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# Sugarcane Breeding of Early Maturing Clone with High Sucrose Content for Earlier Harvest in Japan

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## Abstract

Sugarcane production in Japan dropped to a record low of 1,186,000 tons in 2004. Severe drought and tropical storms (typhoons) often reduce sugarcane yields. In order to avoid these environmental stresses, an early harvest system and early maturing cultivars are required. The maturing characteristics of one early maturing clone ("KY96T-547") were thus investigated in breeding experiments to clarify effective methods of identifying early maturing clones. The results of spring planting crops in a regular breeding program and autumn planting crops intended for early harvest were also analyzed. Among the spring planting crops, the early maturing clone exhibited earlier increases in brix value at the top position of the stem, with higher orders of brix for this clone also being observed at the top. The coefficient of variance for the top brix among approximately 50 clones was higher than that for other stem positions. The coefficient of variance was higher at the beginning of October, when the brix values of early maturing clones increased. This is the best time for screening at the research site . Among the autumn planting crops, the early maturing clone matured October or November at the same level as in the regular harvest season.

**Discipline:** Plant breeding
**Additional key words:** Autumn harvest crop, brix, selection

## Introduction

The amount of sugarcane produced in Japan reached a record 3,257,000 tons in 1964,[10] and then subsequently decreased amidst a background of lower ratoon crop yield due to an infestation of wireworms (click beetle larvae) triggered by effective pesticides being banned under revised safety policies. Although the growing areas for sugarcane recovered about 80% of the maximum in the 1980s, sugarcane production did not recover as much. The summer planting of a single harvest crop that takes one and half years to harvest also helped to maintain less harvesting area. In the 1990s the areas for growing sugarcane began decreasing again and sugarcane production dropped to an all-time low of 1,186,000 tons in 2004.[10] Due to a shortage of milling materials, sugar mills face difficulties in terms of operation. The short milling period also interferes with each farmer's total yield per year. Famers consequently reduce the available area for growing sugarcane. The decrease in milling materials due to less growing area thus causes a negative chain reaction.

In order to overcome these serious conditions, the Japanese government initiated a movement to encourage sugarcane cultivation. Both national and local governments drew up action plans. Along with being provided with financial and engineering support, sugarcane growers are required to use fundamental growing techniques. Scientists also had to develop new technologies.

Sugarcane is generally planted in Japan during the summer or spring and then harvested in winter. Severe drought and tropical storms (typhoons) frequently occur from July to September. The "autumn harvest" (in October to November) was identified as having a higher and

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more stable yield under a severe climate. Any delays in planting and ratooning due to planting and harvest conflicts affect next season's harvest on a consistent basis. Small sugarcane plants are sensitive to drought. Typhoons often break sugarcane stem at the early growing period, however, they just cause lodging when plants are tall. The advantage of summer planting from July to September (i.e., higher and more stable yield under drought and typhoons conditions) and that of autumn harvest (i.e., better ratooning ability at early harvest) are both expected to be combined. And expanding the milling term to its earlier length also benefits the operating rates of mills and cane harvesters, and alleviates work conflicts among growers. The rather dry climate in November and December allows cane harvesters to work well, while winter season is typically rainy. Therefore, the breeding of early maturing cultivars ready for harvest two months earlier is required.

Maturing sugarcane increases the sucrose concentration in cane, the value of which correlates to juice brix.[15] There is also a high percentage of sucrose (i.e., juice purity) in matured sugarcane.[1] A high sucrose concentration, high brix, and high juice purity are typical characteristics of matured sugarcane.

The peak in sucrose content may sometimes determine sugarcane maturity.[7] As the sucrose content must be continuously measured in order to detect its peak, simple and easy indexes are needed for the breeding program.

Julien (1975) showed that field brix values measured from the sap of a standing stem by using a hand refractomater are good indicators of overall stem quality.[4] The mean value of brix measured from the top, middle, and bottom portions of a stem indicates the overall stem brix value. Nagatomi (1985) also reported that the brix value measured at the middle portion of a stem reflects the brix value of the whole stem.[9] Field brix values of convenient measurement are commonly used as a quality index.

The difference in brix values between the top and bottom portions of a stem is less in matured sugarcane than in immature sugarcane.[3, 9, 18] The top brix increases when sugarcane matures.[5, 19] Julian (1975) also indicated that the top brix in autumn is a good index of early maturity.[4] The top/bottom brix ratio also indicates maturity as previously reported.[18, 19] Thangavelu and Rao (2005) observed that the ratio increased according to the growing period, and that early maturing cultivars increased earlier.[18] Juice purity also clearly increases during the maturing process.[16, 19] Though juice purity can be an index of screening early maturing clones,[17] the complicated measurement process may be too inconvenient in breeding.

