

# Seed Production and Germinability of Cucurbit Crops

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## ABSTRACT

Cucurbit crops are mostly produced for their immature or mature fruits. However, a relatively high proportion of cucurbit fields are destined for seed production, either for seed consumption or for propagation material. Production of cucurbits for seed consumption (as a snack food) is very popular in some parts of the globe and almost unknown in others. Open-pollinated cultivars (inexpensive seeds) are used in almost all crops for seed consumption. In the last decades the proportion of hybrids has dramatically increased because of the advantages of heterosis, improved technology and utilization of controlled environments. Cucurbit crops are insect-pollinated, and the introduction of honey-bee colonies into cucurbit seed production fields is an essential step for success. However, isolation is required to prevent outcrossing, both for open-pollinated cultivars and hybrid cucurbit seeds. Understanding the role of phytohormones and growth regulators in sex expression of cucurbits has greatly facilitated hybrid seed production. The germination ability of cucurbit seeds is related both to external and internal factors. Variability in germination ability of any seed population harvested at a particular site during a given season is based on inter- and within-plant variations. The failure of cucurbit seeds to germinate may at times have no relation to seed quality but may also be due to the lack of specific requirements. This is probably the case in conditional dormancy which is typical for some cucurbits. Appropriate temperature is probably the most important factor, but gas exchange, water potential and hormones are also involved in regulating germination. Seed quality can be affected by the maternal environment, seed maturity at harvest, extraction procedure, and storage conditions. Priming treatments can improve germination, especially when applied to poor quality seeds, or under stressful environments.

**Keywords:** *Citrullus lanatus*, *Cucumis melo*, *Cucumis sativus*, *Cucurbita* spp.

**Abbreviations:** DAP, days after pollination; PGR, plant growth regulator

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## SEED PRODUCTION

Cucurbit seeds are variable in size, shape and structure, traits which are used in family classification (Chakravarty and Hore 1979). The high economic value of some species including cucumber, melons and squash increases the importance of studying their optimal seed production (Welbaum 1999). Most seed production in the *Cucurbitaceae* is directed for propagation. However, in some parts of the world cucurbit seeds (mainly watermelons and squash) are produced and consumed as snack food, because their

nutritive values are high (Nadaan and Lal 1984; Sharma *et al.* 1986). For example, melon seeds may be served as nutritive additives to pasta dishes (Kaur *et al.* 1988), and those of a wild watermelon ancestor can be used as a source of protein for human food and animal feed (Sawaya *et al.* 1986).

### Cultural practices

Most cultural practices for successful cucurbit seed production are not different from those for successful cucurbit fruit

production. Therefore the present discussion of cultural practices will emphasize only those factors most important to a seed producer. Most cucurbits have at least some degree of parthenocarpy (Sari *et al.* 2006). This means that in many cases cucurbit fruit-set can occur without pollination or fertilization. Nevertheless, in almost all cucurbit crop production areas, there is a recommendation to add bee colonies in order to achieve maximal pollination and yield. Successful seed production requires the presence of optimal pollinator agents since no one single seed will be produced without fertilization. A recent study in three species of *Cucurbita* showed the importance of honey bee hives in seed production under field conditions (Walters and Taylor 2006).

Appropriate water supply during the growing season is an essential factor in cucurbit production. When crops are grown for fruits, there is a tendency to reduce irrigation as fruit maturation occurs in order to increase fruit sweetness and shelf-life. When crops are grown for seeds and no eating-quality considerations are involved, the crop has to be irrigated all the way to harvest, and where the yield is harvest by multiple pickings (diffused fruit set and development) the supply of water has to continue even later, into the harvest period.

Seed production of open-pollinated cucurbits is conducted, in all cases, under field conditions and in warm seasons. The economic value of these seeds does not merit their production under protected conditions. In contrast, production of higher-valued hybrid seeds is often conducted in greenhouses that may include supplemental heating. Most cucurbit crops have a prostrate growth habit, but when they are grown in greenhouses or plastic walk-through tunnels, they are trailed upward to increase space for more plants. Robinson (1999) published a comprehensive review of modern methods used in cucurbit hybrid seed production.

