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The Effects of Chemical Seed Treatments on Horticultural Characteristics in Cucumber (*Cucumis sativus* L.)*

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ABSTRACT

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Seeds of the cucumber line WI 1606 were treated with Cytozyme, Cytex, Erogstim, Progib, $Ga_{4/7}$ or $GA_{4/7}$ + ethephon using acetone and water as infusion media. Days to germination (DTG) and percentage germination (PG) at 15 and 25°C after 2 and 20 weeks storage were calculated. No significant differences in PG could be detected among control seeds at 15°C 2 and 20 weeks after treatment. The DTG of control or chemically treated seed at 2 weeks was consistently lower than at 20 weeks, regardless of infusion medium. In contrast, the DTG was increased with storage. The PG of seeds treated with $GA_{4/7}$ + ethephon was higher than that of all other treatments after 2 and 20 weeks of storage regardless of infusion medium. Moreover, the PG and DTG of seeds treated with $GA_{4/7}$ and Progib were higher after acetone infusion. Seeds treated with Cytex, Cytozyme or Ergostim and infused with acetone did not germinate at either 15 or 25°C. The rate and total emergence of seedlings, sex expression, maturity date and fruit yield were not affected by seed treatment or infusion media when tested in field studies.

Keywords: chemical infusion; cold tolerance; emergence; germination; gibberellin.

Abbreviations: DTE = days to emerge; DTG = days to germinate; GA_3 = gibberellic acid; $GA_{4/7}$ = gibberellins A_4 and A_7; PE = percentage emergence; PG = percentage germination; PGR = plant growth regulators; PO = percentage oversized fruit.

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INTRODUCTION

Poor field emergence and erratic stands lead to increased variation in plant development which can result in yield reductions. The survival and performance of seed after sowing is affected by physical, mechanical, chemical and biotic factors. Temperature, light, drought, flooding and gaseous environments are physical factors which influence seedling emergence (Khan et al., 1979; Hegarty, 1979; Thomas, 1981). Low temperatures after the sowing of many warm-season vegetables can lead to asynchronous seedling emergence (Kotowski, 1962; Thompson, 1974a, b). This asynchrony is consistently observed where spring temperatures fluctuate dramatically. In areas where crops are harvested once-over mechanically, non-uniform emergence is of particular concern.

Stand uniformity can be enhanced by various seed treatments (Ells, 1963; Pollock, 1969; Malnassy, 1971; Heydecker, 1973/1974; Salter, 1978; Gray, 1981; Sosa-Coronel and Motes, 1982). Germination rate (RG) and percentage of several vegetable species have been shown to increase after seed treatment with growth regulators and various osmotica (Fieldhouse and Sasser, 1975; Darby and Salter, 1976; Yaklich and Orzolek, 1977; Nelson and Sharples, 1980).

Cucurbit seeds require relatively high temperatures for successful germination and seedling emergence (Harrington and Minges, 1954; Hegarty, 1973). For instance, cucumber (*Cucumis sativus* L.) seed germinates rapidly at 20°C, but the time to 50% germination at 14°C decreases substantially (Simon et al., 1976; Nienhuis et al., 1983) and below 11°C only a small percentage of the seed germinates (Simon et al., 1976). Germination of watermelon seed (*Citrullus lanatus* (Thumb.) Matsum. and Nakai) was improved at 15°C after priming with inorganic osmotica (Sachs, 1977). Likewise, infusion of $GA_{4/7}$ and ethephon by acetone increased the percentage of germination in cucumber and muskmelon (*Cucumis melo* L.) seed at 12 and 16°C, respectively (Nelson and Sharples, 1980). Although GA_3 seed treatment has proved to be effective in increasing the low-temperature germination of several crop species (Wittwer and Bukovac, 1957; Coats, 1967; Yen and Carter, 1972; Cole and Wheeler, 1974), it was less effective in cucumber and muskmelon than $GA_{4/7}$ alone or in combination with ethephon (Nelson and Sharples, 1980).

