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Assessment of Day-Neutrality Scoring Methods in Strawberry Families Grown in Greenhouse and Field Environments

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Abstract: A strawberry plant is considered day-neutral if it can form flower buds under both long and short day conditions; however, researchers use different methods to score day-neutrality. We studied the relationship among several different evaluation methods for day-neutrality and analyzed the possibility that greenhouse screens can be used to predict field flowering performance. The evaluation methods included: 1) flowering within 100 days from germination in a greenhouse; 2) flowering during the first summer after planting in the field; 3) flowering under both short and long days in the second year in a greenhouse; and 4) flowering under both short and long days in the second year in a field. Scoring day-neutrality within 100 days from germination was a poor predictor of field performance. However, greenhouse screens were accurate in predicting field performance, if the flowering behavior of individuals was followed through a whole season. The percentage of day-neutral progeny observed in our second year greenhouse results was highly correlated with the subsequent field evaluations, and the families with the highest flowering strength in the field also had the highest percentage of day-neutral individuals in both greenhouse and field screens. Several horticultural traits were measured in the field including runner production, crown production, flower number and fruit weight. Of these, only mean runner number in families was negatively correlated with % day-neutrality.

Key Words: strawberry, day-neutrality, breeding, greenhouse, correlation

Sera ve Açık Alan Koşullarında Yetiştirilen Çilek Ailelerinde Gün-Nötr Değerlendirme Yöntemlerinin İncelenmesi

Özet: Bir çilek bitkisi hem uzun hem de kısa gün koşullarında çiçek tomurcuğu oluşturabiliyorsa gün-nötr olarak değerlendirilir. Ancak araştırmacılar gün-nötr özelliğini değerlendirmek için değişik yöntemler kullanırlar. Bu çalışmada, değişik gün-nötr değerlendirme yöntemleri arasındaki ilişki ve sera ile açık alan koşullarındaki çiçeklenme davranışlarının tahmini için kullanım olasılığı üzerinde çalışılmıştır. Kullanılan değerlendirme yöntemleri: 1) çimlenmeden sonraki 100 gün içinde serada çiçeklenme; 2) yaz boyunca açık alanda çiçeklenme; 3) hem uzun hem de kısa gün koşullarında serada çiçeklenme; ve 4) hem uzun hem de kısa gün koşullarında açık alanda çiçeklenme. Çimlenmeden sonraki 100 gün içinde serada çiçeklenme, açık alan çiçeklenme davranışlarının başarısız bir tahmincisi olmuştur. Ancak, bireylerin çiçeklenme davranışları tüm bir sezon boyunca izlendiğinde, seralar, açık alan davranışlarının tahmininde başarılı olmuştur. İkinci yıl sera değerlendirilmesindeki yüzde; gün-nötr birey sayısı, arazi değerlendirilmesiyle yüksek oranda ilişkili bulunmuş, çiçeklenme gücü en yüksek aileler, hem sera hem de açık alan değerlendirmelerinde en yüksek gün-nötr birey yüzdelerini vermişlerdir. Yavru bitki, gövde, çiçek sayıları ve meyve ağırlığı gibi bazı bahçe bitkileri özellikleri de açık alanda belirlenmiştir. Bu özellikler arasından sadece yavru bitki sayısı gün-nötr özelliğiyle ilişkili bulunmuştur.

Anahtar Sözcükler: çilek, gün-nötr, ıslah, sera, ilişki

Introduction

The first successful introgression of day-neutrality (DN) into commercial octoploid strawberries was done by Bringhurst and Voth (1984) at the University of California, Davis, when they transferred genes from a native clone of *Fragaria virginiana* subsp. *glauca* from the Wasatch Mountains of Utah. This introduction revolutionized the strawberry industry and DN cultivars currently account for about 60% of Californian production (Hancock, 1999). However, DN cultivars

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carrying the same source of DN remain a minor component of the strawberry industry in continental climates (Dale et al., 2002). Current DN cultivars suffer from summer heat outside of Mediterranean climates and flower bud initiation is completely inhibited at or above 30/26 °C day/night temperatures (Durner et al., 1984). These cultivars have reduced yields and produce small, soft fruits in the middle of the summer (Draper et al., 1981).

