Proceedings of the International Conference for Agricultural Machinery & Process Engineering
October 19-22, 1993, Seoul, Korea

EVALUATION OF BABY CORN SILK DETACHMENT SYSTEMS

Bharata Kunjara, Yoshio Ikeda and Takahisa Nishizu
Graduate Student, Professor and Instructor
Laboratory of Farm Processing Machinery
Department of Agricultural Engineering, Faculty of Agriculture
Kyoto University, Kyoto, Japan

ABSTRACT

Two types of baby corn silk detachment systems called fixing and moving baby corn and based on applying frictional force on the silk were developed and evaluated. In the fixing mode the baby corn was fixed on a pin and a hollow frictional cylinder was moved concentrically and vertically along the baby corn towards the branch end. In the moving mode the baby corn was forced vertically towards the tip to pass through the same silk detachment cylinder. Traveling speeds of the detachment cylinder and the baby corn were 44.5 and 166.9 mm/s.

In the fixing mode at silk moisture content of 91 % (w.b.) silk detachment efficiencies at low and high speeds were 99.1 and 99.2 %. The silk detachment efficiencies in the moving mode at low and high speeds were 96.6 and 98.5 %. Damaged baby corn at low speed was less than at high speed in both modes. Minimum damage was nil in the fixing mode at low speed and the maximum was 47.5 % in the moving mode at high speed. The damage was due to ovaries removal at the base near the joint between the baby corn and the branch.

Key Word : Baby corn , Silk detachment systems, Performance

INTRODUCTION

Baby corn or young corn has been recognized recently as vegetable. The edible part which is inside the ear is in the early stage of ear development. The ear consists of four components, namely, husk, branch, baby corn and silk which inter-connect to each other from outside to inside respectively as husk-branch, branch-baby corn and baby corn-silk, Ikeda et. al. (1992). The separating process of baby corn from non-edible parts called dehusking is the most important and unique postharvest operation for this kind of vegetable. The conventional dehusking process can be classified into three consecutive operations as, cutting one trace along the top surface to open the ear, separating the baby corn from the branch by cutting or breaking the joint between the branch and the baby corn and detaching silk from the ovaries. The study of silk detachment force and characteristics has been reported by Kunjara et. al. (1992) that the silk detachment operation should be in the direction parallel to the longitudinal axis towards the branch due to the minimum force required without tearing the silk before completing detachment. According to this findings, silk detachment systems were developed and experimental investigation was conducted.

The objective of this study was to construct baby corn silk detachment systems, evaluate the feasibility of their performance and verify modification where necessary.

MATERIALS AND METHODS

Silk Detachment Systems

Silks which are the receptive organs for pollen grain emerge from each ovary on baby corn and cover the edible part lengthwise and occupy 21 % of the total mass of young corn ear, Ikeda et. al. (1992). Since the detachment should be in the direction parallel to the longitudinal axis towards the branch due to the minimum force required the following factors have been considered in the design of the detachment systems.

The force which is going to detach the silks cannot be straight pull because the silks group as a bundle around the baby corn. The force should be able to detach the silks in group instead of individual silk. In this case, the application of frictional force is considerably appropriate. Position of the baby corn is another important factor, while the silks are being detached the position of the baby corn should be suitable that the detachment mechanism can approach the silks in all directions. Thus, the best position should be in vertical. The silk detachment can be operated in two ways i.e., the detachment mechanism moves concentrically along the baby corn or the baby corn travels through the detachment mechanism.

Two modes of silk detachment systems i.e., fixing and moving baby corn which employed the frictional force to detach the silks from baby corn ovaries were developed. In the fixing mode the baby corn was inserted on a small pin which was a means for positioning the baby corn in vertical and the silk detachment cylinder moved concentrically and vertically along the baby corn towards the branch end. In the moving mode the baby corn was put in a container and forced vertically towards the tip to pass through the same silk detachment cylinder.

As the silk detachment cylinder moves concentrically along the baby corn towards the branch end or the baby corn travels through the detachment cylinder towards the tip, a scrubbing action acts on the silk and causes the silk to be detached. The silk detachment cylinder, Fig.1, was made of 38 mm external diameter polyethylene pipe. A hollow cylinder sponge material of 32 mm external diameter was glued as a liner inside the pipe. A 32 mm diameter and 1 mm thickness rubber plate was cut at the center into 15 radial segments of which the inner diameter was 11 mm and glued to the top surface of the liner. In both modes the baby corn tip enters the lower part of the silk detachment cylinder and passes through the rubber plate.

