Requirement for Pollenizer in New Monoecious Hybrid Cucumber 'NC-Sunshine'

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Summary. Monoecious cucumber (*Cucumis sativus*) plants generally produce enough pollen for fruit set. The amount of pollen required for fruit set depends on the number of pistillate flowers produced by the cultivar. 'NC-Sunshine' is a new monoecious slicing hybrid cucumber with a high percentage of pistillate nodes. Because of the high percentage of pistillate nodes, a pollenizer might be required to maximize pollination to get high total and early yield. Hence, an experiment was conducted at three locations to evaluate the effect of the pollenizer 'Poinsett 76' on yield of 'NC-Sunshine' compared with no pollenizer 'Gray Zucchini' squash (*Cucurbita pepo*). Differences ($P \geq 0.05$) due to pollenizer, location, and the interaction of pollenizer and location on 'NC-Sunshine' yield traits were detected. Pollenizer influenced cucumber yield at two of three locations. Results indicated that the pollenizer 'Poinsett 76' significantly increased total, marketable, and early yield of 'NC-Sunshine'. The percentage of early and marketable yield was also higher with the pollenizer 'Poinsett 76'. In addition, the use of a pollenizer decreased cull yield. Therefore, a pollenizer is needed for monoecious hybrids having a high percentage of pistillate nodes.

Breeding for increased yield in cucumber has been an important objective of many cucumber breeding programs since the 1900s (Staub et al., 2008). Yield of pickling cucumber has been improved by breeding for disease resistance, as well as through the use of improved cultural practices (Lower and Edwards, 1986; Peterson, 1975; Staub et al., 2008; Wehner, 1989). The increased yield of cucumber cultivars has also been achieved through improvements in gynoecious sex expression, improved fruit color (improved percentage of marketable fruit), and direct yield improvement (Wehner, 1989).

Although cucumber plants produce different sex phenotypes (Staub et al., 2008), the wild type is monoecious with staminate flowers appearing first, followed by pistillate flowers at later nodes. 'NC-Sunshine' is a monoecious, early maturing, and high yielding slicing hybrid with a high percentage of pistillate nodes. The plant has medium dwarf size vines with short hypocotyls and dark green leaves, and a dwarf-determinate plant type (Wehner, 2005). 'NC-Sunshine' is a F_1 hybrid of NC-62 (dwarf-determinate, monoecious) × NC-63 (dwarf-determinate, monoecious). These inbreds were developed at North Carolina State University. The fruit of 'NC-Sunshine' have good fresh market quality and good keeping ability with very dark green fruit averaging 8 inches in length. 'NC-Sunshine' is resistant to anthracnose (*Colletotrichum* sp.), powdery mildew (*Sphaerotheca fuliginea*), and scab (*Cladosporium cucumerinum*).

The amount of pollen required for fruit set depends on the number of pistillate flowers produced by the cucumber cultivar. Generally, monoecious cucumber plants are planted in the field, and plants produce enough pollen for fruit set. Since 'NC-Sunshine' produces more pistillate flowers than regular monoecious cultivars, it might need more pollen for effective pollination and fruit set. An important aspect of the pollenizer is the ability to produce enough staminate flowers to pollinate the available pistillate flowers, and ≈12% to 15% monoecious pollenizers are used in the field to pollinate highly gynoecious cultivars. However in comparison, ≈25% to 33% of pollenizer is planted to ensure adequate pollen supply for triploid watermelon (*Citrullus lanatus*) production (Fiacchino and Walters, 2003; Walters, 2005). Therefore, it is important to determine if planting a pollenizer in the field will significantly increase yield of 'NC-Sunshine'.

Cucumber is an allogamous crop that requires frequent pollinators (bees) visit to carry pollen for fertilization. Honeybees (*Apis mellifera*) and bumblebees (*Bombus terrestris*) are the main pollinators in cucumbers (Gajc-Wolska et al., 2011). The absence of sufficient pollinators can result in low fruit set and reduced fruit size (Walters and Taylor, 2006). Moreover, pistillate flowers require multiple bee visitations after visiting male flowers (Stanghellini et al., 1997, 1998). In triploid seedless watermelon, 16 to 24 honeybee visits are required to achieve maximum fruit set at a 33% pollenizer frequency (Walters, 2005).

