage as human did. The prototype could handle up to one cabbage/second and showed practical feasibility in the sense of system cost, labor reduction and maintenance of the cabbage quality during harvest operation.

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