Some Characteristics of Two Andigena (*S. tuberosum* ssp. *andigena*) Strains in Terms of Dry Matter Production and Canopy Structure*

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For many years it has been pointed out that cultivated potatoes (*S. tuberosum* ssp. *tuberosum*) have a narrow gene background, so that many attempts have been made to introduce the genes of wild and related species to such cultivars. In doing so, however, although specific genes for disease resistance, e.g., late blight (*Phytophthora infestans*), leaf-roll virus, etc., have already been introduced, potato breeders have paid little attention to genes that are likely to contribute to the improvement of yield capacity.

In 1957, a selection experiment was started to produce Andigena (*S. tuberosum* ssp. *andigena*) parents suitable for incorporation into potato breeding programmes. An excellent population with high yield was created after selection for adaptability to long-day conditions and yield, and named 'Neo-Tuberosum'^{8,9)}. After that, Andigena attracted the attention of potato breeders as materials for improving yield capacity by crossing and/or selection^{2,3,11)}.

A better understanding of the characteristics of parent materials and the proper selection of superior types are the first steps for effective progress in breeding programmes. However, there is little about the fundamental information on the growth processes for Andigena strains. In this experiment, we used two Andigena strains with different shoot morphology, and compared their dry matter accumulation patterns, canopy structure and light interception with those for two main cultivars.

Materials and Methods

Two Andigena strains, W553-4 and C10193-1, with typically different types of canopy, were selected from the 59 strains stocked at the Potato Breeding Center of the Hokkaido National Agricultural Experiment Station and were used in this experiment. Norin No.1 and Hokkai No.61, high yielding late cultivars, were used as comparative cultivated potatoes.

On May 6, mother tubers were planted in 75 cm-width rows and spaced 30 cm within the row. Each plot comprised five rows 11.4 m in length (38 plants per row) and designed as a randomized complete block with two replications. A combination of N:P:K as a fertilizer at the ratio of 63, 99 and 81 kg/ha respectively, was banded just before planting.

From June 12, six plants from the center three rows were harvested from each plot at intervals of two weeks, and the leaf, stem and tuber dry weight of the four plants excluding the largest and the smallest one were recorded after oven drying for 48 hours at 80°C. The leaf area of a representative plant was measured by an automatic leaf area meter (Hayashidenko, AAM-7). The leaves were then dried and weighed for calculation of specific leaf area (SLA, cm²/g). The leaf area index (LAI) was calculated as the mean dry weight per unit land area (g/m²) × SLA. At the same time, the relative light intensities at the bottom of the canopy were recorded at 63 points on a 10 cm square grid within a land area 0.75 m (across the rows) × 1 m at about noon using the relative light intensity photometer to sensible the

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range of 450 nm to 700 nm (Sanshinkogyo Corp., NS-II).

On July 14, at the flowering stage when the canopy had already closed, the vertical distribution of leaf area, leaf size and compound leaf inclination were measured with plants. At the same time, relative light intensities at the horizontal level were recorded at the 10 cm height intervals (10 points) within canopies.

On October 21 (the days of leaf yellowing for Norin No.1 and Hokkai No.61 were October 4 and September 16, respectively. And the Andigena strains did not turn their leaves to yellow by October 21), eight plants were taken from each plot and tuber fresh weight, number of tubers and their gravity were measured. About 700 g of sliced tubers taken at random from plot samples were dried for determination of dry matter content.

Net assimilation rates (NAR) were calculated from the equation indicated by WATSON¹²⁾, and photosynthetically-active radiation intercepted by plant canopy (Δ PAR) and efficiency of dry matter accumulation per unit PAR intercepted (E_{PAR} , g/MJ) were also calculated from the equation indicated by NAKASEKO and GOTOH⁶⁾.

Note. ■: root + stolon, ■: leaf, □: stem and □: tuber.

Fig. 1. Dry matter accumulation on each organ.