Climatic factors have also been reported to influence pollen flow (Gingras et al., 1999; Whitakar and Bohn, 1952). Wind velocity, temperature, and other environmental factors may influence honeybee behavior thereby affecting pollination; and unfavorable environmental conditions such as extreme temperature, moisture stress, and low irradiance can result in flower abortion and low fruit set (Kalbarczyk, 2009). Wehner and Jenkins (1985) reported that the mean rate of natural outcrossing varied from 23% to 77% across three locations in cucumber families. Therefore, it is imperative to study the effect of pollenizers in different environmental conditions (locations) and the interaction of pollenizer with location.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
1.6093	mile(s)	km	0.6214
2.2417	ton/acre	$Mg \cdot ha^{-1}$	0.4461

'NC-Sunshine' was planted in field plots with 'Poinsett 76' as the pollenizer and 'Gray Zucchini' squash as the control. 'Poinsett 76' is a monoecious slicing cucumber type with excellent color and is resistant to downy mildew (*Pseudoperonospora cubensis*), powdery mildew, anthracnose, and angular leaf spot (*Pseudomonas syringae* pv. *lachrymans*). 'Gray Zucchini' is an early maturing squash with a bushy habit similar to 'NC-Sunshine' and also has long, straight fruit. The objective of this study is to evaluate the effect of the pollenizer 'Poinsett 76' on fruit set and yield of 'NC-Sunshine' cucumber.

Materials and methods

Experiments were conducted at the Horticultural Crops Research Station in Clinton, NC, and two locations at the Tobacco Research Station in Oxford, NC, (Oxford-North and Oxford-South) during the Spring 2005. The soil type in Clinton was a mixture of Norfolk and Orangeburg loamy sand (fine-loamy, siliceous, thermic, Typic Kandiudults) with some Goldsboro (fine-loamy, siliceous, thermic, Aquic Paleudults). The soil type in Oxford was a mixture of Helena sandy loam, Vance sandy loam, and Appling sandy loam.

Recommended horticultural practices were used for all experiments (Schultheis, 1990). Fertilizer was incorporated before planting as ammonium nitrate at a rate of 80 lb/acre nitrogen (N), 80 lb/acre phosphorous (P), and 80 lb/acre potassium (K), with an additional 40 lb/acre N (as sodium nitrate) applied at the vine tip-over stage. Ethalfluralin at 1.1 lb/acre preemergence (Curbit; Loveland Products, Greeley, CO) was applied for weed control. Irrigation was applied when needed for a total (irrigation plus rainfall) of 1 to 1.5 inches per week. Honeybees were placed in the field at the stage of first flowers opening using the recommended rate of two active hives per hectare (Schultheis, 1990).

The experiment was conducted in a randomized complete block design planted in Spring 2005 with two pollenizer treatments ('Poinsett 76' and 'Gray Zucchini') across three locations in North Carolina. There were four replications nested in each location. Treatment combinations were assigned their own isolation block and separated by 1 mile to eliminate pollen transfer between treatments as shown in Fig. 1.

