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# Tuber Sink Potential in Sweet Potato (*Ipomoea batatas* Lam.)

## II. Estimation of tuber sink potential of cultivars using single leaf grafts*

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**Abstract** : An estimation of the tuber sink potential of several sweet potato cultivars was attempted. For this purpose we used stocks of single rooted leaves of several cultivars grafted with uniform single leaf scions of a single type of cultivar, because the source potentials i.e. leaf area and photosynthetic potential were able to be uniform and sink organs other than tuber were restricted.

The source activity, i.e. leaf area and apparent photosynthetic rate, did not differ statistically among stock cultivars. However, the tuber dry weight correlated significantly with the leaf area, therefore the tuber sink potential was estimated by the tuber dry weight per unit leaf area. The apparent photosynthetic rate was regulated by mesophyll resistance of $CO_2$ diffusion, and the mesophyll resistance was influenced by tuber sink potential through the control of leaf starch content. Thus, the matter production of grafts was largely depended on the tuber sink potential in this system.

The tuber sink potential was different among stock cultivars significantly at 1%. It was higher in cv. Koganesengan and Shirosatsuma and lower in cv. Tsurusengan.
**Key words** : Cultivar, Grafting, Photosynthesis, Single rooted leaf, Sink potential, Sweet potato, Tuber.

**サツマイモ塊根の Sink 能力に関する研究**　第2報　一葉挿し接ぎ木植物による塊根 Sink 能力の評価：
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**要　旨**：サツマイモ品種・系統の塊根 Sink 能力を定量的に評価するため，Source 活性や塊根以外の Sink 量を一定にできる一葉挿し接ぎ木植物を作成した．すなわち 14 品種•系統の一葉挿し植物の台木に葉柄部分でコガネセンガンの葉を接ぎ，2ヵ月後に塊根重や光合成速度などを調査した．

接ぎ木の成功率はつる割れ病が発生したシロユタカ台木では4割程度であったが，それ以外の台木ではいずれも7割以上で，比較的容易に接ぎ木が行えた．また，生育も良好で接ぎ木不親和などの現象は認められなかった．

一葉挿し接ぎ木植物の葉面積と光合成速度には台木間で統計的に有意な差はなかった．しかし，塊根乾物重と葉面積との間には有意な相関が見られたので，塊根 Sink 能力は単位葉面積当たりの塊根乾物重で評価した．光合成速度は葉肉抵抗に律速されていた．葉肉抵抗は葉身のデンプン含量の調節を通じて塊根 Sink 能力の影響を受けていた．このため一葉挿し接ぎ木植物の物質生産には塊根 Sink 能力の影響が大きかったと思われ，塊根 Sink 能力を評価する系としては優れていることが示唆された．

このように評価された塊根 Sink 能力には品種・系統間で有意な差があり，コガネセンガンやシロサツマで大きく，ツルセンガンで小さかった．
**キーワード**：塊根，光合成，サツマイモ，Sink 能力，接ぎ木，一葉挿し．

In sweet potato it has been recognized that tuber sink potential is one of the most important factors governing the yield[1] and matter production[4]. The tuber effect on the matter production appears through "Source-Sink interrelationship". There are many reports[3,16] on the subject. For the increase in the yield and matter production, therefore, tuber sink potential should be considered.

However, the substantiation of tuber sink potential is not so clear and the physiological and biochemical factors regulating the tuber sink potential are still unknown. We think at first that the tuber sink potential should be

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estimated quantitatively to clarify these problems. In the present experiment one of the indicators of the tuber sink potential is thought to be the tuber dry weight. In intact plants the tuber dry weight is the product of the source activity, sink potential and their interaction. Sometimes top source effects interfere the estimation[12]. Thus, the tuber sink potential should be estimated under a uniform source potential.

The tuber sink potential of cultivars has been estimated using the grafts with scion of uniform cultivars[11] or the reciprocal grafts[1] in the field. However, the amount of source and sink organs other than tuber is not uniform even in the graft with scion of uniform cultivar, because the top growth of grafts fluctuated due to the stock cultivar[11,12].