To breed DN cultivars suitable to continental climates, breeders are very interested in identifying new, much stronger DN sources. For this purpose, native strawberry clones have been collected from Alaska, Alberta, Minnesota, New York, the northern Rocky Mountains, Ontario, Pennsylvania and western North Carolina (Luby et al., 1992; Hancock et al., 1993; Hokanson et al., 1993; Sakin et al., 1997). Over 2,500 native strawberries, originating from a wide geographical range, including climates with high summer temperature, have been evaluated for their flowering types and horticultural attributes. Out of this group, several elite day-neutral clones of *F. virginiana* have been selected including Frederick 9, LH 39-15 and RH 30, as they have better than average horticultural characteristics, were multiple cropping in the field and proved useful in breeding multiple cropping progeny (Hancock et al., 2001 a, 2001 b, 2001 c; Serçe and Hancock, 2002; Serçe et al., 2002).

The genetics of day-neutrality has been studied extensively with no consistent results (for review see Hancock, 1999). Several different models have been proposed to explain the genetic control of photoperiod in strawberries including: 1) regulation by a single-gene, 2) two complementary genes without modifiers, and 3) two complementary genes with modifiers (Clark, 1937; Powers, 1954; Ahmadi et al., 1990; Hancock et al., 2002). In these models, the genes regulating day-neutrality have been proposed to be dominant, recessive or both with no maternal effects (Macoun, 1924; Clark, 1937). Unfortunately, these studies were conducted using several different genetic sources of day-neutrality and various evaluation methods.

Most researchers consider a strawberry plant as DN if it can form flower buds under both long and short day conditions. The most precise method of evaluating day-neutrality is to monitor the plants during the whole growing season in the field; however, several less time-consuming methods have been used including 1) presence of flowers on mother and runner plants in the planting year 2) how fast seedlings flower, and 3) crossing individuals to short day (SD) *F. chiloensis* and analyzing the percentage of day-neutral progeny produced (Nicoll and Galletta, 1987; Ahmadi et al., 1990). Greenhouse screens could also be used, but it is not known how well field and greenhouse are correlated in terms of expression of DN. Since the use of greenhouse and seedling data is the fastest way to identify DNs for cultivar development, knowledge about how well the various methods correlate is of great interest to strawberry breeders.

The timing of evaluation is particularly critical. Ahmadi et al. (1990) noted that SD genotypes with little chilling requirement might initiate flower buds in August and flower in November. If the progeny had been scored during that time, the genotype could have been misjudged as DN. Additionally, SD genotypes flower semi-continuously in the second year in mild climates. The various investigators who have studied the genetics of day-neutrality rarely used the same dates. For example, Richardson (1917) scored his genotypes from May to October, while Powers (1954) evaluated them from July to September.

In this study, experiments were designed to develop an efficient screening method to identify day-neutral progeny, to aid in the breeding of new day-neutral *F. ×ananassa* cultivars. A wide range of crosses between elite clones of native *F. virginiana* and cultivars of *F. ×ananassa* were used in these evaluations. The specific objectives were to determine: 1) the relationship between several different evaluation methods for DN, and 2) if greenhouse screens can be used to predict field flowering performance. We also evaluated a number of yield components in the various families to determine if there were any negative associations between DN and horticultural performance.

Materials and Methods

Segregated populations were constructed in a partial-diallel fashion using the genotypes listed in Table 1. To maximize the segregation in the families, the genotypes were selected from both Californian and Eastern US representatives of SD and DN cultivars, as well as elite *F. virginiana* clones (Sakin et al., 1997; Hancock et al., 2001 a, 2001 b, 2001 c). DHL 1336 ('Tribute' x

Table 1. The genotypes crossed in a partial-diallel fashion to study the correlation among different evaluation methods of day-neutrality.

