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Studies on the Pulling Forces Associated with Strawberry Harvesting

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Abstract

This study was carried out to accomplish two primary objectives. The first was to obtain quantitative information on the relationships between fruit maturity, berry sizes, pulling angles, and pulling forces. Second was to compare the pulling forces of *Akihime* and *Toyonoka* varieties.

The results of regression analysis showed that the pulling force has no significant relationship with either fruit weight or stem diameter as indicated by the low correlation coefficients for the two varieties. On the other hand, the force-to-weight ratio when correlated linearly with fruit weight produced higher regression coefficients. Also, the force required to detach the berry from the stem clearly decreased as the angle of pull increased from 0 to 90 degrees for the three maturity levels considered. However, there was no distinct variation between pulling force and maturity levels for all the three pulling angles used. This indicates that selective strawberry harvesting based upon a force differential between maturity levels is not probable. On the other hand, force-to-weight ratio decreased significantly as the strawberry matures and as the pulling angle increased. This suggests that force-to-weight ratio could be a useful selection factor in harvesting fresh strawberries mechanically. The results in both *Akihime* and *Toyonoka* varieties were found to yield the same trends with slightly different magnitudes.

Keywords : strawberry, harvesting, pulling force, pulling angle

Introduction

In Japan, strawberry shares a significant portion of the fresh fruit market and seems to remain in the coming years. However, based on the assessment of the Ministry of Agriculture, Forestry and Fishery (MAFF), one problem facing Japanese agriculture today is the decreasing available manpower for farming activities and the rapid aging of farmers with just few potential successors in sight. If this trend is unabated, the strawberry production will certainly be affected in the near future. This is due to the fact that strawberry harvesting and sorting, in particular, are still done manually.

For some years now, research on strawberry sorting methods using computer and machine vision technologies has been going on in our labo-

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ratory and has made some important and relevant advances towards sorting process automation. On the other hand, research on strawberry harvesting has yet to start. The authors have the opinion that a sustained investigation on the possibility of mechanical strawberry harvesting has to begin as soon as possible. And just like any other machine design and development work, some basic studies which will provide important knowledge useful to more advanced researches at present and in the future, are necessary.

Purpose of the Study

In the 1960's and early 1970's, several researches were done on harvesting of different fruits to study the relationship between pulling force and pulling angles for oranges[1], lemons[2], apples[3], and strawberry[4], to cite a few. The results obtained were similar, that is, the force required to detach the mentioned fruits decreased as the pulling angle increased. Some studies were also done on the relationship of fruit maturity, time of harvest, and detachment force[5,6,7]. For fruits without an abscission layer, the pulling force did not show any significant variation with respect to fruit maturity. However, the force-to-weight ratio was found to decrease as the fruit matured. This study was done to obtain quantitative data on the relationships between strawberry maturity, size, pulling angle and pulling force, and analyze and compare the forces associated with the harvesting of two strawberry varieties grown in Japan, *Akihime* and *Toyonoka*.

Materials and Methods

Strawberries used in the experiments were the *Akihime* and *Toyonoka* varieties grown inside vinyl houses in Kibana and Aoshima, Miyazaki, respectively. Three levels of maturity based on color were used namely : the green (immature), pink (color-inception), and red (ripe color) strawberries (Figure 1). A total of 1,245 strawberries were tested in all three experiments. There were 15 samples per maturity level per pulling angle for each of the 3 trials.

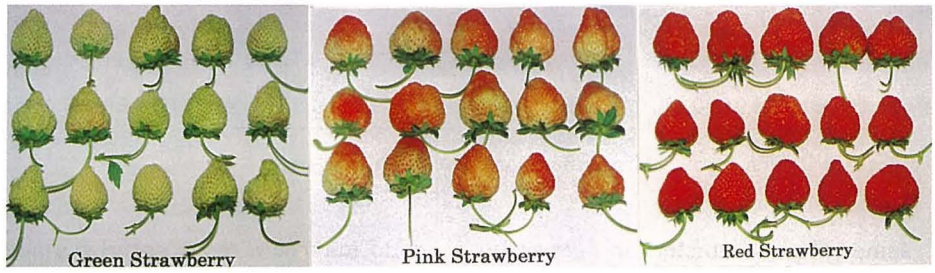
The three sets of experiments were done on (a) May 9, 12, and 15, 1997 ; (b) December 11, 18, and 19, 1997 ; and (c) April 16, 30, and May 12, 1998. Strawberries were removed from the plant between 8 : 30 and 10 : 30 a.m. by cutting the stem as close as possible to the plant crown using a pair of scissors. Detachment tests were done in the laboratory just right after harvesting.

