Internode Characteristics of Sweet Sorghum (*Sorghum bicolor* (L.) Moench) during Dry and Rainy Seasons in Indonesia

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Abstract: We have studied establishment of cultivation technique of sweet sorghum for monosodium glutamate (MSG) production on dry land in Indonesia, where the supply of raw materials has become restrictive recently. Previously, we confirmed the feasibility of cultivation in this area during the rainy season. Meanwhile, cultivation during the dry season is also important because vast expanses of heretofore unirrigated fields have remained unused. The stem, which comprises internodes, is the main product of sweet sorghum used as a raw material by fermentation industries. This study analyzes differences in growth and yielding ability between dry and rainy seasons by comparing internode characteristics. A sweet sorghum cultivar – Wray – was cultivated in the rainy season from 1995 and in the dry season of 1996 in Madura Island of East Java, Indonesia. Stems of sweet sorghum cultivated during the dry season were shorter and lighter, with two fewer elongated internodes than those of plants raised during the rainy season. They accumulated sugar slower and to a lower peak, but they were inferred to be harvestable for a relatively long period during 30–60 days after anthesis. Through research of internode characteristics, the difference in stem length was inferred to result from differences in internode numbers (25%) and in individual internode length (75%). The difference in weight seemed to result mainly from the fewer elongated internodes. Further experiments must explore the cultivation period (sowing and ratoon crop), varieties, and planting density to establish a sweet-sorghum cultivation technique that is suitable for the dry season.

Key words: Dry land, Dry season, Growth, Indonesia, Internode, Monosodium glutamate, Rainy season, Sweet sorghum.

In East Java, Indonesia, monosodium glutamate (MSG) has been produced commercially mainly from cane molasses, a by-product of sugar cane. Recently, use of irrigable land for rice cultivation has been promoted and sugar cane production has decreased because of the increased production of rice to feed Indonesia’s growing population. Consequently, it has become difficult for MSG-producing companies to secure their raw material from East Java. Sweet sorghum (*Sorghum bicolor* (L.) Moench) accumulates high content of sugar in its stem and has strong drought tolerance. It is a promising crop as a raw material for fermentation industries in unirrigable dry lands where sugar cane cultivation is difficult (Tsuchihashi and Goto, 2004).

Sweet sorghum has been well studied in the United States (Jackson et al., 1980), Japan (Hoshikawa et al., 1988; Inoue, 1988) and other countries. Nevertheless, it has not been cultivated commercially on a large scale. In Indonesia, sweet sorghum has been studied mainly by the Indonesian Sugar Research Institute since its introduction there in the 1980s (Sumantri and Purnomo, 1997). Notwithstanding, little is known regarding growth of sweet sorghum on tropical dry land. Therefore, basic research regarding growth characteristics must be conducted to facilitate large-scale commercial cultivation.

In the Savanna area, so-called semi-arid tropics, a year consists of a dry season and a rainy season. Previously, we conducted field experiments in the Savanna area in Indonesia during the rainy season focusing mainly on growth and yield. Our studies confirmed that sweet sorghum was cultivatable in the rainy season. Simultaneously, we determined the optimum harvesting time from aspects of sugar and grain production (Tsuchihashi and Goto, 2004). The sweet sorghum stems, containing high concentrations of sugar, are the most important product for use as a raw material for fermentation in MSG factories. Considering the operating efficiency of MSG factories, sweet sorghum would ideally be harvestable throughout the year, but it was reported that stem length and stem diameter are affected by the amount of irrigation (Salih et al., 1999). The
sweet sorghum stem consists of internodes, similarly to other gramineous crops. Nakamura et al. (1995, 1998) reported that cultivation conditions such as planting density and fertilization amount had affected the stem length and stem weight by affecting characteristics of internodes. For this reason, the difference in internodes probably accounts for the difference in stem and sugar yield between dry and rainy seasons. This study specifically addresses internode characteristics of sweet sorghum and explores the different yields by comparing cultivation in dry and rainy seasons in 1995 and 1996.

Concerning internode characteristics of sweet sorghum, Nakamura et al. (1994, 1995, 1997a, 1997b, 1998) and Goto et al. (1994, 1995) conducted a series of fruitful studies in Japan. Nevertheless, none reported cases of the tropics, which have totally different climate conditions from Japan. Though Salih et al. (1999) reported about the relation between water (irrigation) amount and stem characteristics, no reports have explored the relation between the water amount and characteristics of individual internodes. The present study is intended to obtain basic knowledge to develop cultivation techniques through exploration of internode characteristics in the dry season.

