バレイショにおける Andigena × Tuberosum 雑種系統の乾物生産特性

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著者	礒田, 昭弘 中世古, 公男 後藤, 寛治
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Productivity of Some Hybrid Strains between Andigena and Tuberosum in Potato*

Akihiro ISODA**, Kimio NAKASEKO, Kanji GOTOH and Sachio NISHIBE***

(*Faculty of Agriculture, Hokkaido University, Sapporo 060,*
***Hokkaido National Agricultural Exp. Station, Eniwa 061-13*)

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In order to broaden the genetic background for improving yield capacity in potato plant, Andigena (*Solanum tuberosum* ssp. *andigena*) has been used in breeding programme since 1957[2,3,4,5,11,12,13,14].

We reported previously that the two Andigena strains, W553-4 and C10193-1, has some interesting characteristics as a breeding material[7,8], and produced the two hybrid populations (total 790 clones) derived from the crosses between the Andigena strains and the Tuberosum cultivar (*S. tuberosum* ssp. *tuberosum*, cv. Norin No.1)[9]. In 1982, 55 clones with high yield were selected from these hybrid populations based on the results of single hill progeny trials.

In this experiment, eight excellent clones (strains) with high yield selected from the progenies of the population 80135 (W553-4 × Norin No.1) were grown under the general planting system, and their productivities were assessed from the viewpoint of dry matter production.

Materials and Methods

In 1980, two Andibena strains (W553-4 and C10193-1) as a female parent were pollinated with Norin No.1, one of the leading cultivars in Japan. Seedlings of each cross were raised, and 511 and 229 clones were derived from the crosses between W553-4 × Norin No.1 (register number: 80135) and between C10193-1 × Norin No.1 (80136) in 1981. From the results of single hill progeny trials in 1982[9], 42 and 13 clones were selected from the population 80135 and 80136, respectively. In 1983, these clones were planted with two replications (16 hills per clone), and 8 clones (strains) with higher yield were selected. Consequently, all of them were the progenies of the population 80135 (No.4, 5, 6, 16, 21, 23, 30 and 40). In this experiment, these eight strains were used in comparison with their parents (W553-4 and Norin No.1).

In 1984, mother tubers were planted on 8 May with 30 cm spaced hills and 65 cm wide rows. Each plot comprised of five rows with 6 m in length (21 plants per row), and was arranged as a randomized complete block with two replications. A combination of N : P_2O_5 : K_2O as a fertilizer at the ratio of 63, 99 and 81 kg/ha respectively, was banded just before planting.

Beginning on 19 June, six plants of the center three rows were harvested from each plot at the intervals of 18 days, and leaf, stem, tuber and stolon + root dry weights of four plants excluding extremely large and small ones were measured after oven drying for 48 hours at 80°C. About 2000cm² of leaf areas from the representative plants of each plot were recorded with an automatic leaf area meter (Hayashi Elec. Corp., AAM-7).

On 4 October, ten plants were taken from each plot, and tuber fresh weight, number of tubers and their gravity were measured. About 1000 g of sliced tuber taken at random from plot samples were dried for determination of dry matter content.

Results

1. *Maturity, total dry weight, yields and yield components*

All of the hybrid strains except No.30 had

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** The present adress is Faculty of Horticulture, Chiba University, Matsudo, Chiba 271.

late maturity, and did not reach to the leaf yellowing stage by early October (Table 1). No.6, 40 and the Andigena parent (W553-4) which had very late maturity maintained rather large leaf area index till early October (see Fig.2). Only No.30 was earlier than the Tuberosum parent (Norin No.1).

The means of total weight and tuber yield as dry weight base for the hybrid strains were 22% and 17% greater than those for the Tuberosum parent, respectively. Particularly, No.40 which recorded the highest yield (79 t/ha as fresh weight) was superior to Norin No. 1 by 89%.