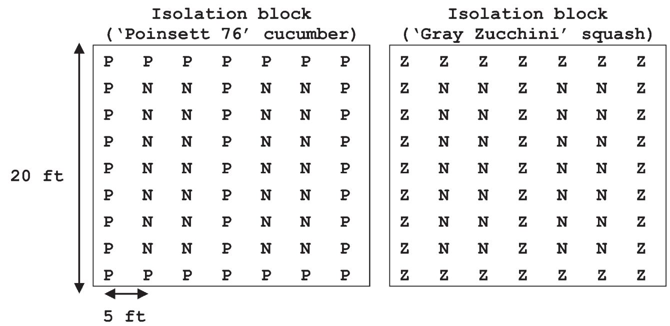

Fig. 1. Layout of 'NC-Sunshine' cucumber (N) plots in isolation blocks of 'Poinsett 76' (P) cucumber and 'Gray Zucchini' squash (Z) pollenizer treatments at three locations in North Carolina (Clinton, Oxford-North, and Oxford-South). 'Poinsett 76' cucumber was treated as the pollination treatment, whereas 'Gray Zucchini' squash was the no pollination treatment. Each isolation block had seven rows where two rows of 'NC-Sunshine' cucumber were alternated with a row of pollenizer. Each row represented a plot with 80 plants. Each isolation block had four rows of 'NC-Sunshine' cucumber. Pollenizer treatments were assigned their own isolation block at each location and were separated by 1 mile (1.6 km) to eliminate pollen transfer between treatments; 1 ft = 0.3048 m.

The effect of the pollenizer was studied on a new cucumber hybrid 'NC-Sunshine', which has more pistillate flower nodes. Field plots of 'NC-Sunshine' were 20-ft long and 5-ft apart (row spacing) with 6-ft alleys at each end. Plots were planted with 100 seeds and thinned to a uniform stand of 80 plants per plot. 'NC-Sunshine' plots were surrounded by two different pollenizer treatments, 'Poinsett 76' and 'Gray Zucchini'; 'Poinsett 76' was the pollen source for highly pistillate 'NC-Sunshine', whereas 'Gray Zucchini' is a squash cultivar and did not supply any pollen. 'Gray Zucchini' is a cucurbit with plants about the same size as 'Poinsett 76', so they provide a border effect that is similar. Two rows of 'NC-Sunshine' were alternated with each row of pollenizer, so that the rows of 'NC-Sunshine' were always adjacent to the pollenizer row (Fig. 1). 'Gray Zucchini' was planted to mimic the competition provided by 'Poinsett 76'. 'Poinsett 76' was treated as the pollination treatment, whereas 'Gray Zucchini' was the no pollination treatment.

Plots were harvested two times at 2-week intervals. Data were recorded for fruit yield: total, marketable, percent marketable, cull, early, percent early, early marketable, and percent early marketable. These measurements are important because amount of pollination is reflected on yield. All straight neck and healthy looking fruit were counted as marketable, whereas deformed fruit (crook-necked and bottle-necked) were treated as cull. The effect of using a pollenizer on early fruit production was studied, with fruit harvested from the first harvest treated as early setting.

Analysis of variance procedures were performed using MEANS and GLM procedures of SAS (release 9.1 for Windows; SAS Institute, Cary, NC) to determine the effect of pollenizer on 'NC-Sunshine' cucumber yield. Means were separated with least significant difference ($P \leq 0.05$). Location × pollenizer interaction was significant (Table 1), so locations are presented separately (Table 2). Data are means of four replications summed over two harvests. Whole plot effects (location) were tested using whole plot error (replication × location), and subplots (replication × other factors) were tested using residual error (replication × other factors).

Results

The total, marketable, cull, early, early marketable, percent marketable, and percent early yields were influenced by both pollenizer and location (Table 1). Pollenizer and location also show an interaction indicating that the pollenizer responded differently at various locations. Therefore, data are presented to show the effect of pollenizer treatment at each location (Table 2).

Location differences were detected at Clinton and Oxford-South for yield. The total, marketable, early, and early marketable yield of 'NC Sunshine' from plots paired with 'Poinsett 76' at Clinton and Oxford-South were

Table 1. Mean square of main and interaction effect in the analysis of variance for yield in 'NC-Sunshine' cucumber at three locations in North Carolina.