### Sex expression and plant growth regulators

Sex expression in the *Cucurbitaceae* family is variable across genus and species as well as within species. The knowledge of sex expression for any cultivar among cucurbit crops is essential in planning the best methods for seed production. Sex expression is regulated by phytohormones and an effective way to manipulate this trait is by external supply of these natural hormones or their artificial derivatives (plant growth regulators - PGR) to the plant. Application of the correct PGR at the appropriate time and concentration is a cornerstone in modern cucurbit seed production. Cucumbers are an excellent example of significant advances in manipulating sex expression over the last decades. Most old cucumber cultivars were monoecious; having many staminate and few pistillate flowers on the same plant. Modern cucumber cultivars have a strong tendency to produce female flowers exclusively (up to complete gynoecy) combined with different degrees of parthenocarpy. In early research on the relationships between hormones and sex expression it was found that cucumber genotypes differing in sex expression could be identified early at germination by measuring the different amount of evolving ethylene (Rudich *et al.* 1978). However, Den Nijs and Milotay (1991) found that neither sex type nor the strength of parthenocarpy affected the number of seeds or the seed yield in cucumber fruit. On the other hand, the length of the mature fruit (which has a high positive correlation with ovary length) affected seed number and both characters have a significant negative correlation. One of the main PGRs to affect sex expression is Ethrel or Ethephon (an ethylene release compound), which is able to shift sex expression from maleness to femaleness and have an important role in successful hybrid seed production. The main contribution of Ethrel is the ability to prevent the production of male flowers (for a certain time), so the female parent of the hybrid can be pollinated by bees instead of using laborious hand-pollination. Silver nitrate and several gibberellins are also very effective agents, shifting cucurbit

plants in the reverse path from femaleness to maleness. Their main use is to maintain gynoecy genetic material. Spraying a gynoecious plant with either of these chemicals will result in the production of male flowers that will enable self pollination and pure line seed production. The effects of Ethrel application (at 250-500 ppm) on seed germinability have been reported in squash (*Cucurbita maxima*) and no differences were recorded in germination percentages and rates as compared to control (untreated) seeds (Korzeniewska and Niemirowiczszczytt 1993). Another compound, Fusicoccin was intensively studied 2-3 decades ago and found to promote (at 10 µg/ml) seed germination and seedling growth in many species including the cucurbits (Ballio *et al.* 1981). Different phytohormones and their combinations were effective in alleviation of environmental stresses during germination (Braun and Khan 1976).

### Seed maturity

Cucurbit seed maturity occurs over a large range of days after pollination (DAP), depending primarily on temperatures during development. In most orthodox seeds, desiccation is part of the maturation process and a pre-requisite for germination (Kermode *et al.* 1986; Kermode 1990). However, like tomato (*Lycopersicon esculentum*) seeds (Berry and Bewley 1991), most cucurbit seeds develop in a fully hydrated environment and do not require a desiccation process in order to mature and transition from the developmental to germinative mode. Precocious germination in the cucurbit fruit is mostly prevented by the osmotic pressure of the fruit juice, by germination inhibitor metabolites (Botha and Grobbelaar 1981), and, in some cases by light that penetrates through the fruit rind (Botha *et al.* 1983).

### Seed extraction procedure

In most cucurbit seed production systems, seed fermentation in the juicy endocarp and mesocarp tissues of the fruits is the first step after fruit cutting and is employed for up to four days. Longer fermentation of cucumber seeds can decrease germination percentage and germination rate (Nienhuis and Lower 1981). This procedure not only facilitates the seed separation from the surrounding tissues, but also may result in increased seed nutrition value (Achinewhu and Ryley 1986) and seed germination (Harrington 1959). The relationship between fruit age at harvest and fermentation was investigated in most cultivated cucurbits (Edwards *et al.* 1986; Nerson 1991), and variable responses were recorded for different species. Generally, germination of fully-mature seeds is not affected by fermentation. Immature seeds of cucumber, melon and watermelon had a better germination, whereas the germination of immature squash seeds decreased after fermentation. Under small scale production of melons and cucumber, fermentation may be neglected and clean seeds can be extracted directly from the fruit (Reed 1981; Wehner *et al.* 1983). Commercial seed lots generally are washed after fermentation with tap water, and the cleaned seeds disinfected for several minutes with hypochlorite solutions followed by drying in ambient air in the sun until attaining ~5% moisture. In muskmelon (*Cucumis melo* L.) washed seeds had higher germination percentages, lower mean time to germination, and greater resistance to controlled deterioration than unwashed seeds (Oluoch and Welbaum 1996a). In watermelon the effects of light intensity and light quality during seed development and drying were mostly non-significant (Fritts and Loy 1981). In mature watermelon [*Citrullus lanatus* (thumb.) Matsum and Nakai] seeds, the temperature at drying had no effect on germinability, but immature seeds retained their germinability better after storage if they were slowly dried (at low temperature) compared to seeds dried at 20-40°C (Nerson 2002a). Comparable data were obtained in muskmelon, where primed seeds were dried back at different temperatures and their storability was increased by decreasing the drying temperature from 38 to

18°C (Nascimento and West 2000).