Emergence in cucumber has been shown to be a function of the time required for radicle elongation and hypocotyl development at a given temperature (Simon et al., 1976). Moreover, it appeared that seedling emergence at 15°C was independent of the physiological processes which promote germination (Staub et al., 1986). Therefore, the efficacy of a chemical seed preconditioning treatment on emergence under suboptimal temperatures may depend on its ability to influence several biochemical and physiological processes simultaneously. In the present study, several plant growth regulators and a nutrient seed treatment were compared for their effects on horticulturally important traits of cucumber in controlled and field environments. Studies were designed to: (1)

determine whether gibberellin seed treatment alone or in combination with ethephon could increase emergence of cucumber at suboptimal temperatures; (2) define the effectiveness of infusing growth regulators with acetone; (3) evaluate the field performance effects of various chemical seed treatments in addition to $GA_{4/7}$ on germination and seedling emergence, sex expression and first harvest yield.

MATERIALS AND METHODS

Seed treatment. – Seeds of the gynoecious USDA processing cucumber inbred line WI 1606 were aerated in either distilled water or reagent-grade acetone for 6 h at 32 °C or 16 h at 25 °C, respectively. Infusion liquids were: control, aerated in distilled water and acetone without growth regulators; Cytex (10% v/v; Atlantic and Pacific Research, Inc., North Palm Beach, Florida) contains cytokinins; Cytozyme, (10% v/v; Cytozyme Inc., Salt Lake City, Utah), contains cytokinins; Ergostim, (10% v/v; Montedison U.S.A., Inc., New York, NY) a nutrient solution (fertilizer) with active ingredients of folic acid (0.1%) and *n*-acetyl thiazolidin-4 carboxylic acid (5%); gibberellin $GA_{4/7}$, (1.0 mM, Abbott Laboratories, North Chicago, Illinois), contains gibberellin A_4 and A_7; gibberellin $GA_{4/7}$ in combination with ethephon (3.5 mM); Progib, (7 mg l^{-1}; Abbott Laboratories, North Chicago, Illinois), contains gibberellic acid GA_3.

After treatment, seeds were air dried at 25 °C and stored under laboratory conditions (21 ± 3 °C and approximately 70% relative humidity) for approximately 2 or 20 weeks prior to evaluation.

Controlled environment experiments. – Seeds were germinated at 15 and 25 °C in temperature-controlled chambers 2 and 20 weeks after treatment. Chambers were dark except for a low-intensity fluorescent work light (30 μmol s^{-1} m^{-2}) used 4 h each day. Relative humidity was 80%. Treatments were single 60-mm diameter Petri dishes containing 25 seeds placed on 2 layers of filter paper (Whatman No. 2) moistened with 4 ml of distilled water. The dishes were covered with a sheet of clear plastic (2 mm) to reduce evaporation. The treatment arrangement within each chamber (temperature) was a randomized complete block with 4 replications. Seeds were considered germinated when the radicles protruded $\geqslant$ 5 mm.

Field experiments . – Beginning 3 weeks after chemical treatment, seeds in each treatment were planted twice in field nurseries at Clinton (North Carolina), Hancock (Wisconsin) and Napoleon (Ohio) on 18/4 (day/month) and 27/4, 9/5 and 23/5, 10/5 and 16/5/1984, respectively. Treatments were arranged as a randomized complete block design with 3 replications. Fifty seeds of each treatment were sown about 0.12 m apart in rows 6.1 m long, spaced 1.5 m apart. Plants were considered emerged when the cotyledons were free of the soil surface. Seedlings were thinned to 40 plants row^{-1} at the 3-true-leaf stage. Irri-

gation was used along with standard cultural practices. Minimum and maximum daily temperatures were recorded at a soil depth of approximately 25 mm during the period of seedling emergence.

Data collection and analysis. – Data were collected on germination (controlled environments) and seedling emergence, flowering date, sex expression and fruit yield (field studies). For each treatment, percentage germination (PG), percentage emergence (PE) and the average number of days to germination, radicles $\geqslant 5$ mm (DTG), and emergence (DTE) were calculated, using the following formulae:

$$\text{PG or PE} = (T/50) \times 100, \text{ and}$$

$$\text{DTG or DTE} = \sum_{i=1}^{N} (N_i \times D_i)/T$$

where: T = total number of seedlings which germinated or emerged; 50 = total number of seeds planted plot^{-1}; N_i = number of seedlings germinated or emerged on the ith day after experiment initiation; D_i = the number of days after experiment initiation (Smith and Millett, 1964).

Final percentages of germination and emergence were determined when no further germination was observed for 72 h, in controlled environments and 18 days after sowing in the field. Those treatments in which seeds did not germinate or emerge were not assigned a numerical value and not used in the analysis of the germination and emergence characters evaluated.

