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채소 자동결속기의 개발(Ⅰ)
- 개발방향 및 재료의 공급장치 -

Development of Automatic Vegetables Binding Machine(Ⅰ)
- Research scope and materials feeding mechanism -

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적 요

이 연구는 채소의 생산에서 가장 많은 노동력이 소요되고 단순·반복적인 결속작업의 기계화기술을 개발하기 위하여 수행되었다. 본 논문은 이 연구의 제1보로서 채소의 결속작업실태를 조사분석하여 결속기의 개발방향을 설정하고, 채소의 이송 및 결속끈의 공급장치를 개발한 결과를 수록한 것이다.

채소의 결속작업은 철심이 내장된 끈을 사용하여 타원형으로 결속하고 있었으며, 작업자가 경험적으로 계량하여 결속된 단의 크기는 작물별 차이는 있으나 동일 작물에서 작업자간 차이는 없는 것으로 나타났다. 따라서 결속기는 작업자가 채소를 공급하면 일정 길이의 결속끈을 사용하여 타원형으로 결속하여 배출하는 방식으로 개발할 필요성이 있다고 생각된다. 이를 위해서 결속기는 작업자가 채소를 용이하게 공급할 수 있으며 결속장치까지 흐트러짐이 없이 이송하는 채소의 이송장치, 결속끈의 길이를 조절하여 공급하는 결속끈의 공급장치, 이송된 채소를 결속끈을 꼬아서 타원형으로 결속하는 결속장치 등으로 구성되어야 할 것이다.

채소의 이송장치는 작업자가 채소의 일정량을 용이하게 공급할 수 있도록 폭의 조절이 가능한 트레이를 체인콘베이어에 부착한 구조, 결속끈의 공급장치는 압축력이 걸려 있는 우레탄 재질의 구동 및 종동롤러로 원하는 길이의 결속끈을 피딩하면 칼날로 절단하는 구조로 개발하였다.

Keywords : Binding machine, Vegetables, Twine, Oval shape tying.

1. INTRODUCTION

Vegetables such as leek, shallot and spring onion are important crops in korean diet, in which consumption of these vegetables are ever increasing recently. Therefore, production areas of these vegetables are too expanding every year(MAF, 2000; YADTC, 1999).

Labor input times per 10a for leek, shallot and spring onion production are 691, 171, 174 hours, respectively, different by crops(FMB, 1999). Of which, grading and packaging operation take up 11

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to 53% in the total labor inputs where several operations such as cleaning yellowish leaves and foreign materials, binding and packaging process are included. Among the various processes after harvest, binding operation is the most time consuming and laborous work, of which produces markets in the most places recommend all incoming produces bound in the production sites.

Binding operation currently conducted by hands should be mechanized in prompt in order to alleviate labor burdens of farmers. However, no research information is available at this moment in this country, but a vegetable binding machine using adhesive tape of abroad is not proper for our binding situation since we are binding vegetables in oval shape instead of round shape that is prevailing in foreign countries(JSAM, 1996; Suzuteck, 1998).

Thus, this study was initiated in order to develop a binding machine which can bind vegetables in oval shape with twine contained iron string. This is the first part of this research that defines research direction through surveying current binding practices and reports on the results of vegetable carrying and twine feeding devices of the binding machine.

2. MATERIALS AND METHODS

A. Status of vegetables binding practices

Survey on the current status of binding operation for leek, shallot and spring onion was conducted in the major production sites in which one farm per each vegetable was randomly selected and interviewed by a researcher. Questions were on bundle specification and efficiency of operation. For each vegetable, 25 bundles, five bundles from five workers, were selected.

B. Development of materials feeding mechanism

(1) Design of Feeding devices

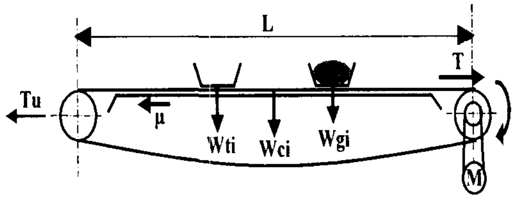


Fig. 1 Structure of the vegetable carrying device.

