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Sowing Dates and Priming Influence African Marigold Field Emergence

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Additional index words. **african marigolds, solid matrix priming, osmotic priming, emergence time, emergence uniformity, total emergence percentage, direct-seeded, stand establishment, *Tagetes erecta***

Summary. **Field seedling emergence of four african marigold (*Tagetes erecta*) breeding lines, A-975, E-1236, I-822, and 'Orange Lady', was examined using three or four spring sowing dates and either osmotic or solid matrix priming. Delayed sowing decreased emergence time. Sowing from middle to late April [average soil temperatures 77.0 to 84.2 °F (25 to 29 °C)] resulted in the highest total emergence percentages. Greater flower quantities [4.9 to 5.1 million/acre (12.11 to 12.60 million/ha)] and estimated yield [7.5 to 10.8 tons/acre (16.81 to 24.20 t·ha^{-1})] indicate mid to late April is the optimum time period for direct sowing unprimed seed in the southern Great Plains. Differences between lines were evident in emergence parameters and flower harvest data for each year examined, but results were inconsistent from year to year. However, A-975 and E-1236 produced harvestable flowers most quickly, about 15 d before I-822, which could result in an additional harvest during a season. Osmotic priming of E-1236 and I-822 seed shortened emergence time, increased emergence uniformity, and increased total emergence percentage at early sowing dates as compared to both solid matrix primed and unprimed seed.**

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African marigold petals are commercially valuable as a natural source of xanthophyll pigments used primarily by the poultry industry to color egg yolks and poultry skin yellow-orange. Currently, marigold plants are grown for pigment production in Mexico, Peru, and India, but the quality of extracted pigments is low. Baldwin et al. (1993) conducted an 8-year study in Virginia and Mexico and concluded that the two greatest problems for marigold production were plant stand establishment and weed control. Stand establishment was unsuccessful unless large quantities of de-tailed seed were used in a precision seeder. Raw marigold seed has bristles at one end of the seed; de-tailed seed has the bristles removed mechanically, allowing for easier use in automatic seeders. Otherwise, repeat plantings were necessary to achieve adequate stands.

One factor limiting field seedling emergence is cool soil temperatures in early spring. Suboptimal temperatures have been correlated with a reduction in germination rate, total germination percentage, and seedling emergence (Blackshaw, 1991; Kondra et al., 1983; Livingston and de Jong, 1990). While early sowing could result in poor stand establishment and plant death due to cold temperatures, it could also result in earlier harvests. In addition, direct sowing is more economical for the producer than using transplants. Labor costs are reduced, especially if a precision seeder is used, and there are no propagation and transplant production expenses. Thus, direct-seeding on the earliest optimum sowing date is beneficial for producers.

Priming may be used to enhance germination of direct-seeded plants, increase seedling emergence uniformity under adverse environmental conditions, and improve stand establishment (Parera and Cantliffe, 1994). Priming improves seedling uniformity and reduces seedling exposure to soil crusting, soilborne pathogens, and unfavorable temperatures by shortening the length of time necessary for initial stand establishment (Bennett et al., 1992). Seedling growth and development of primed seed are indistinguishable from untreated seed except under stressful conditions (Parera and Cantliffe, 1994). Danneberger et al. (1992) found that perennial ryegrass (*Lolium perenne*) seed primed using PEG 8000 had a greater germination percentage and seedling root growth than control seed at suboptimum germination temperatures of 41.0, 50.0, and 59.0 °F (5, 10, and 15 °C). Jalapeno (*Capsicum annuum*) seed primed in a 3% potassium nitrate solution germinated at 41.0 and 50.0 °F while untreated seed did not germinate (Rivas et al., 1984).

During the osmotic priming (OP) process, ions from a potassium nitrate and potassium phosphate solution accumulate within the seed, reducing the water potential and increasing water absorption. Solid matrix priming (SMP) is another priming method that consists of combining seeds with water and either an organic or inorganic material, such as vermiculite, calcined clay, or sodium polypropionate gel, for a predetermined time period (Parera and Cantliffe, 1994). The solid organic or inorganic material allows water to adsorb to the particles' surfaces regulating the seeds' water uptake. Compared to other priming techniques solid matrix priming is inexpensive and can be used on large quantities of seed (Khan, 1992).

Commercial production of direct-seeded african marigold plants would benefit from a priming method that enhances emergence at cool soil temperatures and produces quicker and more uniform stand establishment. Objectives for this research were to evaluate the effect of field sowing date on unprimed african marigold seed emergence, identify an effective priming method for african marigold seed, and compare primed seed to unprimed seed in field emergence and stand establishment.

