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

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Abstract: We cultivated sweet sorghum cultivars – Wray, Keller and Rio – to confirm the feasibility of cultivation in dry land of Indonesia for monosodium glutamate (MSG) production. Stem yield of Wray was 4,790 ~ 6,593 g m\(^{-2}\). Sweet sorghum reached anthesis at 73 days after sowing (DAS) and was harvested 3.5 months after sowing. Stem length increased to 36 DAS, then rapidly to 320 cm by 80 DAS. Stem diameter reached 18 mm by 36 DAS. Stems enlarged for 1 month, then elongated. Thinning and weeding for 1 month after sowing produced heavy-stem plants with high yield because stem length and diameter determine stem volume and yield. Stem sugar weight increased after anthesis and reached a peak at 26–33 days after anthesis (DAA). Grain grew until 26 DAA and dried. It was harvestable after 30 DAA. Stem sugar content closely correlated with Brix indicating its value as an index of sugar in stem juice. Consequently, the optimum harvest time is determined by measuring Brix after 30 DAA (103 DAS). Yields were highest in cv. Wray: stems (4,790 g m\(^{-2}\)) and sugar (286 g m\(^{-2}\)). The juice extraction rate was ca. 50% by single-step milling without imbibition water. Using imbibition water and multiple milling steps can provide more than 400 g m\(^{-2}\) of sugar with a greater than 75% juice extraction ratio. Grain yield of other cultivars was similar to cv. Wray’s 238 g m\(^{-2}\). Sweet sorghum could be cultivated on dry land in the rainy season.

Key words: Cultivation, Dry land, Fermentation, Harvest time, Indonesia, Monosodium glutamate, Rainy season, Sweet sorghum.

In East Java, Indonesia, sugar cane has been widely cultivated mainly in plantation fields since the Netherlands colonial era. Monosodium glutamate (MSG) producing companies from Japan, Taiwan and Korea started MSG production in Indonesia in the 1970s. They use cane molasses, a by-product of sugar cane, as a raw material. Recently, use of irrigable land for rice fields has been promoted and sugar cane production has decreased because of the rice shortage due to the population growth. Consequently, cane molasses production decreased; it became difficult for MSG companies to secure their raw materials from East Java.

In contrast, in East Java, with its savanna climate, vast expanses of unirrigated fields were not useful as sugar cane fields. In the dry season, limited areas were useful as maize fields.

Sweet sorghum belongs to a group of sorghum [*Sorghum bicolor* (L.) Moench.]. High concentrations of its sugar juice can be extracted from the stem by milling (Hoshikawa, 1990). It can be harvested within 4 – 6 months after sowing even in temperate areas. It is a promising plant as a raw material for fermentation. In general, sorghum has stronger drought resistance than maize. In the western part of the Corn Belt in the USA, grain sorghum has replaced maize (Kramer and Ross, 1970). It has been reported that dry matter production of sweet sorghum per unit amount of applied water is higher than that of grain sorghum (Mastrorilli et al., 1996). These reports imply that sweet sorghum is a strong drought resistant crop. If sweet sorghum cultivation becomes possible in an-irrigated field in East Java, it could solve the raw material issue for MSG industries and would greatly contribute to East Java agriculture.

From the 1970s to 1980s, sweet sorghum was well-studied as a raw material for ethanol in the USA (Jackson et al., 1980), Europe (Dalianis, 1997) and other countries because of the first and second oil crises. It was anticipated for application to...
fication industries by the end of the oil crisis. In Japan, many studies were done on sweet sorghum from the 1970s, not only as raw material for ethanol, but also as biomass resources using its entire plant structure: stems, leaves, etc. Nevertheless, this project was never put into operation (Hoshikawa et al., 1988; Inoue et al., 1988). Regarding tropical dry land, wide ranges of studies on sweet sorghum from cultivation to process have been done in India for jaggery, ethanol, syrup, and others (Rajavanshi and Nimbkar, 1997). In Indonesia, sweet sorghum was first introduced in the 1980s and was studied mainly by the Indonesian Sugar Research Institute as a raw material for sugar (Sumantri and Purnomo, 1997). However, little was known about growth and sugar accumulation of sweet sorghum, especially on tropical dry land. Therefore, basic research on growth must be performed to establish a sweet sorghum cultivation method.