### Seed yield

Seed yield per unit area is a product of the multiplication of three components; the number of fruits per unit area, the number of seeds per fruit and the mean weight of the individual seed. In many species, including cucumber (*Cucumis sativus* L.) (Zobel and Davis 1949; Globerson *et al.* 1975; Nerson 2005a), melon (*Cucumis melo* L.) (Nerson 2002b) and squash (*Cucurbita* spp.) (Nerson 2005b) the dominant component is the number of fruit per unit area. In a wide range of conditions maximal seed yield in cucurbits is positively correlated with fruit number per unit area and more fruits of smaller size produce more seeds than fewer fruits of larger size. In other words, and by example, two melon fruits of 1000 g each will always produced greater seed yield than one fruit of 2000 g (Nerson 2002b). Squash (*Cucurbita* spp.) known for its diversity in fruit shape and size and is divided to cultivar groups accordingly. Large differences in seed yield were observed both among and within these fruit-type groups (Nerson and Paris 2002). Large variation in seed yield components was also observed in the wild squash Buffalo gourd (*Cucurbita foetidissima* HBK), an expected crop for seed production (Scheerens *et al.* 1989). Seed yield in all cucurbit crops grown in the field is greatly affected by environmental conditions out of the grower's control such as light intensity or temperature, but also by cultural practices including irrigation and fertilization management as well as pest and disease control. Under protected cultivation (greenhouse, etc.) environmental factors are better controlled but unexpected events still occur. Plant population density was found to be a main factor determining seed yield in all cucurbit crops (Edelstien and Nerson 2002; Nerson 2002b, 2005a, 2005b), and a larger population was required for achieving maximal seed yield than for obtaining optimal fruit yield.

### The significance of seed size

In most seeded plants there is a positive correlation between fruit size and seed size. If larger seeds are preferable in order to achieve better germination or to form more productive plants, seed growers must produce a crop with large fruits. Most cucurbit crops follow this rule (Widders and Kwantes 1995) with the exception of watermelon in which fruits of a given cultivar with a large range of sizes produce the same seed size (Edelstein and Nerson 2002).

Large seeds do not ensure excellent germination in all cases. In sunflower, for example, small seeds have better germination than larger ones (Saranga *et al.* 1998). In Banksia, seed size had no effect on germination, seedling survival or shoot to root ratio but nevertheless seedlings developed from larger seeds were bigger than those developed from smaller seeds especially under poor soil conditions (Vaughton and Ramsey 2001). Similar findings were reported in different species of squash (Wilson and Splittstoesser 1979; Edelstein *et al.* 1987), where plants in the vegetative stage, obtained from large seeds, had higher mass than plants developed from smaller seeds. This vegetative difference, however, did not affect any reproductive character. An early study in Israel using seven muskmelon cultivars showed that larger seeds germinate better than small seeds and this difference was also expressed in seedling vigor (Gelmond and Peles 1975). To the contrary, a later study demonstrated that this finding was valid only when extremely small seeds were compared to large seeds, while no differences were obtained in germination of muskmelon seeds of a wide range of sizes (Nerson 2002b).

### Seed storage

A main concern of cucurbit seed growers is to produce pathogen-free seeds (Lovic and Hopkins 2003). In order to