Results

1. Dry matter accumulation and growth parameters

Fig.1 shows dry matter accumulation patterns with season progress. The cultivars started to form tubers about June 23, but tuberization of the Andigena strains did not occur until, approximately two weeks later, early July. After tuber formation, C10193-1 produced significantly ($p=0.05$) less biomass than the others, mainly because of lower tuber growth rate. The Andigena strains tended to produce relatively larger shoot weight, especially stem weight, so that the percentage of shoot dry weight was always higher than those for the cultivars throughout the season. For example, on August 6, the shoot percentages were 61, 63, 34 and 35% for W553-4, C10193-1, Norin No. 1 and Hokkai No. 61, respectively. In addition, W553-4 had considerably large amount of root and stolon dry weight.

The changes with time in growth parameters are illustrated in Fig.2. The leaf area index (LAI) for both the strains and the cultivars attained a maximum (3.3 to 4.2) at about July 7. After that, however, the LAI of C10193-1 became lower than those of the others because of infection of late blight and lodging. On the other hand, W553-4 maintained a near maximum value till the

Note. ●: W553-4, ▲: C10193-1, ○: Norin No.1 and △: Hokkai No.61. TGR means tuber growth rate.

Fig. 2. Changes with time in growth parameters.

middle of September, indicating high field resistance to late blight and lodging. The LAI of the cultivars decreased temporarily in early August, owing to lodging caused by heavy rain.

The crop growth rate (CGR) of the Andigena strains tended to be lower, in particular, C10193-1 had lower values throughout the season. CGRs decreased drastically when plants lodged in the early and late August. The net assimilation rate (NAR) for both the strains and the cultivars showed a tendency to decrease with time. The Andigena strains had lower NARs in the early stages compared with the cultivars. The cultivars had higher tuber growth rate (TGR, $\Delta \text{tuber} / \Delta t$) in the early stages, reflecting earlier tuber formation. On the other hand, the TGR of the Andigena strains with very late maturity tended to increase in the later stages. The CGR during the period from July 21 to September 16 (after tuber formation) was closely correlated with NAR ($r = 0.878^{***}$) and with TGR ($r = 0.882^{***}$), irrespective of the strains and the cultivars.

2. Radiation interception and efficiency of dry matter accumulation

The exponential values of relative light intensities (%) at the bottom of the canopy were linearly related to LAI on a number of occasions during the season (Fig.3). The light interception coefficient (K_s) differed little among the strains and the cultivars, although there was some variance in LAI of 3 to 4. The K_s value calculated without regard to the strains and the cultivars was 0.703, and the LAI required for 95% light interception was estimated to be about 3.3.

Photosynthetically-active radiation intercepted by plant canopy (ΔPAR) and leaf area duration (LAD) were slightly high for W553-4, but efficiency of dry matter accumulation per unit PAR intercepted (E_{PAR}) was adversely high for the cultivars (Table 1). The ΔPAR and LAD for Hokkai No.61 was the lowest, reflecting its early defoliation.

3. Canopy structure and leaf morphology

As shown in Fig.4, the canopy structures of the Andigena strains were quite different from those of the cultivars at the flowering stage. The leaf area of W553-4 was distributed uniformly over all layers and the light penetrated gradually to the bottom.

Fig. 3. The relationships between LAI and relative light intensities at the bottom of the canopy during the period from June 12 to Aug.6.

Note. Symbols are the same as those in Fig.2.

Table 1. Photosynthetically-active radiation intercepted by crop canopy (ΔPAR), efficiency of dry matter accumulation per ΔPAR (E_{PAR}) and leaf area duration (LAD).

Stain and cultivar	Experimental period	ΔPAR (MJ/m ²)	E_{PAR} (g/MJ)	LAD (m ² /m ² ·day)
W553-4	June 12 - Sept. 16	586. 6a*	1. 80ab	287. 2a
C10193-1	June 12 - Sept. 16	516. 8a	1. 65b	206. 2b
Norin No. 1	June 21 - Sept. 1	507. 5a	2. 46a	245. 3ab
Hokkai No. 61	June 21 - Aug. 16	424. 7b	2. 33ab	185. 7c

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

Fig. 4. Vertical distribution of leaf area (left) and arrangement of petioles on the main stem (right) at the flowering stage.