A more active approach for selecting clones was reported by Miyagi et al. (1997).[6] They grew sugarcane clones under hostile maturing conditions (i.e., in a well-irrigated paddy field, with clones of higher sucrose content being screened). This successfully produced a new early maturing cultivar ("Ni15") with a higher sucrose content.[7] However, special treatments causes extra troubles in breeding program.

In order to refine and optimize the methods of screening early maturing clones, an early maturing clone ("KY96T-547") was analyzed through a breeding program. The brix values in autumn at various stem locations were investigated to identify early maturing clones. The clone KY96T-547 is characterized by moderate cane yield and very high sugar content, and its harvest season is expected to begin two months earlier. The autumn harvest crop is also discussed in relation to maturity.

## Materials and methods

### 1.Third selection stage experiment

Conventional third stage selection in sugarcane breeding was conducted in 1998 using spring planting crops (planted in spring and harvested the following winter) at the NARO Kyushu Okinawa Agricultural Research Center's (NARO/KARC) Tanegashima station (N30° 43′, E131° 04′). This year's third stage selection was conducted using 250 clones that included KY96T-547 and commercial cultivars NiF3, NiF8, Ni12, F177, and NCo310 in two different types of soil fields. Black andosol is carbon-rich soil originating from volcano ash. Red andosol also originates from volcano ash, but has poor nutrients without a rich surface. Clones were planted on February 24 and brix was measured on November 16.

The experiments were conducted in a raw 3.3 $m^2$ plot with 110 cm of space between the rows and 15 cm of plant space with single bud cuts without replication. Fertilizers (N 70 kg $ha^{-1}$, $P_2O_5$ 120 kg $ha^{-1}$, and $K_2O$ 60 kg $ha^{-1}$) were applied as a basal dressing, with an additional dressing of N 90 kg $ha^{-1}$ and $K_2O$ 90 kg $ha^{-1}$ being applied from May to June. Carbosulfan (a pesticide) was applied to eradicate wireworms.

In November, the field brix values of stems were measured along trails. Measurements were taken from the middle point (about halfway between the top and bottom) and bottom point (just above ground). The mean value of six stems by position was then calculated in each plot.

### 2. Spring planting crop experiments

Field trials for selecting release candidates were conducted from 2000 to 2007 at KONARC's Tanegashima station using spring planting crops in the field of black andosol. The field trials involved both plant cane and ratoon crop. About 50 clones, including KY96T-547 and several commercial cultivars and other release candidate clones, were used as materials for the plant cane experiment; about 40 continued clones were used for the first ratoon crop in the following year.

The experiments were conducted in a 9.9 $m^2$ plot with 110 cm of space between the rows and 15 cm of plant space with single bud cuts, in a configuration of three rows in a completely randomized block design with three replications. The canes were planted at the beginning of March and harvested in January; therefore, the ratoon crop was started in January. Both the plant cane and ratoon crop were initially covered with clear plastic film to keep warm. Fertilizers (N 70 kg $ha^{-1}$, $P_2O_5$ 120 kg $ha^{-1}$, and $K_2O$ 60 kg $ha^{-1}$) were applied as a basal dressing, with an additional dressing of N 90 kg $ha^{-1}$ and $K_2O$ 90 kg $ha^{-1}$ being applied from May to June for the plant cane, and at the end of May for the ratoon crop. Carbosulfan (a pesticide) was applied to eradicate wireworms. Additional pesticides and herbicides registered for sugarcane cultivation were also occasionally applied.

In autumn, the field brix values of stems were measured in the trails. Measurements were taken from the top, middle and bottom points. The mean value of six stems was then calculated in each plot.

Plant canes were harvested in January; ratoon crops were harvested in December. Ten well-grown cane stems were selected from each plot and the cane qualities were measured. The cane was shredded and then a cylinder presser processed 500 g of well-mixed samples, so that the juice could be sampled. The juice was used for sucrose measurement.

The "Sucromat" automatic saccharimeter (Dr. Karnchen) was used to measure the sucrose concentration of the juice. Prior to measurement, 4 g of calcium hydroxide and 6 g of aluminium chloride 6 hydrate were added to 100 ml of juice, and then filtrated by a paper filter. An electro-fractomater (Atago RX-5000) was also used to measure the brix value of the juice. Juice purity was calculated as follows: "sucrose concentration / brix x 100"

### 3. Autumn harvest experiments

Standard cultivars and breeding materials for early harvest (including KY96T-547) were planted at the end of September 2006 as autumn planting crops in the field of black andosol. Plant density and plot size were the same as in the spring planting experiments. Two experiments were conducted for an October harvest and a November harvest in complete randomized block designs with three replications. The October harvest plots included NiF8 and five breeding clones; the November harvest plots included NiF8, Ni22, and three breeding clones. The plant canes were harvested in October and November 2007.