In some plants[6,14] single rooted leaves have been used as a "Source-Sink model" plant since the source potential can be uniform. In sweet potato single rooted leaves have been used for the studies on the translocation of assimilates[7], tuber cracking[13] and for screening growth regulators[10,17]. Recently Yoshida et al.[19] have tried to use single rooted leaves in screening for breeding purpose, and reported that the tuber weight in the single rooted leaves correlated with the tuber yield in the field. Strictly speaking, however, the source potential, i.e. leaf area and photosynthetic potential, differs among cultivars even in the single leaf. In the present study we tried to make the source potential and the amount of sink organs other than tubers uniform by grafting scion leaf of the same cultivar to single rooted leaf stocks of several different cultivars, and the tuber sink potential was estimated.

## Materials and Methods

Fourteen cultivars were used for the stock. The characteristics of these cultivars were shown in Table 1. The third or fourth unfolding leaves from the apex were cut with a part of the stem from the nursery bed. The materials were selected from these by their weight and petiole length in each cultivar. The stems were cut to about 1 cm in length and the lateral bud primordia were removed at their base. The leaves were planted in plastic pots (11cm$\phi$ × 14cm in height) filled with vermiculite (2—5mm$\phi$) about 4cm in depth. After planting they were watered and placed in a phytotron. They rooted for a week under the condition of 28°C from 6 : 00 to 18 : 00, 20°C from 18 : 00 to 6 : 00, about 70% relative humidity, 24h weak light. After that BOC lamps (Mitsubishi Electric Inc.) were lighted up from 8 : 00 to 16 : 00 with light intensity of 330$\mu$Em$^{-2}$s$^{-1}$ at leaf level. When a few lateral buds came out in some materials, they were removed as soon as possible.

At 2 weeks after the planting of stock materials the grafting was carried out in the manner shown in Fig.1. For scions the 3rd or 4th unfolding leaves of cv. Koganesengan were selected by the length (11—13cm) and the width (10—12cm) of the leaf blades. The petioles of the scion leaves were cut to 10cm in length. Cleft grafting was done on the stock petiole at 5cm above the surface of vermiculite. After grafting each pot was covered with a vinyl bag to keep in moisture, and the

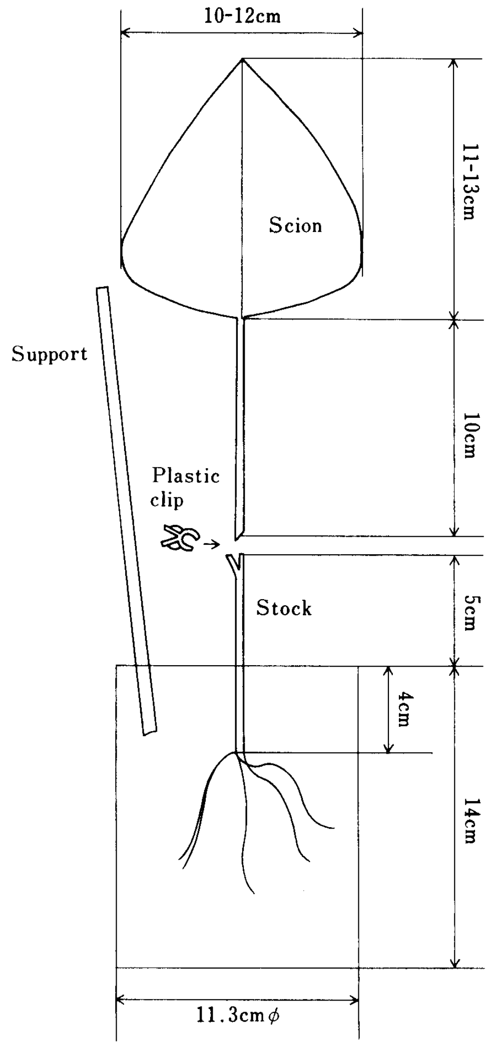


Fig. 1. Grafting of single rooted leaf.

Table 1. Characteristics of intact plant

| Cultivar | | Tuber yield | Earliness of tuber growth | Dry matter content of tubers |
|---|---|---|---|---|
| Kogenesengan | (KOG) | High | Early | High |
| Kokei 14 | (KO 14) | Medium | Early | Medium |
| Beniaka | (BEN) | Low | Late | Medium |
| Okinawa 100 | (O 100) | High | Early | Low |
| Norin 1 | (N 1) | Medium | Medium | Medium |
| Fukuwase | (FUK) | Medium | Early | Low |
| Chugoku 25 | (CH 25) | Low | Late | Low |
| Minamiyutaka | (MIN) | High | Late | High |
| Tsurusengan | (TSU) | Low | Late | High |
| Kyushu 89 | (KY 89) | Medium | Medium | Very high |
| Shiroyutaka | (SHY) | High | Early | High |
| Beniazuma | (AZU) | High | Early | Medium |
| Kanto 92 | (KA 92) | Medium | Medium | Medium |
| Shirosatsuma | (SHI) | High | Late | High |