Fragaria ×ananassa		*Fragaria virginiana*	
Day-neutral	Short day	Day-neutral	Short day
'Aromas'	DHL 1336	Frederick 9	Eagle 14
'Fort Laramie'	'Camarosa'	LH 39-15	High Falls 22
'Ogallala'	'Honeoye'	RH 30	Montreal River 10
'Tribute'	'Glooscap'		RH 18

Montreal River 10) is a selection from the Michigan State University (MSU) Strawberry Breeding Program.

Parental genotypes were potted in 18 x 16 x 13 cm pots in the summer of 1999, and then placed in a greenhouse at MSU with natural day lights and a mean temperature of ~ 21 °C. Crosses were made by transferring pollen with a camel hairbrush after removal of stamens using sharp tweezers to avoid self-pollination. In general, fresh pollen was collected from open flowers; however, on some occasions, pollen was stored in petri dishes at -16 °C for future use. The fruits were harvested when they were fully ripe and seeds were extracted by smashing the fruits on paper towels. Seeds were then placed on soil in pots and held in a growth chamber at 4 °C with continuous inflorescent light and moisture to promote germination. When the seeds started to germinate, in February 2000, they were placed in a growth room at ~ 18 °C and with continuous light.

Each seedling was evaluated using 5 methods to score day-neutrality: 1) They were planted in March 2000 in 14 x 12 x 12 cm pots and placed in a greenhouse at MSU under long day conditions (13 h days created with ~ 800 µmol s^{-1} m^{-2} of supplementary light) at 18-22 °C. Any genotype that flowered within 100 days from germination was considered DN (DN1-100 days to flowering). 2) The seedlings were transplanted in the field at the Southwestern Michigan Research and Extension Center in Bentin Harbor, Michigan, on 25 July 2000 at 60 x 120 cm spacing and any that flowered in that same summer before 9 September 2000 were considered DN (DN2-1st year field flowering). 3) Rooted 1-year-old runner plants were collected from each of these mother plants and placed in an unheated greenhouse in September 2000, and allowed to flower in the spring of 2001 without supplementary light. Those plants that flowered again before 1 September 2001 were considered DN (DN3-2nd year greenhouse flowering). 4) All of the original field-grown plants were monitored another year for flowering in the spring and summer of 2001. Those that flowered in the spring and again before 9 September 2000 were considered DN (DN4-2nd year field flowering). 5) During this same period in the field, genotypes that produced flowers on their newly formed runners were considered DN (DN5-runner flowering).

Greenhouse surveys can only be used to identify elite DN progeny if the photoperiod response of progeny is similar in the greenhouse and field, or if there are fewer DN progeny in the greenhouse, those that do produce multiple greenhouse crops are at least the strongest DN genotypes in the field. To evaluate this possibility, each field grown genotype was given a flowering strength rating (FSR) of 0-10 in the summer of 2001, after its photoperiod sensitivity had been rated in the 2000 greenhouse screens. Those plants with no flowers were rated 0, and those with the most were given a 10. In all experiments, each family was maintained in a single plot without replication.

A number of horticulturally important traits were also evaluated for each of the hybrids in the summer of 2001. Crown and runner numbers were counted on 6 May 2001, and inflorescence and flowers per inflorescence were recorded on 9 May 2001. Four randomly picked fruits from each plant were harvested on 13 June 2001 and weighed to calculate average fruit weight.

The percentage of DN progeny was calculated for each family and the grand mean for each family using each evaluation method was determined. Correlations among these scores, using family means, were calculated using the SAS program (SAS Institute, Cary, NC). The mean and standard errors of the horticulturally important traits were also determined for each family.

Results and Discussion

Different mean percentages of DN values were observed across the evaluation methods. DN5 (runner flowering) had the lowest overall mean of 18%, while DN1 (flowering in 100 days) had the highest mean of 55% (Table 2). The greenhouse evaluations produced higher means than the field evaluations (55 and 49% vs. 41 and 40%). Large amounts of variation were observed across families in the % mean DN progenies for each

Table 2. The number of individual and percent day-neutral progenies of strawberry families grown in a greenhouse at Michigan State University, East Lansing, MI, and in the field at the Southwest Michigan Research and Extension Center Benton Harbor, MI., in 2000 and 2001.