Fertilizers (N 70 kg $ha^{-1}$, $P_2O_5$ 120 kg $ha^{-1}$, and $K_2O$ 60 kg $ha^{-1}$) were applied as a basal dressing for all crops. An additional dressing of N 22.5 kg $ha^{-1}$ and $K_2O$ 22.5 kg $ha^{-1}$ was applied at end of May to the November harvesting crop. Other forms of management were the same as in the spring planting crop experiments.

The brix values of the field stands at the top, middle and bottom points were measured monthly from August until harvest. The cane qualities were measured the same way as in the spring planting crop experiments at harvest.

## Results

### 1. Third selection stage experiment

In order to determine the early maturing level of KY96T-547 and other standard cultivars at an earlier selection stage, the brix values observed among the third selection stage clones (as shown in Fig. 1) were compared with those of commercial clones NCo310, F177, NiF3, NiF8, and Ni12. Though the values were higher in canes grown in red andosol than those grown in black andosol, each clone showed the similar brix values in both types of soil. Most of the breeding clones did not qualify as commercial cultivars. The early maturing clone

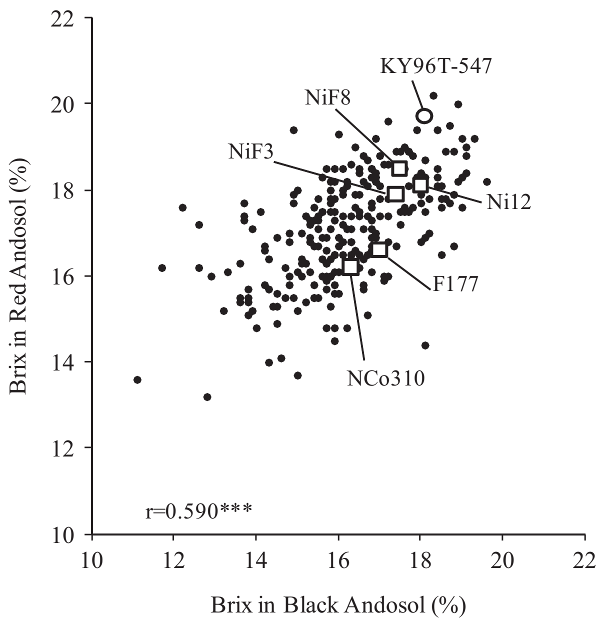


**Fig. 1. Distribution of the Brix values of the third selection stage clones in two different soil types**

**Table 1. The orders of extra early maturing clone"KY96T-547" in the autumn Brix at the different stem positions and top / bottom ratio among tested clones of spring p1anting crop and its ratoon crop**