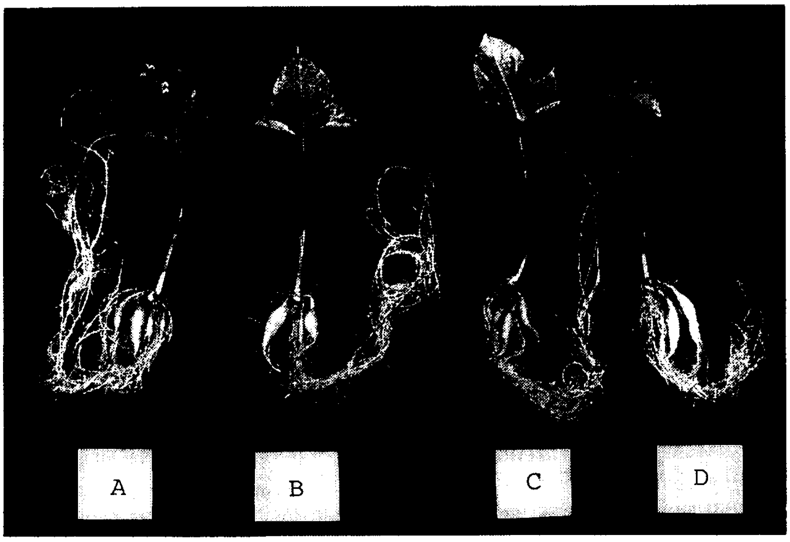


Fig. 2. Examples of some grafts at 2 months after grafting.
The stock cultivars in the figure are as follows :
A : Kokei 14, B : Fukuwase, C : Beniaka, D : Kyushu 89.

light was turned off for a week. At one week after grafting the plants were placed under conditions with light intensity of $750 \pm 100 \mu E \cdot m^{-2} \cdot s^{-1}$ at leaf level from 8 : 00 to 16 : 00. They were irrigated with culture solution[13] twice a week. Finally 8 plants per stock cultivar were used for the measurements.

At 2 months after grafting the apparent photosynthetic rate (Pn)and transpiration rate (TR) of the grafts were measured with a facility described by Hozyo and Kato[5]. Measuring conditions were as follows : 25°C, 50% relative humidity, 6$l$/min flow rate, about 370—410$\mu E \cdot m^{-2} \cdot s^{-1}$ light intensity and about 370ppm $CO_2$ concentration. The diffusive resistance of $CO_2$ was calculated from Pn and TR[9]. After the measurement of Pn the dry weight of each organ was determined. The dry samples of leaf blades and tubers were ground with a vibration mill into particles of less than 100 mesh. The reducing sugar and starch contents were analyzed with 80% hot ethanol extracts and residues of these materials according to the method described by Hozyo et al.[4], and the sucrose content was measured by Handel's method[2].

## Results

The ratio of sound grafts obtained was over 70% except the stock of cv. Shiroyutaka. In in cultivars used for the stock.

| Stem length | Size of a leaf | Size of a tuber | Using | Other characteristics |
|---|---|---|---|---|
| Medium | Large | Large | Starch | |
| Medium | Medium | Medium | Food | |
| Long | Small | Small | Food | |
| Medium | Medium | Large | Food, Feeding | |
| Long | Large | Medium | Food, Starch | |
| Medium | Medium | Medium | Food, Feeding | |
| Medium | Small | Small | Feed | Many tuber setting |
| Long | Large | Large | Starch | |
| Medium | Large | Small | Top feeding | |
| Short | Small | Medium | Starch | |
| Long | Large | Large | Starch | |
| Medium | Large | Large | Food | |
| Medium | Large | Medium | Processing | $\beta$-amylase less in tuber |
| Long | Large | Large | Starch | |