Detachment Force Measuring Instrument

A simple cantelever beam of 25 x 75 x 2 mm made of phosphor bronze was constructed for measuring vertical detachment force. Two multiple type strain gages were bonded on the upper and lower surfaces of this beam. Schematic diagram of the silk detachment force measuring instrument is shown in Fig.2. The strain gages were calibrated with known mass before commencing the experiment.

The silk detachment cylinder was fixed on this cantelever beam. In the fixing baby corn mode this unit was attached to an air cylinder rod which provided vertical movement. The air cylinder was fixed to a frame and the position of the detachment cylinder was set to be in the centerline with the pin on which the baby corn was going to be inserted. In the moving baby corn mode an air cylinder rod provided a pushing action to force the baby corn to pass through the measuring unit which was fixed on the frame. The baby corn was put in a vertical container made of a polyethylene pipe of which the external diameter and length were 26 mm and 96 mm. The container was positioned 2–3 mm above a round nut which was screwed to the air cylinder rod end. The silk detachment cylinder was 30 mm above the container. The detachment cylinder, the container and the cylinder rod were positioned along the same centerline. The baby corn which was still covered with the silks was put in the container and seated on the round nut. Since the clearance was appropriately set, the cylinder rod was able to push the baby corn upward to pass through the silk detachment cylinder eventhough there were some variation in the baby corn diameters.

Sample

Sweet corn 'Partner Sweet' commercial cultivar was grown at Takatsuki Experimental Farm of Kyoto University in order to produce baby corn for the study. Planting and harvesting dates were 22 May and 17 July 1992 respectively. After harvesting the ears were delivered to Laboratory of Farm Processing Machinery, Kyoto University, and stored in cold storage at 5°C (67% RH). The ears were randomly selected to use as samples and conditioned at room temperature for at least 6 hours prior to conducting the experiment.

The ears were trimmed off the tissue which was still available at the branch end since harvesting. Physical properties i.e., mass, length, major and minor diameters of the ear were measured before the experiment. Kunjara et. al.(1993) reported the advantage of trimming off the ear tail, thus, in this study the ear were trimmed off the tail to an appropriate length of 170 or 200 mm. The baby corn was separated manually from the ear. While separating it was done carefully in order not to remove the silk. Then branch length was measured.

Samples for the fixing mode experiment were cut at the branch approximately 15 mm from the joint in order that this section could be inserted on the pin for holding the samples vertically without damaging the baby corn. Mass of baby corn with branch and silk was measured. The samples for the moving mode experiment were cut exactly at the joint and the mass of baby corn with silk was determined. After the experiment, detached and torn silk which distributed over the baby corn were cleaned manually and mass of the baby corn and undetached silk of the samples in both modes were measured. Then the undetached silks which were available on the baby corn were detached manually. In the fixing mode, mass of the baby corn sample together with the branch was determined first, after cutting the branch portion, the baby corn mass, length, major and minor diameters were determined. The same physical properties of the samples in the moving mode were measured directly after undetached silks were removed. Later each sample was examined to determine the silk detachment performance.

Traveling speeds of the detachment cylinder and the pushing rod to force the baby corn to enter the detachment cylinder were set at two levels i.e., 44.5 and 166.9 mm/s. Before loading a new sample the silks which accumulated in the detachment cylinder were cleaned manually.

Computation of System Performance

The system performance could be classified as, silk detachment efficiency, percentage of damage and passed baby corn.

Silk detachment efficiency can be computed from the following relation.

silk detachment efficiency (%) = (mass of silk which is detached)/(mass of total silk) x 100 **.......(1)**

The damage is defined as any sample which is defected due to the detachment operation such as broken baby corn or ovaries removal. The damage can be computed as

damaged baby corn (%) = (number of baby corn which is defected)/(number of total baby corn) x 100 **..........(2)**