The number of days to first flower was recorded when 3 fully expanded corollas were observed on 5 plants within each treatment. Sex expression was determined by examining the first 10 nodes of 10 plants in each treatment. Plants were classified as gynoecious (0 staminate flowers), predominantly gynoecious (1–3 staminate flowers) or monoecious (more than 7 staminate flowers). At each location, fruits were harvested once when approximately 10% were >51 mm in diameter (oversized), and the numbers of fruits plant^{-1} were recorded. The percentage of oversized (PO) fruits was calculated for each treatment and location.

Analyses of variance were performed separately for each trait at each location. Arcsine square root transformations of data percentages did not affect the results of the analyses and variances were homogeneous. Therefore, analyses of untransformed data are presented. Correlations were calculated among all traits, chemical seed treatments and infusion media collectively, using means of locations, planting dates and replications for the field, and storage times and replications for controlled environments.

RESULTS

Controlled environment experiments. – Significant differences in chemical treatments, infusion media and storage duration were observed for PG and

DTG at 15 and 25°C (Table 1). Treatment with $Ga_{4/7}$+ethephon (15°C, water or acetone, 2 or 20 weeks storage) gave higher PG and DTG than most other treatments. In some instances $GA_{4/7}$ (15°C, water, 20 weeks storage or ace-

TABLE 1

Mean germination percentage (PG) and days to germination (DTG, radicals ⩾5 mm long) of cucumber (*Cucumis sativus* L.; WI 1606) seed treated with either PGR or fertilizer using 2 infusion media, and germinated at 15 or 25°C, 2 or 20 weeks after treatment

Chemical treatment	Infusion medium	Storage time (weeks)	PG (%) and DTG (days) at 15 and 25°C			
			15°C		25°C	
			PG	DTG	PG	DTG
Control	Acetone	2	75^{efgh}	11.7^{ef}	96^{ab}	3.4^{ab}
		20	76^{defg}	15.0^{ab}	94^{b}	1.0^{e}
	Water	2	64^{ghij}	7.5^{l}	100^{a}	3.2^{bcd}
		20	63^{hij}	11.0^{efgh}	97^{ab}	1.0^{e}
Cytex	Acetone	2	0	–	0	–
		20	0	–	0	–
	Water	2	57^{jkl}	10.8^{fgh}	95^{b}	3.3^{bc}
		20	70^{fghi}	15.5^{a}	97^{ab}	1.0^{e}
Cytozyme	Acetone	2	0	–	0	–
		20	0	–	0	–
	Water	2	45^{lm}	11.7^{ef}	97^{ab}	3.0^{d}
		20	63^{hij}	16.1^{a}	94^{b}	1.1^{e}
Ergostim	Acetone	2	0	–	0	–
		20	0	–	0	–
	Water	2	40^{m}	10.1^{hi}	98^{ab}	3.0^{d}
		20	58^{ijk}	13.1^{cd}	95^{b}	1.0^{e}
$GA_{4/7}$	Acetone	2	88^{abcd}	10.4^{ghi}	95^{b}	3.1^{cd}
		20	86^{abcde}	12.2^{de}	94^{b}	1.0^{e}
	Water	2	58^{ijk}	8.8^{jk}	97^{ab}	3.2^{bcd}
		20	84^{bcde}	13.2^{cd}	100^{a}	1.1^{e}
$GA_{4/7}$+ethephon	Acetone	2	94^{ab}	8.8^{jk}	96^{ab}	3.6^{a}
		20	93^{abc}	10.3^{hi}	98^{ab}	1.1^{e}
	Water	2	80^{cdef}	7.7^{kl}	97^{ab}	3.0^{d}
		20	98^{a}	9.5^{ij}	97^{ab}	1.0^{e}
Progib	Acetone	2	88^{abcd}	11.6^{efg}	96^{ab}	3.0^{d}
		20	76^{defg}	14.9^{ab}	98^{ab}	1.0^{e}
	Water	2	49^{klm}	9.9^{hij}	100^{a}	3.4^{ab}
		20	56^{jkl}	14.1^{bc}	97^{ab}	1.0^{e}
LSD			12	1.2	4	0.2

Superscripts indicate significant differences among means in columns by LSD ($P<0.05$).

tone, 2 or 20 weeks storage) and Progib (15°C, acetone, 2 weeks storage) was as effective as $GA_{4/7}$+ethephon in increasing PG. The PG and DTG of $GA_{4/7}$-containing seed treatments (15°C, acetone) was higher than controls (15°C, water), regardless of storage duration. The PG of some Progib-treated seed (15°C, acetone, 2 or 20 weeks storage) was higher than others (15°C, water, 2 or 20 weeks storage) or corresponding water controls. One Progib treatment (15°C, water, 2 weeks storage) caused a reduction in PG when compared to water controls.