Vegetable carrying device shown in Fig. 1 is based on the conceptual design diagram of the binding machine in Fig. 4. It shows the upper part supported by the guide, and driving roller is rotating by a motor. Idle roller with sprocket could maintain proper tension in the chain conveyor. Tray shall be designed to supply a bundle amount of vegetable to the worker. Chain conveyor holds and moves trays, and vegetable in the tray shall not be shattered during transferring process. This means chain selection and its deployment are critical, and motor power that can change transferring speed shall be determined. Following equations (1) and (2) are used to calculate the motor power and the maximum tension force of the chain conveyor(HC, 1998; Kim, 1998; Park & Lee, 1993).

$$P = \frac{T \times V}{6120} \times \frac{1}{\eta} \quad \cdots\cdots (1)$$

$$T = (\sum Wci + \sum Wti + \sum Wgi) L \cdot \mu + Tu \cdots (2)$$

There,

P : Motor power for Transferring of chain conveyor(kw)

T : Tension force of chain conveyor(kgf)

V : Transferring speed of chain conveyor (m/min)

Wci : Weight per unit length of chain(kgf/m)

Wti : Tray weight per unit length of chain (kgf/m)

Wgi : Vegetable weight per unit length of chain (kgf/m)

L : Distance between sprockets(m)

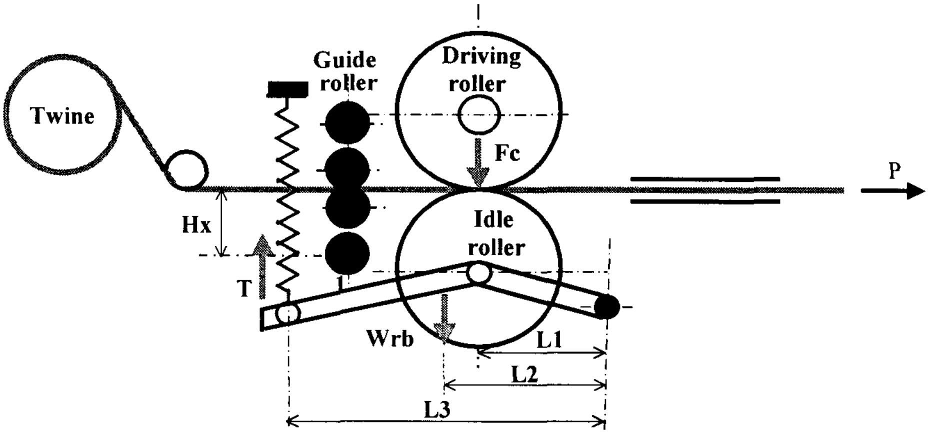


Fig. 2 Structure of the twine feeding system.

Tu : Tension force in sprocket(kgf)

η : Mechanical efficiency of the motor

μ : Friction coefficient between chain and guide

Twine feeding device could supply twine by a certain length to the binding device evolved from the conceptual diagram of binding machine(Fig. 4). Fig. 2 shows the twine feeding device where twine length can be manipulated by rpm of driving roller. As mentioned before, since twine has wire and is not straight that could be an obstacle in straight feeding between driving and idle roller so a guide roller was added to the device.