| Crop / Year | Number of clones | Top Brix Avg. (%) | Top Brix KY96T-547 Brix (%) | Top Brix KY96T-547 Order | Middle Brix Avg. (%) | Middle Brix KY96T-547 Brix (%) | Middle Brix KY96T-547 Order | BottomBrix Avg. (%) | BottomBrix KY96T-547 Brix (%) | BottomBrix KY96T-547 Order | Stem average Avg. (%) | Stem average KY96T-547 Brix (%) | Stem average KY96T-547 Order | Top / Bottom ratio Avg. | Top / Bottom ratio KY96T-547 Ratio | Top / Bottom ratio KY96T-547 Order |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant cane | | | | | | | | | | | | | | | | |
| 2000 | 48 | 11.4 | 15.1 | 2 | 13.3 | 15.5 | 11 | 14.2 | 16.2 | 8 | 13.0 | 15.6 | 3 | 0.797 | 0.932 | 2 |
| 2001 | 48 | 10.9 | 13.4 | 4 | 14.9 | 17.1 | 5 | 15.6 | 17.6 | 4 | 13.8 | 16.0 | 4 | 0.699 | 0.761 | 9 |
| 2002 | 48 | 13.9 | 18.9 | 1 | 18.0 | 20.7 | 2 | 18.7 | 21.0 | 1 | 16.9 | 20.2 | 1 | 0.745 | 0.898 | 1 |
| 2003 | 46 | 10.0 | 12.5 | 1 | 12.6 | 14.8 | 1 | 14.5 | 16.7 | 1 | 12.4 | 14.7 | 1 | 0.689 | 0.749 | 4 |
| 2004 | 46 | 11.6 | 15.7 | 2 | 14.7 | 16.7 | 3 | 15.5 | 17.1 | 2 | 13.9 | 16.5 | 2 | 0.747 | 0.920 | 1 |
| 2005 | 48 | 8.4 | 11.0 | 2 | 13.4 | 14.5 | 12 | 14.9 | 15.4 | 19 | 12.2 | 13.6 | 6 | 0.560 | 0.712 | 2 |
| 2006 | 46 | 13.1 | 17.1 | 3 | 16.4 | 19.4 | 2 | 17.1 | 19.4 | 3 | 15.5 | 18.6 | 1 | 0.767 | 0.883 | 5 |
| 2007 | 49 | 9.3 | 13.1 | 1 | 14.5 | 16.9 | 3 | 16.5 | 18.1 | 5 | 13.4 | 16.0 | 2 | 0.567 | 0.723 | 2 |
| average | 47.4 | 11.1 | 14.6 | 2.0 | 14.7 | 17.0 | 4.9 | 15.9 | 17.7 | 5.4 | 13.9 | 16.4 | 2.5 | 0.696 | 0.822 | 3.3 |
| Ratoon crop | | | | | | | | | | | | | | | | |
| 2001 | 32 | 11.8 | 14.2 | 4 | 14.2 | 15.4 | 6 | 15.2 | 16.0 | 9 | 13.7 | 15.2 | 6 | 0.773 | 0.888 | 1 |
| 2002 | 32 | 13.0 | 15.3 | 5 | 17.4 | 18.4 | 7 | 18.4 | 19.0 | 9 | 16.3 | 17.6 | 6 | 0.706 | 0.805 | 4 |
| 2003 | 32 | 10.1 | 12.8 | 1 | 15.6 | 17.6 | 2 | 17.0 | 18.1 | 8 | 14.2 | 16.2 | 2 | 0.592 | 0.708 | 1 |
| 2004 | 36 | 11.8 | 13.4 | 2 | 14.0 | 15.6 | 2 | 15.1 | 16.2 | 6 | 13.7 | 15.1 | 2 | 0.782 | 0.827 | 8 |
| 2005 | 35 | 9.0 | 12.0 | 2 | 13.2 | 14.6 | 8 | 15.4 | 16.5 | 9 | 12.5 | 14.4 | 4 | 0.584 | 0.727 | 1 |
| 2006 | 36 | 10.5 | 9.7 | 10 | 15.1 | 14.0 | 16 | 16.6 | 16.4 | 13 | 14.1 | 13.3 | 15 | 0.631 | 0.590 | 8 |
| 2007 | 38 | 9.3 | 13.1 | 1 | 14.5 | 16.9 | 3 | 16.5 | 18.1 | 5 | 13.4 | 16.0 | 2 | 0.567 | 0.723 | 2 |
| average | 34.4 | 10.8 | 12.9 | 3.6 | 14.9 | 16.1 | 6.3 | 16.3 | 17.2 | 8.4 | 14.0 | 15.4 | 5.3 | 0.662 | 0.752 | 3.6 |

Note: Spring planting crop; March planting and January ratooning. The dates of measurements are written in Table 3.

**Table 2. Juice quality of major cultivars of spring planting crop and its ratoon crop**

| Crop / Clone name | Autumn Brix Top (%) | Autumn Brix Middle (%) | Autumn Brix Bottom (%) | Autumn Brix Average (%) | Cane juice quality at the harvest Brix (%) | Cane juice quality at the harvest Sucrose content (%) | Cane juice quality at the harvest Purity (%) |
|---|---|---|---|---|---|---|---|
| Plant cane | | | | | | | |
| NCo310 | 10.6 c | 13.4 bc | 14.5 bc | 12.8 cd | 16.8 c | 14.8 c | 87.8 d |
| F177 | 9.7 c | 12.2 c | 13.5 c | 11.8 d | 16.8 c | 14.9 c | 89.0 cd |
| NiF8 | 10.7 c | 14.4 b | 15.7 b | 13.6 c | 18.0 b | 16.3 b | 90.6 bc |
| Ni22 | 12.1 b | 16.1 a | 17.2 a | 15.1 b | 18.7 a | 17.2 a | 92.1 ab |
| KY96T-547 | 14.4 a | 16.9 a | 17.7 a | 16.3 a | 19.1 a | 17.6 a | 92.3 a |
| Ratoon crop | | | | | | | |
| NCo310 | 9.7 c | 13.0 b | 14.6 c | 12.4 c | 16.6 bc | 14.5 c | 87.4 bc |
| F177 | 9.2 c | 12.6 b | 14.0 c | 11.9 c | 16.1 c | 13.8 c | 86.2 c |
| NiF8 | 10.8 bc | 14.7 a | 16.1 b | 13.9 b | 17.7 ab | 15.7 b | 88.8 abc |
| Ni22 | 11.7 ab | 16.2 a | 17.8 ab | 15.2 ab | 18.5 a | 16.7 a | 89.7 ab |
| KY96T-547 | 13.2 a | 16.3 a | 17.3 a | 15.6 a | 18.5 a | 17.2 a | 90.7 a |

Note: Plant cane was planted in March and harvested in January. Ratoon crop was initiated in January and harvested in December. Average of 8years in plant cane and 7 years in ratoon crop were shown. The same characters indicate no difference in Tukey's test.