Some seeds treated with Cytex, Cytozyme or Ergostim (15 and 25°C, acetone, 2 or 20 weeks storage) did not germinate. Addition of these compounds to acetone resulted in a brown, flocculent precipitate. The solvent maintained a reddish-brown coloration during the infusion period. The PG and DTG of seeds which did germinate (15 and 25°C, water, 2 or 20 weeks storage) was not lower than controls (15 and 25°C, water, 2 or 20 weeks storage water). With the exception of $GA_{4/7}$+ethephon, all chemicals infused with water (15°C, 20 weeks storage) promoted higher DTG when compared to the water controls (15°C, 20 weeks storage).

The DTG of seed (15 or 25°C, water or acetone) was greater after 20 weeks than after 2 weeks. However, the germination of some seed treated with $GA_{4/7}$+ethephon (15°C, water, 20 weeks storage) was delayed to a lesser extent than seed of water controls (15°C, 20 weeks storage). Increasing storage duration from 2 to 20 weeks increased PG of all chemically treated seed (15°C, water), except Progib (15°C, water).

The lower DTG of seeds treated with water alone (15°C, 2 and 20 weeks storage) when compared to acetone controls (15°C, 2 and 20 weeks storage) was associated with lower PG values. The large differences in germination performance recorded at 15°C were not observed at 25°C where PG ranged between 94 and 100%. The PG of seeds treated with acetone alone (25°C, 20 weeks storage) was lower than some water-treated seeds (25°C, 2 weeks storage). Differences in PG and DTG between seed treatments were infrequent and demonstrated no consistent response pattern.

Field experiments. – Soil temperature (25 mm below surface) during seedling emergence ranged from 7 to 30, 8 to 31 and 4 to 33°C in Wisconsin, Ohio and North Carolina, respectively. Temperature minima in Wisconsin were lower, on average, than in other locations. In North Carolina, minimum and maximum temperatures were notably lower during the first 9 days of the first planting than during subsequent days.

Significant differences were recorded for PE, DTE, fruit yield and PO fruit among locations and between planting dates (Table 2). However, no differences were detected for any character measured with regard to seed treatments (infusion media or chemical treatments).

The mean DTE of all seed treatments at all locations was highest in the first

TABLE 2

Mean percentage (PE) and days (DTE) to emergence, once-over harvest fruit yield and percentage oversized (PO) of cucumber (*Cucumis sativus* L.; WI 1606) plants grown from chemically treated seed which was sown at 3 locations in 2 plantings

Location	Planting	Emergence		Fruit	
		PE	DTE	Plant	PO (>51 mm)
Ohio	1	87[a]	13.1[b]	1.1[a]	23.4[a]
	2	72[b]	10.6[d]	0.7[b]	2.8[c]
North Carolina	1	72[b]	11.7[cd]	0.7[b]	15.8[b]
	2	71[b]	12.1[bc]	0.6[b]	12.6[b]
Wisconsin	1	88[a]	14.9[a]	0.6[b]	14.4[b]
	2	95[a]	7.7[e]	0.6[b]	13.4[b]

Superscripts indicate significant differences among means in columns by LSD ($P<0.05$).

planting. In Ohio, consistently higher values for all characters were observed during the first planting. When averaged over planting dates, the mean PE of treatments in Wisconsin was 92% compared to 72 and 80% in North Carolina and Ohio, respectively. The DTE in Ohio was longer (11.9 days) than that of seeds sown in Wisconsin (11.3), but was similar to that in North Carolina (11.8). Likewise, the numbers of fruits harvested from plants originating from treated seed were on average higher in Ohio (0.9) when compared to either North Carolina (0.7) or Wisconsin (0.6).

Phenotypic correlation coefficients provide a measure of association among the characters monitored. Since interactions among main effects were infrequent in either controlled environment or field evaluations, data from chemical seed treatments and infusion media were merged for analysis. Significant ($P<0.01$) positive correlations were detected among DTG and DTE at 15°C (0.98), PG and yield at 15°C (0.90) and PG and PE at 15°C (0.88). Significant negative correlations were obtained among DTG and yield at 15°C (−0.96) or 25°C (−0.98).