In the twine feeding device, diameter of driving and idle roller can be estimated by the twine length fed. Compression force can be found by using spring tension and weight of bar & idle roller as shown in equation (3). Motor power requirement for driving roller can be decided the torque calculated by the twine feeding force and roller radius.

$$F_c = \frac{T \cdot L_3 - W_{rb} \cdot L_2}{L_1} \quad \cdots\cdots\cdots\cdots (3)$$

There, F_c : Compression force(kgf)

T : Spring tension(kgf)

W_{rb} : Weight of bar and idle roller(kgf)

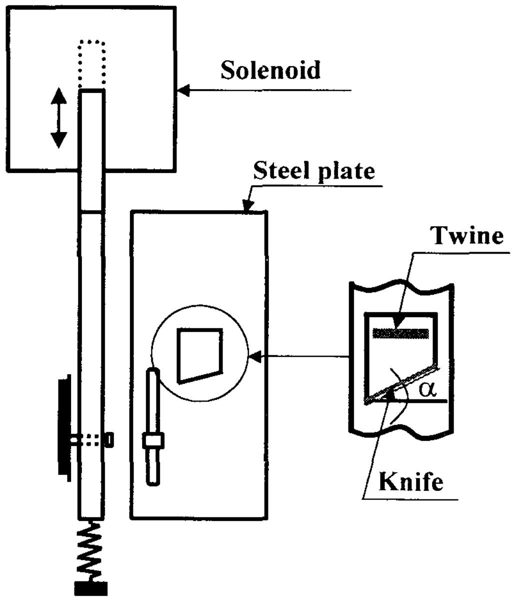


Fig. 3 Structure of the twine cutting system.

Twine cutting device is shown in Fig. 3 employing knife driven by solenoid where knife position was placed in the center of steel plate for functioning guide role for twine feeding. It helps to reduce cutting force with inclining knife.

(2) Design Parameters of the feeding mechanism

Tray developed in this study that is elliptical shape in bottom and width can be adjusted manually. Roller materials. urethane for idle roller and urethane and aluminum for driving roller of the twine feeding device were tested. Twine feeding device where twine feeding condition with four positions of guide roller was investigated at five compression levels between the two rollers ranged from 2.5 to 13.5kgf by 2.5kgf interval. Roller diameter was 44.6mm determined based on twine length of 420mm that could round up the three kinds of vegetables in this experiment.

Cutting rate of twine affected by the suction force of solenoid and three knife inclined angle was investigated. Table 1 shows the factors investigated in this study.

3. RESULTS AND DISCUSSIONS

A. Current status of vegetables binding practices

Table 2 shows the surveyed farms and their details. Cultivation area by the different vegetables was ranged from 1.0 to 2.3ha, and number of hired worker, all females except a worker in shallot's, were 5～8 per farm with work experience of 6.6～7.4 years. This gender disproportion comes from the fact that female hands are more suitable to binding works attributed by delicate operations such as removing yellowish leaves and foreign materials.

When the vegetables are shipped to agricultural markets, it recommends that leek and shallot be bound in twine and spring onion be packaged in box(MAF, 1997). But, the survey revealed that all the three vegetables were shipped in bound condition, of which bound position and part in the vegetables are quite different as tabulated in Table 3. Bound position from the bottom are 65～75mm in leek, 65～85mm in shallot and 90～110mm in spring onion.

Width and height of bound cross-section are (105～125)×(50～71)mm in leek, (90～104)×(37～48)mm in shallot and (80～90)×(42～55)mm in spring onion. And, ratio of height versus width are

Table 1 Factors investigated in the design of twine feeding device

Items		Variables
Feeding system	Roller materials	urethane, aluminum
	Compression force between the two rollers(Fc)	2.5～13.5kgf, interval of 2.5kgf
	Attachment position of guide roller(Hx)	±10mm, ±30mm
Cutting system	Solenoids(suction force/stroke)	(1.5kgf/10mm, 3.0kgf/20mm)
	Inclined angle of knife(α)	0°, 5°, 10°

Table 2 Investigated areas and binding workers

Vegetable	Investigated area	Cultivation area (ha/farm)	Binding worker (persons/farm)			Binding experience of workers (yrs/person)
			Male	Female	Total	
Leek	Yangpyong, Kyeongki	2.3	0	7	7	7.0
Shallot	Dangjin, Chungnam	1.5	1	4	5	7.4
Spring onion	Ilsan, Kyeongki	1.0	0	8	8	6.6