This study is intended to establish a cultivation method of sweet sorghum in East Java, Indonesian dry land, by basic growth research, and to use analysis of sugar accumulation to determine the optimum harvest time. That knowledge will form the basis of a discussion addressing the feasibility of cultivation on Indonesian dry land. Sorghum seeds were sown in the rainy season to elucidate the basic growth pattern of sweet sorghum in dry tropical areas; then growth patterns and sugar accumulation were examined to determine the optimum harvest time.

**Materials and Methods**

Three sweet sorghums cultivars, Wray (introduced from South Africa to USA), Keller (Mer 50-1 × Rio), and Rio (MN1048 × Rex) (Salunkhe and Desai, 1988), were grown in a field on Madura Island (7°S, 113°E) in East Java, Indonesia, during the rainy season of 1994/1995. Wray was grown at the same location during the rainy season of 1995/1996 and that of 1996/1997. A year at that area can be divided into two seasons: a rainy season (6 months from October or November) and a dry season (6 months from April or May). Seeds were sown on 18 November (1994/1995), 24 October (1995/1996) and 4 November (1996/1997). The seedlings were thinned out to allow them to stand alone at each point. The plants' spacing was 0.75 m between rows and 0.1 m within rows (13.3 plants m⁻²). The field was designed for three replications of randomized blocks. The planting area was 10 × 15 m with three replications containing 20 sampling plots. Each sampling plot was 2.25 × 1.5 m and contained 45 plants. Fertilizer totaling to 118 kg N, 92 kg P₂O₅, and 123 kg K₂O per hectare was given three times: before sowing, 15 DAS, and 30 DAS. Fungicides (Dithane) and insecticides (Carbofuran and Thiodane) were applied several times to control pests and diseases.

Twenty standard plants were taken with roots from a sampling plot for all replications in every week from the first week after sowing until harvest in the first year (1994/1995). Stem length, stem diameter and the number of internodes (> 1 cm) of those 20 plants were measured. Stem length was measured as the height to the neck node of ear, or as the height to the collar of the highest leaf before heading. Stem diameter was measured at 10-15 cm from the base including the leaf sheath.

Ear and stem (excluding leaf sheath) fresh weights
of these plants were measured. At 10 weeks after sowing and thereafter, extracted juice from the stems (using a three roller machine miller without imbibition water) was also weighed. In addition, the juice quality, such as total sugar (Lane and Eynon, 1923; 1925) and Brix were examined by refractometer. Sugar weight was calculated by multiplying the juice weight by total sugar content.

After seed maturity, all plants of a sampling plot were harvested from the field to research yield and yield-related traits for 3 years of cultivation (1994/1995, 1995/1996 and 1996/1997). Harvest was done at 111 DAS (38 DAA) in 1994/1995, 105 DAS (36 DAA), and 107 DAS (40 DAA) in 1996/1997. After harvest, stems were counted and the stem yield (excluding leaf sheath) was measured. Then stem juice was extracted with a three-roller machine miller and was weighed. The juice extraction ratio was calculated dividing stem juice weight by stem weight. Brix of stem juice was measured by refractometer for 3 years. The total sugar was calculated using its correlation to Brix; the sugar yield was calculated by multiplying stem yield by the juice extraction ratio and total sugar content calculated from Brix. The grain yield and yield components of grain (i.e.; ear number, grain number and 1,000 grain weight) were examined after sun drying in the first year (1994/1995).

Results and Discussion

1. Overview for the 3 years of cultivation

Table 1 shows the stem yield and sugar yield-related traits of cv. Wray. The stem yield was highest in 1996/1997 (6,593 g m⁻²), followed by 1995/1996 (5,296 g m⁻²) and 1994/1995 (4,790 g m⁻²). Whereas the sugar yield was highest in 1995/1996 (401 g m⁻²), followed by 1996/1997 (293 g m⁻²) and 1994/1995 (286 g m⁻²). In 1995/1996, birds ate much of the grain during the early stage of grain filling. Broadhead (1973;1979) reported an increase of stem juice Brix and sucrose production as a result of bagging sweet sorghum ears and by removing ears. In our experiment, it was suggested that the decrease of grain number (sink) enhanced the Brix and stem sugar yield. In 1996/1997, however the stem yield was highest among three years, the Brix was lowest and the sugar yield was only slightly higher than that in 1994/1995. From these results, the cultivation in 1994/1995 could be thought as the representative of 3 years.