(KY96T-547) achieved a higher position than any of the cultivars.

**2. Spring planting crop experiments**

The spring planting crop experiments from 2000 to 2007 were conducted as part of a yield trial test in the breeding program. The results of KY96T-547 were analyzed to confirm the method of selecting early maturating clones. The clone KY96T-547 consistently showed a high brix value in autumn. Table 1 lists the rank of KY96T-547 in brix value among the tested clones. Ranking is an important index in selection. Table 3 lists the dates of measurements. This clone ranked higher than fifth at the top stem position, except for the ratoon crop in 2006, and slightly lower at the lower position (Table 1). In terms of stem average, KY96T-547 ranked lower compared to its ranking at the top position, because late maturing clones with higher brix at the lower position tend to rank higher in stem average. Table 1 also lists the top/bottom ratios. This clone also ranked higher in terms of top/bottom ratio. In the experiments, KY96T-547 had the highest average rank in top brix, and a generally higher average rank in terms of stem average brix, top/bottom ratio, and middle brix in plant canes. Regarding the ratoon crop KY96T-547 also had the highest average rank in top brix and top/bottom ratio. Therefore, the top brix was the best index for selecting such early maturing clones as KY96T-547.

Table 2 shows the juice quality of major cultivars and KY96T-547 in the spring planting crop and subsequent ratoon crop. In autumn, the brix value of Japanese standard cultivar NiF8 was higher than those of the old cultivars (NCo310 and F177). At harvest, the brix, juice sucrose content, and juice purity of NiF8 also tended to be higher than those of the old cultivars. The quality of standard cultivar NiF8 reached approximately 18% in brix, 16% in sucrose content, and 89 to 90% in purity. The brix value of Ni22—the earliest maturing released cultivar—was higher than that of NiF8 in autumn. The brix, juice sucrose content, and juice purity of Ni22 were higher than those of NiF8 at harvest. The top brix of KY96T-547 was higher than that of Ni22, whereas the middle and bottom parts did not differ significantly. The brix, juice sucrose content, and juice purity of KY96T-547 recorded the highest values in all quality indexes. The clone KY96T-547 showed the best quality among these

**Table 3. Coefficient of variances of the autumn Brix in different stem positions and top / bottom ratio among tested clones of spring planting crop and its ratoon crop**

| Crop / Year | Date | Stem position Top (%) | Middle (%) | Bottom (%) | Average (%) | Top / Bottom ratio (%) |
|---|---|---|---|---|---|---|
| Plant cane | | | | | | |
| 2000 | 4-Oct | 17.6 | 15.4 | 12.8 | 14.6 | 9.5 |
| 2001 | 15-Oct | 17.4 | 10.3 | 8.1 | 10.1 | 13.7 |
| 2002 | 15-Oct | 11.5 | 7.3 | 5.5 | 7.0 | 9.3 |
| 2003 | 30-Sep | 8.3 | 8.8 | 7.7 | 7.8 | 5.6 |
| 2004 | 26-Oct | 13.3 | 7.9 | 6.5 | 8.0 | 10.6 |
| 2005 | 4-Oct | 18.1 | 10.2 | 8.6 | 10.0 | 15.7 |
| 2006 | 19-Oct | 14.8 | 10.4 | 8.5 | 10.4 | 9.2 |
| 2007 | 2-Oct | 15.0 | 14.4 | 9.1 | 11.2 | 12.0 |
| average | | 14.5 | 10.6 | 8.3 | 9.9 | 10.7 |
| Ratoon crop | | | | | | |
| 2001 | 11-Oct | 15.1 | 10.6 | 9.1 | 10.9 | 9.2 |
| 2002 | 15-Oct | 14.3 | 7.7 | 5.5 | 7.6 | 12.4 |
| 2003 | 29-Sep | 11.5 | 8.9 | 8.4 | 8.6 | 8.5 |
| 2004 | 25-Oct | 8.5 | 6.3 | 6.2 | 6.2 | 7.1 |
| 2005 | 28-Sep | 18.3 | 11.4 | 9.3 | 11.2 | 14.4 |
| 2006 | 28-Sep | 15.1 | 12.2 | 9.0 | 11.1 | 10.1 |
| 2007 | 3-Oct | 16.4 | 11.3 | 8.2 | 10.0 | 14.5 |
| average | | 14.2 | 9.8 | 7.9 | 9.4 | 10.9 |

Note: Spring planting crop; March planting and January ratooning. Number of clones are shown in Table 1.