A simple pulling setup shown in Fig. 2 was used. The berry stem was clipped to the end of a TOA spring scale (80-200g and 800-2000g capacities) and pulled while the fruit was held at a specific angle by an adjustable metal holder supported by hand. Three pulling angles, 0, 45 and 90 degrees relative to the vertical line, were used (Fig. 3). The upward pulling of the spring scale increased the strain in the stem until the fruit is detached from the calyx. The magnitude of the pulling force was then read from the scale and recorded. After detachment, several berry physical characteristics were measured. These were stem diameter at the fracture point, major and minor diameters, distance from the calyx to the major diameter, berry length, weight, volume and density. Water displacement method was used to measure the volume.

Results and Discussion

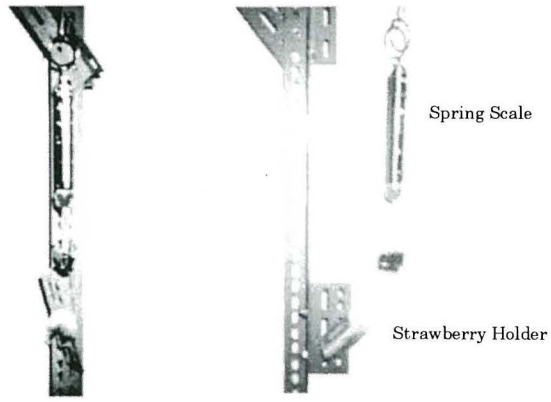
The physical properties of *Akihime* and *Toyonoka* varieties (Table 1) revealed that on the average, *Akihime* strawberry is heavier, longer, has a higher density and a longer calyx-to-maximum cross-section distance than *Toyonoka* strawberry. On the other hand, *Toyonoka* has larger major and minor diameters than *Akihime strawberry* and therefore, are more rounded in shape. Both varieties have approx-

(a) *Akihime* variety



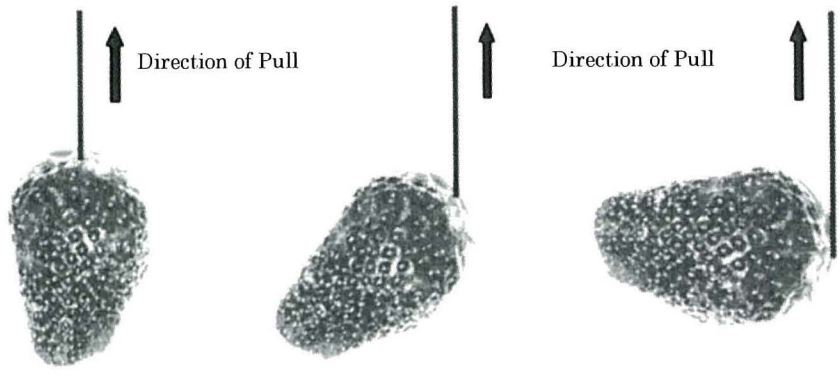
(b) *Toyonoka* variety

Fig. 1. The three maturity levels of *Akihime* and *Toyonoka* strawberries used in the experiment.



(a) Front View (b) Side View

Fig. 2. Setup used in the strawberry pulling tests.



(a) 0 degree (b) 45 degrees (c) 90 degrees

Fig. 3. The three pulling angles used in the experiment.