Table 1. Minimum, maximum, and average daily soil temperatures for 2-week periods after each sowing date over a 3-year period. Temperatures were measured at 1200 HR at 1 inch (2.5 cm) below the soil surface.

	Temp °F (°C)		
Sowing date	Min[z]	Max[z]	Avg[y]
1998			
17 Apr.	51.0 (10.56)	96.1 (35.61)	69.8 (21.00)
1 May	69.1 (20.61)	102.0 (38.89)	85.6 (29.78)
15 May	82.0 (27.78)	97.0 (36.11)	88.9 (31.61)
1999			
1 Apr.	63.0 (17.22)	93.0 (33.89)	77.2 (25.11)
15 Apr.	52.0 (11.11)	96.1 (35.61)	75.9 (24.39)
29 Apr.	52.0 (11.11)	91.0 (32.78)	77.5 (25.28)
13 May	66.0 (18.89)	100.0 (37.78)	82.9 (28.28)
2000			
6 Apr.	59.0 (15.00)	100.9 (38.28)	75.0 (23.89)
20 Apr.	73.0 (22.78)	96.1 (35.61)	84.0 (28.89)
5 May	59.0 (15.00)	97.0 (36.11)	78.1 (25.61)
19 May	64.9 (18.28)	102.9 (39.39)	83.1 (28.39)

[z]Measured minimum and maximum soil temperatures represent the lowest and highest recorded temperatures during the respective 2 weeks.
[y]Soil temperatures are average of three measurements taken daily over 2 weeks following the sowing date.

Materials and methods

Seed of three african marigold experimental breeding lines, A-975, E-1236, and I-822, (Goldsmith Seeds, Inc., Gilroy, Calif.) and one commercially-available cultivar, Orange Lady (OL), were examined for field emergence over 3 years. Seeds were planted in raised beds in Stillwater, Okla. (USDA climatic zone 6b–7a), in Norge Loam (fine-silty, mixed, thermic Udic Paleustolls), pH 6.5. Plots were 4 ft (1.2 m) across and 5 ft (1.5 m) long with 2 ft (0.6 m) between plots. Soil was watered as required to maintain field capacity using drip irrigation. Three sowing dates at 14-d intervals were used in 1998: 17 Apr., 1 May, and 15 May; four in 1999: 1 Apr., 15 Apr., 29 Apr., and 13 May; and four in 2000: 6 Apr., 20 Apr., 5 May, and 19 May. Rows were spaced 9 inches (22.9 cm) apart, and spacing between plants within each row was 9 inches resulting in 20 planting locations per plot. Three seeds were planted by hand in each location. Number of emerged seedlings was recorded daily and the soil temperature (average of three measurements) was recorded daily at 1200 HR at 1 inch (2.5 cm) below the soil surface (Table 1, Fig. 1). Seedlings were considered emerged after plumule emergence and cotyledons were fully opened. Three weeks after the first seedlings emerged, plants were thinned to one per location. Data collected were emergence time [days to 50% emergence (T50)], emergence uniformity [days from 10% to 90% seedling emergence (T1090)], and total emergence percentage (TEP).

The T50 was calculated according to Orchard (1977). In 1998 and 1999, days from seeding to first flower harvest (three or more mature flowers in a plot), flower number, and fresh flower yield per replication were recorded at each harvest. Mature flowers with outer petals reflexed were hand-picked at 18 weekly harvests (1998) or 6 biweekly harvests (1999). Since mechanical harvesting collects fewer flowers than hand harvesting, flower yields were multiplied by 43.6% to approximate mechanical harvesting (Bosma et al., 2003). Within each plot, data were collected only from the six interior plants to eliminate the edge effect. The experimental design was completely randomized with four replications (4 × 5-ft plots) and 20 plants per treatment. For germination parameters, 60 subsamples per replication (20 locations and 3 seed/location) were used; for production parameters 6 subsamples (interior plants) per replication were used.