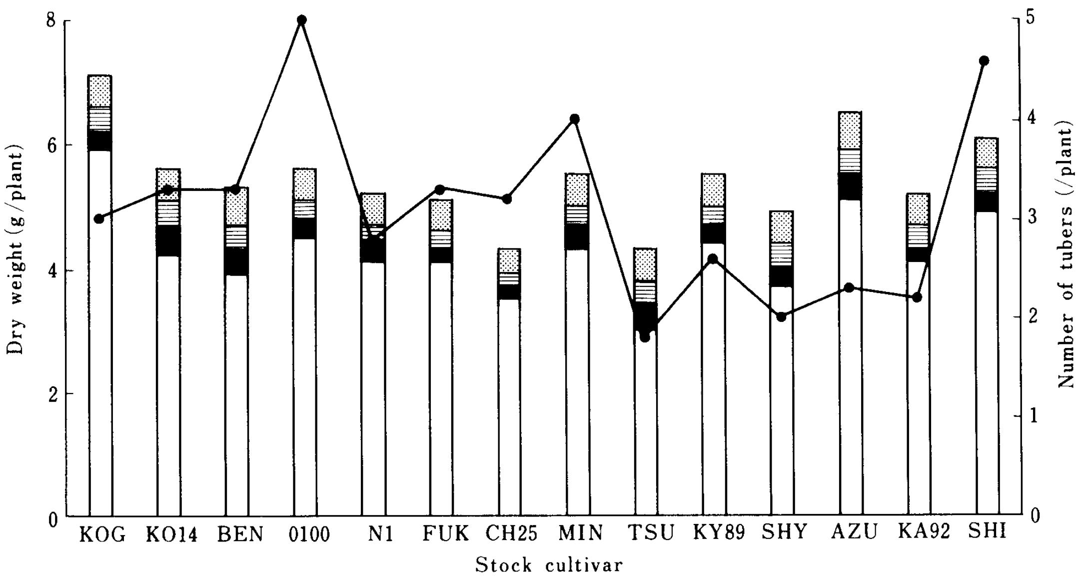


Fig. 3. Dry weight of each organ and number of tubers in single leaf grafts at 2 months after grafting.

Shiroyutaka stock the ratio was about 40% because of stem rot disease at the petiole. Except for this the growth of the grafts seemed to be normal. At 2 months after grafting the leaf blades browned a little, but leaf defoliation was not observed except Shiroyutaka stocks, half of which were dead from the disease. Therefore, the results were obtained by using 4 plants of Shiroyutaka and 8 plants of the other cultivars. Examples of some grafts at that stage were shown in Fig. 2.

The dry weight of each organ and the number of tubers at 2 months after grafting were shown in Fig.3. Significant differences among stock cultivars were observed in the number, dry weight of tubers and fibrous roots at 5, 1 and 5% level, respectively. The tuber dry weight was higher in the stock of Koganesengan, Shirosatsuma and Beniazuma, and lower in the stock of Tsurusengan. The dry weights of leaf blades and petioles were not different. The tuber sink potential, leaf

Table 2. Leaf area, tuber sink potential, photosynthetic rate (Pn), transpiration rate (TR) and diffusive resistance of stomata (RS) and mesophyll (RM) in the single leaf grafts at 2 months after grafting.

| Stock cultivar | Sink potential gDW/dm² | Leaf area cm² | Pn $mgCO_2$ /dm²/h | TR $gH_20$/ dm²/h | RS s/cm | RM s/cm |
|---|---|---|---|---|---|---|
| KOG | 4.57 a | 129 a | 11.4 a | 1.70 a | 5.56 a | 16.9 a |
| KO 14 | 3.74 abc | 112 a | 12.6 a | 1.81 a | 4.90 a | 14.7 a |
| BEN | 3.29 bc | 119 a | 11.1 a | 1.73 a | 5.32 a | 19.2 a |
| O 100 | 3.69 abc | 121 a | 9.6 a | 1.72 a | 5.01 a | 21.1 a |
| N 1 | 3.67 bc | 111 a | 10.5 a | 1.85 a | 5.07 a | 17.2 a |
| FUK | 3.71 abc | 111 a | 10.1 a | 1.73 a | 6.04 a | 19.0 a |
| CH 25 | 3.42 bc | 103 a | 10.5 a | 1.81 a | 5.07 a | 19.0 a |
| MIN | 3.68 bc | 118 a | 10.5 a | 1.72 a | 5.00 a | 17.7 a |
| TSU | 2.80 c | 108 a | 8.8 a | 1.75 a | 5.46 a | 27.2 a |
| KY 89 | 3.97 abc | 110 a | 10.4 a | 1.79 a | 5.20 a | 18.3 a |
| SHY | 3.19 bc | 116 a | 9.6 a | 1.81 a | 5.61 a | 20.8 a |
| AZU | 4.01 abc | 128 a | 10.2 a | 1.64 a | 6.01 a | 17.9 a |
| KA 92 | 3.62 bc | 113 a | 10.4 a | 1.82 a | 5.41 a | 18.5 a |
| SHI | 4.22 ab | 117 a | 9.8 a | 1.86 a | 5.64 a | 19.5 a |

Note : Figures within a column followed by the same letter did not differ at 5% level of significance according to Duncan's test.
The name of stock cultivars are the same as those in Table 1.