Source of variation[z]	Total yield[y]	Marketable yield[y]	Cull yield[y]	Early yield[y]	Early marketable yield[y]	Percent marketable yield[y]	Percent early yield[y]	Percent early marketable yield[y]
Location[x]	84,770***	78,277***	11,839**	40,470**	40,084***	1,208***	221*	488NS
Pollenizer[w]	55,040**	104,503***	7,861*	87,070***	85,082***	1,858***	1,392***	1,111NS
Location × pollenizer[w]	14,174*	24,001***	6,198*	17,903*	13,521*	1,112***	344**	407*

[z]Locations (main effect): Clinton, Oxford-North, and Oxford-South. Pollenizer (main effect): 'Poinsett 76' cucumber was treated as the pollination treatment, whereas 'Gray Zucchini' squash was the no pollination treatment. Location × pollenizer is an interaction effect.
[y]Total yield (tons/acre) = total yield from harvest 1 and 2, marketable yield (tons/acre) = total yield minus cull yield, cull yield (tons/acre) = yield from deformed fruit, early yield (tons/acre) = total yield from harvest 1, early marketable yield (tons/acre) = yield from harvest 1 that is marketable, percent marketable yield (by weight) = (marketable yield/total yield) × 100, percent early yield (by weight) = (early yield/total yield) × 100, percent early marketable yield (by weight) = (early marketable yield/early yield) × 100; 1 ton/acre = 2.2417 $Mg{\cdot}ha^{-1}$.
[x]Tested by error – replication (location).
[w]Tested by error – residual error.
NS,*, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

higher than plots paired with 'Gray Zucchini' (Table 2). Similar results were also obtained for percent early and percent marketable yield. 'NC-Sunshine' plots planted with the 'Poinsett 76' at Clinton produced a higher percent marketable yield and lower cull yield than plots paired with 'Gray Zucchini'. However, no differences were observed in Oxford-South for these two traits. Location differences were not detected for percent early marketable yield at any location. In Oxford-North, no significant differences between pollenizer treatments were found for any trait.

Overall, the use of the pollenizer 'Poinsett 76' produced higher total yield, marketable yield, early yield, and percent early yield compared with no pollenizer. In addition, the use of 'Poinsett 76' as pollenizer decreased the cull yield (misshapen fruit) in 'NC Sunshine' cucumber.

Discussion

Diverse production areas were selected around the main cucumber areas of North Carolina. Some isolation blocks (locations) produced higher yield and lower culls when pollenizer was provided; some were able to function the same with or without pollenizer. 'NC-Sunshine' responded positively to the inclusion of a pollenizer in Clinton and Oxford-South locations. The results indicated that the use of a pollenizer increased total, marketable, and early yield while reducing cull yield. The use of a pollenizer provided more viable pollen resulting in fertilization of more pistillate flowers. Since 'NC-Sunshine' produces more pistillate flowers than most monoecious cucumbers, which relates to insufficient pollen to pollinate all the pistillate flowers early in the season, thereby reducing total and early yield; whereas, when plots were surrounded by a pollenizer ('Poinsett 76'), it produced enough viable pollen for fertilization coinciding with pistillate flower production early in the season, thus producing high early yield. Dittmar et al. (2010) reported that pollenizer treatments had more than 10% and 20% early and total yield, respectively, compared with treatments that had no pollenizer in triploid watermelon production. NeSmith and Duval (2001) also reported decrease in triploid watermelon yield as the availability of pollen decreased and vice versa. Percentage of early marketable fruit was similar for all treatments. This might be attributed to increased activity of pollinators or sufficient pollen availability early in the season; therefore, marketable fruit were comparable irrespective of pollenizer treatment.

Field plots that were not planted with a pollenizer produced more cull fruit as compared with field plots that included a pollenizer. The process of pollination stimulates the ovary to enlarge, therefore, fruit set and enlargement is dependent upon growth regulators produced from pollen and developing seeds (Hayata et al., 1995). The low amount of pollen available to pollinate pistillate flowers may have resulted in production of cull fruit due to partial development of fruit tissues at stem end. Dittmar et al. (2010) reported more than 50% inferior fruit in watermelon due to hollow heart in no pollenizer treatment. Fiacchino and Walters (2003) observed more deformed fruit (hollow heart) in watermelon due to lower pollen availability.