In 2000, E-1236 and I-822 seeds were primed by two methods, OP and SMP. Unprimed seeds served as the control. Seed Dynamics, Inc. (Salinas, Calif.) developed the OP method using restricted methodology unavailable for publication. With the SMP method, 50 seed were placed in a 2 × 3-inch (5.1 × 7.6 cm) zip-lock polyethylene bag filled with calcined clay (Super Absorbent, 500 µm, pH 7.0; Balcones Mineral Corp., Flatonia, Texas) at a weight ratio of 1 seed : 5 calcined clay. Calcined clay was pasteurized at 170.6 °F (77 °C) for 24 h before use. Bags were filled with deionized water at 10% volume by weight of the seeds plus calcined clay and mixed. Water potential (Ψ) at 10% moisture content was –2.0 MPa. Previous trials revealed priming with 10% moisture for 1 d yielded primed marigold seed without radicle emergence (unpublished data). Bags were stored upright in an environmental growth chamber (model 1-35LL; Percival Manufacturing Co., Boone, Iowa) for 1 d at 68.0 °F (20 °C) with cool-white florescent lighting [20.7 µmol·m^{-2}·s^{-1} (138 fc)] as specified by the Association of Official Seed Analysts (AOSA, 1993) for african marigold seed. After removal from the chamber, seed and calcined clay were sifted, and seeds were weighed. Seeds were surface-dried on paper towels for 24 h at 73.4 °F (23 °C) and weighed again. The OP and SMP seed were primed simultaneously on 3 Apr. and then stored with unprimed seed at 35.6 °F (2 °C) until planted in the field on 6 Apr., 20 Apr., 5 May, and 19 May. Four replications were used for each priming treatment and planted as previously described.

The relationship between Ψ and moisture content on a dry weight basis was determined for Super Absorbent. Water potential was measured with a chambered in situ pyschrometer (Merrill Specialty Equipment, Logan, Utah) and read with a water potential system (HP-115; Wescor, Inc., Logan, Utah) calibrated against potassium chloride standards. Super Adsorbent was determined three times with three repetitions before sample analysis.

Seed viability was determined by placing 50 seeds in a petri dish with a paper towel moistened with deionized

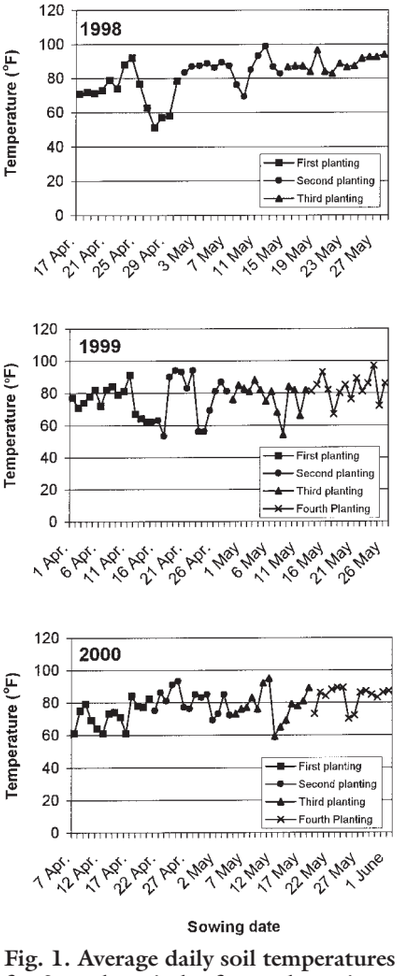

Fig. 1. Average daily soil temperatures for 2-week periods after each sowing date over a 3-year period. Temperatures were measured at 1200 HR at 1 inch (2.5 cm) below the soil surface. Symbols represent the average of three measurements; °C = 5/9(°F – 32).

Table 2. African marigold seed viability for experiments conducted in 1998, 1999, and 2000. Values shown are mean of two 50-seed replications. Seeds were placed in petri dishes (replications) with paper towels moistened with deionized water and held at 73.4 to 78.8 °F (23 to 26 °C) with continuous flourescent light [80 µmol·m^{-2}·s^{-1} (533.3 fc)]. Seeds were considered germinated after the radicle had penetrated the seed coat and was visible to the naked eye.

Year	Breeding line	Priming method	Viability (% ± SE)
1998	A-975	Unprimed	96 ± 2
	E-1236	Unprimed	53 ± 15
	I-822	Unprimed	77 ± 1
	Orange Lady	Unprimed	73 ± 5
Significance			NS
1999	A-975	Unprimed	82 ± 2
	E-1236	Unprimed	51 ± 11
	I-822	Unprimed	88 ± 10
	Orange Lady	Unprimed	73 ± 3
Significance			NS
2000	E-1236	Unprimed	89 ± 5 b[z]
		Osmotic	96 ± 2 b
		Solid matrix	90 ± 2 b
	I-822	Unprimed	100 ± 0 a
		Osmotic	100 ± 0 a
		Solid matrix	100 ± 0 a
Significance			
Breeding line (B)			***
Priming method (PM)			NS
B × PM			NS

