

## Elongation Patterns of Basal Internodes in Sweet Sorghum (*Sorghum bicolor* Moench)

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**Abstract** : Based on the plant age (AL) indicated by leaf number, we analyzed the elongation patterns of basal internodes from the third internode (IN3) through IN10. Using two cultivars, Syrup sorgo 2 (S2, late-maturing) and High-sugar sorgo (HI, early-maturing) grown under field conditions in 1993, 20 plants were sampled when the leaf blade of the 4th through the 14th just fully expanded, and every internode length in the main stem was recorded. All internodes in IN9 and IN10 were classified as 'elongated internodes' (EIN : defined as that with final length more than 1.0 cm), while those from IN3 through IN6 were classified as non 'elongated internodes' (non-EIN : defined as that with final length less than 1.0 cm). In IN7 and IN8, both EIN and non-EIN existed. The EIN rapidly elongated from AL (n+1) when the (n+1) th leaf had just fully expanded to AL (n+3) and reached its maximum length by AL (n+4). This elongation pattern was similar to that of IN10 through IN19 as was reported previously. The non-EIN elongated from AL (n+1) to AL (n+2) and reached its maximum length by AL (n+3). At log phase of internode growth, the elongation rate of non-EIN was remarkably lower than that of EIN. It was suggested that the formation of intercalary meristem did not occur in the non-EIN. It is not likely that the elongation pattern of EIN and that of non-EIN were influenced by the cultivars.

**Key words** : Age, Elongated internode, Growth curve, Internode position, Length of internode, Non elongated internode, Sweet sorghum.

スイートソルガム (*Sorghum bicolor* Moench) の基部節間の伸長様式 : 中村 聡・後藤雄佐 (東北大学農学部)

**要 旨** : 外観で容易に判断できる葉位齢 (葉身が前の葉の葉鞘から抽出し終わった時点ごとに、抽出を完了したばかりの葉の葉位で表す個体の齢) を用いて、スイートソルガムの茎基部 (地表面付近) の第3節間から第10節間までの伸長を解析し、非伸長節間 (1 cm未満) と伸長節間 (1 cm以上) との伸長様式を比較した。晩生のシロップソルゴー2号 (S2) と早生のハイシュガーソルゴー (HI) を、第4葉から第14葉の各葉身がちょうど抽出完了するごとに20個体ずつサンプリングし、節間位ごとの節間長を調査した。第3節間から第6節間はすべて非伸長節間、第9、10節間はすべて伸長節間であったが、第7、8節間は、非伸長節間と伸長節間が混在していた。タイムスケールに葉位齢を用いて、非伸長節間と伸長節間の伸長様式を解析した結果、次のようにまとめられた。伸長節間 (第n節間) は、葉位齢 n+2 頃に急速に伸長し、葉位齢 n+3 から葉位齢 n+4 にかけての時期にほぼ伸長が終わった。この伸長様式は、前報での第10節間から第19節間までの伸長様式と同様であり、品種の早晚によらず普遍的な伸長様式であると考えられた。一方、非伸長節間では、両品種とも第n節間は葉位齢 n+1 から葉位齢 n+2 頃にかけて増大し、葉位齢 n+3 頃に最終長に達する伸長様式を示した。以上から、非伸長節間の伸長様式も葉位齢によって把握することが可能となった。また、非伸長節間の伸長と伸長節間の伸長とは質的に異なり、この違いは介在分裂組織の形成の有無によるものと推察された。