Materials and Methods

The sweet sorghum cultivar, Wray (introduced from South Africa to the United States, Salunkhe and Desai, 1988), was used for field testing on Madura Island (7° S, 113° E) in East Java, Indonesia.

A year in this area is divisible into two seasons: 1. a rainy season (from October or November until March or April); and 2. a dry season (from April or May to September or October). Seeds were sown on 7 April in 1996 to cultivate sweet sorghum during the dry season. As a control, seeds were also sown on 24 October in 1995 (rainy season). The soil type of the field was Luvisol of FAO classification (or Alfisol of USDA soil taxonomy). The seedlings were thinned out to stand alone at each point in the plants’ spacing of 0.75 m between rows and 0.1 m within rows (13.3 plants m⁻²).

The field was designed for three replications of 10 m × 15 m (150 m²) each. Each replication contained four growth research plots (20 plants × 4 rows) and 16 sampling plots (20 plants × 4 rows). Fertilizer totaling to 11.8 g m⁻² N, 9.2 g m⁻² P₂O₅, and 12.3 g m⁻² K₂O was used in three applications: before sowing, 14 days after sowing (DAS), and 30 DAS. Fungicides (Dithane) and insecticides (Carbofuran and Thiodane) were applied several times to control pests and diseases.

Stem length and basal stem diameter (including leaf sheath) of 20 marked plants from four growth research plots (5 plants × 4 plots) were measured for each replication in every week from 1 week after sowing until 15 weeks after sowing. Stem lengths were measured as the height to the neck node of the ear, or as the height to the collar of the highest leaf before heading. Basal stem diameter was measured at 10–15 cm from the base including the leaf sheath. At 15 weeks after sowing, these above-mentioned 20 plants from growth research plots per replication were harvested and then divided into individual internodes. Internodes of longer than 1 cm were treated as elongated internodes. They were measured for length, diameter and weight. Internode volume was also calculated from the length and diameter of internode as a cylinder solid.

From 8 weeks after sowing and thereafter, 20 plants were harvested from the center part of (10 plants × 2 rows) a new sampling plot every week for three replications. After measuring the stem weight, extracted juice from the stems was weighed using a three-roller machine miller without imbibition water. In addition, total sugar (Lane and Eynon, 1923; 1925) and brix were examined using a refractometer. The juice extraction ratio was calculated dividing the stem juice weight by stem weight. Sugar weight was
calculated by multiplying the juice weight by the total sugar content. At 15 weeks after sowing, 20 plants from the center part (10 plants × 2 rows) of a new sampling plot were harvested from each replication to measure single-stem weight and the single-stem sugar.

**Results and Discussion**

1. **Climate and Growth**

Fig. 1 shows the monthly mean temperature and monthly precipitation on Madura Island during cultivation from 1995 to 1996. The average of monthly precipitation was 75 mm in dry season and 340 mm in rainy season. The monthly average temperature of 32.7°C in dry season was 4.0°C higher than 28.7°C in rainy season. Considering the respective differences in precipitation and temperature, the precipitation might be the major factor to cause the seasonal differences of sorghum growth.

Fig. 2 shows stem length growth. The stem length in the dry season increased gradually until 35 DAS; it then increased rapidly at almost the same rate as that in the rainy season until 70 DAS. Nevertheless, stem of the plants in the dry season thereafter ceased elongation. The final stem length in the dry season (ca. 300 cm) was shorter than that in the rainy season (ca. 360 cm). Dalianis et al. (1992) conducted irrigation tests in field conditions and reported that plants with little irrigation (300 mm) were shorter than those with more irrigation (600 mm). Shorter stem length likely results from less rainfall during the dry season.

Fig. 3 shows changes in basal stem diameter. Different tendencies were shown depending upon the precipitation amount. Basal stem diameter reached a maximum height at 50 DAS in the dry season, later than that (35 DAS) in the rainy season. Basal stem diameter at 50 DAS was 14.5 mm in the dry season and 74.5% of that in the rainy season. Salih et al. (1999) conducted field tests of sweet sorghum with irrigation totaling 700 mm and 300 mm by 50 mm in 5-day and 12-day intervals; they reported morphological differences in vascular bundles, etc. The total precipitation during the growth period of this experiment was 260 mm in the dry season and 1,190 mm in the rainy season, suggesting that different interior morphological characteristics were discernible.
between the two conditions. Previously we reported that the sweet sorghum stem thickens initially, then rapidly elongates in the rainy season (Tsuchihashi and Goto, 2004). In contrast, stems in the dry season thickened at a more moderate rate than those in the rainy season. They also elongated during thickening. In other words, the basal stem continued thickening during stem elongation. Sweet sorghum grown in the dry season reached heading at 57 days after sowing (DAS) and anthesis at 63 DAS, earlier than that grown in the rainy season at 66 DAS and at 73 DAS.