[z]Mean separation within column by Duncan's multiple range test. Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS,***]Nonsignificant or significant at $P \leq 0.001$

Table 3. Effect of breeding line and three sowing dates for african marigold seedling emergence and flower yield. Main effects only are shown as no interactions occurred. Values shown are means of four replications of 64 seed each for seedling emergence time and uniformity and four replications of 16 plants each for 18 weekly harvests for days to first flower harvest and fresh flower yield (1998). 1.0 ton/acre = 2.24 t·ha^{-1}

Treatment	Emergence time (T50) (d)	Emergence uniformity (T1090) (d)	Days to first flower harvest[z]	Estimated fresh flower yield (tons/acre)
Sowing date				
17 Apr.	10.3 a[y]	6.0 a	86 a	6.2[NS]
1 May	7.1 b	4.0 b	77 b	5.5
15 May	5.7 c	3.9 b	68 c	4.7
Breeding line				
A-975	7.4 b	4.2[NS]	70 c	5.4 b
E-1236	7.7 b	4.2	70 c	5.4 b
I-822	8.4 a	5.6	88 a	3.9 b
Orange Lady	7.1 b	4.5	79 b	7.5 a

[z]From sowing.
[y]Mean separation within columns by Duncan's multiple range test. Means followed by the same letter are not significantly different at $P \leq 0.05$.
[NS]Nonsignificant.

water (Table 2). Two petri dishes per breeding line were used and maintained at 73.4 to 78.8 °F (23 to 26 °C) with continuous flourescent light [80 µmol·m^{-2}·s^{-1} (533.3 fc)]. Daily germination counts were made. Seeds were considered germinated after the radicle had penetrated the seed coat and was visible to the naked eye.

All data were analyzed using the general linear model procedure, trend analysis, and Duncan's multiple test range where applicable (SAS Institute, Inc., Cary, N.C.). Percent data were transformed using the arcsin procedure before statistical analysis. Correlation analysis was used to evaluate the relationship between average daily soil temperature and T50, T1090, or TEP.

Results

1998 GERMINATION PARAMETERS. Average daily soil temperature was inversely correlated with both T50 (R^2 = –0.89, $P \leq 0.0001$) and T1090 (R^2 = –0.45, P = 0.0014). No correlation ($P \leq 0.05$) occurred between temperature and TEP. Delayed sowing decreased T50 (Table 3). I-822 had the longest T50 while T50 for the other breeding lines was similar. Delayed sowing decreased T1090 with the 15 May sowing date 2.1 d shorter than 17 Apr. (Table 3). Breeding lines had similar T1090. Delayed sowing produced 36% and 29% higher TEPs for I-822 and OL, respectively, compared with the earliest sowing date (data not presented). The TEPs were similar for the second and third sowing dates with I-822 (76%) and OL (86%). Total emergence for A-975 decreased from 88% to 34% as sowing date progressed. Sowing date had no effect on E-1236 TEP.

1998 HARVEST PARAMETERS. Delayed sowing decreased the number of days from sowing until the first flower harvest by about 18 d (Table 3). I-822 had the greatest number of days (88) from sowing until the first flower harvest compared to the other breeding lines. OL was the next longest with 79 d, and A-975 and E1236 were statistically similar at 70 d. No significant interactions existed. Total A-975 flower number decreased from 8.8 to 5.4 to 3.7 million flowers/acre (21.74, 13.34, and 9.14 million flowers/ha), respectively with delayed sowing (data not presented). The other breeding lines were similar and averaged 4.9 million flowers/acre (12.10 million flowers/ha) for the entire season. OL yielded the most fresh flowers, which was 25% higher than the next highest line, which was similar to the other breeding lines (Table 3). Sowing date did not influence fresh flower yield.

1999 GERMINATION PARAMETERS. A freeze occurred on 18 Apr. with the minimum air temperature reaching 28.94 °F (–1.7 °C). About 20% of the emerged seedlings from the first sowing date, 1 Apr., were visibly affected with a dark, water-soaked appearance indicative of plasma membrane leakage. No difference occurred in number of dead seedlings among the lines ($P \leq 0.05$) (data not presented). Average daily soil temperature was inversely correlated with T50 (R^2 = –0.44, P = 0.0003). No correlations occurred between temperature and either T1090 or TEP. Sowing date had a curvilinear effect on T50 with the shortest T50 (7.3 d) on 29 Apr. and the longest on 1 Apr. (10.3) (data not presented). The T50 values for 15 Apr. and 13 May