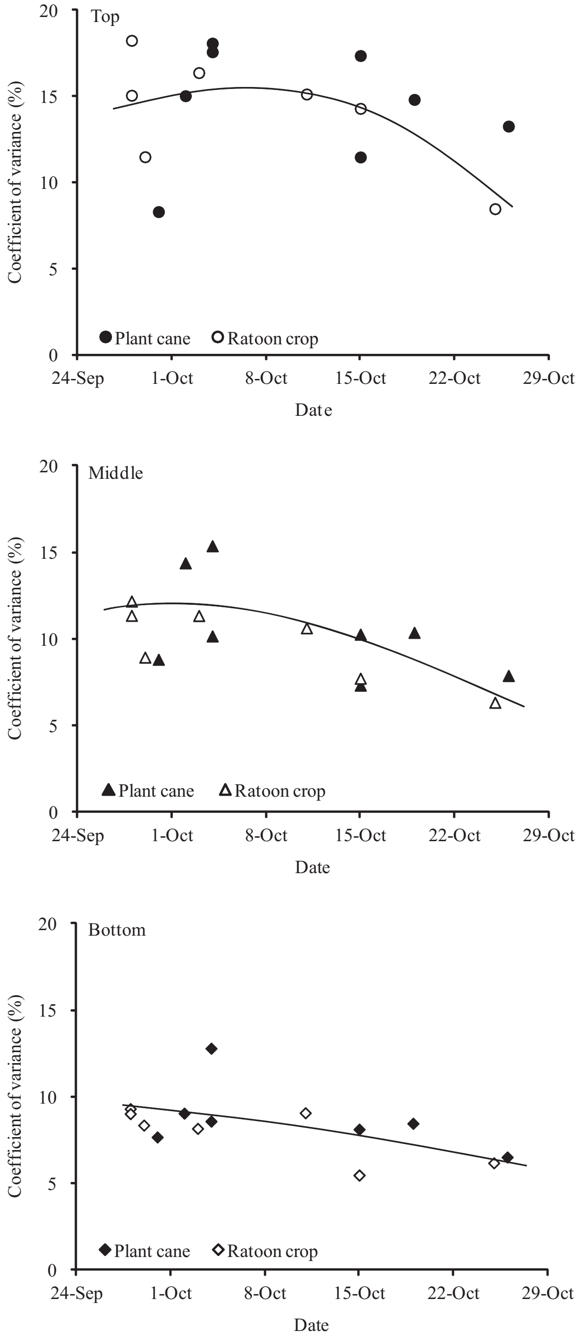


**Fig. 2. Relationships between measuring dates and the coefficient of variance of the autumn brix at different part of the stem position through 2000 to 2007**

cultivars.

Table 3 lists the coefficient of variance of brix value at the different positions in autumn. This value indicates the brix variation among clones. Here, the greater the value, the more reliable the selection. The coefficient of variance for the top position was greater than that for the other positions, and smallest for the bottom position.

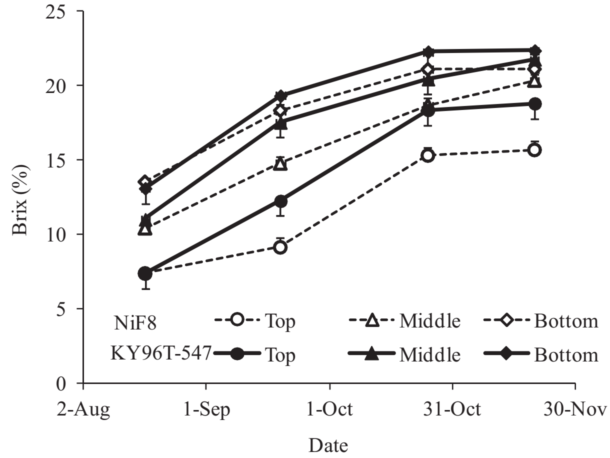


**Fig. 3. Changes in Brix at different positions for NiF8 and KY96T-547 of autumn planting crop harvested in November**

These coefficients for the top/bottom ratio were at the same level as for the middle position. The top brix had greater variation compared to other indexes.