DISCUSSION

Nelson and Sharples (1980) demonstrated that the rate and percentage of germination of cucumber seeds incubated at 12°C was markedly increased by acetone infusion with $GA_{4/7}$. Our data at 15°C support these results and provide evidence that this germination response potential could be sustained during at least 20 weeks storage following treatment. Moreover, the PE at 15°C of all water-infused chemical treatments 20 weeks after storage was higher than at 2 weeks, suggesting that the driving mechanism for germination was enhanced by long-term storage.

Infusion of cucumber seed with water increased germination rate at 15°C 2 weeks after storage but not after 20 weeks. Although water infusion did not affect percentage germination in controls, germination was consistently higher 20 weeks after water infusion of chemicals. Water-infused $GA_{4/7}$ and GA_3 (Progib) treatments improved percentage of germination, while rate was decreased after 20 weeks of storage. The germination performance at 15°C was enhanced by GA_3 + ethephon treatment, but its effect on rate of germination dissipated during storage regardless of infusion medium. The data indicate that while initial germination performance can be enhanced by these treatments, their beneficial effect on germination rate diminishes with increasing storage time.

Reasons for the differences in efficacy between infusion media are not known. The amount of GA_3 penetrating the seeds during acetone infusion depends on seed type, permeation time and the concentration of the solution (Tao and Khan, 1974). The penetration of GA_3 is presumably restricted by its molecular weight. Since Progib contains GA_3, one might predict that its activity in promoting germination would not be as high as that of $GA_{4/7}$ (Ikuma and Thimann, 1963; Nelson and Sharples, 1980). Differences between the PG of acetone and water-infused Progib-treated seeds may be attributed to a lack of penetration by GA_3 or related to differences in the active form of GA itself. However, the data are equivocal and this hypothesis is being tested. Extending the water infusion period or increasing the concentration may increase the effectiveness of the Progib treatment.

Acetone is water miscible and unreactive with proteins, but can change its conformation through dehydration (Scopes, 1978). A wide range of plant species produce acetone at various stages of seed germination. A strong positive correlation exists between acetone production at embryo axes and lipid content of the seed, suggesting that acetone production is closely associated with some aspect of lipid metabolism during germination (Murphy, 1985). The observed increased effectiveness of acetone infusion in combination with gibberellin treatment may be caused by conformational changes in protein components of the cell membrane resulting in increased mobility of these growth regulators. This hypothesis requires testing.

There were no chemical treatments which could be consistently associated with increasing PE and decreasing DTE in field studies. Although isolated fruit yield differences did occur between treatments, none of these differences could be directly attributed to increases in rate and total emergence. It appears, from available information (Simon et al., 1976; Staub et al., 1986), that those growth regulators which promote germination under prolonged exposure at suboptimal temperatures do not necessarily decrease DTE under field conditions. This is due, in part, to the fact that the biochemical processes required for germination and hypocotyl elongation are dissimilar (Staub et al., 1986), and to fluctuating soil temperatures which may negate any advantages pro-

vided by chemicals which might increase the ability of seed to germinate at suboptimal temperatures.

REFERENCES

Coats, G.E., 1967. Effects of growth regulators on germinating cotton. Miss. Agric. Exp. Stn. Bull., 752, pp. 1–8.

Cole, D.F. and Wheeler, J.E., 1974. Effect of pregermination treatments on germination and growth of cottonseed at suboptimal temperatures. Crop Sci., 14: 451–454.

Darby, R.J. and Salter, P.J., 1976. A technique for osmotically pretreating and germinating quantities of small seed. Ann. Appl. Biol., 83: 313–315.

Ells, J.F., 1963. The influence of treating tomato seed with nutrient solutions on emergence rate and seedling growth. Proc. Am. Soc. Hortic. Si., 83: 684–687.

Fieldhouse, D.J. and Sasser, M., 1975. Stimulation of pepper seed germination by sodium hypochlorite treatment. HortScience, 10: 622.

Gray, D., 1981. Fluid drilling of vegetable seeds. Hortic. Rev., 3: 1–27.

Harrington, J.F. and Minges, P.A., 1954. Vegetable seed germination. Univ. Calif. Agric. Ext. Serv. (mimeo).