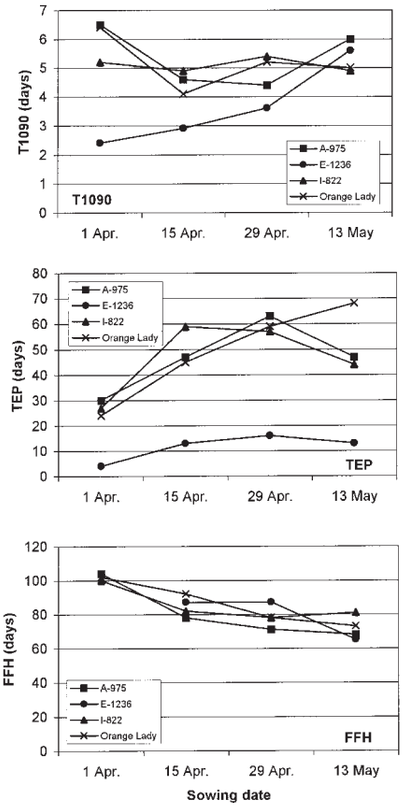

Fig. 2. Effect of breeding line and four sowing dates (S) on african marigold seedling emergence uniformity (T1090), total emergence (TEP), and days to first flower harvest (FFH). Symbols represent means from four replications of 64 seed each for seedling emergence uniformity and total emergence and four replications of 16 plants each for days to first flower harvest. With the 1 Apr. E-1236 planting only three replications had emerged seedlings due to spring frost and data are not shown. For emergency uniformity, the interactions of A-975 × S quadratic (Q) and E-1236 × S linear (L) were significant ($P < 0.01$). For total emergence the interactions of A-975 × SL, A-975 × SQ, I-822 × SQ and 'Orange Lady' × SL were significant ($P < 0.01$). For days to first flower harvest the interactions of A-975 × SL, A-975 × SQ, E-1236 × SL, E-1236 × SQ, I-822 × SL, I-822 × SQ and 'Orange Lady' × SL were significant ($P < 0.01$) (1999).

were 9.7 and 8.0 d, respectively. Delayed sowing linearly increased T1090 for E-1236 and curvilinearly decreased T1090 for A-975 (Fig. 2). No differences occurred among the other treatment combinations. Total emergence for OL linearly increased with delayed sowing, but TEP for A-975 and I-822 had curvilinear responses, peaking 15-29 Apr. (Fig. 2). Sowing date did not effect E-1236 TEP.

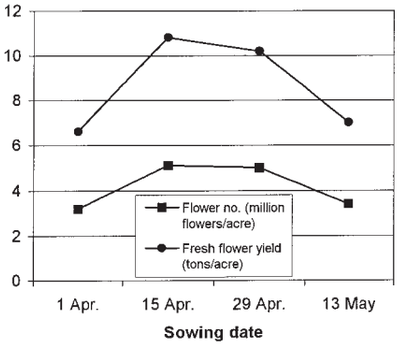

Fig. 3. Effect of four sowing dates on african marigold flower harvest. Symbols represent means of four replications of 16 plants each for six biweekly harvests. Main effects only are shown as no interactions occurred. There was a significant quadratic effect ($P < 0.001$) of sowing date on both flower number and fresh flower yield (1999). 1 flower/acre = 2.47 flowers/ha, 1.0 ton/acre = 2.24 t·ha^{-1}.

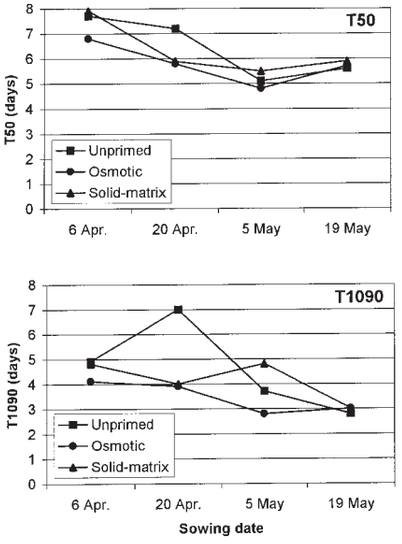

Fig. 4. Effect of unprimed (UP) or osmotic (OS) or solid-matrix (SM) primed seed and sowing date (S) on african marigold seedling emergence time (T50) and emergence uniformity (T1090). Symbols represent means of four replications of 64 seed each. For emergence time the interactions of UP × S linear (L), UP × S quadratic (Q), UP × S cubic (C), OP × SL, OP × SQ, SM × SL, and SM × SQ were significant ($P < 0.01$). For emergence uniformity the interactions of UP × SL, UP × SQ, UP × SC, and SM × SL were significant ($P < 0.01$) (2000).