Fig. 4 shows changes in overall sugar weight in the stem. Sugar weight increased linearly from immediately before anthesis and reached 20–30 g plant\(^{-1}\) at 30–40 days after anthesis (DAA; 0 DAA=63 DAS) in the dry season. Subsequently it became stable until ca. 60 DAA. In contrast, in plants grown in the rainy season, sugar weight reached its maximum value of 50 g plant\(^{-1}\) at 40 DAA, declining gradually thereafter. Sugar weight reached a higher value at its maximum compared to our last report (Tsuchihashi and Goto, 2004), but the tendency seemed quite similar. This fact indicated that the optimum harvest time was 30–40 DAA, and that the sugar yield might be decreased after 40 DAA because of declining sugar weight. On the other hand, sweet sorghum was inferred to be harvestable over a relatively long duration of 30–60 DAA in the dry season.

2. **Internode Characteristics**

Table 1 shows the stem length, basal stem diameter and number of elongated internodes of sweet sorghum cultivar Wray at 105 days after sowing in Indonesia.

| Cropping season | Stem length (cm) | Basal stem diameter (mm) | Number of elongated internodes (>1 cm) |
|-----------------|------------------|--------------------------|---------------------------------------|
| Dry season      | 279 ± 4          | 17.5 ± 0.4               | 12.0 ± 0.3                            |
| Rainy season    | 360 ± 4          | 19.6 ± 0.4               | 14.1 ± 0.2                            |

Data are represented as means ± standard deviations (n=60).

*** 0.1% level of significance by t-test.

Table 2. Stem weight and sugar related parameters in one stem of sweet sorghum cultivar Wray at 105 days after sowing in Indonesia.

| Cropping season | Single stem weight (g stem\(^{-1}\)) | Juice extraction ratio (%) | Extracted juice Brix | Extracted juice Total sugar (%) | Single stem sugar Single stem sugar (g stem\(^{-1}\)) |
|-----------------|--------------------------------------|---------------------------|----------------------|---------------------------------|---------------------------------------------------|
| Dry season      | 346 ± 54                             | 57.7 ± 2.0                | 13.4 ± 1.5           | 12.3 ± 1.1                      | 24.3 ± 3.6                                        |
| Rainy season    | 451 ± 1                              | 55.5 ± 0.9                | 15.6 ± 0.3           | 14.0 ± 0.5                      | 35.0 ± 1.8                                        |

* Juice extraction ratio, Brix, and total sugar content are data from 20 samples.

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2. **Internode Characteristics**

Table 1 shows the stem length, basal stem diameter and number of internodes at 15 weeks after sowing. All plant characteristics addressed herein showed smaller values for plants cultivated in the dry season than those cultivated in the rainy season. The number of elongated internodes was two internodes smaller (dry, 12.0; wet, 14.1 in average). Table 2 portrays the single stem weight, juice extraction ratio from stems, juice quality, and single-stem sugar weight. In the dry season, single-stem stem weight was 76.7% and the sugar weight was 69.4% that of plants cultivated in the rainy season. Dalainis et al. (1992) reported shorter stems and lighter stem weight obtained by cultivation with less irrigation. We confirmed similar results and confirmed the decrease of internode number, suggesting that the smaller internode number was one attribute of shorter stems resulting from less precipitation.
Fig. 5 shows the distribution of plants for each internode number. As respectively representative plants of dry and rainy seasons, we used plants with 12 elongated internodes (12-INs) and those with 14 elongated internodes (14-INs). Plants with the same number of elongated internodes (14-INs) in the dry season were also used to compare internode characteristics.

Fig. 6–8 show the length, diameter and fresh weight of 12-INs and 14-INs in the dry season, and 14-INs in the rainy season. The number of internodes of plants cultivated in the dry season was two internodes smaller than that in the rainy season (Table 1). The length of the neck internode was the longest among all internode positions in both seasons (Fig. 6). Stem lengths of 12-INs and 14-INs in the dry season were almost identical from the first elongated internode from the base (IP-1) to the tenth elongated internode (IP-10). The top two elongated internodes of 12-INs (IP-11 and IP-12) were longer than those in 14-INs (IP-13 and IP-14). Comparison of 14-INs for dry and the rainy season revealed that the elongated internodes were shorter in the dry season than those in the rainy season for all internode positions.