achieve this goal, cucurbit seeds must be produced in warm and dry climates, in plots under rotation, to use drip irrigation systems and to provide effective protection from plant pests and diseases. The critical stages of seed contamination by pathogens during seed extraction are at seed fermentation and seed drying. Germination of watermelon seeds stored at room temperature and relatively high seed moisture (11-13%) declined after one year from nearly 100% to 50%, partly due to mould contamination (Bankole 1993). A popular tool for seed protection is disinfection with hypochlorites (Abdul-Baki and Moore 1979; Sauer and Burroughs 1986). Another effective treatment to protect seeds from pathogenic agents is dry heat at 70-75°C after decreasing seed moisture content to 0.5-1.5% (Nakamura 1982). Seed longevity (Roberts and Ellis 1977; Ellis 1991) is also significantly affected by the culture protocol, seed age at fruit harvest (Demir and Ellis 1993) and the environmental conditions in storage (Benne 1986). Almost all cucurbit species produce orthodox seeds that are desiccant tolerant at maturity, but there are also a few species such as the fluted pumpkin (*Telfairia occidentalis*) that can be stored only under high moisture conditions (Akoroda 1986). Generally, orthodox seeds have long storability, mainly because biochemical activities are slowed down at low water content (Vertucci 1989). Cucurbits, like other orthodox seeds, are best stored when the seed moisture decreases by drying to ~5% (Styer *et al.* 1980). Drying to very low water content (~1-2%) is harmful to most seeds (over-dried) and reduces their storability (Kong and Zhang 1998). Melon and watermelon seeds are successfully stored at 75% relative humidity (Kour and Berry 1989), but in most storage facilities lower relative humidity (RH) values are provided (Clark *et al.* 1991). The best conditions in storage include low temperature and low relative humidity in order to slow the deterioration processes during ageing (Anderson and Baker 1983; Matthews 1985). Long-term storage of cucurbit seeds can be achieved by placing them in deep freeze such as liquid nitrogen (Stanwood and Roos 1979). If watermelon seeds are stored under high temperature (40°C), a mild pre-accelerated ageing at 30°C and high relative humidity is effective to prolong survival (Demir and van de Venter 1999b). Fruit age at seed harvest has a marked effect on their storability. Seeds of 'TopMark' muskmelon harvested at 30-35 days after flowering have less than 25% germination after six years of storage compared to seeds harvested ten days later that retained germination of ~90% (Oluoch and Welbaum 1996a). Similar data were obtained with watermelon seeds; immature seeds harvested 28 days after flowering lost their ability to germinate after only 4-5 years of storage, whereas mature seeds (42-49 days after flowering) retained their fully potential to germinate even after 10 years of storage (Nerson 2002a).

### Techniques for evaluating viability, germinability and storability

Evaluation of seed storability is very important in managing commercial seed lots and continues to be a major challenge for seed physiologists. Initially, scientists determined seed viability and longevity by simple methods of monitoring germinability over time (Kivilaan and Bandurski 1981). As a part of a large study of seed longevity including 92 species at 13 locations, the half-viability (P 50) period of cucumber seeds was estimated to be 5 years (Priestley *et al.* 1985).

Using such direct methods, it was found also that muskmelon and cucumber seeds can be stored longer than watermelon seeds (Roos and Davidson 1992). Many seed viability assays were used in the past (Palta *et al.* 1978) and there was a tendency to prefer assays based on biophysical rather than biochemical or metabolic functions. A useful method is "Accelerated Ageing" (AA) in which a sample of a seed lot is artificially exposed to high temperature at high relative humidity before being subjected to a standard germination test (Delouche and Baskin 1973; Ellis and Ro-

berts 1981). The basic rationale for this test is that there is a negative correlation between seed vigor and seed damage created during the AA process. Another approach to this method is "controlled deterioration" (CD) (Matthews and Powell 1986) in which the ageing effect was expressed in cucumber by deterioration of membrane lipids (Koostra and Harrington 1969; Salama and Pearce 1993) and in wheat by decreasing the synthesis of DNA and proteins (Dell'Aquila 1987). Recently, the best temperature and the length of AA treatment for melon and cucumber seeds were refined and determined (Demir *et al.* 2004). In cucumber, germination rate was more sensitive to a short AA treatment than germination percentage (Alsadon *et al.* 1995). Large differences in storability of melon cultivars and seed lots of two *Brassica* species were detected using this technique (Doijode 1985a; Powell and Matthews 1985). Evaluation of seed vigor and storability can also be determined by a combination of accelerated ageing treatment and ethylene evolution measurement (Siriwitayawan *et al.* 2003), or the ability of seeds to convert ACC to ethylene (Khan 1994). Pesis and Ng (1984a) proposed that the rate of ethanol and acetaldehyde accumulation in melon seeds during the first hours of imbibition inversely related with seed germinability. Quality assurance of seeds was also evaluated by staining with tetrazolium salts, by a germination test under cold temperatures and by measuring the conductivity of the leakage of seeds soaked in water (Matthews 1981; Roos and Wiesner 1991). Measurement of the conductivity or the component determination of seed solute leakage over time of soaking in water (Givelberg *et al.* 1984b), is easy to conduct and therefore very popular. Preliminary observations in different cucurbits demonstrated that this method is reliable to evaluate seed germinability also for these seeds (Nerson *et al.* unpublished data).

