Field Performance of June Yellows-affected Clones of 'Blomidon' Strawberry

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Abstract. Clones of 'Blomidon' strawberry (*Fragaria ×ananassa* Duch.) exhibiting a range of June yellows symptoms were grown in field plots to measure effects on productivity and fruit characteristics. Self-pollinated seedlings grown from these clones were evaluated for symptom expression as an additional measure of severity of June yellows. Large differences in yields were recorded among clones, ranging from 1.9 to 14.7 t·ha⁻¹ in 1994 and 8.4 to 28.3 t·ha⁻¹ in 1995. Clones with severe symptoms produced smaller fruit than clones with slight symptoms in 1994 but not in 1995. Small differences existed for the titratable acidity of the fruit but not for soluble solids concentration. The frequency of normal green seedlings among selfed progeny ranged from 48% to 98% and was negatively correlated with symptom severity ratings of the parent clones. Severity ratings and selfed seedling abnormality rates were good predictors of fruit yield. No clones of 'Blomidon' were free of June yellows.

June yellows is a degenerative disorder of strawberry plants with symptoms ranging from mild yellowing of the leaves to severe chlorosis that can result in plant death (Hughes, 1989). A unique feature of June yellows is its delay in expression; several years may pass after a cultivar is introduced before symptoms appear (Rose, 1992). Despite critical attempts for more than 60 years to discover a causal agent responsible for this disorder (Plakidas, 1932; Watkins et al., 1992), none has been conclusively implicated. The evidence points to a genetic cause (Hughes, 1989; Rose, 1992). Early studies of strawberry progenies suggested that either a single recessive gene (Richardson, 1920) or more than one gene (Demaree and Darrow, 1937) were responsible for the disorder. The interpretation of segregation ratios is made difficult because *Fragaria ×ananassa* is an autoallopolyploid (Senanayake and Bringham, 1967) and seedlings classed as unaffected may eventually show symptoms. Williams (1955) hypothesized that a rogue cytoplasmic gene, not associated with any organelle, was responsible for the delay in symptom expression. This gene was envisaged as increasing in concentration as it replicated, and when a thresh-

old was reached, chlorophyll synthesis would be inhibited. More recently, Rose (1992) suggested that June yellows may be an example of hybrid variegation that arises after interspecific crosses in plants with biparental plastid inheritance, resulting in a nonharmonious interaction between the plastids of one parent and the hybrid genome. An unequal distribution of the two types of plastids to the daughter cells at mitosis will tend to sort out the plastids into homoplasmatic lines. This process will take time and is hypothesized to account for the delay in symptom expression; it also may explain why persistent green clones of cultivars affected by the disorder can be found.

Demaree and Darrow (1937) suggested and Rose (1992) reaffirmed that selfing might prove useful as a test to reveal potential yellowing in the genetic stock. Williams (Brown, 1954) reported that a symptomless clone of 'Blakemore' gave 5% yellow seedlings when selfed in 1952 and 13% when selfed in 1953. Symptoms of June yellows appeared in the clone in 1954. Williams (1955) also found that the percentage of yellowed seedlings given on selfing was proportional to the severity of the symptoms shown by the parental 'Blakemore' clones. June yellows is especially troublesome for strawberry breeders because it can, without warning, cause the loss of a useful cultivar.

'Blomidon' was selected in 1976 and introduced in 1984 from the strawberry breeding program of the Kentville Research Centre (Craig et al., 1991). By 1990 it had become the principal late-season variety in Nova Scotia and was gaining in popularity throughout northeastern North America. In Spring 1990, abnormally yellow foliage on 'Blomidon' was reported from several localities. With the appearance of white streaks and leaf puckering during the following spring, symptoms had become more severe and the June yellows disorder was diagnosed (Maas, 1984). Supporting the diagnosis was the observation that a high proportion of 'Pandora' × 'Blomidon' seedlings from the breeding program, planted in 1989, were symptomatic of June yellows in 1990.

The following study was undertaken to 1) determine the effect of June yellows on yield and fruit characteristics of 'Blomidon' clones from various sources; 2) identify clones free of June yellows; and 3) determine if selfed seedlings from clones reflected yields and severity of June yellows.