Passed or accepted baby corn is defined as the baby corn which has satisfactory appearance after leaving the silk detachment system and can be computed as

passed baby corn (%) = 100 - damaged baby corn (%) **..........(3)**

RESULTS AND DISCUSSION

Silk Detachment Efficiency

Silk detachment system performance and the Duncan's multiple range test for the silk detachment efficiency and force at mean silk moisture content of 91 % (w.b.) are shown in Table 1. In the fixing mode, detachment efficiencies at low and high speeds were 99.1 and 99.2 % and not significantly different at 5 % level. Since the baby corn was inserted on the pin, the silks separated individually from each other because of the gravity and bent down as shown in Fig.3. As the silk detachment cylinder moved concentrically and downward along the baby corn the silks were forced slowly to the same direction as the cylinder and by scrubbing action the silks were detached easily. Thus, the speed of detachment had no effect on the detachment efficiency in the fixing mode. In the moving mode, silk detachment efficiencies at low and high speeds were 96.6 and 98.5 % and significantly different at 5 % level. The baby corn was put in the container as shown in Fig.4. The silks did not separate individually as in the fixing mode and still covered around the baby corn as usual. At high speed the silk mass was forced rapidly to pass the detachment cylinder which induced the resistant force in the detachment cylinder to increase rapidly or in other words increasing the scrubbing action inside the detachment cylinder. This probably caused the silk detachment more efficient than at low speed and resulted higher efficiency. However, in this mode at high speed the silk detachment efficiency was not significantly different at 5 % level from the detachment efficiencies in the fixing mode for both speeds. It could be said that the fixing and moving modes at high speed produced the same effect for silk detachment efficiency.

The difference of silk detachment characteristics between the fixing and moving modes did exist. In the fixing mode, undetached silks were long and generally left on the upper part of the baby corn especially around the tip and the detached-torn silks distributed on the baby corn. In the moving mode, two different types of undetached silks were available. The long silks were in the same location on the baby corn as in the fixing mode and undetached-torn silks were short and distributed unevenly on the baby corn. In the moving mode the detached-torn silks spread over the baby corn as in the fixing mode. While the baby corn was passing through the detachment cylinder, the silks were forced to enter the cylinder in a bundle manner rather than individual as in the fixing mode. Since the exit on the rubber plate was narrow, bending or compression might exist in the detachment cylinder and some of the silks were torn but not detached from the ovaries leaving undetached-torn and also detached-torn silks on the baby corn.

Detachment Force

Silk detachment forces are also presented in Table 1. At low and high speeds of the fixing mode the detachment forces were 8.29 and 9.73 N and not significantly different at 5 % level. This might be because the silks separated individually by the gravitational force and this condition enhanced ease of detachment. However, in the moving mode the detachment force at low and high speeds were 16.09 and 25.01 N and significantly different at 5 % level and increased accordingly with speed. The maximum detachment force was 25.01 N at the speed of 166.9 mm/s. When comparing between the fixing and moving modes the detachment forces were significantly different at 5 % level.

Typical graphs of silk detachment force and time are shown in Fig.5. The silk detachment force increased non-linearly as the detachment cylinder moved concentrically along the baby corn (in the fixing mode) or as the baby corn traveled through the detachment cylinder (in the moving mode). The peak occured when the base of the baby corn which had the largest width exited the rubber plate. The force dropped rapidly as the detachment was completed.

Baby Corn Quality

Damage of baby corn was significantly affected by the high speed and the moving mode. At high speed in the fixing and moving modes damaged baby corns which were 10 and 47.5 % were greater than that of low speed which were nil for the fixing and 15 % for the moving modes. The moving mode resulted more damage than the fixing mode. Damaged baby corn was mainly due to ovaries removal around the base of the joint between the baby corn and the branch. Probably there were two reasons, firstly, the ovaries around that point developed initially and there were no any other ovaries behind them in the same row, thus, when detaching the rubber plate could remove those ovaries easily as there were no neighboring ovaries to support. Secondly, the arrangement of those ovaries in each row were abnormal such as emerging over other ovaries, thus, when the rubber plate detached the silks those ovaries were also removed. Broken baby corns were very few in both modes.

Baby Corn Dimensions and Performance

Distribution of baby corn length, major and minor diameters of each treatment are shown in Fig.6. The length of baby corn in all treatments of more than 85 % fell in the class mark of 72.5–92.5 mm except that of the moving mode at low speed which were in the class mark of 77.5–97.5 mm. Major diameters of the baby corn were in standard (major diameter $\leq$ 15 mm) more than or equaled to 80 % in all treatments except that of the moving mode at low speed which were in standard only 60 % (40 % oversize).