### Seed quality

High quality seeds are largely defined as seeds with high vigor (Brocklehurst 1985) and are often evaluated by laboratory tests based on biochemical and biophysical characters (Bierhuizen and Feddes 1973; Abdul-Baki 1980) and lately also by cytometry manipulations (Bino *et al.* 1998). Laboratory test data, however, are not always in accord with field performance (Hall and Wiesner 1990). At the field level, seed vigor means the ability to germinate, to emerge and to produce healthy seedlings rapidly, uniformly, under a wide range of environmental conditions, and to maintain this ability for a long period. In many cases (but not always) laboratory tests of germination may predict field performance (Johnson and Wax 1978). Many internal and external factors affect seed vigor. For melon seeds, the fruit set order within the plant, fruit age at harvest, and the duration of storage before seed extraction are dominant factors in determining seed quality (Alverenga *et al.* 1984; Welbaum and Bradford 1991; Nerson 2002b, 2004). Fruit age and storage duration also affect seed quality in squash and cucumber (Holmes 1953; Goldbach 1978; Valerstein *et al.* 1981; Pedrosa *et al.* 1987; Barbedo *et al.* 1993). Cultural practices applied to the mother plants, such as fertilization and irrigation had a significant effect on seed yield but no effect on seed quality in cucumbers and melons (Nerson and Bradford, unpublished data). However, another observation in cucumber revealed that calcium deficiency reduces seed quality (Frost and Kretchman 1989).

### SEED GERMINABILITY

Germination is the first developmental step in the life cycle of a plant to produce a new generation and the ability to accomplish this task is a prerequisite to start this cycle (Bewley 1997). Analytical methods to measure germination ability and speed have been reported (Tucker and Wright 1965; Heydecker 1966; Goodchild and Walker 1971; Janssen 1973; Scott *et al.* 1984; Tipton 1984; Hunter *et al.* 1984). However germinability is not a predictable event that en-

ures a plantlet will have a successful life cycle. For this purpose scientists frequently use the term seed vigor. This term describes how rapidly and uniformly the early vegetative growth of a population from germination to seedling establishment will occur (Perry 1982). Seed vigor has significant effects on yields of crops harvested at the vegetative or early reproductive phases but only a slight effect in species grown for their mature fruits (Tekrony and Egli 1991).

### Seed dormancy

Seed dormancy is most common in wild flora mainly for survival purposes under unfavorable environmental conditions (Hilhorst 1995; Bewley 1997; Geneve 2003; Baskin and Baskin 2004). Seed dormancy can be described as a temporary inability to germinate under conditions in which all the requirements for germination are fulfilled. Incorporation of native plants to agriculture was always accompanied by selection against this character. However, many modern crops still carry genes for seed dormancy. In most cases seed dormancy is not absolute where the entire seed population is dormant or non dormant. Therefore it should be expressed quantitatively (Richter and Switzer 1982). In cucurbit crops, it is common to have seed lots with delayed germination (Shiffriss and George 1965), partial dormancy (Young 1949; Nerson 2002a) or short-term dormancy (Odland 1937) which are characterized by improved seed germination with increased storage compared to germination at seed harvest. Partial- and short-term dormancy are more likely to occur in immature compared to fully mature seeds (Saadiah and Junaidah 1986). The genetic control of seed dormancy in cucumber has been studied (Ali *et al.* 1991) using the dormant cultivar 'Boroda' and a non dormant cultivar 'Marketer'. Secondary dormancy in cucumber induced by two short cycles (15-60 minutes) of red – far red light during seed incubation also was reported (Amritphale *et al.* 1993).

The occurrence and intensity of dormancy in muskmelon is cultivar dependent and markedly affected by environmental conditions (Conditional Dormancy – CD) at the time of seed development and maturation on the mother plant (Nerson unpublished data).

Many methods have been studied in attempts to break seed dormancy. Potassium hydroxide (KOH), a simple inorganic compound, at high concentrations was found to be very effective in breaking dormancy of five native species in America (Gao *et al.* 1998) and seed priming in polyethylene glycol solutions alleviated thermodormancy in lettuce (Valdes *et al.* 1985). *Solanum nigrum*, a wide spread weed in Israel, has a seasonal dormancy that can be alleviated by oxygen-rich atmospheres or seed soaking in gibberellins (Givelberg *et al.* 1984a). The plant growth regulator Ethrel was effective in dormancy breaking in forage crops seeds (Globerson 1978). Smoke is also an effective agent in breaking seed dormancy of many species (Minorsky 2002).