2. General meteorological conditions

Fig.1 shows the weekly mean temperature and weekly accumulation of precipitation on Madura Island during cultivation in 1994/1995. The temperature changed markedly around 60 DAS: it was 35 – 39°C before 60 DAS, and relatively lower 31 – 39°C after 60 DAS. Precipitation hardly occurred until 30 DAS. After the rainy season began around 30 DAS, it rained frequently until harvest. However, there was occasionally little precipitation for 1-2-weeks intervals.

3. Stem growth

Fig. 2 and 3 show changes in stem length and stem diameter. The stem length increased gradually until 36 DAS, then increased rapidly (5.8 cm d⁻¹) to become ca. 320 cm at 80 DAS. No remarkable differences were found among cultivars. On the other hand, the stem diameter increased rapidly soon after emergence (0.56 mm d⁻¹). It later reached about 18 mm at 36 DAS, remaining almost stable until maturity. The diameter was largest in cv. Wray, followed by cv. Rio, and cv.
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Keller in this order. The sweet sorghum stem diameter is considered to be determined by four factors until 5 weeks after sowing: climate, soil, fertilizer, and plant density. Internodes elongated more than 1 cm were counted as "elongated internodes"; Fig. 4 shows their number. Elongated internodes were first observed at 36 DAS. Though that of cv. Keller was lower than cv. Wray and cv. Rio until 78 DAS, it became 13.4 (cv. Keller) and 13.8 (cv. Wray and cv. Rio) at 78 DAS. These results suggest that the sweet sorghum stem initially thickens, then rapidly elongates. It was reported for sweet sorghum that the stem volume as calculated from the internode diameter was correlated closely with the stem dry-weight (Nakamura et al., 1997a; 1997b). Therefore, we infer that the field conditions until ca. 30 DAS are of critical importance because the stem diameter is probably determined by that time. Stem diameter influences the stem yield potential. In addition, diameter is closely related to lodging during stem elongation.

These results further suggest that appropriate field management is needed, including thinning at an early stage, weeding, etc., to engender thicker stems and higher yield. Single-plant stem weight is influenced by stem diameter and stem length, as mentioned above; it affects the stem yield through multiplication by plant density. That plant density must be decided carefully for each method of cultivation and fertilization. Internode number of plant under low plant density was reportedly larger than those of plants under high density.

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4. Heading and Anthesis
The plant reached heading and anthesis at 66 DAS and 73 DAS, respectively, showing no difference among cultivars. In spring wheat, grain growth was reported to be related closely with sugar accumulation in the stem (Takahashi et al., 1993). The grain filling process of sweet sorghum that starts from anthesis must be observed to elucidate the mechanism of sugar accumulation in the stem. For that purpose, grain growth and sugar accumulation will be indicated by DAA (days after anthesis, 73 DAS = 0 DAA) hereafter.

5. Grain growth
The stem is the most important product in connection with cash flow of sweet sorghum cultivation. It has a high concentration of sugar. However, the grain is also an important product that can be sold as chicken feed. Therefore, the harvest time must be determined according to two parameters: sugar accumulation in the stem, and grain production (seed growth). Fig. 5 shows changes in ear weight. The ear fresh weight is a simple parameter that indicates seed growth. The ear weight increased rapidly until 26 DAA. After 2–3 weeks of decrease, it became almost stable in cv. Wray and cv. Rio. In cv. Keller, however, the ear weight was almost stable after 26 DAA. These results suggested that the grain grew until 26 DAA, and dried thereafter. Sweet sorghum was thought to be harvestable after 30 DAA for purposes of grain production.

6. Sugar accumulation in stem
Sugar accumulation mechanisms in stems must be elucidated to determine the optimum harvest time because sweet sorghum is used for its stem sugars as a raw material for fermentation.