Hegarty, J.W., 1973. Temperature relations of germinations in the field. In: W. Heydecker (Editor), Seed Ecology, Chap. 23. Proc. 19th Easter School Agric. Sci., Univ. Nottingham, 1972. Butterworths, London, pp. 411–432.

Hegarty, J.W., 1979. Factors influencing the emergence of calabrese and carrot seedlings in the field. J. Hortic. Sci., 54: 194–207.

Heydecker, W., 1973/1974. Germination of an Idea: The Priming of Seeds. Univ. Nottingham School of Agric. Rep., pp. 50–57.

Ikuma, H. and Thimann, K.V., 1963. Activity of gibberellin 'D' on the germination of photosensitive lettuce seeds. Nature (London), 197: 1313–1314.

Khan, A.A., Karssen, C.M., Leve, E.F. and Roe, C.H., 1979. Preconditioning of seeds to improve performance. In: T.K. Scott (Editor), Plant Regulation and World Agriculture. Plenum Press, New York, pp. 395–414.

Kotowski, F., 1962. Temperature relations to germination of vegetable seeds. Proc. Am. Soc. Hortic. Sci., 23: 176–184.

Malnassy, P.G., 1971. Physiological and biochemical studies on a treatment hastening the germination of seeds at low temperatures. Ph.D. Thesis, Rutgers University, New Jersey, 131 pp.

Murphy, J.B., 1985. Acetone production during the germination of fatty seeds. Physiol. Plant., 63: 231–234.

Nelson, J.M. and Sharples, G.C., 1980. Effect of growth regulators on germination of cucumber and other cucurbit seeds at suboptimal temperatures. HortScience, 26: 253–254.

Nienhuis, J., Lower, R.L. and Staub, J., 1983. Selection for improved low temperature germination in cucumber (*Cucumis sativus* L.). J. Am. Soc. Hortic. Sci., 108: 1040–1043.

Pollock, B.M., 1969. Imbibition temperature sensitivity of lima bean seeds controlled by initial seed moisture. Plant. Physiol., 44: 907–911.

Sachs, M., 1977. Priming of watermelon seeds for low-temperature germination. HortScience, 102: 175–178.

Salter, P.J., 1978. Fluid drilling of pregerminated seeds: Progress and possibilities. Acta Hortic., 83: 245–249.

Scopes, P.J., 1978. Protein Purification: Principles and Practice. 2nd edn. Springer-Verlag, New York, 282 pp.

Simon, E.W., Minchin, A., McMenanmin, M.M. and Smith, J.M., 1976. The low temperature limit for seed germination. New Phytol., 77: 301–311.

Smith, P.G. and Millett, A.H., 1964. Germination and sprouting responses of the tomato at low temperatures. Proc. Am. Soc. Hortic. Sci., 84: 480–484.

Sosa-Coronel, J. and Motes, J.E., 1982. Effect of gibberellic acid and seed rates on pepper seed germination in aerated water columns. J. Am. Soc. Hortic. Sci., 107: 290–295.

Staub, J.E., Nienhuis, J. and Lower, R.L., 1986. Effects of seed preconditioning treatments on the emergence of cucumber populations. HortScience, 21: 1356–1359.

Tao, K.L. and Khan, A.A., 1974. Penetration of dry seed with chemicals applied in acetone. Plant Physiol., 54: 956–958.

Thomas, T.H., 1981. Seed treatments and techniques to improve germination. Scientia Hortic., 32: 47–59.

Thompson, P.A., 1974a. Characterization of the germination responses to temperature of vegetable seeds. I. Tomatoes, Scientia Hortic., 2: 35–54.

Thompson, P.A., 1974b. Effects of fluctuating temperature on germination. J. Exp. Bot., 25: 164–175.

Wittwer, S.H. and Bukovac, M.J., 1957. Gibberellin and higher plants. VIII. Seed treatments for beans, peas, and sweet corn. Mich. Agric. Exp. Stn. Q. Bull., 40: 215–224.

Yaklich, R.W. and Orzoleck, M.D., 1977. Effect of polyethylene glycol-6000 on pepper seed. HortScience, 12: 263–264.

Yen, S.T. and Carter, O.G., 1972. The effect of seed pretreatment with gibberellic acid on germination and early establishment of grain sorghum. Aust. J. Exp. Agric. Anim. Husb., 12: 653–661.