Table 3. Profile of the bounds made by manual work

Items			Leek	Shallot	Spring onion
Length of vegetable(mm)		Range	300~320	300~350	680~750
		Average	311	333	723
		C.V.	2.1	3.6	2.8
Bound position(mm)		Range	65~75	65~85	90~110
		Average	70	74	97
		C.V.	3.4	7.1	7.0
Size of bound cross section (mm)	Width	Range	105~125	90~104	80~90
		Average	115	98	82
		C.V.	4.1	3.6	3.0
	Height	Range	50~71	37~48	42~55
		Average	62	42	46
		C.V.	5.4	8.1	6.3
Weight of bundle(g)		Range	407~450	582~700	740~976
		Average	431	626	806
		C.V.	2.7	5.4	8.2
Oval shape(Width/Height)			1.6~2.5	2.1~2.7	1.6~1.9
Twine(mm)		Length	450	450	450
		Width	15/21	21	21
		No. of wire	1~2	2	2
Performance(bundles/h)			61	86	116

1.6~2.5 for leek, 2.1~2.7 for shallot and 1.6~1.9 for spring onion, where all are bound in oval shape. Coefficient of variations for bound position, bound area size, bundle weight are less than 10% showing no difference among workers. It indicates vegetables supply job in the binding machine could be accomplished by workers rather than machine.

Twine specification was 450×(15 or 21)mm for leek and 450×21mm for both shallot and spring onion. 15mm width twine had one wire of ϕ 0.4mm, and 21mm twine had two wires of ϕ 0.4mm. It was found that two types of twine were used, though physical differences existed among the various vegetables. Though twine lengths of bundles were different due to the vegetables amount in bundles, the farms used the same kind twine of same length because they purchased cut twine in the market.

After removing yellowish leaves and foreign materials, the number of binding bundles by the manual in a hour were 61 bundles for leek, 86 bundles for shallot and 116 bundles for spring onion. These variations came from difficulty in measurement where leek bundle had to be measured two or three times.

B. Research scope for binding machine development

According to the survey conducted, binding

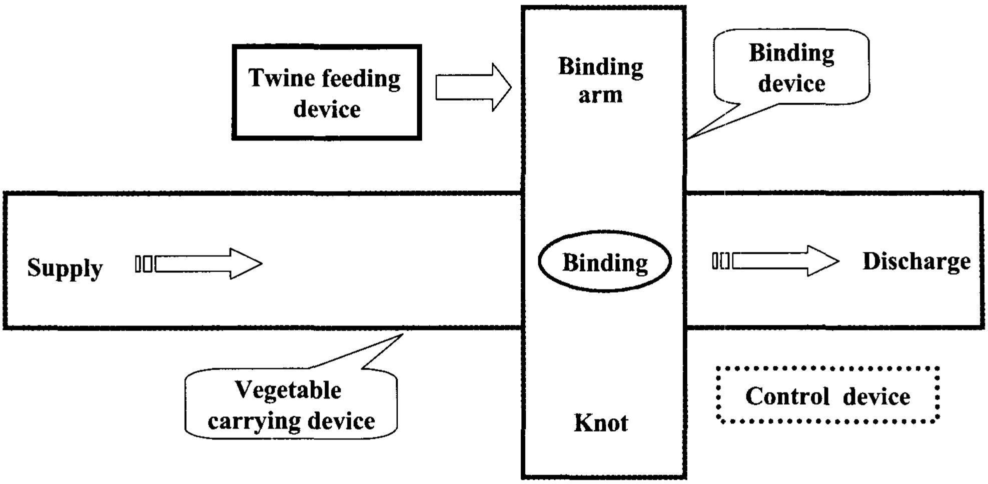


Fig. 4 Conceptual design diagram of the binding machine.

operation with twine is simple and repetitive work and gives fatigue to certain parts of body. This indicates that binding operation needs to be mechanized in order to save labor and relieve work load. And bundle weight showed no difference among workers. It indicates vegetables supply job in the binding machine could be accomplished by workers rather than machine. And, the binding machine to be developed has to deal with various vegetables since many farmers are cultivating three to five types of vegetables in a year.