Figure 2 shows the relation between the measuring date and the coefficient of variance for brix, in order to identify the optimum screening season. The coefficient of variance for the top brix tended to increase before October and decline after mid-October. These coefficients for the middle part varied at the beginning and tended to decline in late October. Those for the bottom part tended to decline throughout the season. The optimum screening season was thus determined to be early October when the indexes showed wide-ranging variation at the top.

### 3. Autumn harvest experiments

In the autumn harvest experiment, several clones were applied and compared at two different harvest times. Figure 3 shows the changes in brix value of NiF8 and KY96T-547 of the November harvest crop, in order to compare typical patterns of maturation. In August, the brix values of both clones were at the same level at each stem position. The brix values increased rapidly from August to October, and then slowly increased during October and November. The rate of increase for KY96T-547 was higher than that for NiF8 and KY96T-547 reached a higher brix value. Particularly in September, KY96T-547 showed obviously higher rates of increase for the top and middle positions than those of NiF8.

Table 4 lists the cane qualities of the autumn harvest crops. The quality of standard cultivar NiF8 did not reach the spring planting crop level (i.e., juice sucrose content of 16%). However, several breeding clones reached a juice sucrose content exceeding 16% at autumn harvest.

For the crop harvested in October, the brix of standard cultivar NiF8 was lower than that of other clones. The highest quality was observed in KY96T-547 that contained approximately 17.9% sucrose and 88.1% purity. This clone also showed the highest value of top brix. Categorized as extra early maturing clone, KTn94-88 also showed a higher top brix, higher sucrose concentration, and higher juice purity than the other clones. For the crop harvested in November, the brix of KY96T-547 and Ni22 were higher than that of NiF8. Those values of the other clones were mostly less than that of NiF8. The highest quality was observed in KY96T-547 with 17.6% sucrose and 88.0% purity. This clone also showed the highest top brix value. Throughout the two harvest experiments, KY96T-547 reached sufficient quality for milling as compared to the spring planting crop.

## Discussion

Early maturing cultivars are expected to produce a high and stable quality of cane for milling, and hopefully expand the harvest season. An earlier harvest is expected to result in a higher yield in next year's crops by extending the subsequent growing periods. However, an earlier harvest itself shortens the first growing period and reduces yield in the spring planting crop cycle. In particular, low sugar content is a severe problem in sugar mills.

In order to increase yield and quality, Ouchiyama et al. (1958) investigated autumn planting in Japan.[11] Autumn planting is generally categorized as late-term summer planting. Ouchiyama et al. indicated that autumn crops result in higher yield and better quality than spring crops. A longer growing period generally produces a higher yield and better quality.[12, 13]

Although an earlier harvest, such as in November, has yet to be introduced in Japan, the results of this study showed that the quality of sugarcane harvested in October and November reached the same level as in the regular harvest season (Table 4). In autumn (October), the brix level of spring planting crops did not reach a sufficient level for harvest (Table 2), while the autumn planting crop quality afforded by the extra early maturing clone was sufficient for milling (Table 4). Srinivasan (1989) obtained a similar result, where the crop of an early maturity cultivar with high sucrose content planted in India in August reached a very high level of quality in October.[12]

Early maturing clones with high sucrose content are generally developed in a regular breeding program. For example, brix values measured in autumn are regularly used in consideration of breeding at Japanese breeding stations.[14] In the third selection stage, clones are grown in two different types of soil. Even though clones showed the same tendency in different soils, the reappearance of brix has certain latitude. It is thus better to evaluate in several different environments.

From the results of this study, an early maturing clone having the top brix typically increases earlier and

**Table 4. Juice quality of autumn planting crop at harvest in October and November**

| Crop / Clone name | Field Brix in stem position: Top (%) | Middle (%) | Bottom (%) | Average (%) | Cane juice quality at the harvest: Brix (%) | Sucrose (%) | Purity (%) |
|---|---|---|---|---|---|---|---|
| Autumn planting crop October harvest | | | | | | | |
| NiF8 | 14.0 b | 20.4 b | 21.3 b | 18.5 c | 17.5 cd | 14.9 bc | 85.1 bc |
| KTn94-88 | 18.3 a | 23.1 a | 22.7 a | 21.4 ab | 20.2 ab | 17.7 a | 87.2 a |
| KY96T-547 | 19.3 a | 23.1 a | 23.3 a | 21.9 a | 20.3 a | 17.9 a | 88.1 a |
| KY99-85 | 17.9 a | 22.8 a | 22.7 a | 21.1 ab | 20.3 ab | 17.6 a | 86.9 ab |
| KY99-132 | 14.3 b | 22.1 ab | 22.1 ab | 19.5 bc | 18.8 bc | 15.9 b | 84.5 c |
| KY99-138 | 13.6 b | 20.3 b | 21.5 b | 18.5 c | 16.8 d | 14.1 c | 84.2 c |
| Autumn planting crop November harvest | | | | | | | |
| NiF8 | 15.7 b | 20.3 a | 21.1 ab | 20.1 ab | 18.0 b | 15.1 bc | 84.2 b |
| Ni22 | 17.2 ab | 21.3 a | 22.2 a | 20.2 ab | 19.0 ab | 16.5 ab | 86.9 a |
| KY96T-547 | 18.8 a | 21.8 a | 22.3 a | 21.0 a | 20.0 a | 17.6 a | 88.0 a |
| KY98-1002 | 16.8 ab | 20.3 a | 19.7 bc | 18.9 bc | 18.2 b | 15.4 b | 84.3 b |
| KY99-81 | 15.7 b | 18.3 b | 18.9 c | 17.6 c | 16.3 c | 13.6 c | 82.9 b |