**キーワード** : 伸長節間, スイートソルガム, 生長曲線, 節間位, 節間長, 非伸長節間, 葉位齢.

Previously<sup>2,5)</sup>, we analyzed the elongation patterns of sweet sorghum internodes based on the plant age (AL) accounted by leaf number. The pattern of internode elongation showed a sigmoidal growth curve : the (n) th internode (n is a natural number) rapidly elongated from AL (n+1) to AL (n+3) and reached its maximum length by AL (n+4)<sup>2,5)</sup>. This model of elongation pattern of internode was not influenced by cultivars or plant densities<sup>2,5)</sup>. However, this model of elongation pattern was made based on the observation of

internode elongation above the 9th internode (about 10 cm above ground) although the 3 to 5 internodes below the top were also excluded. Little was known for the elongation pattern of internodes below the 9th internode. In general, the basal internodes are more compact and shorter than the upper ones. In gramineous plants the difference in length between the basal internode and the upper internodes is due to the existence of intercalary meristem located at the base of the internode<sup>3,4,6,8,9)</sup>. Thus, it is suggested that the

elongation process of basal internodes is essentially different from that of upper internodes<sup>6,8,9</sup>). To clarify the elongation pattern of these basal internodes, we analyzed here the elongation pattern of 8 sequence basal internodes, and compared this to those observed previously<sup>2,5</sup>).

### Materials and Methods

Plants of two commercial sweet sorghum cultivars, Syrup sorgo 2 (S2, late-maturing cultivar) and High-sugar sorgo (HI, early-maturing cultivar), were grown in the experimental field of Tohoku University in 1993. The seeds were sown on May 28 and seedlings were thinned after the establishment of seedlings. The spacing of plants was 0.80 m between rows and 0.15 m within rows. Basal fertilizer was given at the rate of 10 g N, 8.9 g P<sub>2</sub>O<sub>5</sub> and 10 g K<sub>2</sub>O per m<sup>2</sup>. Heading date was Aug. 29 and Oct. 5 for HI and S2, respectively. The number of leaves produced on the main stem was 15 to 17 and 17 to 22 for HI and S2, respectively.

Twenty plants were sampled whenever each leaf blade of the 4th through the 14th just fully expanded (AL4 to AL14). At harvest, 20 plants of both cultivars were also sampled. The length of all internodes in the main stem was recorded. The length of internode was defined as a distance between the points of two consecutive leaf-sheaths attached, and that in the apical region was measured using a stereoscopic microscope. The internode enclosed with the (n) th leaf sheath (Ln) was defined as the (n) th internode (INn) (Fig. 1a).

The ALn represents the plant age that indicates the time when the (n) th leaf blade has just fully expanded above the (n-1) th leaf sheath<sup>2,5</sup>). The 10th leaf blade, for example, is fully expanded above the 9th leaf sheath. In this case, the plant age is defined as AL10. The AL is represented only by natural number that reflects the leaf position in the main stem and it does not have a decimal fraction. Thus, for analyzing the internode elongation pattern we consider the AL as continuous numerical value.

### The classification of internodes in stem

We classified sweet sorghum internodes into two groups based on their length as follow: (1) the EIN (the elongated internode<sup>2,5</sup>)

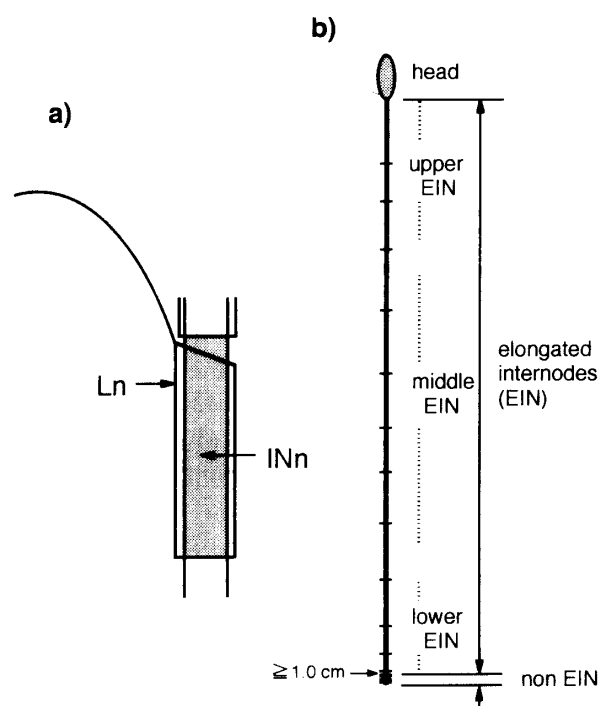


Fig. 1. Position of the leaf (Ln) and the internode (INn) (a) and diagram of internodes in a stem (b). Small n indicates the n position of leaf or internode.