For these requirements, it needs to fulfill following conditions ; ① cross- section of bound part should be oval shape, ② adjustment of bundle size, twine length, binding firmness should be obtained, ③ operation speed considering work preparations and workers' abilities should be adjustable, ④ easy machine manipulations and vegetable supplying.

Fig. 4 shows the conceptual design diagram of the binding machine. Trays containing vegetables supplied by a worker on the top of chain conveyor move to the binding section and be discharged continuously, where operation speed is controlled by tray travelling speed. Twine feeding device supplies proper length of twine to the binding device. Binding mechanism is the core part of this study that binds vegetables in bundles with twisting twine meeting the bundle sizes and the required firmness. Control device of the binding machine should manipulate all the components functioning systematically and satisfy the binding characters of various vegetables as well.

C. Vegetables carrying device

(1) Shape and size of tray

Fig. 5 shows the tray developed in this study. The tray is elliptical shape in bottom, and width can be adjusted manually. And, binding is performed in the space betweem two trays. Table 4 shows the specifications of tray for the different vegetables. Width(Wcf) and width(Wcr), height(Hc), and length (L_1 and L_2) of tray are 130±30, 200±20, 90, 67 and 623mm for the three vegetables as of universal dimension.

(2) Chain conveyor system

For developing chain conveyor system, we have selected two chains for light load conveying, the smallest RF2040 and 2050 in KS(KSA, 1997). Of the four trays appeared in the upper side in Fig. 6, two trays are for vegetables supplying and one tray is for binding, the rest one is for discharging. Thus,

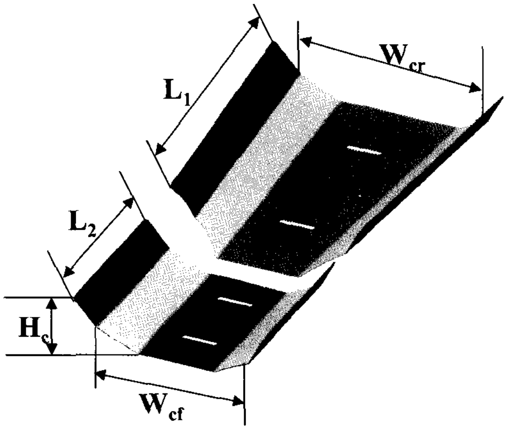


Fig. 5 Structure of tray for vegetable carrying.

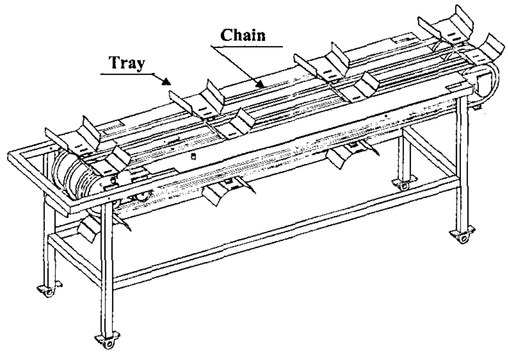


Fig. 6 Structure of chain conveyor system.

eight trays are attached to the chain conveyor system. Interval between two trays is 70cm that makes chain length of 560cm. Distance between two sprockets shown in Fig. 6 is 260cm.

With this data, we constructed chain conveyor system as shown in Fig. 6 and investigated the performance of conveyor. With trays of stalk and leaves attached to one set of chain, it showed some unstability during conveyance but attaching to two set of chain stability has achieved. Therefore, with two set of chain holding stalk and leaves tray maximum tension were 30.7 and 37.6kgf, higher than rupturing strength by 54 to 73 times that justifies selection of RF2040 as proto-chain in this study. When chain speed was 2~10m/min, motor power requirement was 13~63W that subsequently enabled us to select AC90V/90W motor with maximum chain speed of 10m/min.