Materials and Methods

In Fall 1991 or Spring 1992, plants of 'Blomidon' were obtained from commercial strawberry growers who had old blocks that were planted soon after the cultivar was introduced (see Table 1). Growers selected plants that appeared vigorous, healthy, and free from June yellows. For comparison, several clones expressing severe symptoms (JY), three clones maintained as nuclear stock in the Kentville Research Centre screenhouse (SH), and one clone from the Ontario Strawberry Certification Program (OMAF) were included. Mild symptoms of June yellows had been observed on the SH clones, but the OMAF clone was reported to be free of symptoms. Clones from Thornley and Whenham were received too late to be included in the field trial, but they were included in the selfing test. Individual plants from each source were graft-indexed to detect viruses, which could reduce yields and confound research results. Virus-negative clones were propagated in field beds in 1992 and set out in a field trial at Kentville in 1993 with four blocks in a randomized complete block design. Matted rows were developed from five plants set at 45 cm within and 1.4 m between rows. Matted rows were narrowed to 55 cm in the fall. The severity of symptom expression was rated in May 1994 to provide a baseline for comparison with clonal productivity. Plots were harvested in 1994 and 1995

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Table 1. List of 'Blomidon' clonal accessions.

Clones	Source	Year from nursery
SH4, 5, 6	Kentville Research Centre, nuclear stock	---
OMAF	Ontario Strawberry Certification Program, foundation stock	---
JY7, 8, 11, 12	Various sources in NS ²	1989 or 1990
McInnis#5, #6	McInnis Bros. Farms, St. Peters Bay, P.E.I.	1988
Webster#1, #2, #13	Webster Farms, Cambridge, N.S.	1987
Thornley#1, #2	Campbellton Berry Farms, Campbellton, Nfld.	1985
Whenham#1, #2	Terry Di Farm, Bass River, N.S.	1985

²The JY clones were collected by R.A. Murray, extension horticulturist with the Nova Scotia Dept. of Agriculture and Marketing. The four clones showed severe symptoms of June yellows in the field.

Table 2. Severity of June yellows in 'Blomidon' strawberry, titratable acidity (TA) of fruit in 1994, and field performance of clones harvested at Kentville in 1994 and 1995.

Clones	Symptom rating ^z (0-3)	TA (%)	Marketable yield (t·ha ⁻¹)		Fruit size (g/fruit)	
			1994	1995	1994	1995
1. Webster#1	1.0	1.37	14.7	28.3	12.2	11.2
2. Webster#2	1.0	1.39	14.2	26.6	12.5	10.6
3. Webster#13	2.0	1.41	12.3	23.0	12.0	10.9
4. McInnis#5	1.0	1.33	12.4	22.2	11.2	11.6
5. McInnis#6	2.0	1.39	11.5	22.1	12.4	10.9
6. OMAF	2.2	1.39	11.4	24.5	11.1	10.9
7. SH4	2.2	1.40	8.3	20.2	11.0	11.2
8. SH5	2.8	1.44	7.6	21.8	11.3	12.0
9. SH6	2.0	1.46	6.2	17.8	10.2	11.1
10. JY7	3.0	1.52	1.9	8.4	7.0	10.8
11. JY8	3.0	1.39	6.5	19.8	12.6	11.9
12. JY12	2.8	1.45	3.6	14.0	8.4	9.8
SEM (n = 4, df = 33)	0.15	0.028	1.05	1.64	0.64	0.42
F significance						
Clone	***	**	***	***	***	NS
JY vs. rest ^y	***	**	***	***	***	NS
SH vs. rest ^x	***	*	***	***	*	NS

^zRatings on a four-point scale (0 = no symptoms, 3 = severe symptoms) taken on 9 May 1994.

^yOrthogonal contrast of the three JY clones vs. the remaining nine clones.

^xOrthogonal contrast of the three SH clones vs. the remaining nine clones.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 3. Frequency of normal green seedlings among selfed progeny of 'Blomidon' clones.

Clone	Normal seedlings ^z (%)
Thornley#2	98.0 a
Webster#1	74.0 b
Whenham#2	69.0 bc
Whenham#1	68.0 b-d
McInnis#6	64.5 b-e
SH6	64.5 b-e
SH4	62.5 b-f
SH5	62.0 b-f
McInnis#5	61.0 c-f
Webster#13	60.5 c-f
Webster#2	60.0 c-g
Thornley#1	58.5 c-g
OMAF	56.7 d-g
JY11	54.5 e-g
JY12	54.0 e-g
JY7	51.5 fg
JY8	48.0 g
SEM (n = 4, df = 49)	4.24

^zMean separation by least significant difference test at $P \leq 0.05$.

Fig. 1. Scatter plot with linear regression line showing relationship between cumulative yield (1994 + 1995) in field plots (response variate) and (a) June yellows symptom rating or (b) percentage of normal seedlings among selfed progeny (independent variates).

by picking all ripe fruit twice weekly and separating the marketable berries from the unmarketable. The weight of 25 marketable berries was recorded for each row at each harvest date. Seasonal berry weight was calculated as described by Moore (1970). Fruit samples were taken at midseason in 1994 and frozen for subsequent analysis of soluble solids concentration (SSC) using a refractometer and for total acidity (TA) as citric acid, by titrating with 0.5 N NaOH to pH 8.1 with a Mettler DL40RC automatic titrator (Mettler Instruments, Zurich).