The mean tuber number (/pl.) for the hybrid strains was slightly less than that for the mid-parent (16.5/pl.), but No.16, 21 and 40 produced significantly larger numbers of tubers than the Tuberosum parent (Table 2). All of the strains had larger sizes of tubers (mean single tuber weight) than the Andigena parent. No.5 and 23 had particularly higher percentages of LL sized tubers (180 g -) than that of the Tuberosum parent. Although there was a highly negative correlation ($r=-0.803^{**}$) between size and number of tubers, No.40 which produced the highest yield had nearly similar values to that of the Andigena parent in tuber number and to that of the Tuberosum parent in tuber size. The mean starch value of the hybrid strains did not so different from those of their parents.

2. Partitioning of dry matter

Changes with time in percentages of leaf (a), stem (b), and tuber (c) dry weights to total dry weight are presented in Fig. 1. There was a tendency in the percentages of leaf and stem dry weights that later maturing strains changed with higher values after July; very late strains, No.6 and W553-4, had especially high values, and the earliest strain (No.30) had lower ones. On the other hand, the percentage of tuber dry weight showed a reciprocal relation to those of leaf and stem dry weights. The time of tuber initiation was different among the strains (Fig.1-c). No.5, 30,40 and the Tuberosum parent set tubers already on 19 June. No.4, 16, 21 and 23 formed tubers in early July, and tuber formations of No.6 and the Andigena parent were very late (in the late of July). As a general trend, tuber initiation and partitioning of dry matter would be closely related to maturity. No.40 with the highest yield, however, showed exceptionally early tuber formation, relatively low percentages for leaf and stem and high one for tuber in spite of being very late. In addition, the strains which set tubers earlier had lower percentages of stem dry weight during the growing season.

The hybrid strains except No.5 and 30 had heavier root + stolon dry weights, which were

Table 1. Maturity, total dry weight and tuber yields of 8 hybrid strains and their parents.

Strain and parent	Maturity*	Total dry weight (g/m^2)	Tuber yield	
			Fresh (g/m^2)	Dry (g/m^2)
Hybrid strain				
80135-4	L	1386bc**	4783cd	975bcd
5	L	1172bc	4548cd	921cd
6	VL	1500bc	4312cd	897cd
16	L	1244bc	4262cd	928cd
21	L	1469bc	5575bc	1182bc
23	L	1612b	6394b	1291ab
30	EM	1010c	4386cd	913cd
40	VL	2094a	7941a	1542a
Mean	—	1434	5275	1080
Parent				
W553-4	VL	1401bc	3771d	778d
Norin No.1	ML	1172bc	4197cd	923bcd

* ; EM : early or medium, ML : medium or late, L : late and VL : very late.

** ; Means followed by the same letter are not significantly different at $p=0.05$ level of probability by DUNCAN's Multiple Range Test.

Table 2. Yield components and tuber size of 8 hybrid strains and their parents.

Strain and parent	Tuber number (/pl.)	Mean single tuber weight (g)	Starch value (%)	Percentage of tubers at different sizes (%)				
				LL	L	M	S	SS
Hybrid strain								
80135- 4	12.9b**	72.7bc	14.8ab	9	18	28	18	27
5	8.8b	100.6a	15.1ab	20	18	24	25	13
6	12.6b	67.1bc	14.4ab	4	15	30	29	22
16	19.6a	43.2d	16.1a	2	4	21	40	33
21	19.3a	57.0cd	14.5ab	7	9	19	26	39
23	12.7b	98.4a	14.5ab	14	22	32	21	11
30	11.9b	71.8bc	15.0ab	6	17	30	23	24
40	19.1a	81.9ab	13.7b	13	13	28	24	22
Mean	14.6	74.1	14.7	9	15	26	26	24
Parent								
W553- 4	23.4a	30.7e	14.9ab	1	2	13	35	49
Norin No.1	9.6b	85.8ab	15.9a	9	20	36	22	13

* ; LL : 180g～, L : 120～179g, M : 60～119g, S : 20～59g and SS : ～19g.
** ; Means followed by the same letter are not significantly different at p=0.05 level of probability by DUNCAN's Multiple Range Test.

superior to the Tuberosum parent by 45 to 228% at the maximum stage of root + stolon dry weight (10 Aug.). Percentages of root + stolon dry weight for them also tended to be larger than that for the Tuberosum parent throughout the growing season.