D. Twine feeding device

(1) Feeding system

Fig. 7 shows the relationship between twine pulling force and compression force between the two rollers. It indicates that pulling force became greater as distance between guide roller and the center line gets wider, and it became bigger in upper position than lower position placed guide roller. The reasonable explanation for this is contact area difference between guide roller and twine where obviously greater contact area is needed if guide roller is placed upper position and further from center line. Motor torque by the twine feeding was 1.8~8.6kgf · cm, by that we could choose driving roller motor of DC24V/15W having torque of 14.4 kgf · cm and 100 rpm.

Table 4. Size of tray by the different vegetables

Vegetable	Width(mm)		Height(Hc) (mm)	Length(mm)	
	Wcf	Wcr		L_1	L_2
Leek	150±15	200±15	90	40	220
Shallot	150±15	210±15	65	44	246
Spring onion	100±15	195±15	80	67	623
Universal dimension	130±30	200±20	90	67	623

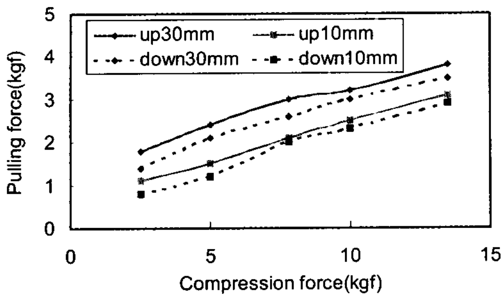


Fig. 7 Twine pulling force at the different position of guide roller subjected to the various compression forces.

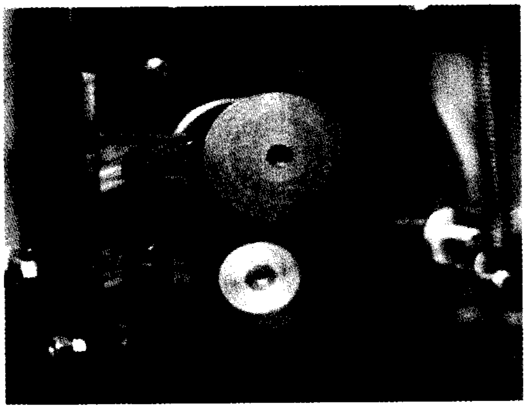


Fig. 8 Unfeeding picture of twine.

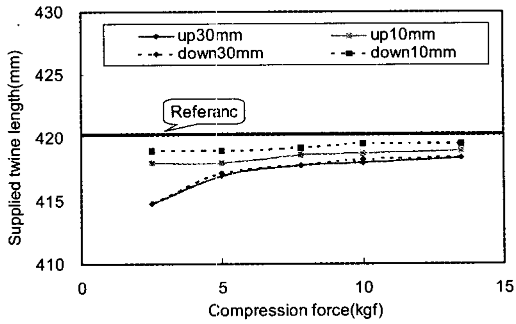
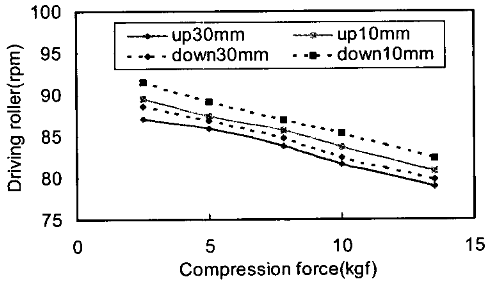
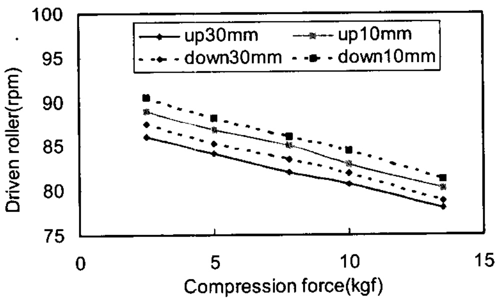


Fig. 9 Twine length varitions by the compression force.