Note: The same characters indicate no difference in Tukey's test.

reaches a higher level, as compared to later maturing clones (Tables 2 and 4). The order of brix measured at different stem positions clearly showed this tendency. The brix of KY96T-547 ranked higher at the top position and slightly lower at the lower positions. Though this clone ranked higher at the middle position or in terms of stem average, the top brix is obviously a better index than the others. In terms of brix variation, the top brix showing the largest coefficient of variance is considered the best index.

The coefficient variance for the top brix increased in September and decreased after mid-October. The best time for taking measurements at this research site is in early October, when the top brix has a larger coefficient of variance. However, strong selection pressure in the earlier selection stage may be harmful due to variable levels of maturity. To secure early maturing clones at the earlier selection stage, relatively later evaluation may yield good results.

The coefficient of variance for brix at the middle and bottom positions did not increase in autumn (Fig. 2). The brix of NiF8 and KY96T-547 at the bottom positions increased similarly from August to November in the autumn planting crop (Fig. 3). These results imply that brix at the bottom position increased similarly in most of the clones, and that the range of variation did not change. In contrast, the brix of KY96T-547 at the top position increased significantly before October in the autumn planted crop (Fig. 3). At the top position, the brix of early maturing clones increased rapidly compared to those of late maturing clones, and the range of variation increased significantly in this phase. When brix at the top position increased in most of the clones, the coefficient of variance decreased. Although early October is considered the best time for screening in this study, the time when the top brix of early maturing clones increases and that of late maturing clones remains stable must therefore be the general screening season anywhere.

The order of top/bottom ratio also ranked higher for KY96T-547 (Table 1). The result supports the theory that the ratio adapts to maturing indexes. However, the clone's rank in top/bottom ratio was slightly lower than its top brix rank. The ratio may be a good indicator of maturity level.

The higher rank of the top brix of KY96T-547 may reflect this clone's higher sucrose content characteristics in the whole stem. Most early maturing cultivars have high sucrose content characteristics.[14] For early maturing breeding purposes, the top brix is a better index than the top/bottom ratio. However, the early maturing characteristics and high sucrose characteristics must be separated for physiological considerations.[19] Some late maturing cultivars have reportedly reached a high level of sucrose content.[14] These cultivars accumulate sucrose very slowly, particularly at the top position. To detect high sucrose content ability apart from maturity, brix at the bottom must be targeted. The physiological basis of both early maturity and high sucrose characteristics must be investigated for more efficient breeding.

A top brix value in October can be an index of early maturity at the experimental site for developing early maturing cultivars. However, in a breeding program, breeders must handle thousands of clones that belong to different selection stages. In order to gradually increase selection pressure according to the selection stage in a breeding program, the clones in an earlier selection stage can be evaluated after the optimum period. It would be ideal to initiate brix measurement operations in the optimum period with oldest generation clones in the last selection stage, and complete measurements with the youngest generation clones in a season.

In 2010, sugarcane production in Japan recovered to about 1,469,000 tons under the movement to promote sugarcane cultivation. Along with this increased sugarcane production, a method of disrupting the mating of wireworms using pheromone was established,[2] and an effective bait-type pesticide containing fipronil to eradicate wireworms was developed. In response to the availability of more milling materials, the milling term can be started even earlier. Early maturing cultivars such as Ni15 and Ni22 are now popular among both growers and mills. New cultivars such as Ni28 and Ni29 are also ready for use. Avoiding severe drought and tropical storms using early maturing cultivars, and providing cane protection against wireworms may result in higher yields. And higher yields will serve as a stimulus for the expansion of growing areas. Sufficient canes enable earlier harvest through an expanded milling term. Therefore, the development of earlier maturing cultivars is essential.

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