	DN1[1]		DN2[2]		DN3[3]		DN4[4]		DN5[5]		FSR[6]	
Family	N	%	N	%	N	%	N	%	N	%	N	Mean
'Aromas' x 'Aromas'	6	60	6	67	3	67	6	100	6	33	6	2.8
'Aromas' x 'Fort Laramie'	6	67	6	67	---	---	6	50	6	0	6	1.0
'Aromas' x 'Ogallala'	9	58	9	89	4	100	9	78	9	22	9	3.8
'Aromas' x 'Tribute'	14	50	14	36	---	----	14	57	14	14	14	3.1
'Aromas' x LH 39	8	67	8	50	---	---	8	25	8	0	8	0.3
'Fort Laramie' x 'Tribute'	19	79	19	68	5	100	19	68	18	33	19	2.6
'Fort Laramie' x Frederick 9	7	100	7	71	7	57	7	71	7	14	7	1.1
'Tribute' x Frederick 9	14	93	14	43	13	77	14	57	14	64	14	1.4
LH 39 x LH 39	13	100	13	54	12	33	13	38	13	23	13	0.9
RH 30 x RH 30	33	90	33	64	27	48	33	33	33	9	33	0.8
DHL 1336 x DHL 1336	19	0	19	5	17	41	19	16	19	0	19	0.3
'Camarosa' x 'DHL 1336	20	0	20	20	19	0	20	5	19	0	20	0.1
DHL 1336 x 'Honeoye'	6	33	6	17	6	0	6	17	6	0	6	0.3
DHL 1336 x 'Glooscap'	24	5	24	13	23	39	24	4	24	4	24	0.0
DHL 1336 x RH 18	15	88	15	20	15	20	15	13	15	0	15	0.2
'Camarosa' x 'Honeoye'	19	50	19	26	18	50	19	32	19	11	19	1.1
'Camarosa' x 'Glooscap'	21	24	21	33	16	63	21	62	21	14	21	2.5
'Camarosa' x Eagle 14	25	40	25	40	25	24	25	20	25	8	25	0.2
'Camarosa' x Montreal River 10	19	25	19	42	18	44	19	68	19	53	19	1.5
'Camarosa' x RH 18	24	50	24	63	17	59	24	67	24	50	24	1.9
'Honeoye' x Eagle 14	23	65	23	35	22	9	23	9	23	0	23	0.1
'Honeoye' x RH 18	5	80	5	80	4	100	5	40	5	0	5	0.4
'Glooscap' x RH 18	16	47	16	38	15	27	16	6	16	0	16	0.3
Eagle 14 x Eagle 14	28	61	28	0	28	32	28	0	28	4	28	0.0
High Falls 22 x High Falls 22	35	57	35	29	34	26	35	34	35	31	35	0.7
High Falls 22 x Montreal River 10	13	42	13	38	12	42	13	15	13	0	13	0.6
Montreal River 10 x Montreal River 10	14	47	14	36	13	38	14	29	14	21	14	0.4
Montreal River 10 x RH 18	13	53	13	8	10	20	13	8	13	8	13	0.2
'Aromas' x RH 18	12	50	12	58	8	50	12	58	12	50	12	1.5
'Fort Laramie' x 'Camarosa'	12	75	12	33	12	50	12	33	12	8	12	0.5
'Fort Laramie' x Eagle 14	11	85	11	55	9	56	11	64	11	27	11	1.6
'Ogallala' x 'Camarosa'	14	47	14	64	9	89	14	50	14	21	14	1.9
'Tribute' x 'Honeoye'	40	10	40	10	38	37	40	18	40	10	40	0.2
'Tribute' x Eagle 14	8	57	8	50	8	100	8	75	8	38	8	3.4
'Tribute' x Montreal River 10	11	45	11	36	9	44	11	45	11	36	11	1.8
'Tribute' x RH 18	18	35	18	39	17	65	18	61	18	39	18	3.4
Frederick 9 x 'DHL 1336'	15	33	15	53	13	62	15	53	15	20	15	2.3
'Honeoye' x Frederick 9	22	75	22	32	18	44	22	18	22	14	22	0.8
RH 30 x Montreal River 10	10	100	10	30	9	44	10	50	10	30	10	1.0
Total/mean	641	55	641	41	533	49	641	40	639	18	641	1.2

[1]Flowering within 100 days from germination in a greenhouse in 2000.