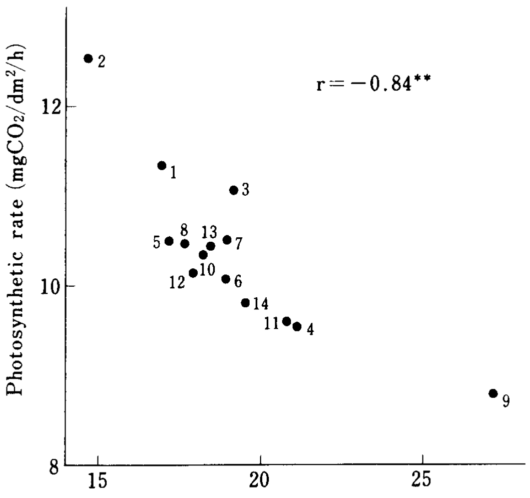


Fig. 4. Relationship between mesophyll resistance and photosynthetic rate of single leaf grafts.
The numbers in the figure show cultivars of stock as follows :
1 : Koganesengan, 2 : Kokei 14, 3 : Beniaka, 4 : Okinawa 100, 5 : Norin 1, 6 : Fukuwase, 7 : Chugoku 25, 8 : Minamiyutaka, 9 : Tsurusengan, 10 : Kyushu 89, 11 : Shiroyutaka, 12 : Beniazuma, 13 : Kanto 92, 14 : Shirosatsuma.

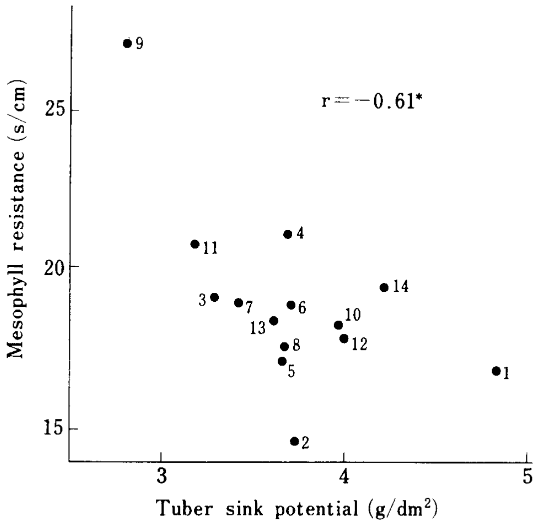


Fig. 5. Relationship between tuber sink potential and mesophyll resistance of single leaf grafts.
The numbers in the figure are the same as in Fig. 4.

area, Pn, TR, stomatal resistance (RS) and mesophyll resistance (RM) are shown in Table 2. Leaf area, Pn, TR, RS and RM were not different statistically among stock cultivars.

A positive correlation (r = 0.68) was observed between leaf area and tuber dry weight. Therefore, an estimation of the tuber sink potential was attempted by measuring the tuber dry weight per unit leaf area. The estimated values showed a significant difference at the 1% level, and were higher in

Table 3 Contents of reducing sugar, sucrose and starch of leaf blades and tubers in the single leaf grafts at 2 months after grafting