### Within seed lot germination variability

Variability in germination of any seed lot/population includes inter-plant and within plant sources. The variable germinability of seeds in-plant is mainly due to different fruits developing at different times and positions, but may be also a result of different seed positions in the same fruit as reported in cucumber (Jing *et al.* 2000). In muskmelon, large differences in germination percentage and germination rate were observed among seeds of neighbor plants of six cultivars (Nerson unpublished). Significant differences in germinability of muskmelon seeds were obtained when the comparison was among seeds from different fruits of the same plant (Nerson 2004). The germination percentage of seeds from the first/early fruit was ~70% compared to 90% and up in the second to the fifth fruits. The germination speed of seeds from the first fruit was also slower as compared to seeds from later fruit-set orders. Similar results were repor-

ted in soybean (Illipronti *et al.* 2000). No such significant differences were obtained for germination of muskmelon seeds from different positions in the same fruit (Nerson unpublished).

### Regulation and limitation of germination

Many environmental and seed internal factors limit germinability as recently reviewed for melons (Edelstein and Nerson 2005). Temperature at germination is probably the main limiting environmental factor and each species has its characteristic requirements. In various vegetable seeds the rate of germination is well defined by the heat-sum value taking into consideration temperatures above the minimum temperature for a given species (Wagenvoort and Bierhuizen 1977). Cucurbits are warm-season crops and most of them require relatively high temperatures for germination. Generally, cucumber and watermelon will not germinate in soil temperatures below 17-19°C (Wilcox and Pfeiffer 1990), and the optimal temperature for watermelon seed germination is around 30°C (Hassell *et al.* 2001). Cucumber cultivars differ in their requirements for the minimal temperature for germination (Roeggen 1987). Selection for low-temperature germination within a heterogenic population of cucumber was effective (Nienhuis *et al.* 1983), but after years of study it did not result in any horticultural advantage (Staub *et al.* 1988). Chilling temperatures (below 12°C) during germination (24-48 hours after the initiation of incubation) cause damage to young melon seedlings (Harrington and Kihara 1960). Melon cultivars differ in their response to temperature and water stress (Dunlap 1988). Melon cultivars such as cucumbers also differ in their abilities to germinate under low temperatures (Nerson *et al.* 1982; Edelstein *et al.* 1991; Hutton and Loy 1991), and this has been attributed to differences in gibberellin content and the seed coat anatomical structure (Edelstein *et al.* 1995b). In *Momordica charantia*, another species in the *Cucurbitaceae*, the upper and lower temperature limits for germination are 45 and 15°C, respectively, with large differences among cultivars (Singh 1991). Early in the previous century it was clear that gas exchange between squash seed and the environment was essential for proper germination (Brown 1940). Excess water around imbibing seeds of bittergourd limit this gas exchange and reduce germinability (Krishnasamy 1992). Oxygen concentration has a regulatory effect on respiration and water absorption during the early stages of imbibition (2-15 h after the initiation of incubation) in priming muskmelon seeds (Yeoung *et al.* 1995). Decrease of oxygen concentration by 20% or more decreased the respiration and the water uptake of the imbibing seeds. In contrast to other cucurbits, cucumber seeds germinate even if they are surrounded by water and the oxygen absorption declines significantly (Rabie *et al.* 1989). Anaerobic atmosphere induce ethanol production in germinating seeds of melon and prevent the germination process (Pesis and Ng 1984b). In cucumber, the inhibition of germination under anaerobic conditions was attributed to the arrest of lipid degradation and carbohydrate supply to the developing embryonic axis (Pharr and Motomura 1989). The presence of chemicals such as ammonia or cinnamate in the seed environment also restricts or prevents germination in cucumber (Tyagi *et al.* 1983; Khan and Vaidyanathan 1987). Germination of various cucurbits has also been reported to be reduced by gamma rays (Narang and Prakash 1983). The seed coat of melon seeds may play an important role in controlling germination, especially under stressful environments, and its removal improved germination (Pesis and Ng 1986; Edelstein *et al.* 1995a). The inner envelope of melon seed, the perisperm, also plays an important role in the regulation of germination. Its tissue must be weakened during imbibition to allow the radicle to penetrate through it (Welbaum *et al.* 1995). The seed coat (testa) of *Citrullus colocynthis*, a close species of watermelon, prevents seed germination, and the inhibition can be elevated by decoating the seeds (Koller *et al.* 1963). Similar germination dif-