Note. The petiole length is indicated by the same scale for plant height.

C10193-1 had the highest leaf area density at the middle of the layers (ellipse type) and almost all incoming light was intercepted above these layers. On the other hand, the cultivars showed a typical table type with high light extinction coefficient (K)⁵. More than 90% of incoming light was intercepted by the upper three layers only, so that 6 or 7 leaves had already defoliated before flowering. The petiole inclination in the plane of laminae tended to be arranged horizontally on the basal-half nodes, but vertically on the top-half nodes, though the arrangement was slightly scattered for C10193-1.

Sizes of compound leaves and terminal leaflets were largest on slightly lower nodes than the middle, and became smaller towards the stem terminal with all the strains and the cultivars (Fig.5). C10193-1 and Hokkai No.61 had small narrow leaflets, although the compound leaves were open for C10193-1 and closed for Hokkai No.61. In contrast to these, W553-4 and Norin No.1 had closed compound leaves with heart-shaped broad leaflets. The average leaf size, compound or leaflets, was the largest for W553-4 and the smallest for C10193-1.

From the results with the leaf morphology (Fig.4 and Fig.5), the canopy structure seems to be depended mainly on the petiole arrangement, not on leaf size in each node.

4. Yield and yield components

Table 2 shows yield and yield components. The *Andigena* strains produced larger number of small tubers; W553-4 and C10193-1 produced twice and four times as many as Norin No.1, and their mean single tuber weights were adversely about one half and

Fig. 5. Compound leaf area and terminal leaflet area of each node on the main stem at the flowering stage.

Note. Symbols are the same as those in Fig. 2.

one quarter, respectively. The percentage of tubers below 60 g was 77% for W553-4 and 99% for C10193-1. The starch value ranged from 11.4 to 17.6%, being the lowest for C10193-1 and the highest for Hokkai No.61. C10193-1 produced a significantly low yield in both fresh and dry weight, but W553-4 had a similar yield to that of Norin No.1. The yield of Hokkai No.61 was the lowest in fresh weight, but not different from that of Norin No.1 in dry weight because of high dry matter content.

Discussion

SIMMONDS⁷) reported that *Andigena* clones unadapted to long-day conditions had 1) greater inter-node length, 2) taller stem height, 3) heavier stem weight, 4) a smaller

Table 2. Yield and yield components

Strain and cultivar	Yield (g/m ²)		Tuber number (/pl.)	Mean single tuber weight (g)	Starch value (%)	Percentage of tubers at different sizes (%)				
	Fresh	Dry				LL*	L	M	S	SS
W553-4	5517a**	1200a	30.8b	37.7bc	13.8b	1	4	18	32	45
C10193-1	4210bc	774b	62.4a	14.2c	11.4b	—	—	1	21	78
Norin No. 1	5232ab	1102a	15.2c	73.4a	13.8b	7	10	30	36	17
Hokkai No. 61	3882c	1010a	13.7c	59.6ab	17.6a	1	9	34	38	18

Note. * LL : 180g-. L : 120-179g, M : 60-119g, S : 20-50g and SS : -19g.

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

compound leaf, and 5) larger stem number per plant when compared with *Tuberosum*. In this experiment, the *Andigena* strains had also late tuber formation, heavier stem weight and lower tuber growth rate during the early half of growing season. W553-4, however, had larger compound leaves at basal nodes, vigorous early growth and long leaf area duration, resulting in producing the same yield as one of the high yielding cultivars, Norin No.1. TAGUCHI et al.¹⁰⁾ pointed out that the early establishment of the optimum LAI (3 to 4) and its long duration are one of the factors for high yielding. CGR was closely related to NAR and TGR during the period after tuberization and these parameters decreased drastically when plants lodged severely. From these facts, W553-4, which had high field resistance to late blight and lodging, and long leaf area duration, seems to have some desirable characteristics.