3. Growth parameters

Fig.2 illustrates the changes in leaf area index (LAI) during the growing season. In the early growth stage (emergence to 19 June). leaf expansion rates were very different among the hybrid strains. Only No.40 had a higher rate than the Tuberosum parent. After that, No.30 (EM), the Tuberosum parent (ML) and two late strains, No.4 and 5, attained maximum LAI (2.9 to 3.4) in about early July, although most of the late strains increased leaf area until late August and had rather high LAIs (maximum LAI : 3.8 to 5.6). Especially, two very late strains (No.6 and 40) maintained near maximum values till the end of the season.

Table 3 presents mean crop growth rate (CGR), mean net assimilation rate (NAR), leaf area duration (LAD) and mean tuber growth rate (TGR) throughout the period from emergence to 4 October and the period from tuber initiation to 4 October. Mean CGRs of the hybrid strains were almost similar to those of their parents, but only No.40 showed a significantly higher value than the others. Mean NARs of the hybrid strains ranged from 3.72 to 5.74 g/m^2/day and their mean value was slightly higher than that of the mid-parent. After tuberization, every strain and parent except No.30 increased mean CGRs, and the rise for No.40 was especially large. Mean NARs also tended to increase, but the mean value for the hybrid strains was just lower than that for the mid-parent. All of the hybrid strains except No.30 had similar or higher LADs compared with the Tuberosum parent. The two late strains, No.6 and 40, had especially higher values. The mean value of mean TGR for the hybrid strains was superior ot those of their parents, but only No.23 and 40 had significantly higher values than the Tuberosum parent. Total dry weight and tuber dry yield were closely correlated positively with mean CGR, LAD and mean TGR, but the r value between tuber dry yield and LAD was not significant (Table 4).

Relations of CGR with LAI, NAR and TGR at each experimental period are presented in Table 5. At the period from emergence to 19 June, CGR showed a significantly positive correlation with LAI. On the other hand, there was a close relationship between CGR

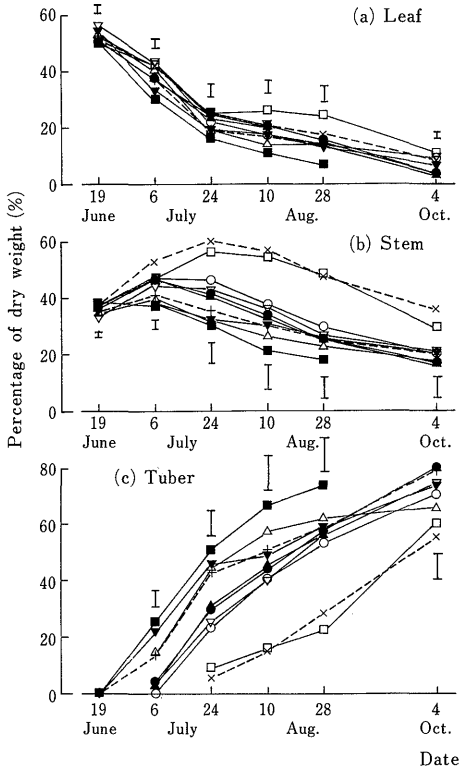

Fig.1. Changes with time in percentages of leaf (a), stem (b) and tuber (c) dry weight to total dry weight.
○ : 4, △ : 5, ▽ : 6, □ : 16, ● : 21, ▲ : 23, ▼ : 30, ■ : 40, × : Norin No. 1 and + : W553-4, —— : hybrid strain, ····· : parent. Bars indicate L.S.D. ($p=0.05$).