The sum of elongated internode lengths (Table 3) of 14-INs was 60 cm shorter in the dry season (307 cm) than in the rainy season (367 cm). In the dry season, the sum of 12-INs (288 cm) was ca. 20 cm shorter than that of 14-INs. Regarding components of that stem length differential of ca. 80 cm between dry and rainy seasons (Table 1), ca. 20 cm (25%) was attributable to a decreased number of elongated internodes, and ca. 60 cm (75%) was attributable to the shorter lengths of respective elongated internodes. Nakamura et al. (1997b) reported that the number of elongated internodes did not greatly affect the stem length. That study compared internode lengths of plants with a different number of elongated internodes under identical conditions. The experiment showed that the contribution ratio of the effect of elongated internode number on the stem length was 25%. Furthermore, the number of elongated internodes can affect the stem length depending upon conditions.
The diameters of elongated internodes (Fig. 7) tended to become smaller acropetally under both conditions. In the dry season, the diameter of 14-INs was thicker than that of 12-INs in basal 10 elongated internodes and two elongated internodes from the top. Diameters of 14-INs in the dry season were thicker in eight elongated internodes from IP-1 to IP-8, but were thinner in IP-10 and above than those of 14-INs in the rainy season. Comparison of plants with average numbers of elongated internodes, that is 12-INs in the dry season and 14-INs in the rainy season, revealed that the diameter was less in basal 10 elongated internodes and two elongated internodes from the top of 12-INs in the dry season than those of 14-INs in the rainy season. Consequently, the basal stem diameter would be most probably, on average, thinner in the dry season than in the rainy season.

Fig. 8 shows the fresh weight of elongated internodes. The fresh weight was greatest in IP-3 or IP-4 and tended to become lighter basipetally. Under the dry season, the fresh weight of 14-INs was heavier in basal ten elongated internodes and two elongated internodes from the top than that of 12-INs. Fresh weights of 14-INs in the dry season were heavier in six elongated internodes from IP-3 to IP-8. However, they were lighter in two elongated internodes from the base and for positions at and above IP-9 than that of 14-INs in the rainy season.

The sum of elongated internode fresh weights (Table 3) of 14-INs was almost identical in the dry season (691 g) and in the rainy season (685 g), whereas that of 12-INs in the dry season (472 g) was 68.3% of that of 14-INs in the dry season. These results suggest that the difference of stem weight resulted mainly from the decrease in the number of elongated internodes.

Fig. 9 shows the calculated volume of elongated internodes of 12-INs and 14-INs in the dry season and 14-INs in the rainy season. In the dry season, the volume of 14-INs was greater in basal 10 elongated internodes and two elongated internodes from the top than that of 12-INs. Volumes of 14-INs in the dry season were greater in five elongated internodes from IP-4 to IP-8, but were smaller in two elongated internodes from the base and in the position at and above IP-9 than that of 14-INs in the rainy season. This measurement showed an almost identical tendency to that of fresh weight.

The sum of elongated internode volumes (Table 3) of 14-INs was smaller for plants of the dry season (550 cm³) than for those of the rainy season (566 cm³), whereas that of 12-INs in the dry season (418 cm³) was ca. 80% of that of 14-INs in the dry season. A smaller difference was seen than in the case of fresh weight. Consequently, we inferred that the dry season have a greater effect on stem weight than on the plant’s appearance, e.g. stem volume.

3. Conclusions

This experiment showed that the single-stem weight and single-stem sugar weight of sweet sorghum were lighter in the dry season than in the rainy season. Whereas Slunkhe et al. (1988) reported that the juice extraction ratio of a stem of sweet sorghum typically declines after a long period of storage, it is not
efficient to store stems for months. If economically sustainable cultivation of sweet sorghum were possible during the dry season, factories of fermentation industries could operate over a longer period, and land utilization ratio of unirrigated fields during dry season could be enhanced. The difference of growth and yield between cultivation during dry and rainy seasons must be clarified to achieve high yields of sweet sorghum cultivated during the dry season. Results of this experiment indicated that sweet sorghum is harvestable over a relatively long duration of 30–60 DAA in the dry season. This experiment also suggested that sweet sorghum cultivated in the dry season has smaller and fewer elongated internodes, engendering a lower stem weight.

The growth and yield of cultivated plants of the dry season are also thought to vary depending on the sowing date or cultivation period. Further experiments should explore the influence of the sowing date within the dry season. In addition to cultivation by sowing, raton cropping is possible for sweet sorghum. Optimal cultivation of sweet sorghum throughout the year could be arranged using a combination of a seed crop and a raton crop. Different varieties of high drought-resistance and high yield (stem and sugar) can be tested to assess their performance during the dry season. Field experiments must be continued regarding, e.g. high plant density in the dry season to secure a stem number that provides a high yield of sweet sorghum cultivated during the dry season.

