Inheritance of Cold Germinability in Muskmelon

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Abstract. A cold-germinable (CG) line of muskmelon (*Cucumis melo* L.) derived from PI 126156 was crossed to a noncold-germinable (NCG) line derived from 'Delicious 51'. Seed of parents and reciprocal F₁, F₂, and BC families were incubated for 14 days on absorbent wadding in petri dishes at 15C. Days elapsed to radicle emergence among progeny from reciprocal crosses and segregating populations indicated the existence in the CG line of a cytoplasmic factor and recessive nuclear genes for cold germinability. Based on F₂ and BC segregation, it appears that at least three or four recessive genes confer cold germinability. High levels of cold germinability in a seed population required the presence of both the cytoplasmic factor and nuclear genes for cold germinability.

Fluctuating soil temperatures often exist during the early part of the growing season in many regions. Under low temperatures, germination and seedling establishment of many warm-season crops, such as muskmelon, are severely hindered. Because melon seedlings are usually transplanted into the field in northern latitudes, considerations for

survival and growth of young plants in cold soils are important. In more-southerly regions, melons are often direct-seeded, so that cold germinability may be an important factor in seedling establishment.

Muskmelon genotypes capable of germinating at low (15C) temperatures have been identified (Hutton and Loy, 1991; Nerson et al., 1982). Cold-germinable (CG) lines also showed more rapid early seedling growth than noncold-germinable lines (Hutton, 1988). Since knowledge of the genetics of cold germinability is limited in vegetable species, information regarding low-temperature germination in muskmelon would be useful to breeders. Therefore, we determined the inheritance of cold germinability in muskmelon, using strains previously screened for cold germinability.

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DAYS TO GERMINATION (15C)

Fig. 1. Percent germination (radicle emergence >3 mm) over time (days) at 15C for the cold-germinable (CG) line and the F₁ and segregating families from crosses between PI 126156 (CG) and 'Delicious 51' (NCG) muskmelons. NG = nongenerated.

Two muskmelon cultigens were selected for the inheritance study, based on their germinability at 15C. PI 126156 germinates within 10 days at 15C (Hutton and Loy, 1991) and is referred to as CG. 'Delicious 51' was used as the noncold-germinable (NCG) parent because it shows no radical emergence after 14 days of incubation at 15C. Each parent was inbred for two generations, and selection pressure was applied to the CG line for cold germinability and seedling vigor after 14 days at 15C. The selected plants were grown in a glasshouse, self-pollinated, and the resulting seed subjected to an additional

cycle of selection. Seed of the NCG cultigen were incubated for 14 days at 15C, at which time no seed had germinated. Seed were transferred to a 28C incubator and, after 96 h, the most vigorous seedlings were selected, transplanted to a glasshouse, self-pollinated, and the selection cycle repeated.

During Fall 1986, CG and NCG second generation lines were grown in a glasshouse and reciprocal F₁ crosses were made. Seed of parental lines and reciprocal F₁ hybrids were sown into Jiffy 7 peat pellets and transplanted into the field in Spring 1987 to produce seed of the parental lines, reciprocal

F₁s, and the following segregating generations: F₂ seed from each F₁ and reciprocal BC₁s. Seed of mature fruit were harvested, fermented 4 days in open jars, rinsed with tap water, and dried in a forced-air dryer at room temperature ($\approx 30C$). Dry seed from individual fruit were stored at room temperature (22 to 25C) for at least 5 months to minimize seed dormancy. Seedlots derived from up to five fruit were bulked for F₁ and BC populations before germination experiments were started.

The germination-inheritance experiment was conducted at 15C in a Percival E-30B growth chamber (Percival, Boone, Iowa). Seed treated with Captan (Blue Ribbon Protector-2, Agway, Syracuse, N.Y.) were germinated in 25 x 100 mm plastic petri dishes (15 seeds per dish) lined with absorbent wadding (Curity No. 7067, Atlantic Healthcare Products Div., Westbrook, Maine) that was saturated with 12 ml prechilled dH₂O. A randomized complete-block design with four replications was used, with each set of petri dishes randomly arranged in each of four plastic germinating boxes (27 x 37 x 16 cm). Boxes were systematically rotated within the growth chamber each day to minimize effects of temperature variation. Seed populations for each replication or box were as follows: 15 parental lines, 30 F₁s, 210 F₂s, and 60 BCs.