| | Leaf blade | | | Tuber | | |
|---|---|---|---|---|---|---|
| Stock cultivar | Reducing sugar mg/gDW | Sucrose mg/gDW | Starch mg/gDW | Reducing sugar mg/gDW | Sucrose mg/gDW | Starch mg/gDW |
| KOG | 2.96 | 8.22 | 57.1 | 5.56 | 24.6 | 420.6 |
| KO 14 | 2.21 | 7.50 | 55.1 | 5.92 | 28.0 | 447.8 |
| BEN | 5.20 | 5.21 | 65.5 | 4.76 | 22.4 | 475.0 |
| 0 100 | 2.59 | 7.00 | 66.0 | 4.44 | 22.7 | 467.0 |
| N 1 | 3.08 | 7.08 | 62.8 | 5.31 | 24.6 | 501.3 |
| FUK | 2.10 | 8.54 | 62.7 | 7.62 | 34.2 | 480.9 |
| CH 25 | 0.84 | 6.50 | 61.0 | 4.20 | 24.6 | 478.4 |
| MIN | 3.19 | 7.09 | 65.5 | 5.01 | 17.7 | 468.0 |
| TSU | 1.65 | 5.68 | 69.0 | 3.75 | 21.0 | 429.4 |
| KY 89 | 1.77 | 7.44 | 60.8 | 3.54 | 18.0 | 458.8 |
| SHY | 1.44 | 6.98 | 55.4 | 5.91 | 36.1 | 461.0 |
| AZU | 1.34 | 8.52 | 57.5 | 3.57 | 23.6 | 493.0 |
| KA 92 | 1.39 | 8.23 | 60.0 | 1.95 | 23.9 | 470.2 |
| SHI | 1.93 | 8.00 | 59.0 | 3.50 | 18.4 | 462.2 |

Note ; Figures in reducing sugar and starch are presented by glucose equivalent.
Name of stock cultivars are the same as those in table 1.

Koganesengan and Shirosatsuma, and lower in Tsurusengan. As shown in Fig. 4, a high negative correlation was observed between Pn and RM. TR and RS did not correlate significantly with Pn (r=0.05 and −0.32, respectively). The negative correlation was found between the tuber sink potential and RM as shown in Fig. 5. Although the tuber sink potential did not correlate significantly with Pn at the 5% level, the correlation coefficient (r=0.41) was significant at the 15% level.

The starch, reducing sugar and sucrose contents of the leaf blades and tubers are shown in Table 3. Each carbohydrate content was higher in tubers than in leaf blades. Table 4 shows the correlation coefficients among each carbohydrate content of leaf blades or tubers and Pn, RM or tuber sink potential including or excluding the Shiroyutaka stock infected with stem rot disease. A positive correlation was observed between the starch content of leaf blades and RM, and the value of coefficient increased when the data of Shiroyutaka stock were omitted. Also as the Shiroyutaka stock was omitted, a significant negative correlation was observed between Pn and the leaf blades starch content. The soluble sugar content of leaf blades did not correlated with Pn or RM. The relationship between tuber sink potential and leaf starch content was significantly negative as omitting the Shiroyutaka stock. A positive correlation was found between tuber sink potential and sucrose content of leaf blades. There were no correlations among the carbohydrate contents of leaf blades and tubers. The carbohydrate contents of tubers did not influence Pn, RM and tuber sink potential. The gradient of carbohydrate content even in terms of fresh weight between leaf blade and tuber did not influence the Pn and RM.

## Discussion

In the present study the grafting at petiole was not so difficult. Also the rate of translocation of assimilates in the petiole does not limit the translocation from leaf to tuber[7]. It is, therefore, considered that the grafting at petiole does not influence the translocation.

In the present study the leaves of Koganesengan were used for scion because of their relatively high photosynthetic rate[8], large leaf size and longevity of leaves[15]. The leaf area of the scion was adjusted by the length and width of the leaf blades. Although the final leaf area was not different statistically, the tuber dry weight correlated with the leaf area. There seems to be a little difference in the initial leaf area of the scion and the leaf expansion during the growth period. Therefore, the tuber sink potential was estimated by

Table 4 Correlation coefficients among carbohydrate contents and Pn, RM and

| | Leaf blade (dry weight base) | | |
|---|---|---|---|
| | Reducing sugar | Sucrose | Starch |
| Pn | 0.34 | 0.15 | −0.48 |
| RM | −0.19 | −0.50 | 0.60* |
| Tuber sink potential | 0.06 | 0.71** | −0.49 |
| Leaf reducing sugar | … | −0.42 | 0.37 |
| Leaf sucrose | −0.42 | … | −0.59* |
| Leaf starch | 0.37 | −0.59* | … |
| Tuber reducing sugar | 0.28 | 0.06 | −0.12 |
| Tuber sucrose | −0.20 | 0.20 | −0.43 |
| Tuber starch | 0.03 | 0.10 | 0.06 |
| Pn | 0.30 | 0.14 | −0.66* |
| RM | −0.16 | −0.49 | 0.74** |
| Tuber sink potential | −0.01 | 0.72** | −0.70** |
| Leaf reducing sugar | … | −0.45** | 0.31 |
| Leaf sucrose | −0.45 | … | −0.68* |
| Leaf starch | 0.31 | −0.68* | … |
| Tuber reducing sugar | 0.36 | 0.08 | −0.02 |
| Tuber sucrose | −0.08 | 0.32 | −0.25 |
| Tuber starch | 0.02 | 0.10 | 0.05 |

Note : * and **show the singnificance at 5 and 1% level, respectively.

the tuber dry weight per unit leaf area.