The effect of high speed was shown in the fixing mode since the major diameters of the samples at high speed were almost the same as that of low speed, Fig.6 E and F, however, the damage was slightly higher due to the higher speed. In the moving mode at high speed, Fig.6 H, the major diameters of 80 % of the samples were in the same class as in the fixing mode at both speeds, Fig.6 E and F, but the damage of 47.5 % was very significantly different. On the other hand, the major diameter of the samples in moving mode at low speed, Fig.6 G, was 40 % oversize, however, the damage was only 15 % which was much lower comparing to that of the high speed. The silk detachment at the speed of 166.9 mm/s affected significantly the quality of the baby corn.

Dimensions of baby corn and the silk detachment forces which related as the following equation could be used for estimating silk detachment forces.

$$F = \beta_1 L_C + \beta_2 D_C + \alpha \qquad \text{..........(4)}$$

where, F = silk detachment force, N ; β_1= coefficient of L_C
L_C= length of baby corn, mm; β_2= coefficient of D_C
D_C= major diameter of baby corn, mm; α = constant

List of multiple linear regression equations of the experiment are shown in Table 2. Coefficient of determination (R^2) of the fixing mode was higher than that of the moving mode and at low speed was higher than that of the high speed respectively. The best predicted detachment force was from the equation of the fixing mode at low speed.

CONCLUSIONS

In general, the silk detachment systems performance based on applying frictional force to the silk are satisfactory to a certain extent. From the practical viewpoint, the moving mode is preferable because the baby corn can be separated from the ear and put in the container directly as in this experiment. No complicate preparation of the sample is needed as in the fixing mode. In addition, the moving mode at low speed is considerably appropriate if the detachment efficiency can be increased and the damage can be decreased significantly.

Results of the evaluation of baby corn silk detachment systems could be concluded as follows.

1. The silk detachment systems based on applying frictional force on the silks were practically feasible.
2. The fixing mode performance was preferable for the highest detachment efficiencies, the lowest detachment forces required and the minimum damage.
3. Undetached silks were on the upper part of the baby corn around the tip.
4. The damaged baby corn was significantly affected by the high speed and the moving mode.
5. Length and major diameter of baby corn could be used for estimating the detachment forces from the regression equations. The best prediction might be in the fixing mode at low speed.

REFERENCES

1. Ikeda, Y., B. Kunjara and T. Nishizu. 1992. Morphology and physical properties of baby corn, Proceedings of the 51th Annual Meeting of the JSAM, 303–304.

2. Kunjara, B., Y. Ikeda and T. Nishizu. 1992. Characteristics of baby corn silk under tensile loading nad silk detachment force, Proceedings of JICA–IPB 5th Joint Seminar as an International Conference on Engineering Applications for the Development of Agriculture in the Asia and Pacific Region, vol. 2, 311–317.

3. Kunjara, B., Y. Ikeda and T. Nishizu. 1993. Experimental investigation of baby corn separating system, Proceedings of the 52th Annual Meeting of the JSAM, 271–272.

ACKNOWLEDGEMENT

Sincere thanks and appreciation are due to Professor Hisajiro Yukinaga and Instructor Tanjuro Goto of Takatsuki Experimental Farm, Kyoto University for their valuable assistance.

Table 1 Summary of Duncan's multiple range test for the silk detachment efficiency and force

Mode of Detachment	Speed (mm/s)	Silk Detachment Efficiency (%)*	Detachment Force (N)*	Damage (%)	Passed (%)
Fixing	44.5	99.1 a^{**}	8.29 a^{**}	-	100
Fixing	166.9	99.2 a	9.73 a	10	90
Moving	44.5	96.6 b	16.09 b	15	85
Moving	166.9	98.5 a	25.01 c	47.5	52.5

*Average of four replications
**Means with the same letter are not significantly different at 5 % level of significance
***Mean silk moisture content was 91 % (w.b.)