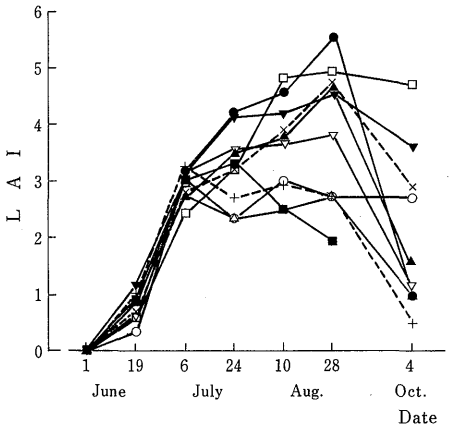

Fig.2. Changes with time in leaf area index (LAI). Symbols are the same as those in Fig.1.

and TGR at the next period (20 June to 6 July) when tubers were beginning to be formed, indicating that tuber formation would affect dry matter production largely. After July, CGR depended mainly on NAR and TGR. In particular, CGR was related to TGR very closely in the later growing season. However, no significant correlation was found between them at the period from 24 July to 10 Aug. The reason for this relationship is not well known, but it might be a consequence that the values of NAR or TGR would not reflect on CGR directly because of effects of mutual shading (the r value between NAR and LAI was -0.829**). In addition, there were significantly positive correlations between CGR and LAI ($r=0.744$*), and between TGR and LAI ($r=0.833$**) at the last period (29Aug. to 4 Oct.), suggesting that the maintenance of crop and tuber growth would depend on source activity in the end of the growing season.

Discussion

The hybrid strains used in this experiment showed relatively high productivity as compared with the leading cultivar. Particularly, the highest yielding strain (No.40) produced 79 t/ha as fresh tuber weight, which is near to the potential yield estimated by ALCOCK[1] (85t/ha). The causes of the best yield may be summariued by 1) early leaf expansion, 2) early tuber formation, 3) longer duration of large leaf area and 4) vigorous tuber growth. There is a general tendency that an early cultivar with early tuberization matures too early to out-yield such as No.30 (short duration of source), while a late one with vigorous shoot growth sets tubers too late to bulk largely such as No.6 (short duration of sink). The highest yielding strain, however, set tubers earlier in spite of very late maturity, suggesting that maturity (growing period) may not always link with tuberization. The time of tuberization was also suggested to be closely related to the partitioning of dry matter to stem. The strains which formed tubers earlier had lower percentages of stem dry weight throughout the season. The early tuberization may be advantageous not only to longevity of tuber bulking period but also to the reduction of respiratory loss in stem.

In addition, root might take an important role in leaf area duration and tuber growth.

Table 3. Mean crop growth rate (CGR), mean net assimilation rate (NAR), leaf area duration (LAD) and mean tuber growth rate (TGR) throughout the experimental period.

Strain and parent	Mean CGR ($g/m^2/day$)	Mean NAR ($g/m^2/day$)	LAD (m^2/m^2 day)	Mean TGR ($g/m^2/day$)
Hybrid strain	1) 2)	1) 2)	1)	2)
80135- 4	11.7b**(12.9)	5.24ab (4.76)	267bc	10.8ab
5	9.7b (10.3)	5.27ab (5.84)	224cd	9.8ab
6	12.3b (14.2)	3.72c (3.66)	407a	11.9ab
16	10.2b (11.3)	4.17bc (5.75)	297bc	10.2ab
21	11.5b (13.4)	4.01bc (7.16)	364ab	13.0ab
23	12.8b (15.1)	4.89ab (7.59)	326ab	14.3a
30*	11.4b (8.4)	5.74a (3.74)	178d	10.6ab
40	16.4a (19.9)	5.21ab (5.94)	402a	14.4a
Mean	12.0 (13.2)	4.78 (5.52)	308	11.9
Parent				
W553-4	11.4b (12.8)	3.93bc (4.18)	356ab	10.4ab
Norin No. 1	9.4b (10.0)	5.10ab (7.64)	231cd	8.7b

1) Estimated throughout the period from emergence to October 4th.
2) Estimated throughout the period from tuberization to October 4th.
* ; Estimated till September 15th.
** ; Means followed by the same letter are not significantly different at $p=0.05$ level of probability by DUNCAN's Multiple Range Test.

Table 4. Correlation coefficients between total dry weight, tuber dry yield and mean growth parameters.

	Mean CGR	Mean NAR	LAD	Mean TGR
Total dry weight	0.904***	−0.160	0.805**	0.828**
Tuber dry yield	0.808**	0.221	0.445	0.817**

Table 5. Relations of crop growth rate (CGR) with mean leaf area index (LAI), net assimilation rate (NAR) and tuber growth rate (TGR) during each experimental period.