The EPARS of the cultivars are comparable with 2.49 g/MJ, but low compared with 3.42 g/MJ for potato at Sutton Bonington⁴⁾. The level of EPARS, 1.80 and 1.65 g/MJ for the *Andigena* strains, were fairly below these values, and the same results were obtained in another experiment conducted in 1983 (unpublished). EPAR may be influenced by some factors such as photosynthetic activity of leaves, light distribution over leaves within the canopy and respiratory activity of non-productive parts. Moreover, a high correlation coefficient between NAR and TGR ($r=0.722^{**}$) suggests that sink capacity is closely

related to source activity. The reason for low EPARS of the *Andigena* strains are not well known in this experiment, but it might be attributed to low photosynthetic activity because the *Andigena* strains intercepted more PAR and had smaller K values compared with the cultivars.

ALLEN¹⁾ has stated that discussion of desirable plant forms is conspicuously absent from the literature on this crop. W553-4 indicated a uniform canopy structure with a small K value seems to be theoretically advantageous for energy utilization. A breeding programme to produce a cross between *Andigena* (W553-4 and C10193-1) and *Tuberosum* (Norin No.1) is now in progress and several excellent hybrids that outyield their mid-parents have already been obtained. The detailed analysis of the hybrid populations may give useful informations about the relationships between plant types and productivity.

Summary

Two *Andigena* (*S. tuberosum* ssp. *andigena*) strains with different canopy structure, W553-4 and C10193-1, were compared with two cultivars (*S. tuberosum* ssp. *tuberosum*), Norin No.1 and Hokkai No.61, to evaluate their yield potentiality as a breeding material in terms of dry matter production. The differences between the *Andigena* strains and the cultivars in dry matter accumulation became clear after tuber formation. The *Andigena* strains had several undesirable yield characteristics; later tuber formation

(by about 2 weeks), lower tuber growth rate during the early half of the growing period, higher partitioning of dry matter to stem, smaller size tubers and lower efficiency of dry matter accumulation per unit PAR intercepted (E_{PAR}). For final tuber yield, however, because of very late maturity and long leaf duration, W553-4 produced the same yield (55 t/ha as fresh weight) as one of the cultivars, Norin No.1.

Morphologically, the two *Andigena* strains had greater inter-node length, taller stem height and heavier stem weight, but W553-4 had large leaves at the basal nodes and a uniform canopy structure with a small K (light extinction coefficient) value.

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* In Japanese with English Summary.

〔和 文 摘 要〕

乾物生産ならびに葉群構造からみた Andigena 系統の特性

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Andigena 系統 (*S. tuberosum* ssp. *andigena*) は栽培種 (*S. tuberosum* ssp. *tuberosum*) の祖先種とされ、現在のバレイショ栽培種の遺伝的背景を拡げる上で重要な育種材料として注目されている。そこで、本報では農林 1 号、北海 61 号を比較品種とし、Andigena 2 系統 (W553-4, C10193-1) の乾物生産特性および葉群構造について検討した。

1. Andigena 系統は栽培品種に比べ、塊茎形成が約 2 週間遅く、生育前半の塊茎乾物増加速度 (TGR) が小さいほか、地上部乾物重、特に茎の割合が大きかった (第 1 図)。

2. CGR, NAR および TGR は、生育前半では Andigena 系統が低く推移し、塊茎形成後の CGR は NAR ($r=0.878^{***}$) および TGR ($r=0.882^{***}$) と高い正の相関を示した (第 2 図)。

3. 植物体が受光した光合成有効放射量当たりの乾物生産効率 (EPAR) は Andigena 系統が小さかった (第 1 表)。

4. Andigena 系統の塊茎は栽培品種に比べ著しく小さかった。最終塊茎収量は C10193-1 が小さいものの、W553-4 は極晩生で長期間葉面積を維持したため、農林 1 号と同程度の高い値を示した (第 2 表)。

5. Andigena 系統は栽培品種と全く異なる葉群構造を示した。特に、W553-4 は均一な葉群構造を示し、下位葉が大きいほか吸光係数 (K) が小さく、受光ならびに群落内部への光の浸透が良好であった (第 4, 5 図)。