Seed germination was recorded daily for 14 days. A seed was considered germinated when its radicle was longer than 3 mm. After 14 days, dishes were transferred to room temperature (RT; 22 to 25C) to determine germinability of those seed that failed to germinate at 15C. The combined germination at 15C and RT exceeded 85% for most seed populations.

Seed populations segregating for cold germinability could be grouped into three classes: 1) seed germinating as rapidly as the CG parent, 2) seed germinating within 14-day incubation period but not germinating as quickly as the CG parent, and 3) seed failing to germinate within 14 days, as with the NCG parent. The lack of a variance component for the latter class and segregating populations as a whole precluded estimates of heritability and partitioning of genetic variance for cold germinability.

The CG line derived from PI 126156 exhibited both rapid and a high percentage of germination (98% by day 7) at 15C (Table 1, Fig. 1). Seed of the NCG line derived from 'Delicious 51' failed to germinate after 14 days at 15C. Segregating seed populations derived from crosses between the CG and NCG lines exhibited varying degrees of cold germinability; however, no population approached the cold germinability of the CG parent (Table 1, Fig. 1).

There were significant differences in cold germinability between seed populations derived from reciprocal crosses of CG and NCG lines (Table 1). F₁ seed from CG x NCG gave 8.3% germination as compared to 0.8% germination for NCG x CG. In segregating BC populations with CG cytoplasm and 3/4 of the nuclear genome derived from the CG

Table 1. Population size, number of cold-germinable (CG) seed, and percent germination at 15C for seed populations derived from crosses between CG and noncold-germinable (NCG) muskmelon lines.

Pedigree	Seed (no.)		Germination at 15C (%) ^a
	Population	Germinated ^a	
Parents			
CG	60	59	98.3
NCG	60	0	0
F ₁ crosses			
CG × NCG	120	10	8.3
NCG × CG	120	1	0.8
F ₂ population			
(CG × NCG)⊗	840	223	26.5
(NCG × CG)⊗	840	15	1.8
Backcross population			
(CG × NCG)CG	240	86	35.8
(NCG × CG)CG	240	15	6.3
CG(CG × NCG)	240	65	27.1
CG(NCG × CG)	240	90	37.5
(CG × NCG)NCG	240	12	5.0
(NCG × CG)NCG	240	0	0
NCG(CG × NCG)	240	0	0
NCG(NCG × CG)	240	0	0

^aGermination scored as radicle emergence >3 mm.

NS,*,**,*Nonsignificant or significant at $P = 0.05, 0.01$ and 0.001 , respectively, by paired t tests.

Table 2. Inheritance of low-temperature germination^a in F₂ and backcross populations derived from crosses between PI 126156 (cold-germinable; CG) and 'Delicious 51' (noncold-germinable; NCG) muskmelons. Chi-square probabilities are given for models hypothesizing either three or four homozygous recessive genes for conferring cold tolerance in the CG parent.

Crosses	Population size	Cold germinable ^a (no.)	Model			
			Expected		χ^2 probability	
			3-gene	4-gene	3-gene	4-gene
(CG × NCG)⊗	840	24	13.1	3.3	<0.01	<0.001
CG(NCG × CG)	240	21	30.0	15.0	0.05–0.1	0.1–0.2
CG(CG × NCG)	240	14	30.0	15.0	<0.01	0.7–0.9
(CG × NCG)CG	240	18	30.0	15.0	0.01–0.05	0.3–0.5
Total (BC) ^a	720	53	90.0	45.0	<0.001	0.2–0.3

^aGermination scored as radicle emergence (>3 mm) at 15C.

^aCG class of seed germinating as rapidly as the CG parent (by day 5 or 6).

^aProbability for homogeneity χ^2 of three BC populations was 0.3–0.5.

parent [CG(CG × NCG), CG(NCG × CG) and (CG × NCG)CG], 27% to 36% of the seed had germinated at 15C by day 14. In contrast, in the backcross (NCG × CG)CG, with the same nuclear genetic component as the populations above, but with NCG cytoplasm, only 6.3% of the seed showed some degree of cold germinability. None of the three BC seed populations with NCG cytoplasm and 1/4 of the nuclear genome derived from the CG parent germinated at 15C; whereas, 5% germinated in the comparable BC population having CG cytoplasm (Table 1). Likewise, F₂ seed from (NG × NCG) ⊗ gave 26.5% germination at 15C, but seed from the reciprocal F₂ with NCG cytoplasm gave only 1.8% germination. The results therefore strongly indicate a maternal component in cold germinability of the CG line derived from PI 126156. Maternal effects conferring some cold germinability or sprouting ability have been reported in other

species (Cal and Obendorf, 1972; Christiansen and Lewis, 1973; De Vos et al., 1981; Marani and Dag, 1962; Ng and Tigchelaar, 1973), and also in a preliminary report on inheritance of low-temperature germination in muskmelon (Nerson and Staub, 1989). In the above studies, neither the nature of the maternal effect nor the existence of cytoplasmic inheritance was shown. Our results with muskmelon indicate involvement of cytoplasmic inheritance.