Fig. 6 shows changes in total sugar weight of extracted juice from the stems. The total sugar weight was estimated from the weight of juice extracted from stems and the concentration of total sugar in extracted juice. Total sugar weight started to increase after anthesis and increased rapidly after slight decrease at 12 DAA. It reached a maximum value on 26 DAA in cv. Wray, and 33 DAA in cv. Rio and cv. Keller. Thereafter, it became stable in all cultivars. The temporary decline of total sugar weight at 12 DAA was inferred to result from the translation of assimilate from stem to grain.
during the period of rapid increase of ear fresh weight (Fig. 5) because only low radiation was accepted during that period.

Sugar weight in the stem was calculated by multiplying stem fresh weight (Fig. 8) by the sugar content of extracted juice from the stems (Fig. 7). Although the stem weight increased after anthesis until 50 DAA, the juice extraction ratio from the stems decreased from 19 DAA (Fig. 9).

After 19 DAA, we inferred that the stem fresh weight increase was caused mainly by the increase of stem tissue (almost similar to bagasse) and lignification of the stem because the juice extraction ratio decreased while the stem fresh weight increased. On the other hand, the stem sugar content increased after anthesis to 33 DAA, except for a slight decline at 13 DAA. It became stable after 33 DAA. Consequently, we concluded that 33 DAA, the time of highest sugar content in stem, is the optimum harvest time for these sweet sorghum varieties.

Fig. 10 shows the relation between Brix and total sugar content of extracted juice from the stems. Brix has been used widely in the global sugar industry as a simple parameter for estimation of total sugar content. In sweet sorghum, high correlation was reported between refractometric Brix and soluble sugar content of juice (Yasui, 1984). High correlation was also seen in this experiment: cv. Wray, \( R^2 = 0.9073 \); cv. Keller, \( R^2 = 0.8960 \); and cv. Rio, \( R^2 = 0.8743 \). Consequently, Brix measurement was useful to evaluate the total sugar content of extracted juice from stems of sweet sorghum cultivated in the rainy season on Indonesian dry land.

### 7. Yield and yield-related traits

Table 2 shows the yield and yield-related traits of stem and grain in the first season (1994/1995). The stem yield was higher in cv. Wray (4,790 g m\(^{-2}\)) and cv. Keller (4,642 g m\(^{-2}\)) than in cv. Rio (3,951 g m\(^{-2}\)). Total sugar content was calculated by the following equation: \( y = 1.1 \times <\text{Brix}> - 3.46 \). Sugar yield was higher in cv. Wray (238 g m\(^{-2}\)) than in either cv. Keller (228 g m\(^{-2}\)) or cv. Rio (231 g m\(^{-2}\)). In this experiment, milling was performed in a single step with a three-roller machine miller without water imbibition. In contrast, in commercial sugar plants, around 85% of juice extraction ratio can be achieved through water imbibition and several milling steps. Reportedly, the water content of sweet sorghum is 76–78% (Nakamura et al., 1998), whereas the water content of sugar cane is 68–80% (Brotherton, 1995). Therefore, the juice extraction ratio of more than 75% is anticipated and a sugar yield higher than 400 g m\(^{-2}\) can be anticipated through use of water imbibition and several milling steps. The grain yield was higher in cv. Wray (238 g m\(^{-2}\)) than in either cv. Keller (228 g m\(^{-2}\)) or cv. Rio (231 g m\(^{-2}\)). According to an animal feed company in East Java, Indonesia, the sorghum grain is sold as chicken feed at 75% of the price of maize.

The stem yield of cv. Wray was 4,790 – 6,593 g m\(^{-2}\) in three years (Table 1). Interregional cultivation trials in USA demonstrated that the maximum dry biomass was 12.0 – 40.5 t ha\(^{-1}\) (Jackson et al., 1980). They were thought to correspond to stem fresh yield of ca. 24 – 79 t ha\(^{-1}\). The stem fresh yield in cv. Rio was reported as 20.0 – 21.65 t ha\(^{-1}\) in Indonesian dry land during the rainy season (Sumantri and Purnomo, 1997). These reports support the feasibility of achieving the cv. Wray fresh stem yield in this study in 1994/1995 (4,790 g m\(^{-2}\)).

In conclusion, sweet sorghum could be cultivated on Indonesian dry land. The optimum harvest time was thought to be around 105 DAS (32 DAA). Further studies must be conducted to reveal the cultivation characteristics and to establish cultivation techniques that include the dry season.

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* In Japanese with English abstract.
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