whose final length 1.0 cm or more, (2) the non-EIN whose final length less than 1.0 cm (Fig. 1b). Furthermore we observed the final length of EIN ranged from 1.0 cm to about 50 cm. We subdivided the EIN into the following three groups: (1) 'the upper EIN', (2) 'the middle EIN' and (3) 'the lower EIN' (Fig. 1b). The upper EIN consists of about 3 to 5 internodes just below the panicle. These internodes were excluded from the previous analysis of internode elongation<sup>5</sup>) as the direct influence of the panicle on internode growth was expected. Some internodes at the middle part of the stem is classified as the middle EIN. The lower EIN consists of about 3 to 5 internodes just above the ground. Usually the lower EIN has many brace roots for supporting the plant. The internodes analyzed in our previous works<sup>2,5</sup>) included the middle EIN and the lower EIN. Here, we analyzed the elongation pattern of basal internodes, including the non-EIN and the lower EIN.

## Results and Discussion

### 1. Final length of internode

IN7 or IN8 was located almost near the soil surface. These internodes and some of the IN9

had many brace roots.

The average final length for IN2 through IN12 is shown in Fig. 2. The internode lengths of IN2 through IN10 of HI were significantly longer ( $P < 0.001$ ) than those of S2. However, only a small difference was detected in length between HI and S2 for IN2 through IN6, and a large increase in length was observed from IN6 to IN7.

The coefficient of variation (CV: the standard deviation/the mean value) of the final length of internode for IN2 through IN12 is shown in Fig. 3. The high value of CV was observed for the internode length of IN7 and IN8 in HI and for that of IN7, IN8 and IN9 in S2. To investigate in more detail the factor causing high CV value in these internode positions, the frequency distribution of the final length from IN6 through IN10 was examined (Fig. 4). The final length of IN6 in both cultivars were less than 1.0 cm, while that of IN9 and IN10 in HI and that of IN10 in S2

was more than 8.0 cm. The length of IN7 and IN8 in HI and that of IN7 through IN9 in S2 were considerably variable. However, in each plant, the final length of internodes was increased in order;  $IN6 < IN7 < IN8$ . Based on our classification (Fig. 1b), all internodes from IN3 through IN6 were classified as to the non-EIN, and IN8, IN9 and IN10 were as to the EIN. In IN7 both non-EIN and EIN were observed.

In field-grown dent corn (*Zea mays* L.), the basal internode with approximately 2.5 cm long was IN4, while it was IN5 in popcorn<sup>7)</sup>, suggesting that the lowest internode more than 1.0 cm long could be IN2 to IN4 in dent corn, while it might be IN3 to IN5 in popcorn. In sweet sorghum, the lowest internode more than 1.0 cm long was IN7 or IN8. Therefore, sweet sorghum had more non-EIN than maize although the morphological features of the basal part of sweet sorghum stem were very similar to those of maize.

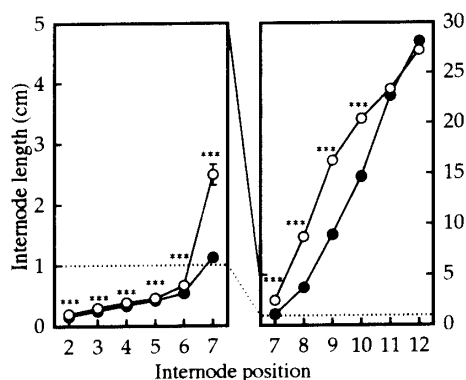


Fig. 2. Final length of IN2 through IN12 in HI (○) and S2 (●). Broken lines show 1.0 cm long. Vertical bars indicate SE. \*\*\* indicates significance at  $P < 0.001$ .