iculties caused by the seed coat were observed in tetraploid breeding lines of watermelons, and germination was markedly improved by cracking the coat or by different priming treatments (Nerson *et al.* 1985). Phytohormones, especially abscisic acid (ABA), play a primary role in the regulation of germination and the induction or loss of dormancy (Black 1980/81). In different beans, for example, a relatively high concentration of ABA in the developing seeds prevents precocious germination and this inhibition may be elevated by embryo washing or slow desiccation (Ackerson 1984; Prevost and Le Page-Degivry 1985). Until the mid-1980s there was no evidence that the early stages of squash germination were accompanied by an increase in gibberellin- or cytokinin-like substrates (Pinfield and Sanchez-Torres 1984). Nevertheless, exogenous application of gibberellic acid (GA<sub>3</sub>) promoted the germination of other cucurbit seeds such as watermelon and muskmelon (Evensen *et al.* 1978; Nerson *et al.* 1982). However, later studies in tomato demonstrated that gibberellins were synthesized *de novo* after imbibition and played an important role in the regulation of germination (Yamaguchi and Kamiya 2002). In lettuce, different plant growth regulators, alone or in combinations improved germination and emergence under salinity or high temperature stresses (Braun and Khan 1976). Light has different levels of influence on cucurbit seed germination (Mancinelli *et al.* 1975). In cucumber and related wild species, postharvest photoperiod (long days) and light source (including red light) affect the phytochrome system and hence germination (Yaniv *et al.* 1967; Gutterman and Porath 1975; Noronha *et al.* 1978; Gutterman 1992). The control of cucumber seed germination by the phytochrome system is temperature dependent and, at temperatures higher than 20°C, FR irradiation does not block germination (Eisenstadt and Mancinelli 1974). The phytochrome system is also involved in the germination process in watermelons which germinate better in dark conditions (Loy and Evensen 1979; Botha *et al.* 1982). Their germinability is positively correlated with the concentration of free amino acids in the sprouting radicle (Thanos 1984). In muskmelon two hours of fluorescent light delayed germination. But, if the delayed seeds were later returned to darkness, the germination percentage and seedling vigor improved (Doijode 1985b). *Luffa aegyptica*, another representative of the family, germinates better in light than in dark (Okusanya 1978), and is different compared to most cucurbit crops with respect to light influence on germination. A later study in this species revealed that cultivar differences exist with respect to germination in light or in dark (Sonaike and Okusanya 1987). Salt stress has a negative effect on germination and seedling development of muskmelon cultivars (Nerson and Paris 1984), but there was no correlation between these two effects (Edelstein *et al.* 1991). In watermelon, a tendency to shift from traditional diploid cultivars toward modern seedless triploid cultivars is underway. The presence of a relatively small triploid embryo in a tetraploid seed coat in these seedless cultivars causes difficulties in gas exchange during the initial stages of germination. These changes make embryo penetration through the seed coat and the seed coat adherence at emergence difficult (Duval and NeSmith 1999, 2000; Grange *et al.* 2003). Germination of triploid watermelons is generally poor especially under stress such as suboptimal temperatures (Yang and Sung 1994).

### Seed priming and seed pre-treatments

The terms seed priming and seed conditioning (Khan 1992) represent a series of treatments applied to a given seed lot in order to improve its germination and emergence. Seed pre-treatment is a more general term than seed priming and it includes all types of treatments given to seeds before seeding in order to gain any benefit during the plant life cycle. Often these terms overlap in the literature, but, in general, priming is a treatment for germination enhancement whereas seed pre-treatments are geared toward improvements beyond the germination process. McDonald (1999), in a com-