Analysis of variance procedures of Genstat 5 (Payne et al., 1993) were used to analyze data. Orthogonal contrasts were chosen to examine differences between the severely affected JY clones vs. the other nine clones, and between the SH clones that had been used in plant propagation programs vs. the other clones. Linear regression of yields and measures of June yellows and correlations between measures of June yellows were calculated with Quattro Pro 5.0 (Borland International, Scotts Valley, Calif.).

Four plants of each 'Blomidon' clone were grown in the greenhouse and self-pollinated. Two clones each of 'Honoe' and 'Mira' with no history of June yellows were included as control cultivars. Each plant was covered with a Delnet pollination bag (Applied Extrusion Technologies, Middletown, Del.) and selfed using a camel-hair brush. Seeds were extracted from ripe fruit and 50 random seedlings per plant were grown to the third-trifoliolate-leaf stage, and scored as either normal or abnormal (yellow).

Results and Discussion

In Spring 1994, severe symptoms of June yellows were evident on the JY clones while only mild symptoms were expressed by Webster#1, Webster#2, and McInnis#5 (Table 2). The three SH clones, which were used until 1992 as nuclear stock plants in several plant propagation programs, exhibited moderate to

severe symptoms in the field plots. Only mild symptoms had been previously observed on these clones while they grew in the screenhouse. Fruit from all clones of 'Blomidon' were typical in appearance for the cultivar and there were no significant clonal differences in the percentage of unmarketable yield (data not shown). This observation differs from 'Auchincruive Climax' in which severely stunted plants produced dull red berries (Posnette and Cropley, 1955). Among 'Blomidon' clones, SSC averaged 8.4% but did not differ significantly; however, there were clonal differences in TA levels. JY7 had the highest TA level.

The 'Blomidon' clones obtained from growers (1–5) were more productive than the JY clones (10–12) or those from the screenhouse stock (7–9) (Table 2). Yields for Webster#1 and Webster#2 were similar to those recorded for 'Blomidon' before its introduction (Craig et al., 1991). The large difference in yields between 1994 and 1995 is attributable to late running and bed filling in the planting year. This effect would be more pronounced on the weakly growing clones showing severe symptoms of June yellows. Fruit weight was similar for all clones, with the exception of JY7 and JY12 in 1994, which weighed the least. Reduced yields and fruit sizes with increases in symptom severity have been reported with 'Auchincruive Climax' (Posnette and Cropley, 1955; Wilson, 1955). Differences among 'Blomidon' clones in mean harvest date were small and inconsistent between years (data not shown).

Webster#1, the most productive clone in the field trial, gave 74.0% normal seedlings when self-pollinated, while JY7, the least productive, gave 51.5% normal (Table 3). The percent normal seedlings produced in the selfing experiment correlated negatively with symptom ratings of parental clones ($r = -0.68$).

Symptom ratings of field plots provided as good an indicator of fruit yields as data from the selfing test (Fig. 1). 'Blomidon' clones from the same location varied widely. Webster#1 and Webster#2 were very productive in the field, but in the selfing test Webster#2 was similar to the JY clones (Table 3). Similarly, the clones from Newfoundland (Thornley#1 and #2), although from the same field, differed greatly in the selfing test. None of the 'Blomidon' clones were completely free of abnormal, yellow seedlings. All of the seedlings of 'Honoe' and 'Mira' were normal.

Although no 'Blomidon' clones completely free of June Yellows were identified, Webster#1 has demonstrated good field performance and Thornley#2 produced the most normal seedlings in the selfing test. If these clones were introduced into plant propagation programs, they would have to be closely monitored for increasing symptom severity. The selfing test applied annually would be a useful supplement to visual observation of parental clones and may indicate degeneration before increased symptom expression.

The use of the selfing test before the release of a cultivar, as suggested by Demaree and Darrow (1937) and Rose (1992), might not have revealed the vulnerability of 'Blomidon'. Had 'Blomidon' been selfed before its release in 1984, results likely would have been at least as good as for Thornley#2 (98.0% normal) and June yellows might not have been suspected, because non-degenerative chimeric variegations occur in some genotypes at low frequencies (Hughes, 1989; Maas, 1984). The selfing test may be useful, however, to confirm diagnosis of June yellows based on mild foliar symptoms. Further research is required to determine if the selfing test results are positively correlated with the rate of degeneration and, therefore, with the longevity of a clone.

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