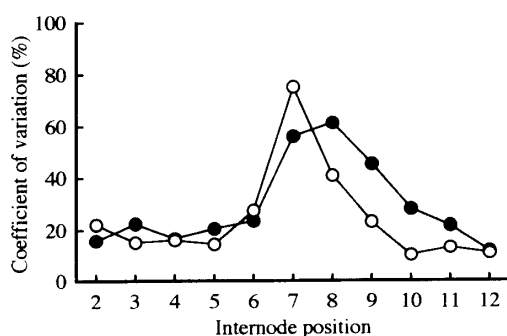


Fig. 3. Coefficient of variation of the final length of IN2 through IN12 in HI (○) and S2 (●).

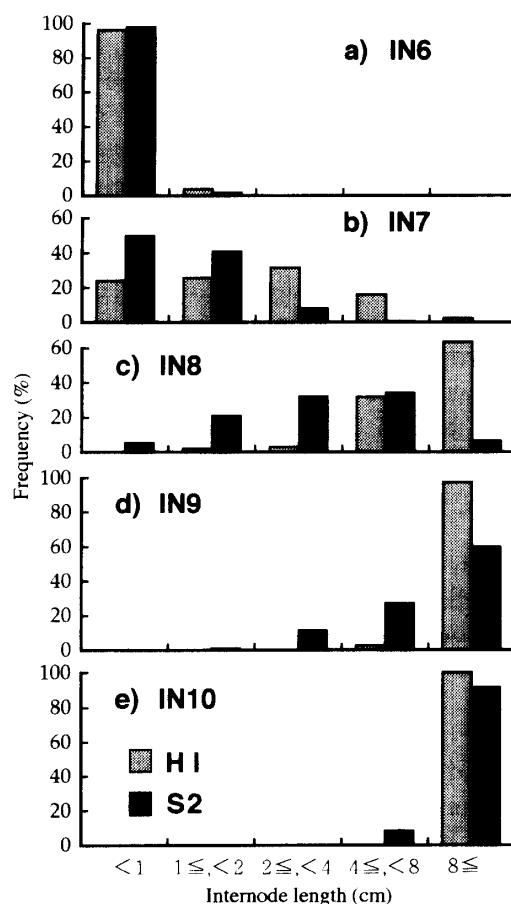


Fig. 4. Frequency distribution of the final length of internode of (a) IN6; (b) IN7; (c) IN8; (d) IN9 and (e) IN10.

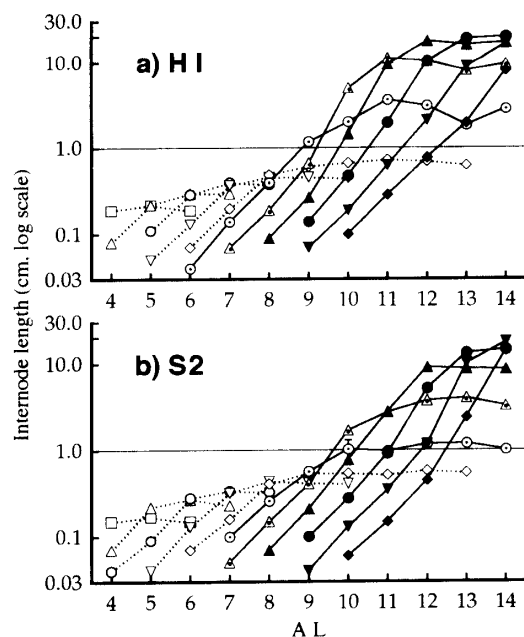


Fig. 5. Changes in length of successive internodes in HI (a) and S2 (b). Broken lines and solid lines show the growth curves from IN2 to IN6 and from IN7 to IN12, respectively. The horizontal line indicates 1.0 cm long. Vertical bars indicate SE.  $\square$ , IN2;  $\triangle$ , IN3;  $\circ$ , IN4;  $\nabla$ , IN5;  $\diamond$ , IN6;  $\odot$ , IN7;  $\triangle$ , IN8;  $\blacktriangle$ , IN9;  $\bullet$ , IN10;  $\blacktriangledown$ , IN11 and  $\blacklozenge$ , IN12.