[2]Flowering before 9 September in field in 2000.

[3]Flowering under both short and long days in a greenhouse in 2001.

[4]Flowering under both short and long days in field in 2001.

[5]Flowering on their newly-formed runner in field in 2001.

[6]Flowering strength ratio of 0-10 (10 having the most flowers during the second cycle of flowering) in field in 2001.

method. In fact, in 3 of the evaluation methods, the range in family values was 0-100% (DN1, flowering in 100 days, DN3 - 2nd year field flowering, DN4 - 2nd year greenhouse flowering). DN x DN crosses generated higher numbers of DN progenies than SD x SD crosses for all methods. For example, when DN 'Aromas' was selfed it produced 60, 67, 67, 100 and 33% for DN1, DN2, DN3, DN4 and DN5, respectively, while SD 'Glooscap' x SD RH 18 produced 47, 38, 27, 6 and 0% (Table 2).

Some of the crosses with high numbers of DN progeny in the field and greenhouse did not produce flowers on their runners; for example, 'Honeoye' x RH 18, (80, 80, 100, 40, and 0% for DN1-DN5, respectively) (Table 2). The highest family values for flowers on their newly-formed runners (DN5-runner flowering) were 64% in 'Tribute' x Frederick 9 (Table 2). The other 'Tribute' crosses also had high values for DN5, e.g., 'Tribute' x RH 18 (39%) and 'Tribute' x Eagle-14 (38%) (Table 2). It has previously been noted that 'Tribute' has a strong tendency to form flowers in its runners (Draper et al., 1981; Maas and Cathey, 1987).

The average flowering strength rating (FSR) across all families was 1.2 (Table 2). Eagle-14 x Eagle-14 had the lowest average FSR (mean = 0.0, N = 28), while 'Aromas' x 'Ogallala' (mean = 3.8, N = 9), 'Tribute' x RH 18 (mean = 3.4, N = 18) and 'Tribute' x Eagle-14 (mean = 3.4, N = 8) had the highest rating. In general, the families with the highest flowering strength in the field also had the highest percentage of DN in both the greenhouse and field screens (Table 2).

Hundred-day flowering (DN1) was significantly correlated with DN2 (1st year field flowering) (R = 0.46, P = 0.003), but not with any of the other methods (Table 3). However, all the other evaluation methods were significantly correlated (Table 3). Likewise, the FSRs were significantly correlated with all the DN evaluation methods except DN1 (flowering within 100 days) (Table 3). The highest correlation was observed between DN4, 2nd year field flowering and FSR. This is not surprising, as these data were collected at the same time in the field and a high value for strength of flowering also indicates the plants are strong day-neutrals (Hellman and Travis, 1988). In addition, the year-to-year correlation in the field (DN4 vs. DN2) was high (71%, P = 0.000), and the greenhouses vs. field evaluations in 2001 were significant (73%, P = 0.000) (Table 3). Detailed pair-wise comparisons of evaluation methods can be found in Serçe (2002).

Table 3. Correlation coefficients, significance (italic), and number of families used in calculation (in parenthesis) for strawberry families grown in a greenhouse at Michigan State University, East Lansing, MI., and in the field at the Southwest Michigan Research and Extension Center Benton Harbor, MI., in 2000 and 2001.