Period	CGR-LAI	CGR-NAR	CGR-TGR
Emergence～19 June	0.944***	−0.539	—
20 June～ 6 July	0.498	0.127	0.893**
7 July～ 24 July	0.721*	0.852**	0.787**
25 July～ 10 Aug.	0.109	0.431	−0.137
11 Aug.～ 28 Aug.	0.620	0.831**	0.958***
29 Aug.～ 4 Oct.	0.744*	0.603	0.921***

IWAMA et al.[10] reported that the vigorous growth of shoot for the late cultivars would be closely associated with volumes of root in the later growing season. In this experiment, therefore, the longer duration of leaf area for most of the strains appears to be supported by their larger volumes of root. Consequently, their vigorous tuber growth might be able to be maintained till the end of the growing season.

In yield components, the highest yielding of the hybrid strain appears to be a multiplicative interaction resulting from the combination of the heavier tuber set of Andigena and the larger tuber size of Tuberosum as similar results reported by CUBILLOS et al.[2] and TARN et al.[14]. Almost cultivars usually set only about 10 tubers per plant in normal planting system, it is therefore necessary to extend sink

size by introducing the character of setting large number of tubers from wild or related species. These species will be simultaneously required to possess the potentiality to bulk tubers as large as cultivars', since some derivatives from crosses with wild species have often failed to bulk large sized tubers (too late tuberization or shortage of source)[6].

The hybrid strains used in this experiment were derived from a small sized population[9]. Judging from this high frequency in appearances of high yielding strains, it seems that W553-4 would have a large possibility as a breeding material to increase biomass in potato crop.

Summary

Eight high yielding strains (80135-4, 5, 6, 16, 21, 23, 30 and 40 ; 80135 is abbreviated as follows), which had been selected from the hybrid population between a Andigena strain (*Solanum tuberosum* ssp. *andigena* : W553-4) and a Tuberosum cultivar (*S. tuberosum* ssp. *tuberosum* : cv. Norin No.1), were planted to assess their productivities in comparison with their parents.

1. All of the hybrid strains except No.30 had late or very late maturities. The means of total weight and tuber yield as dry base for the hybrid strains were 22% and 17% higher than the Tuberosum parent, respectively. The best tuber yield of the hybrid strain (No.40) was 79 t/ha as fresh weight, which was superior to the Tuberosum parent by 89%. The mean tuber number of the hybrid strains was slightly lower than that of the mid-parent, but No. 16, 21 and 40 produced significantly larger numbers of tubers than the Tuberosum parent. All of the hybrid strains had larger sizes of tubers than the Andigena parent. The mean starch value of the strains did not so different from those of their parents.

2. There was a tendency that a later strain had higher percentages of leaf and stem dry weights, a lower one of tuber dry weight, and later tuber initiation. Exceptionally, No.40 showed low percentages for leaf and stem dry weights, a high one for tuber dry weight and relatively early tuber formation in spite of being very late. In addition, the strains which set tubers earlier had lower percentages of stem dry weight throughout the growing season. Almost strains had large volumes of root + stolon dry weight and their percentages to total dry weight were also higher.

3. Only No.40 had a higher leaf expansion rate than the Tuberosum parent in the early growing stage. After that, No.30, the Tuberosum parent and two late strains (No.4 and 5) attained maximum leaf area index (LAI) in early July, although most of the late and very late strains increased leaf area until late August and had rather high LAIs. Mean crop growth rates (CGRs) of the hybrid strains were almost similar to those of their parents, but only No.40 showed a significantly higher value than the others. The mean value of mean net assimilation rates (NARs) for the hybrid strains was slightly higher than that of the mid-parent. After tuberization, almost hybrid strains increased mean CGR and mean NAR. All of the hybrid strains except No.30 had similar or higher leaf area durations (LADs) compared with the Tuberosum parent. The mean value of mean tuber growth rate (TGR) for the hybrid strains was superior to those of their parents. Total dry weight and tuber dry yield were closely correlated positively with mean CGR, LAD and mean TGR, but the r value between tuber dry yield and LAD was not significant. CGR was closely related LAI at the period from emergence to 19 June, and to NAR at the period from 7 July to 24 July and the period from 12 Aug. to 28 Aug. The close relationships were also found between CGR and TGR throughout the growing season except the period from 25 July to 10 Aug.