Table 1. Physical characteristics of *Akihime* and *Toyonoka* strawberries used in the tests.*

Characteristic	*Akihime*			*Toyonoka*		
	Green	Pink	Red	Green	Pink	Red
Weight (g)	7.38±2.67	9.74±3.64	11.94±4.84	6.43±1.61	8.79±3.16	11.62±3.11
Major diameter (cm)	2.27±0.30	2.50±0.36	2.66±0.42	2.49±0.29	2.76±0.34	3.05±0.32
Minor diameter (cm)	2.11±0.29	2.34±0.30	2.45±0.34	2.24±0.22	2.51±0.32	2.80±0.28
Berry length (cm)	3.59±0.57	3.85±0.70	4.16±0.75	2.86±0.27	3.09±0.40	3.37±0.35
Distance from calyx to maximum berry cross section (cm)	1.32±0.34	1.41±0.27	1.57±0.28	1.02±0.12	1.12±0.18	1.21±0.13
Stem diameter (cm)	1.64±0.29	1.53±0.30	1.52±0.33	1.56±0.26	1.55±0.24	1.62±0.24
Berry density (g/cm^3)	0.94±0.140	0.93±0.150	0.92±0.095	0.87±0.060	0.86±0.086	0.87±0.105

*All values are in this form : (Mean±Standard Deviation)

imately the same stem diameter in general. Moreover, the weight, major and minor diameters, length, and distance from calyx to maximum berry cross-section increase as the berry matures for both varieties. The density of *Akihime* strawberry clearly decreases as it becomes mature indicating that the volume increases slightly faster than the weight while the density of *Toyonoka* strawberry appears to remain fairly the same. Also, the stem diameter of *Akihime* strawberry becomes smaller as it matures while the stem diameter of *Akihime* strawberry shows no definite trend. Knowing that the length is significantly longer than the major diameter for both varieties can be an important consideration in determining the correct upright position of a strawberry by a computer in a sorting system.

Tables 2 and 3 show that the pulling force has no significant relationship with either fruit weight or stem diameter as indicated by low correlation coefficients ranging from 0.0009 to 0.5508 and 0.0182 to 0.3796, respectively, for *Toyonoka* and 0.0005 to 0.2733 and 3.69×10^{-6} to 0.4149, for *Akihime*. On the other hand, the force-to-weight ratio when correlated linearly with fruit weight produced higher coefficients in the range of 0.4303 to 0.6703 for *Toyonoka* (Table 4). This suggests that force-to-weight ratio may be a more useful parameter to characterize the forces associated with the harvesting of strawberry than the pulling force itself.

Fig. 4 makes it clear for both *Akihime* and *Toyonoka* the force required to detach the berry from the stem clearly decreased as the angle of pull increased from 0 to 90 degrees for the three maturity levels considered. Although the difference in magnitudes of the average pulling forces for green, pink, and red maturity levels in *Akihime* variety is more distinct, particularly at the pulling angles of 0 and 45 degrees, than that in *Toyonoka*, both show a decreasing trend. However, there was no distinctly clear variation of pulling force with the three maturity levels for all the three pulling angles as can be seen from Fig. 5. This indicates that selective strawberry harvesting based upon a force differential between maturity levels is not probable for both *Akihime* and *Toyonoka* varieties. On the other hand, force-to-weight ratio decreased significantly as the strawberry matures (Fig. 6) and as the pulling angle increased (Fig. 7), for both varieties. This may be an indication that force-to-weight ratio could be a more useful selection factor in harvesting fresh strawberries mechanically.

Table 2. Correlation cofficients from regression analysis of pulling force with respect to fruit weight for three pulling angles and three maturity levels of *Akihime* and *Toyonoka* strawberries.