Table 2 Multiple linear regression equations of baby corn dimensions and silk detachment forces

Mode of Detachment	Speed (mm/s)	Regression Equations	R^{2*}
Fixing	44.5	$F = 2.67L_C - 0.02D_C - 8.52$	0.9225
Fixing	166.9	$F = 4.93L_C - 0.22D_C - 6.58$	0.8929
Moving	44.5	$F = 0.23L_C + 2.90D_C - 46.94$	0.7389
Moving	166.9	$F = 8.40L_C + 3.77D_C - 149.54$	0.6641

*Significant at 5 % level

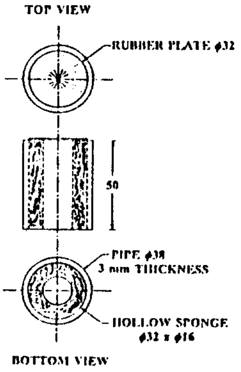

Fig.1 Silk detachment cylinder

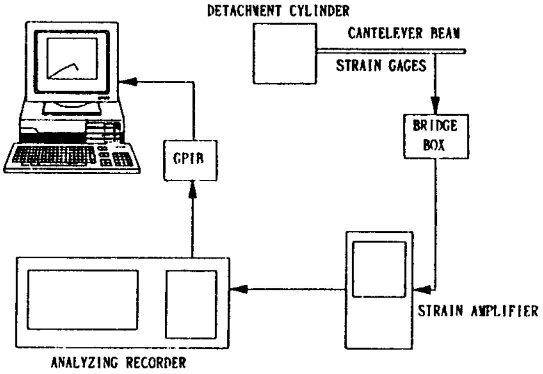

Fig.2 Schematic diagram of silk detachment force measuring instrument

Fig.3 Baby corn on the pin (Fixing mode)
(1) Detachment cylinder
(2) Baby corn
(3) Air cylinder

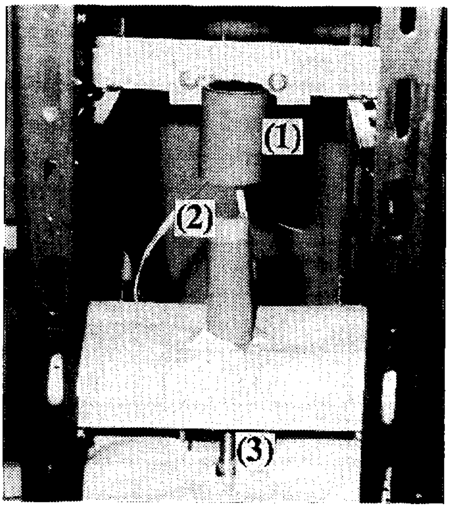

Fig.4 Baby corn in the container (Moving mode)
(1) Detachment cylinder
(2) Baby corn
(3) Air cylinder rod