1999 FLOWER PARAMETERS. Breeding lines and sowing date interacted to affect days from sowing to first flower harvest (Fig. 2). Days to first flower harvest decreased curvilinearly with sowing date for A-975, E-1236, and I-822. The number of days to first flower for I-822 decreased from the first sowing date to the third sowing date with a slight increase for the last sowing. OL days to first flower harvest decreased linearly with delayed sowing. Sowing date curvilinearly affected flower number and yield such that the greatest flower numbers and yields occurred from the 15 and 29 Apr. sowing dates and the lowest from the 1 Apr. sowing (Fig. 3). No differences in flower number and yield among breeding lines were observed.

2000 GERMINATION PARAMETERS. Average daily soil temperature was inversely correlated with both T50 ($R^2 = -0.42$, $P \leq 0.0001$) and TEP ($R^2 = -0.22$, $P = 0.0315$). No correlation occurred between temperature and T1090. Breeding lines did not influence T50 and T1090 and the data were pooled. OP influenced T50 to the greatest degree where seed sown on 5 May had the shortest T50 and the longest T50 occurred with SMP seed sown on 6 Apr. (Fig. 4). Each priming method had a curvilinear response such that the third sowing date, 5 May, had the shortest T50, but the longest period occurred with the first sowing date, 6 Apr. Priming method interacted with sowing date (Fig. 4). Unprimed seed had a curvilinear response with the shortest T1090 occurring for the 19 May sowing date, but the longest T1090 corresponded with the 20 Apr. sowing date. The T1090 was shortest on 19 May for the SMP method, but T1090 for OP seed did not differ among sowing dates. A three-way interaction occurred among breeding line, priming method, and sowing date for the TEP (Table 4). Osmotic prim-

Table 4. Effect of breeding line, priming method, and sowing date (S) on african marigold total seedling emergence percentage. Values shown are means of four replications of 64 seed each (2000).

Breeding line	Priming method	Sowing date	Total emergence (%)
E-1236 (E)	Unprimed	6 Apr.	68
		20 Apr.	59
		5 May	64
		19 May	58
	Solid matrix	6 Apr.	63
		20 Apr.	71
		5 May	66
		19 May	62
	Osmotic	6 Apr.	86
		20 Apr.	93
		5 May	68
		19 May	60
I-822 (I)	Unprimed	6 Apr.	67
		20 Apr.	70
		5 May	74
		19 May	78
	Solid matrix	6 Apr.	73
		20 Apr.	83
		5 May	74
		19 May	59
	Osmotic	6 Apr.	94
		20 Apr.	72
		5 May	67
		19 May	63
Significant interactions ($P \leq 0.05$)			
E × O × S^{L}			
I × O × S^{L}			
I × O × S^{Q}			

[ns]Nonsignificant, L = linear, Q = quadratic.

ing affected both E-1236 and I-822 seed such that there was a linear and curvilinear decrease, respectively, in TEP with delayed sowing. The TEP for OP seed was about 20% higher than SMP seed and the unprimed seed sown on the same date. No difference existed between SMP and unprimed seed with breeding lines and sowing dates.

Discussion

SOWING DATES AND BREEDING LINE. As expected, delayed sowing dates with warmer soil temperatures had higher TEPs than earlier sowing dates for most breeding lines (Table 4, Fig. 2). Sowing from mid-Apr. to the first of May resulted in the highest TEPs for both 1998 and 1999. Soil temperatures during this period ranged from 77.0 to 84.2 °F which is similar to recommended germination temperatures by AOSA (1993) [68.0 to 86.0 °F (20 to 30 °C)] and Dole and Wilkins (1999) [75 to 80 °F (23.9 to 26.7 °C)]. However, soil temperatures higher than 84.2 °F, common in mid-May, resulted in lower TEPs. When examining sowing dates of wildflowers, Salac et al. (1982) reported that sowing in early April rather than early May resulted in the highest TEPs for butterfly milkweed (*Asclepias tuberosa*), roundhead lezpedeza (*Lespedeza capitata*), purple prairieclover (*Petalostemon purpureum*), pitcher sage (*Salvia pitcheri*), and small soapweed (*Yucca glauca*). Percentages in April were about 15 to 30% higher than in May, and corresponding temperatures were not given.