Since the amount of fibrous roots was different between stocks, the activities of water and mineral nutrient uptake might be different. If the difference in these activities had affected the matter production of single leaf grafts, the estimation of the tuber sink potential would be interfered. However, the effect of RM on Pn was dominant (Fig. 4), and TR and RS did not relate with Pn. Thus it seems that at least the difference in the activity of water uptake has not interfered the estimation of the tuber sink potential in this system.

A negative correlation was observed between RM and the tuber sink potential. RM correlated with leaf starch content. The tuber sink potential also correlated negatively with leaf starch content by omitting the Shiroyutaka stock infected with stem rot disease. The negative correlation between carbohydrate content of leaf and photosynthetic activity has been reported[3,14,18]. In the present study the reducing sugar content did not show the relation with the Pn, RM and tuber sink potential. The sucrose content of leaf blades correlated positively with the tuber sink potential and negatively with the starch content of leaf blades, but not correlated with Pn and RM. Sawada et al.[14] have reported that photosynthesis correlates negatively with leaf starch or sucrose content in single rooted leaves of soybean. The above mentioned discrepancy in the relation between leaf sucrose content and photosynthesis is supposed to be derived partly from the difference in the materials used and their age. Shimotsubo et al.[16] have suggested that starch grains deposited in the chloroplast destroy the granum structure and increase RM. Thus it is assumed that the influence of leaf carbohydrate content on photosynthesis through RM depends primarily on the starch content, and the tuber sink potential affects more on the process of starch degradation than on the process of starch synthesis in the leaf. Although the mechanism of this regulatory system is not clear, this phoenomenon cannot be interpreted only by the sucrese gradient between the leaf and tuber.

RM was influenced by the tuber sink potential, and Pn was regulated by RM. The Pn and tuber sink potential did not show a significant correlation but its coefficient was relatively high. Thus, it is suggested that the matter production of single leaf grafts depends largely on the tuber sink potential, and the system of single leaf grafts is well suited for the sink potential including (upper) or excluding (lower) the Shiroyutaka stock.

| Tuber (dry weight base) | | | Difference from tuber to leaf blade (fresh weight base) | | |
|---|---|---|---|---|---|
| Reducing sugar | Sucrose | Starch | Reducing sugar | Sucrose | Starch |
| 0.26 | 0.07 | −0.07 | 0.10 | 0.12 | 0.13 |
| −0.23 | −0.08 | −0.28 | −0.15 | −0.03 | −0.24 |
| 0.04 | −0.19 | −0.15 | 0.05 | −0.27 | 0.10 |
| 0.28 | −0.20 | 0.03 | | | |
| 0.06 | 0.20 | 0.10 | | | |
| −0.12 | −0.43 | 0.06 | | | |
| … | 0.66** | −0.01 | | | |
| 0.66** | … | 0.10 | | | |
| −0.01 | 0.10 | … | | | |
| 0.35 | 0.30 | −0.09 | 0.24 | 0.41 | 0.11 |
| −0.29 | −0.24 | −0.27 | −0.26 | −0.22 | −0.23 |
| 0.13 | −0.00 | −0.18 | 0.21 | −0.09 | 0.08 |
| 0.36 | −0.08 | 0.02 | | | |
| 0.08 | 0.32 | 0.10 | | | |
| −0.02 | −0.25 | 0.05 | | | |
| … | 0.66* | 0.01 | | | |
| 0.66* | … | 0.17 | | | |
| 0.01 | 0.17 | … | | | |

quantitative estimation of the tuber sink potential.

It has been reported that the tuber dry weight of single rooted leaves correlates with the tuber yield in the field grown plants[19]. The tuber sink potential estimated in the present study showed similar results as those obtained in the field grown grafts at the harvesting time[11]. Thus, the single leaf grafts seem to be useful for the estimation of the tuber yield potential of sweet potato cultivars, because they require less materials and shorter time.


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