However, cucumber yield was unaffected by a pollenizer treatment in the Oxford-North. Possibilities may include more bee activity (Dittmar et al., 2010; Kalbarczyk, 2009) or more staminate flower production (Atsmon, 1968; Friedlander et al., 1977) on 'NC-Sunshine' in Oxford-North, which might have nullified the effect of the pollenizer. Environmental factors like high temperature and high light intensity promote an increase in the proportion of staminate flowers (Friedlander et al., 1977). Presumably, a high temperature may have resulted in adequate staminate flowers in Oxford-North, hence ensuring ample pollen availability in plots without a pollenizer. Abundant availability of pollen for pistillate flowers produces a high fruit set (Adlerz, 1966; Dittmar et al., 2010; Stanghellini et al., 1997; Walters, 2005; Walters and Taylor, 2006). However, temperature, bee activity, and the number of staminate flowers were not measured in this experiment.

Overall in this experiment, results indicated that growers might not have to use pollenizer in some locations, but it is recommended that they use pollenizer mixed in hybrid seed to get reliable marketable yield. Moreover, use of pollenizer reduces the cull yield (deformed fruit).

Conclusions

This study demonstrates that the production of sufficient male flowers with viable pollen is important for fruit set of 'NC-Sunshine' cucumber. If a pollenizer is used, cucumber hybrids with more pistillate flowers have early fruit set and higher total and marketable yield. However, additional studies may be carried out to characterize a more suitable pollenizer than 'Poinsett 76'. The pollenizer should have distinct fruit that easily can be distinguished

Table 2. Influence of pollenizers on fruit set and yield of 'NC-Sunshine' cucumber at three locations in North Carolina (Clinton, Oxford-North, and Oxford-South).[z]

Pollenizer	Total yield (tons/acre)[y]	Marketable yield (tons/acre)[y]	Cull yield (tons/acre)[y]	Early yield (tons/acre)[y]	Early marketable yield (tons/acre)[y]	Marketable yield (% by wt)[y]	Early yield (% by wt)[y]	Early marketable yield (% by wt)[y]
				Clinton				
'Poinsett 76' cucumber	19.7 a[x]	15.06 a	4.7 b	12.4 a	9.0 a	76 a	63 a	59 a
'Gray Zucchini' squash	13.0 b	4.0 b	9.0 a	6.7 b	2.0 b	31 b	50 b	49 a
				Oxford-North				
'Poinsett 76' cucumber	25.5 a	18.0 a	7.5 a	16.3 a	12.3 a	70 a	64 a	68 a
'Gray Zucchini' squash	25.5 a	16.8 a	8.8 a	15.3 a	11.2 a	65 a	60 a	67 a
				Oxford-South				
'Poinsett 76' cucumber	24.7 a	19.6 a	5.1 a	16.3 a	13.5 a	79 a	66 a	49 a
'Gray Zucchini' squash	18.5 b	14.1 b	4.4 a	6.9 b	5.7 b	76 a	37 b	39 a
LSD (0.05)[w]	4.4	2.7	2.5	3.9	3.4	5.7	9.8	14.4

[z]Data were averaged over four replications and two harvests at each location in Spring 2005, with 80 plants evaluated in each plot. 'Poinsett 76' cucumber was treated as the pollination treatment, whereas 'Gray Zucchini' squash was the no pollination treatment. Treatment combinations were assigned their own isolation block to eliminate pollen transfer between treatments.
[y]Total yield = total yield from harvest 1 and 2, marketable yield = total yield minus cull yield, cull yield = yield from deformed fruit, early yield = total yield from harvest 1, early marketable yield = yield from harvest 1 that is marketable, percent marketable yield = (marketable yield/total yield) × 100, percent early yield = (early yield/total yield) × 100, percent early marketable yield = (early marketable yield/early yield) × 100; 1 ton/acre = 2.2417 $Mg\cdot ha^{-1}$.
[x]Any two means within a column within a location not followed by the same letter are significantly different at $P \leq 0.05$.
[w]Least significant difference at $P \leq 0.05$.

from field cultivar at the time of harvest. Other interesting research topics would be determining the optimal number of plants per honeybee hive and the optimal ratio of pollenizer to cultivar.

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