	DN2[2]	DN3[3]	DN4[4]	DN5[5]	FSR[6]
DN1[1]	0.46	0.26	0.27	0.16	0.06
	0.003[7]	*0.125*	*0.095*	*0.320*	*0.726*
	(39)	(36)	(39)	(39)	(39)
DN2		0.71	0.71	0.33	0.54
		0.000	***0.000***	***0.042***	***0.000***
		(36)	(39)	(39)	(39)
DN3			0.73	0.45	0.74
			0.000	***0.005***	***0.000***
			(36)	(36)	(36)
DN4				0.70	0.85
				0.000	***0.000***
				(39)	(39)
DN5					0.58
					0.000
					(39)

[1] Flowering within 100 days from germination in a greenhouse in 2000.
[2] Flowering before 9 September in field in 2000.
[3] Flowering under both short and long days in a greenhouse in 2001.
[4] Flowering under both short and long days in field in 2001.
[5] Flowering on their newly-formed runner in field in 2001.
[6] Flowering strength ratio of 0-10 (10 having the most flowers during the second cycle of flowering) in field in 2001.
[7] Significant P values, at 0.05, are bolded.

The families had quite variable averages for all of the horticulturally important traits (Table 4). Mean crown number ranged from 2.1 ('Aromas' x 'Ogallala' and 'Aromas' x 'Tribute') to 6.4 ('Fort Laramie' x 'Frederick 9') (Table 4). 'Aromas' x 'LH 39' did not have any runners, while Eagle-14 x Eagle-14 had very high runner numbers (11.5) (Table 4). 'Aromas' x 'Tribute' produced the lowest inflorescence and crown numbers (mean = 4.4), while DHL 1336 x 'Glooscap' had the highest numbers (mean = 12.5) (Table 4). The range in flowers per inflorescence was from 3.1 ('Aromas' x 'Ogallala') to 6.7 ('Ogallala' x 'Camarosa') (Table 4). The average fruit weight in Eagle-14 x Eagle-14 was extremely low (mean = 1.4), while 'Camarosa' x 'Glooscap' had the largest fruits (mean = 13.8) (Table 4).

%DN progeny and fruit weights were not significantly correlated (18%, P = 0.275). In fact, among horticulturally important traits, only runner number was negatively correlated with %DN in the families (- 49%, P = 0.001) (Table 5). Among all traits, crown and

Table 4. Mean and standard deviations for horticulturally important traits in strawberry families grown in a greenhouse at Michigan State University, East Lansing, MI., and in the field at the Southwest Michigan Research and Extension Center Benton Harbor, MI., in 2001.