## 2. Elongation pattern of internodes

Changes in length of successive internodes for IN2 through IN12 in both cultivars are shown in Fig. 5. There was similarity in the growth pattern of the successive internodes in both cultivars. At the final sampling (AL14), the internodes below IN11 had already reached the maximum length, while the IN11 itself probably reached maximum length by AL14. Also at that time IN12 was elongating. The average length of IN7, which consisted of non-EIN and EIN, exceeded 1.0 cm at AL9 in HI and at AL10 in S2. At the early stage of internode elongation, each internode elongated linearly. The growth curves were parallel to each other and at equal distance, however, there was narrow distance between the growth curve of IN6 and that of IN7 in HI.

To compare the internode elongation for IN2 through IN12 in the early stage of internode elongation, we replotted the length of these internodes against the AL (Fig. 6). Each growth curve in this figure indicates the growth of IN $n$  ( $n$ : 2 to 12). The growth patterns of the non-EIN were obviously differ-

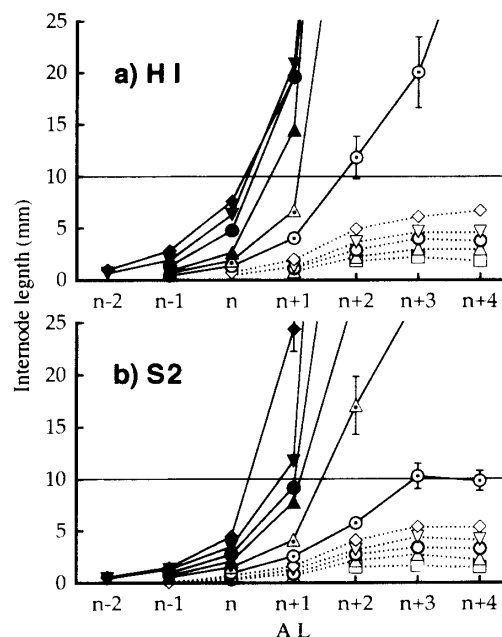


Fig. 6. Changes in length of successive internode in the early internode growth stage in HI (a) and S2 (b). The horizontal line indicates 1.0 cm long. Details are the same in Fig. 5.

ent from those of the EIN. IN3 through IN6 (the non-EIN) of both cultivars elongated slower than the EIN. These internodes reached final length at AL ( $n+3$ ). IN9 through IN12 (the EIN) of both cultivars elongated rapidly from AL ( $n$ ). At the early stage of internode elongation, for example at AL ( $n+1$ ), the length of EIN increased with higher position of internodes. Both IN7 and IN8 showed the intermediate growth pattern.

It is known that rapid internode elongation comes from the elongation of cells, originated in the intercalary meristem (IM) during the early phase of internode development<sup>1,3,6,9</sup>. In maize, the IM formation took place in the internodes when the length exceed 1.0 cm, however, it did not occur when the length is less than 1.0 cm<sup>6</sup>. In sweet sorghum, it is likely that the difference in length between the non-EIN ( $<1.0$  cm) and the EIN ( $\geq 1.0$  cm) is related to the IM formation. Based on the elongation pattern of non-EIN, shown in Fig. 6, the non-EIN probably did not have the IM. The IM also formed in the short EIN (some IN7 and IN8), but its activity is possibly lower compared with the long EIN (IN9 and IN10). This is the reason why the growth curve of IN7 and IN8 showed the intermediate growth pattern (Fig. 6). The narrow parallel distance