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References

Dalianis, C., Christou, M., Sooter, C., Kyritsis, S., Zafiris, C. and Samiotakis, G. 1992. Effect of irrigation and nitrogen fertilization rates on growth and productivity of sweet sorghum. In Biomass for Energy and Industry. Proceedings of the 7th International E.C. Conference Held in Florence, Italy. 1220-1228.

Goto, Y., Nakamura, S., Sakai, K. and Hoshikawa, K. 1994. Analysis of elongation and thickening of internodes in sweet sorghum (Sorghum bicolor Moench). Jpn. J. Crop Sci. 63 : 473-479*.

Goto, Y. and Nakamura, S. 1995. Effect of plant density on volume and dry matter yield of sweet sorghum (Sorghum bicolor Moench). Jpn. J. Crop Sci. 64 (Extra issue 2) : 199-200**.

Hoshikawa, K., Takahashi, K. and Goto, Y. 1988. Characteristics of sweet sorghum with special reference to the cultivation in converted field from paddy. Research Report of Biomass Conversion Program 10 : 28-50**.

Inoue, Y., Koinuma, K., Mochizuki, N. and Tarumoto, I. 1988. Selection of superior varieties in sweet sorghum (Sorghum bicolor). Research Report of Biomass Conversion Program 10 : 1-13*.

Jackson, D.R., Arthur, M.F., Davis, M., Kresovich, S., Lawhon, W.T., Lipinsky, E.S., Price, M. and Rudolph, A. 1980. Development of Sweet Sorghum as an Energy Crop. Volume 1. Agricultural task. Work Performed Under Contract No. W-7405-ENG-92. U.S. Department of Energy. 1-169.

Lane, J.H. and Eynon, L. 1923. Determination of reducing sugar by means of Fehling’s solution with methylene blue as internal indicator. J. Soc. Chem. Ind. 17 : 32-37.

Lane, J.H. and Eynon, L. 1925. Preparation of Fehling’s solution for the volumetric determination of reducing sugars. J. Soc. Chem. Ind. 19 : 150-152.

Nakamura, S., Goto, Y. and Hoshikawa, K. 1994. Relationship between changes of yield, number of elongated internodes and total leaf number of sweet sorghum. Jpn. J. Crop Sci. 63 (Extra issue 2) : 69-70**.

Nakamura, S., Suzuki, Y. and Goto, Y. 1995. Effect of plant density on characteristics of internode of sweet sorghum (Sorghum bicolor Moench). 1. Internodes of main stem. Jpn. J. Crop Sci. 64 (Extra issue 2) : 195-196**.

Nakamura, S., Saito, M. and Goto, Y. 1997a. Effect of fertilizer application method on characteristics of internode of sweet sorghum (Sorghum bicolor Moench). Jpn. J. Crop Sci. 66 (Extra issue 1) : 68-69***.

Nakamura, S., Saito, M. and Goto, Y. 1997b. Relationships between total leaf number and characteristics of plants in a community of sweet sorghum. Jpn. J. Crop Sci. 66 (Extra issue 2) : 51-52***.

Nakamura, S., Saito, M. and Goto, Y. 1998. Effect of topdressing on yield and characteristics of internode of sweet sorghum (Sorghum bicolor Moench). Jpn. J. Crop Sci. 67 (Extra issue 1) : 50-51***.

Salih, A.A., Ali, I.A., Lux, A., Luxova. M., Cohen, Y., Sugimoto, Y. and Inanaga, S. 1999. Rooting water uptake, and xylem structure adaptation to drought of two sorghum cultivars. Crop Sci. 39 : 168-173.

Salunkhe, D.K. and Desai, B.B. 1988. Postharvest biotechnology of sugar crops. Chapter 4 : Sweet Sorghum. CRC Press, Florida, U.S.A. 75-98.

Sumantri, A. and Purnomo, E. 1997. Sweet sorghum research and development in Indonesia. Proceedings of First International Sweet Sorghum Conference. Institute of Botany, Chinese Academy of Sciences, China. 49-57.

Tsuchihashi, N. and Goto, Y. 2004. Cultivation of sweet sorghum (Sorghum bicolor (L.) Moench) and determination of its harvest time to make use as the raw material for fermentation, practiced during rainy season in dry land of Indonesia. Plant Prod. Sci. 7 : 442-448.

* In Japanese with English abstract.
** In Japanese with English summary.
*** In Japanese.