Family	Crown number	Runner number	Inflorescence number	Flower/ inflorescence	Average fruit weight (g)
'Aromas' x 'Aromas'	2.2 ± 0.8	0.8 ± 1.0	8.5 ± 1.6	4.5 ± 1.0	9.6 ± 1.5
'Aromas' x 'Fort Laramie'	3.0 ± 1.1	1.3 ± 1.8	8.3 ± 3.2	4.3 ± 0.8	9.2 ± 3.3
Aromas' x 'Ogallala'	2.1 ± 1.3	0.8 ± 0.7	5.2 ± 2.9	3.1 ± 0.6	8.9 ± 3.3
'Aromas' x 'Tribute'	2.1 ± 1.2	0.6 ± 1.0	4.4 ± 2.6	3.4 ± 1.2	7.9 ± 2.7
'Aromas' x LH 39	2.4 ± 1.1	0.0 ± 0.0	4.5 ± 2.1	3.6 ± 1.6	7.0 ± 3.1
'Fort Laramie' x 'Tribute'	3.0 ± 0.9	0.4 ± 1.0	6.7 ± 2.1	4.6 ± 0.9	12.4 ± 3.9
'Fort Laramie' x Frederick 9	6.4 ± 2.9	6.7 ± 3.8	12.0 ± 3.6	3.9 ± 1.1	3.1 ± 0.4
'Tribute' x Frederick 9	4.7 ± 1.1	4.9 ± 1.8	7.3 ± 1.8	3.7 ± 1.0	3.8 ± 1.7
LH 39 x LH 39	3.8 ± 1.9	3.8 ± 3.6	7.5 ± 5.1	2.8 ± 0.9	3.9 ± 3.0
RH 30 x RH 30	4.3 ± 1.2	4.0 ± 2.9	12.1 ± 5.3	3.6 ± 1.0	1.7 ± 2.6
DHL 1336 x DHL 1336	3.3 ± 1.1	2.1 ± 1.6	5.6 ± 2.4	5.8 ± 2.0	9.5 ± 4.0
'Camarosa' x 'DHL 1336	3.1 ± 1.0	6.7 ± 5.2	8.5 ± 2.5	4.9 ± 1.4	10.2 ± 4.2
DHL 1336 x 'Honeoye'	2.5 ± 0.9	0.7 ± 0.8	5.0 ± 2.1	3.8 ± 0.8	7.1 ± 1.5
DHL 1336 x 'Glooscap'	4.0 ± 0.8	9.7 ± 4.1	12.5 ± 4.2	4.2 ± 1.0	11.2 ± 3.0
DHL 1336 x RH 18	3.4 ± 1.2	5.1 ± 2.3	7.5 ± 4.4	3.3 ± 0.9	2.4 ± 1.7
'Camarosa' x 'Honeoye'	3.5 ± 2.1	3.1 ± 2.5	8.0 ± 3.3	4.6 ± 1.2	11.1 ± 2.7
'Camarosa' x 'Glooscap'	4.2 ± 1.4	2.4 ± 2.9	8.6 ± 3.0	6.1 ± 1.2	13.8 ± 6.9
'Camarosa' x Eagle 14	3.8 ± 1.7	8.2 ± 3.0	8.6 ± 2.8	4.0 ± 0.9	5.4 ± 2.1
'Camarosa' x Montreal River 10	4.1 ± 1.2	3.7 ± 2.6	8.7 ± 3.5	4.3 ± 1.1	7.4 ± 2.6
'Camarosa' x RH 18	3.9 ± 1.2	2.3 ± 1.2	9.3 ± 2.9	4.5 ± 1.1	5.1 ± 2.6
'Honeoye' x Eagle 14	4.1 ± 1.1	5.6 ± 3.2	7.0 ± 2.9	3.5 ± 0.7	2.8 ± 1.2
'Honeoye' x RH 18	4.2 ± 0.8	5.6 ± 1.1	5.4 ± 2.3	3.4 ± 0.5	3.6 ± 1.5
'Glooscap' x RH 18	4.3 ± 1.4	6.9 ± 3.7	11.8 ± 4.1	4.2 ± 0.9	5.2 ± 0.9
Eagle 14 x Eagle 14	4.1 ± 2.6	11.5 ± 6.4	7.4 ± 4.5	3.4 ± 1.3	1.4 ± 1.0
High Falls 22 x High Falls 22	4.5 ± 1.1	9.3 ± 3.7	7.0 ± 3.1	3.2 ± 1.2	2.7 ± 1.3
High Falls 22 x Montreal River 10	3.3 ± 0.9	5.5 ± 2.8	8.6 ± 3.1	4.1 ± 1.0	2.8 ± 1.8
Montreal River 10 x Montreal River 10	3.4 ± 0.9	5.4 ± 2.2	8.8 ± 4.4	4.3 ± 2.1	2.8 ± 1.0
Montreal River 10 x RH 18	3.4 ± 1.4	2.2 ± 2.0	5.9 ± 2.8	4.1 ± 1.0	5.2 ± 2.5
'Aromas' x RH 18	4.0 ± 1.7	2.2 ± 2.6	7.9 ± 4.3	4.1 ± 1.6	4.9 ± 1.2
'Fort Laramie' x 'Camarosa'	5.2 ± 1.3	4.8 ± 2.4	11.9 ± 3.2	3.3 ± 0.5	3.8 ± 2.5
'Fort Laramie' x Eagle 14	5.2 ± 1.7	7.3 ± 3.8	10.8 ± 4.2	3.5 ± 1.4	4.2 ± 1.7
'Ogallala' x 'Camarosa'	4.1 ± 1.7	3.9 ± 4.2	10.8 ± 3.1	6.7 ± 2.8	6.8 ± 2.3
'Tribute' x 'Honeoye'	4.4 ± 1.3	5.7 ± 3.0	8.6 ± 3.0	4.1 ± 0.9	7.5 ± 3.3
'Tribute' x Eagle 14	4.0 ± 1.2	3.4 ± 1.3	7.5 ± 3.0	4.8 ± 1.2	2.9 ± 0.6
'Tribute' x Montreal River 10	3.8 ± 1.0	4.1 ± 3.1	8.1 ± 3.9	4.3 ± 1.2	5.3 ± 2.9
'Tribute' x RH 18	4.0 ± 0.8	2.9 ± 3.4	6.9 ± 2.8	3.9 ± 1.0	3.6 ± 1.7
'Frederick 9 x DHL 1336	3.7 ± 1.3	2.9 ± 2.9	7.9 ± 2.5	4.5 ± 1.1	7.1 ± 3.9
'Honeoye' x Frederick 9	2.9 ± 0.9	6.0 ± 5.2	5.6 ± 2.5	2.8 ± 1.1	3.3 ± 2.0
RH 30 x Montreal River 10	2.2 ± 0.8	4.3 ± 2.7	5.4 ± 2.7	6.4 ± 1.5	2.8 ± 2.3