Delayed sowing reduced T50 regardless of breeding line (Table 3, Fig. 4). As the temperature increased, emergence time decreased. The 1999 T50 values were not as low as in 1998, but soil temperatures were also not as high as in 1998.

In our study, TEPs were lower than a desirable 95% to 100% indicating the need of a suitable priming method for commercial production (Table 4, Fig. 2). In 1999, E-1236 seed quality was a problem as the TEP was below 16% for all sowing dates, and seed viability was only 51% (Table 2). After record examination, Goldsmith Seeds, Inc. reported that E-1236 seed supplied for 1999 was from the previous year's seed lot and had low viability (53%) (Table 2).

Higher soil and air temperatures and light intensities allowed plants that were sown late to flower in fewer days than those sown early (Table 3, Fig. 2). The last sowing date in mid-May had the fewest number of days to first harvestable flower, when compared to previous sowing dates. Breeding lines A-975 and E-1236 produced harvestable flowers in the least amount of time, about 15 d before I-822, which could result in an additional harvest during a season.

Sowing from middle to late April-produced the greatest flower numbers and yield due to longer growing season than May sowing and greater TEP than early April sowing (Tables 3 and 4, Fig. 2 and 3). In working with crisphead lettuce (*Lactuca sativa*) cultivars, Wurr and Fellows (1983) found that within a single crop later emerging seedlings matured later, as would be expected, but also weighed less at maturity. They emphasized that variation in time of maturity and yield at maturity could be reduced by improving emergence uniformity. Breeding line did not affect flower number or yield, with the exception of OL in 1998. OL produced the highest fresh flower yield of 7.5 tons/acre (16.81 $t \cdot ha^{-1}$) in 1998 and 10.8 tons/acre (24.20 $t \cdot ha^{-1}$) in 1999, which was lower than Baldwin et al. (1993) reported for their top-producer, 'Toreador' (14.3 tons/acre, 32.04 $t \cdot ha^{-1}$). However, our data were reduced by 43.6% to approximate mechanical harvest, while the Baldwin et al. (1993) data were based on hand harvesting. Certainly, all yield reports should be treated with caution as results will vary with location and year (Baldwin et al., 1993).

SEED PRIMING. Parera and Cantliffe (1994) stated priming's advantage is most evident when examining emergence parameters under adverse environmental conditions. In our study, OP seed had an advantage when soil temperatures were cool. Under cool temperatures, OP resulted in a lower T50 than either SMP or unprimed seed (Fig. 4). At warmer temperatures, the SMP seed reached T50 as fast as the OP seed. Tall fescue (*Festuca arundinacea*) seed primed in vermiculite (–1.5 MPa, 68 °F, 4 d) reached T50 53% faster than but had similar T1090 or TEP compared to unprimed seed (Pill et al., 1997). In this study, T50s were comparable for all methods at the last two sowing dates. The OP seed had more uniform emergence than unprimed or SMP seed for the first three sowing dates.

Enhanced emergence under adverse conditions was most evident with TEP. The OP seed had about 30% higher TEP at early sowing dates with both breeding lines than SMP or unprimed seed (Table 4). No difference occurred between SMP and unprimed seed for TEP regardless of the sowing date. Thus, SMP was not as effective as OP. Beckman et al. (1993) also found no difference in TEP between untreated big bluestem (*Andropogon gerardii*) seed and seeds exposed to 48-h SMP [–6 MPa, 62.6 °F (17 °C)] while examining seedling field emergence. SMP effectively improved TEP of primed cool-season turfgrass species, especially with slow-emerging species such as kentucky bluegrass (*Poa pratensis*) in cool soil temperatures (Yamamoto et al., 1997). Priming techniques were not specified. The effectiveness of OP in improving germination percentages is documented for several species (Bennett et al., 1992; Haigh et al., 1986; Khan, 1992).

Conclusions

The last 2 weeks of April, when soil temperatures average 77.6 °F (25.33 °C), was the optimum sowing time in Oklahoma for unprimed direct-seeded african marigold plants for both seedling emergence and flower yield. This temperature corresponds to recommended germination temps for african marigold (AOSA, 1993; Dole and Wilkins, 1999). A-975 and E-1236 produced harvestable flowers most quickly, about 15 d before I-822, which could result in an additional harvest during a season. While OP shortened emergence time, increased emergence uniformity, and increased total emergence percentage at early sowing dates, marigold producers would need to determine if the cost of seed priming is offset by increased production. Further research should be conducted with OP methods to improve on the promising results obtained.