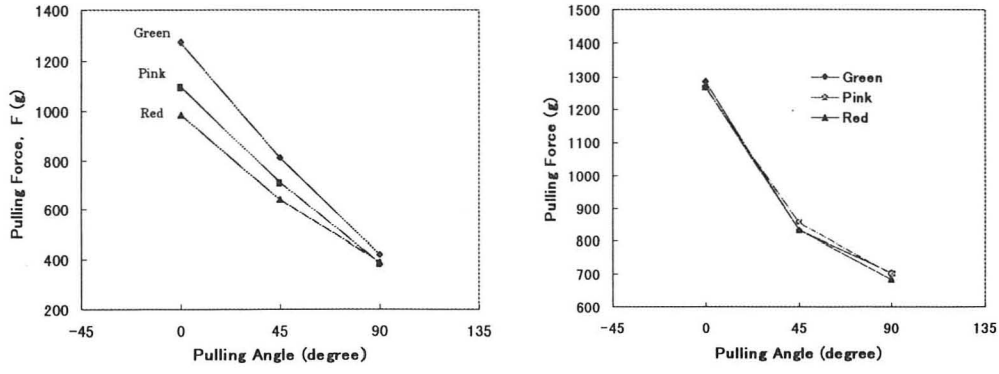
Maturity Level	*Akihime*			*Toyonoka*		
	0	45	90	0	45	90
Green	0.1105	0.1021	0.0005	0.1545	0.0009	0.1781
Pink	0.0659	0.0928	0.0898	0.5508	0.1984	0.0847
Red	0.2733	0.0202	0.0374	0.5279	0.1737	0.4084

Table 3. Correlation cofficients from regression analysis of pulling force with respect to fruit weight for three pulling angles and three maturity levels of *Akihime* and *Toyonoka* strawberries.

Maturity Level	*Akihime*			*Toyonoka*		
	0	45	90	0	45	90
Green	0.0870	3.69×10^{-6}	0.0293	0.2298	0.1109	0.0182
Pink	0.0593	0.0537	0.0491	0.3796	0.0530	0.0430
Red	0.4149	0.0329	0.0069	0.3276	0.0227	0.2795

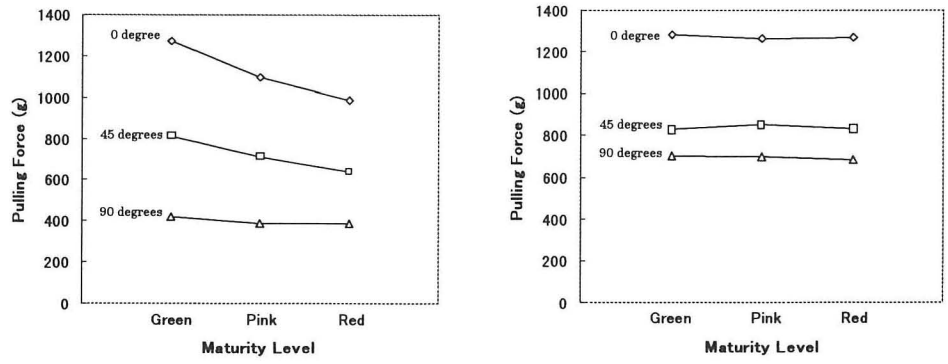
Table 4. Correlation cofficients from regression analysis of force-to-weight ratio with respect to fruit weight for three pulling angles and three maturity levels of *Akihime* and *Toyonoka* strawberries.

Maturity Level	*Akihime*			*Toyonoka*		
	0	45	90	0	45	90
Green	0.7037	0.2198	0.2943	0.6703	0.5609	0.4303
Pink	0.3666	0.1559	0.2892	0.6168	0.6669	0.6490
Red	0.3880	0.2352	0.1810	0.6409	0.5369	0.5904



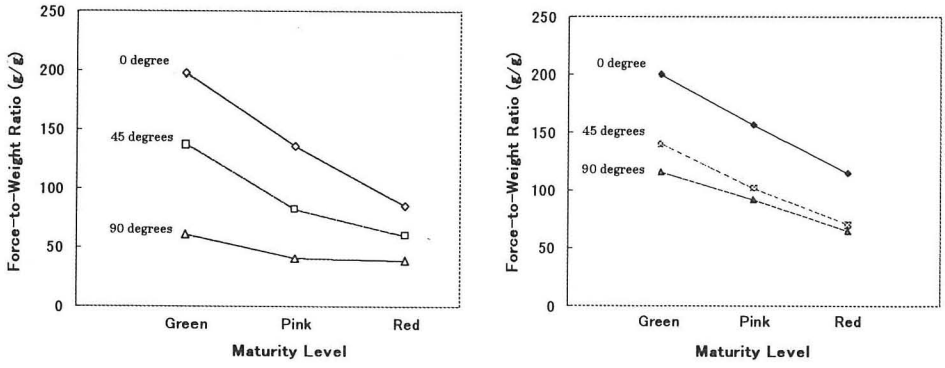
(*a*) *Akihime variety* (*b*) *Toyonoka variety*

Fig. 4. The average pulling forces for three maturity levels of *Akihime* and *Toyonoka* strawberries at three pulling angles.