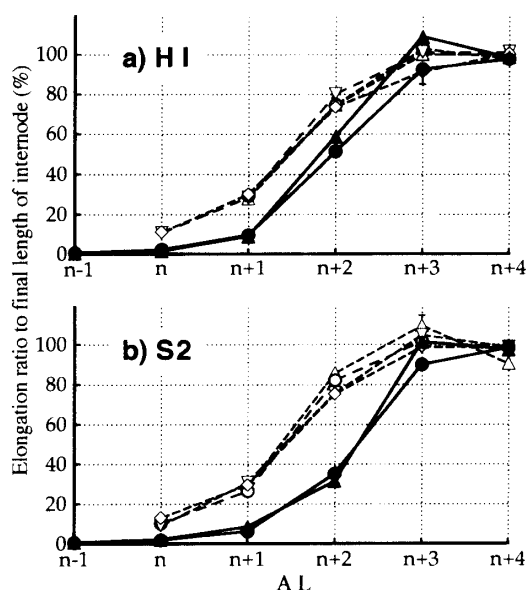


Fig. 7. Changes in the elongation ratio to final length of internode from IN3 to IN6 (----), IN9 and IN10 (—) in HI (a) and S2 (b). Details are the same in Fig. 5.

between the growth curve of IN6 and IN7 in HI (Fig. 5) was probably due to the IM formation in most of IN7. In S2, the distance between the growth curve of IN6 and IN7 was not so narrow because of the existence of non-EIN in half of the IN7.

### 3. General patterns of internode elongation of non-EIN and EIN

To generalize the elongation pattern of the non-EIN and the EIN, we analyzed the elongation ratio of IN3 through IN6 (the non-EIN) and IN9 and IN10 (the EIN). Examination on IN7 and IN8 were excluded from this analysis because their final lengths were variable.

There was a similarity in the elongation pattern of IN3 through IN6 and in that of IN9 and IN10 in both cultivars (Fig. 7). These growth curves were sigmoid. In both cultivars, the non-EIN (IN3 through IN6) started their elongation at AL (n), elongated rapidly from AL (n+1) to AL (n+2) and reached a maximum length at AL (n+3). On the other hand, the EIN (IN9 and IN10) started the elongation at AL (n+1) and reached its maximum length by AL (n+4). Although the elongation ratio of EIN in S2 was slightly lower than that of EIN in HI at AL (n+2), we concluded that the elongation pattern of non-EIN and that of EIN was not affected by cultivars.

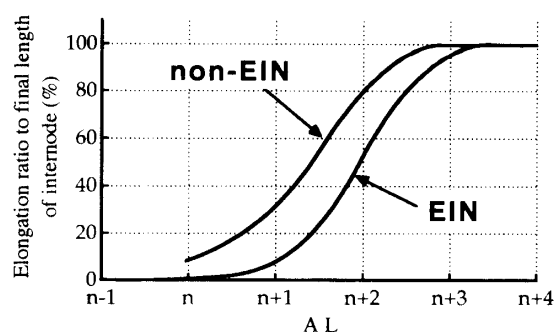


Fig. 8. The model growth curve of the non-EIN and the EIN. This growth curve also shows the elongation pattern of INn.

The model growth curves of non-EIN and EIN are shown in Fig. 8. The elongation patterns of non-EIN and EIN are generalized as follows: the non-EIN started the elongation at AL (n), increased rapidly from AL (n+1) to AL (n+2) and reached the maximum size at AL (n+3). While the EIN started the elongation at AL (n+1), rapidly elongated at AL (n+2) and ceased the elongation by AL (n+4). The general elongation pattern of EIN obtained in the present experiment was similar to that for IN10 through IN19 in our previous work<sup>2,5)</sup>. The elongation of internode in non-EIN occurred earlier than that of EIN. We couldn't examine the growth curves for IN7 and IN8 due to large variation in the final internode length, however, it was suggested that the elongation of internode less than 1.0 cm in IN7 and IN8 probably shows the same pattern with that of the non-EIN, while the elongation of internode more than 1.0 cm in IN7 and IN8 showed to have similar elongation pattern with that of the EIN.

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