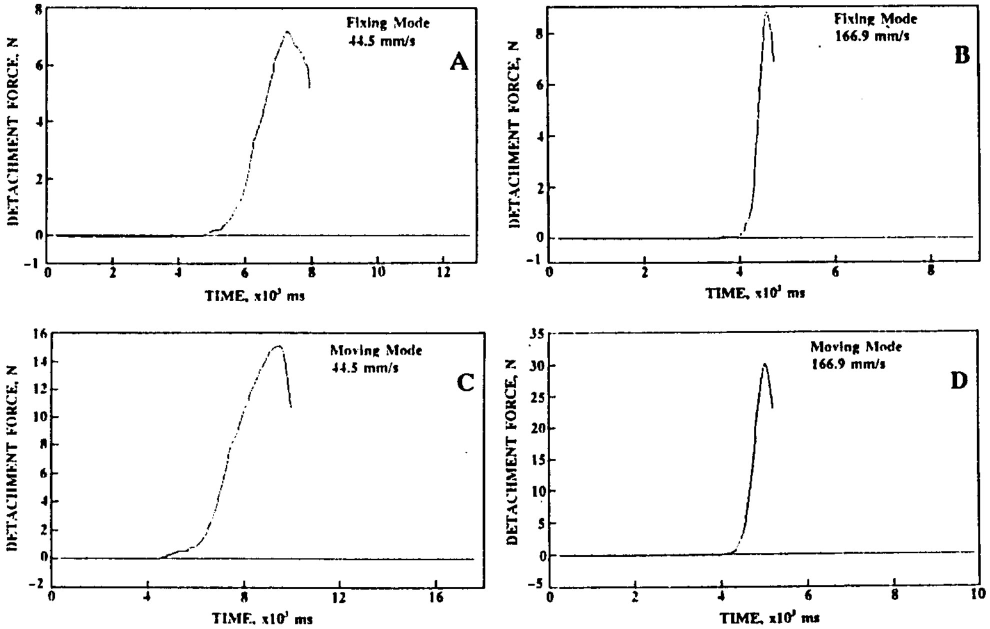

Fig.5 Silk detachment forces

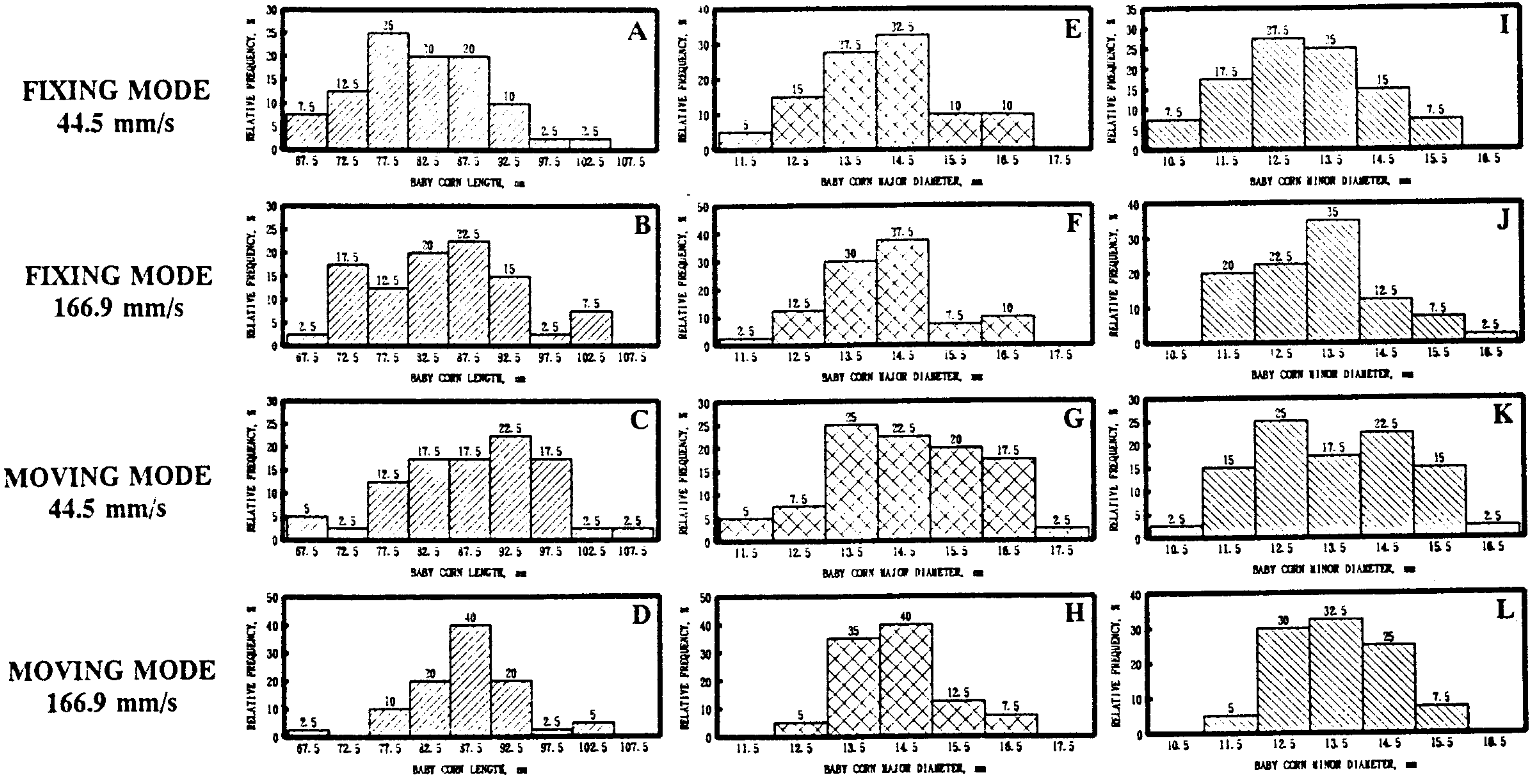

Fig.6 Frequency distribution of baby corn length, major and minor diameters