(a) Driving roller



(b) Idle roller

Fig. 10 Relationship between roller speed and compression forces.

Better twine feeding condition was found in both urethane driving and idle roller. On the other hand, aluminum driving roller, regardless of guide roller positions, could not feed twine properly which happened in the curved twine due to uneven contact area, particularly observed in aluminum roller (Fig. 8).

Fig. 9 shows twine length variations affected by compression force between the two rollers and guide roller positions. Twine length, 420mm is calculated in three rotations of driving roller, however, less twine lengths were fed under all conditions. Of which, with guide roller placed 30mm in upper and lower position when compression force of lower than 5kgf, twine length was shorter by 5mm that is due to the load in the guide roller. Guide roller position 10mm in upper and lower, it showed shorter by 2mm.

Rotating speeds of driving and idle roller of urethane affected by the compression forces and the guide roller positions are shown in Fig. 10. It shows that as compression force increased, rotating speeds of driving and idle roller decreased. At no

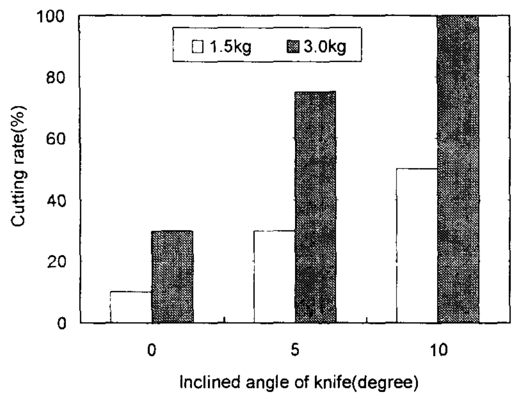


Fig. 11 Cutting rate by inclined angles of knife.

load condition, rotating speed of driving speed was 100 rpm. 11~22% rpm for 30mm upper and lower positioned guide roller and 8~20% rpm for 10mm upper and lower positioned guide roller decreased. And rotating speed of idle roller was less than that of driving roller by about 1 rpm.

By the results so far, the twine feeding system shall be designed where material of rollers be urethane, guide roller position be placed 10mm lower from center line and compression force between rollers be 7.5kgf.

(2) Cutting system

Fig. 11 shows the cutting rate by treatment conditions of solenoids and knife inclined angles. This figure shows that 1.5kg suction force of solenoid could cut twine by 10~50%, however, knife of 10° inclined angle having 3.0kg suction force could cut all twines, 100% completely.

4. CONCLUSIONS

This study was conducted in order to mechanize vegetables binding process that is the most laborous work and simple & repetitive job in the vegetable production. This is the first part of this study where we investigated the current binding practices and tried to determine scope of this research. And, we developed vegetable carrying & twine feeding devices fit for appropriate vegetables. Major findings are followings ;

1) Most binding works were performed by women. Twine contained iron core was used to bind vegetables in elliptical shape. Coefficient of variations for bound position, bound area size, bundle weight are less than 10% showing less difference among workers.

2) The binding machine to be developed could deal with various vegetables that shall adjust twine length, binding tension and operation speed. And, workers could feed vegetables with no difficulty in the machine operation.

3) Universal tray size for all the tested vegetables shall be 130±30×67mm in stalk holder, 200±20×623mm in leaves holder, 90mm in height. For oval shape binding, tray shape shall be elliptical shape.

4) On the chain conveyor system, selected chain was RF2040 and two set of chain was needed for safe vegetables trays delivery. It required 63W motor power to move 8 trays at maximum speed of 10m/min.

5) Twine feeding system shall be designed that material of rollers be urethane, guide roller position be placed 10mm upper from center line and compression force between rollers be 7.5kgf. Knife of 10° inclined angle having 3.0kg suction force could cut all twines, 100% completely.

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