Nuclear genes are also involved in cold germinability of PI 126156 because CG cytoplasm alone did not confer either a high percentage or rapid rate of germination at 15C. The CG nuclear gene(s) are recessive, as indicated by low percentages of germination in seed populations heterozygous for putative nuclear genes contributing to cold germinability (Table 1). These populations are represented by F₁ crosses and BC populations in which the NCG parent contrib-

uted 3/4 of the nuclear genome. Recombination of nuclear genes for cold germinability in the presence of NCG cytoplasm [(NCG × CG) ⊗ and (NCG × CG)CG] resulted in populations with low germinability (1.8% and 6.3%, respectively) at 15C, in contrast, recombination of CG nuclear genes in populations with CG cytoplasm [(CG × NCG) ⊗, NG(NG × NCG), and (NG × NCG)NG] gave relatively high percentages of germination (26.5% to 37.5%) at 15C.

We fit our data to Mendelian inheritance models by determining the percentage of progeny (with CG cytoplasm) in segregating populations that germinated as rapidly (within 6 days) as the CG parent and equating that class as carrying the homozygous recessive complement of genes for cold germinability.

Only ≈3% of F₂ seed from (CG × NCG) ⊗ germinated as rapidly as the CG line (Table 2). These results fit neither a two-gene (6.25% homozygous recessive) nor a three-gene (1.56% homozygous recessive) model but suggest that a maximum of three recessive genes is involved in cold germinability. However, backcross progeny with CG cytoplasm [(CG × NCG)CG, CG(CG × NCG), and CG(NCG × CG)] had between 6% to 9% rapidly germinating recombinants, values consistent with a four-recessive-gene model. We cannot explain the different interpretations of the backcross and F₂ segregation data with our simple inheritance models. Transgressive segregation was not detected in our seed populations (Fig. 1), indicating that the NCG parent did not contribute genes for cold germinability.

Nuclear genes have been implicated in low-temperature germinability of other species (De Vos et al., 1981; El Hassan, 1971; Ng and Tigchelaar, 1973). In muskmelon, Kubicki (1962) reported that the capacity of muskmelon to germinate in cold soils was a dominant trait; the preliminary results of Nerson and Staub (1989) likewise suggested that cold germinability in 'Persian 202' was due to dominant gene(s). Therefore, differences in the genetic basis of cold tolerance in muskmelon likely exist and may involve recessive and dominant genes. Several accessions of muskmelon with varying degrees of cold tolerance have now been identified (Hutton, 1988). It may be possible for breeders to select for more extreme cold tolerance by intercrossing known cold-tolerant lines, thereby producing different gene combinations for cold tolerance.

Selection for cold germinability presents some problems. We were unsuccessful in trying to establish the genetic basis of cold germinability in crosses of PI 126156 to 'Minnesota Midget', a cultivar with moderate levels of cold tolerance (Hutton, 1988). 'Minnesota Midget' had the cold-tolerant cytoplasmic factor but showed considerable instability in cold germinability among different seed lots. Proper harvesting and handling of seed are critical for evaluating germinability (Edwards et al., 1986). We have observed that fresh seedlots of muskmelon, especially those harvested from greenhouse-grown plants, often exhibit a dormancy (unpub-

lished data), and the dormancy is more evident at low than at high temperatures, as has been observed in cucumber (Edwards et al., 1986).

In the present study we equated cold germinability with radicle emergence at 15C because seeds sprouting most rapidly at 15C also showed the most rapid development to the cotyledon stage at 15C (Hutton, 1988). Also, in a comparison of three CG lines (including PI 126156) and two NCG lines, a highly significant correlation ($r = 0.88$) was found between germinability at 15C and relative growth rate of young plants at 15C (Hutton, 1988). The greater growth rate of the CG lines at 15C may have been due to factors other than genes for cold tolerance per se (e.g., large seed and seedlings), but nonetheless, the CG lines may prove to be valuable germplasm for developing muskmelon strains with better capability to ger-

minate and survive in suboptimal climates than NCG lines.

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