prehensive review article summarized the knowledge accumulated to the end of the previous century about seed priming and seed vigor. Priming treatments are successfully applied either to poor germinating seed lots or to seeds which are sown under different stress conditions. A common stress, under field conditions, is low temperatures, and many priming treatments were effective in improving germination under cold temperatures (Nerson *et al.* 1982; Herner 1986; Nerson and Govers 1986; Staub *et al.* 1989). A simple and old method of priming is hydropriming, in which the seeds are subjected to one or more short cycles of hydration-dehydration before seeding (Hegarty 1978; Lush *et al.* 1981; Demir and van de Venter 1999a). Among the other effective priming treatments is seed osmoconditioning (Heydecker *et al.* 1973) which is a pre-sowing hydration treatment, developed to improve seedling synchronization and establishment (Heydecker and Coolbear 1977). Seeds are placed in an aerated osmotic solutions of high molecular weight (like PEG 6000), inorganic salts (like KNO<sub>3</sub>) or in a hydrated solid matrix (such as clay) (Bodsworth and Bewley 1981; Brocklehurst and Dearman 1984; Bradford 1986; Taylor *et al.* 1988) of known water potential. The osmotic solutions induce a water stress that prevents the completion of seed germination (radicle emergence) but does not prevent earlier stages of germination. A priming system was described by Akers and Holley (1986). Such a treatment was very successful in improving immature watermelon seed germination (Demir and Oztokat 2003) or mature watermelon and squash seed germination under suboptimal temperatures (Greenfeld and Rudich 1976; Sachs 1977; Mauromicale *et al.* 1994; Demir and van de Venter 1999a). In muskmelon, osmoconditioning of seeds after long storage (nine years) increased the germination percentages at 20-25°C and decreased it at higher temperatures (Oluoch and Welbaum 1996b). Priming of muskmelon seeds in potassium nitrate solution was more effective for germination improvement under cool temperatures than other salts, PEG or gibberellic acid solutions (Dhillon 1995). Priming muskmelon seeds in nitrogen-salt solutions improved their subsequent germination under salinity stress (Guzman and Olive 2004) and decreased seed coat adherence (Nascimento and West 1998). In cucumber, osmoconditioning improved germination under saline and adverse light conditions (Thanos and Georghiu 1988; Passam and Kakouriotis 1994). Matricconditioning treatment applied to cucumber seeds after accelerated ageing, improved germination by inducing protein hydrolysis, increasing dehydrogenase enzymatic activities and by decreasing electrolyte leakage (Habdas *et al.* 2000). Bittergourd (*Momordica charantia*), a sensitive species to sub-optimal temperature, has poor emergence even at 20°C, because of marked reduction in enzymatic activities associated with carbohydrate and lipid degradation. Hydropriming or soaking in hot water was very useful in decreasing this emergence limit (Lin and Sung 2001). A combination of partial hydration and a short heat shock was effective hardening treatment in cucumber seeds and increased significantly their thermotolerance (Sanchez *et al.* 2001). In pepper, osmoconditioning was found to be also an effective treatment for protecting seeds stored under high temperatures (Georghiou *et al.* 1987).

Pre-germination treatments of seeds with various chemicals have effects on subsequent germination. For example, the natural chemical comptonectin extracted from *Comptotheca acuminata* stems inhibits the germination of many species but promotes germination and seedling development in watermelon (Tao and Buta 1986). Nandi and Mallik (1982) found that presoaking pumpkin seeds in sodium thiosulfate significantly increased their emergence and early vegetative growth.

Cucurbit seeds may also be primed to decrease other environmental germination limits. For example, imbibed cucumber seeds are sensitive to chilling temperature and by priming them for a short time in high temperature they become tolerant (Jennings and Saltveit 1994).

There are many published seed pre-treatments but only

a few of them are largely used. For example to put watermelon or snake cucumber (*Cucumis melo* var. *flexuosus* Naud.) seeds in an electric current before sowing will result in an increase in female sex expression and fruit yield and quality (Abdel-Wahab *et al.* 1980). The effectiveness of such a pretreatment is in dispute. However, it has not become a common treatment since it was reported. A pretreatment of imbibed cucumber seeds in magnetic fields increased the germination and seedling growth rates, but also their sensitivity to UV-B radiation (Yinan *et al.* 2005). Another potential pretreatment is to soak seeds before sowing in a solution in order to uptake beneficial chemicals. In squash, a presoaking of seeds in a micronutrient solution containing manganese and boron significantly increased both female expression and yield (Almishaal *et al.* 1984). In another study femaleness and the yield of summer squash were increased by pre-soaking seeds in cobalt solutions (AttaAly 1998). Pre-soaking of muskmelon seeds in different fungicides was effective in preventing seedling damping-off and controlling powdery mildew (Bradford *et al.* 1988; Cohen and Shtienberg 1994). Recently, Lee (2004) summarized a variety of seed treatments that are successfully used in disease control of horticultural crops. Thirty years ago, a large effort was given to fluid drilling in which pre-germinated seeds were mixed with gelatin material sown in the field to overcome external field stress but this too never became a wide-spread technique (Currah *et al.* 1974; Finch-Savage and Cox 1982; Hall *et al.* 1989).

## CONCLUSIONS

Much knowledge in seed science and particularly in cucurbit crops was accumulated in the last three decades. This knowledge, coming from many disciplines but mainly from the fields of plant physiology and genetics. Talking on seed production and how to maintain seed quality, here a great part of the knowledge is produced by private seed companies, and as being involved with commercial benefits, it leaks very slowly to the public.

Trying to predict the near future of cucurbit crops seed production, it seems that two main developments will occur. First, the importance of hybrid seeds will increase, and second, more seeds will be produced under protected environments. This last tendency is well attached to technology which is dynamic and includes rapid changes. This means that the future research in seed production should be geared by flexible thinking in order to meet the fast artificial changes in plant growing environments.

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