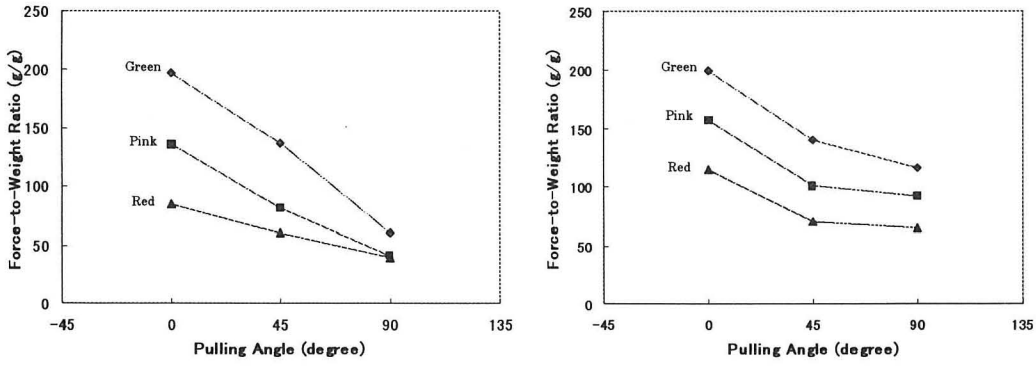
(*a*) *Akihime variety* (*b*) *Toyonoka variety*

Fig. 5. The average pulling forces for three maturity levels of *Akihime* and *Toyonoka* strawberries at three pulling angles.



(*a*) *Akihime variety* (*b*) *Toyonoka variety*

Fig. 6. The average force-to-weight ratio values for three maturity levels of *Akihime* and *Toyonoka* strawberries at three pulling angles.



(*a*) *Akihime variety* (*b*) *Toyonoka variety*

Fig. 7. The average force-to-weight ratio values for three maturity levels of *Akihime* and *Toyonoka* strawberries at three pulling angles.

Conclusion

For both *Akihime* and *Toyonoka* strawberries, there was no significant relationship either between pulling force and weight or between pulling force and stem diameter. However, as the pulling angle increased from 0 to 90 degrees, the force required to separate the berry from the stem decreased. This may have relevance on the optimization of future strawberry harvesting equipment. Furthermore, force-to-weight ratio decreased as the berry matures primarily because of the weight increase during the process of maturing. This parameter may prove to be a useful factor to be considered in the design of a strawberry harvesting system.

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イチゴ収穫における引張力について

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要　約

本研究は，イチゴ収穫時の物理的特性の基礎資料として，“あきひめ”と“とよのか”の2品種について，果柄と果実の引張力の計測および品種間の比較解析を行ったものである．

回帰分析の結果，両品種の引張力は，果重と果柄径との相関が低かったことより，引張力は果重や果柄径には関係ないことが分かった．一方，（引張力／果重）の比は，高い相関があった．イチゴの成熟度合が高くなると（引張力／果重）の比の値は，低くなった．この傾向は両品種とも同様であった．

果柄から果実を引き離す引張力は曲げ角度によって異なった．その角度が0度から90度へと大きくなるにつれて，引張力は減少することが分かった．しかし，同一角度による引張力は成熟度合に関係がなく，ほぼ同一の値であった．

以上より，イチゴの収穫の機械化機構の開発にあたっては，果実と果柄との曲げ角を大きく与えて，引っ張る作用力を加えることが合理的な摘採方法と考えられる．

キーワード：イチゴ，収穫，引張力，引張角度

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