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* In Japanese with English summary.

〔和 文 摘 要〕

バレイショにおける Andigena × Tuberosum 雑種系統の乾物生産特性

礒田昭弘*・中世古公男・後藤寛治・西部幸男**
(北海道大学農学部・**北海道農業試験場)

著者らは，近年育種材料として注目されている Andigena (*Solanum tuberosum* ssp. *andigena*) 系統 (W 553-4) と栽培品種 (*S. tuberosum* ssp. *tuberosum* cv. 農林1号) とを交配し，雑種集団を作成した．本報ではこの集団より高収性について選抜した8系統 (80135-4, 5, 6, 16, 21, 23, 30, 40) を，圃場条件下で植え付け，その乾物生産特性について調査した．

1. No. 30 (以下80135を省略する) を除く他の7系統は Tuberosum 親 (農林1号) に比べ熟期が遅く，とくに No. 6, 40は Andigena 親 (W 553-4) と同程度の極晩生であった．全乾物重および塊茎乾物収量の雑種系統の平均値は Tuberosum 親に比較してそれぞれ22%，17%大きかった．特に最大収量を示した No. 40は，塊茎収量で79 t/ha となり農林1号を89%上回った (第1表)．

塊茎数では雑種集団の平均値は中間親に比べわずかに小さかったが，No. 16, 21, 40 は有意に Tuberosum 親より大きかった．平均1個塊茎重ではすべての系統が Andigena 親と比べ大きな値を示した．また，デンプン価では，いずれの系統も両親の値と大きく異ならなかった (第2表)．

2. 晩生系統ほど葉および茎乾物重割合が大きく，塊茎乾物重割合が小さく，塊茎形成期が遅い傾向が認められた．しかしながら，No. 40は極晩生にもかかわらず比較的塊茎形成期が早く，塊茎乾物重割合も大きかった(第1図)．また，塊茎形成期の早い系統は，生育期間を通じて茎乾物重割合が小さく推移した．No. 5, 30 を除くすべての雑種系統は Tuberosum 親に比べ根＋ストロン乾物重および根＋ストロン乾物重割合が大きかった．

3. Tuberosum 親に比べ，雑種系統のうちただひとつ No. 40 は生育初期の葉面積展開速度が大きかった．大部分の雑種系統では 8 月後半に葉面積指数 (LAI) が最大となり，その値は Tuberosum 親に比較して大きかった．極晩生の No. 6 および No. 40 は 10 月上旬まで大きな LAI を維持した（第 2 図）．

調査期間中(萌芽から 10 月 4 日)の平均個体群生長速度 (CGR) では，雑種系統の平均値は Tuberosum 親に比べわずかに大きく，平均純同化率 (NAR) では小さかった．また，塊茎形成期以降ではほとんどの雑種系統および親品種で平均 CGR ならびに平均 NAR が増大する傾向があった．葉積 (LAD) では大部分の系統が Tuberosum 親に比較して大きな値となった．塊茎形成期から 10 月 4 日の平均塊茎乾物増加速度 (TGR) では，雑種系統および両親の間に大きな差異は認められなかったが，No. 23 ならびに No. 40 は Tuberosum 親に比べ有意に大きかった（第 3 表）．

全乾物重および塊茎乾物収量は，平均 CGR, LAD および平均 TGR と有意な正の相関を示したが，塊茎乾物収量と LAD との間には有意な関係は認められなかった（第 4 表）．CGR は萌芽から 6 月 19 日の期間では LAI と，7 月 7 日から 7 月 24 日ならびに 8 月 12 日から 8 月 28 日の期間では NAR と有意な正の相関を示した．また，CGR と TGR の間には 7 月 25 日から 8 月 10 日の期間を除く全生育期間で有意な正の相関が認められた（第 5 表）．

* 現在，千葉大学園芸学部．