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Efficacy of Paclobutrazol and Gibberellin$_{4+7}$ on Growth and Flowering of Three Curcuma Species

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ADDITIONAL INDEX WORDS. ***Curcuma alismatifolia*, *Curcuma gracillima*, *Curcuma thorelii*, gibberellic acid, paclobutrazol, postproduction elongation, postproduction longevity**

SUMMARY. Rhizomes of *Curcuma alismatifolia* Roxb. 'Chiang Mai Pink', *C. gracillima* Roxb. 'Violet', and *C. thorelii* Roxb. were soaked in gibberellin (GA_{4+7}) at 0, 200, 400, or 600 mg·L^{-1} (ppm) and planted into 15.2-cm-diameter (6 inches) containers. The plants were grown in a greenhouse at 30 °C day/23 °C night (86.0/73.4 °F) temperatures. When shoot height was 10 cm (3.9 inches), the plants were drenched with 118 mL (3.9 fl oz) of paclobutrazol at 0, 2, 3, or 4 mg a.i. per 15.2-cm-diameter container. Gibberellin$_{4+7}$ delayed shoot emergence and flowering but did not affect the flower number. Paclobutrazol rates were not effective in controlling height of *C. alismatifolia* 'Chiang Mai Pink' averaging 85 cm (33.5 inches), *C. gracillima* 'Violet' averaging 25 cm (9.8 inches), or *C. thorelii* averaging 17 cm (6.7 inches). *Curcuma alismatifolia* 'Chiang Mai Pink', *C. gracillima* 'Violet', and *C. thorelii* had postproduction longevities of 4.6, 2.6 and 3.8 weeks respectively, making these three species of curcuma excellent candidates for use as flowering pot plants.

The genus *Curcuma* Roxb. includes about 65 species that are native to southeast Asia. Commonly known as hidden or surprise gingers, these plants possess an attractive inflorescence with colorful bracts that enclose the flowers (Steffey, 1986; Chapman, 1995). Curcuma exhibit diversity in color, form and size (Lekawatana and Pituck, 1998), and have few disease and insect problems (Kuack, 1996; Lekawatana and Pituck, 1998). Cultural practices and optimal environmental conditions for curcuma vary according to species. These plants are commonly propagated from geophytic units that include a rhizome and several storage roots, termed t-roots (Hagiladi et al., 1997). Curcuma rhizomes are planted in early spring, flower from early spring to late fall, and retain vegetative growth until late fall or early winter when senescence begins and plants go dormant in response to short days (Lekawatana and Pituck, 1998).

The international market for curcuma is increasing yearly (E. Welch, personal communication). In 1995, Thailand exported 15 million rhizomes valued at $3 million, compared to $18,000 exported in 1990. Thailand exports curcuma rhizomes primarily to Japan and the Netherlands followed by the United States and New Zealand (Lekawatana and Pituck, 1998).

Curcuma alismatifolia, *C. gracillima* and *C. thorelii* have the most potential as flowering potted plants (Sarmiento, 2000). *Curcuma alismatifolia* has a terminal inflorescence with pink or white bracts, *C. gracillima* has a terminal inflorescence with red-white or red-violet bracts and *C. thorelii* has a white inflorescence (Chapman, 1995).

Marketable flowering potted plants are grown to a standard of 1.5 to 2 times the container height (Nelson, 1998). Some curcuma, *C. alismatifolia* 'Chiang Mai Pink' for example, produce excessively tall inflorescences that result in unmarketable plants. These curcuma, however, possess other redeeming qualities as mentioned earlier and growth retardants offer a potential aid in the production of marketable potted plants.

Gibberellic acid (GA_3) increased the number and size of flowers on rhizomatous plants such as liatris (*Liatris spicata* L.) and calla lily (*Zantedeschia elliottiana* W. Wats. and *Z. rehmannii* Engl.) (Corr and Widmer, 1991; Wanjao and Waithaka, 1983). Gibberellic acid reduced flower and shoot number and in some cases inhibited flowering of edible ginger (*Zingiber officinale* Roscoe) 'Chinese' (Furutani and Nagao, 1986). In potatoes (*Solanum*

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Use of trade names dose not imply endorsement of the products named or criticism of similar ones not named. Louisiana State University manuscript number 01-28-0687. We would like to thank The Fred C. Gloeckner Foundation for supporting this research. We would also like to acknowledge Scotts Co., Uniroyal Chemical, Novartis, Abbot Labs and Set Con Thailand for providing material for this research.