Table 5. Correlation coefficients and significance (italics) between percentage of day-neutral progeny and several horticulturally important traits in strawberry families grown in a greenhouse at Michigan State University, East Lansing, MI., and in the field at the Southwest Michigan Research and Extension Center Benton Harbor, MI., in 2000 and 2001.

	Crown no.	Runner no.	Inflorescence no.	Flower/inf.	Fruit weight (g)
% Day-neutral progeny	0.00	-0.49	0.00	0.17	0.18
	0.985	***0.001***[1]	*0.991*	*0.296*	*0.275*
Crown no.		0.54	0.67	-0.11	-0.34
		0.000	***0.000***	*0.499*	***0.033***
Runner no.			0.43	-0.21	-0.42
			0.006	*0.206*	***0.007***
Inflorescence no.				0.11	-0.05
				0.496	*0.771*
Flower/inflorescence					0.42
					0.007

[1]Significant correlations, at 0.05, are bolded.

inflorescence numbers had the highest correlation (67%, P = 0.000) (Table 5).

Conclusions

These results indicate that scoring DN progenies within 100 days from germination cannot be used to predict field performance. Apparently, the speed with which a seedling begins flowering is not tightly associated with photoperiod sensitivity. However, greenhouses can be used to predict field performance if the flowering behavior of individuals is followed through a whole season. The DN percentage observed in our second year greenhouse screens were highly correlated with the subsequent field evaluations, and the families with the highest flowering strength in the field also had the highest percentage of DNs in both the greenhouse and field screens.

The final decision on whether greenhouses will be utilized in a breeding program will still have to be based on the objective of the breeding program. While the correlation between the field and greenhouse determinations of %DN in families was high, some families had individuals that were rated DN in the field, but not in the greenhouse. For example, the second year greenhouse evaluations of DHL 1336 x 'Honeoye' crosses generated no DNs, while 17% DNs were recovered in the field. If one is interested in finding DNs in the broadest range of families, the populations will need to be evaluated in the field. In addition, we did not evaluate the relationship between %DN progeny and the mean number of fruiting cycles. If the number of cycles is important, populations will need to be screened directly for that characteristic.

Small fruit size is a common problem in DN breeding and it has been suggested that fruit size and DN are negatively correlated (Dale et al., 2002). We did not find this to be the case in our study. In fact, the only significant correlation observed between DN and horticulturally important traits was a negative correlation with runner number that has been previously demonstrated (Hancock et al., 2002). This suggests that with the exception of runner numbers, there are few negative compensations that will impede DN breeding using the parents evaluated in this study. Even though runner number was negatively correlated with %DN, some families produced more runners than the current DN cultivars, indicating that improved runnering types can be recovered.

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