SEED INVIGORATION AND DORMANCY STUDIES IN SNAKE GOURD *(Trichosanthes anguina* L.*)*

By

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THESIS

submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that this thesis entitled **"Seed invigoration and dormancy studies in snake gourd (*Trichosanthes anguina* L.)"** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that this thesis, entitled **"Seed invigoration and dormancy studies in snake gourd (*Trichosanthes anguina* L.)"** is a record of research work done independently by **Mr. N. Mohan** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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DEDICATED TO

MY BELOVED

PARENTS

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Smt. S. Chandramma

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INTRODUCTION

1. INTRODUCTION

Seed is the basic and crucial input that plays a significant role in increasing agricultural production and productivity. The history of agriculture coinciding with the early days of mankind progressed with the history of improvement of quality of seeds brought under cultivation. Seed dormancy, uneven germination or excessively low germinative energy can all lead to considerable adverse impact on crop production. Hence, use of good quality seed plays a critical and decisive role in the development of agriculture.

The production of vegetables during 2003 has touched 97.5 million tonnes (GOI, 2003). This could be achieved by the use of hybrid seeds, scientific irrigation practices, chemical fertilizers and plant protection chemicals. These technologies have almost attained their limits, which can hardly be stretched further. However, the use of good quality seeds significantly makes a difference in the yield potential, even when all other inputs required by the plants are supplied at optimum level. Hence improvement of seed quality with respect to purity, germination, vigour and viability is indisputably the primary mechanism for increasing the productivity of vegetable crops.

Cucurbits are one of the most important and nutritive groups of vegetables grown in tropical and sub-tropical regions of the world. The seeds of major cucurbits like bitter gourd, snake gourd, bottle gourd, pumpkin and ash gourd exhibit different degrees of dormancy in the freshly extracted state and will not germinate evenly for a period upto six months. Snake gourd (*Trichosanthes anguina* L.) occupies a pride of place among vegetables in South India. This crop is supposed to be a native of Indian Archipelago. The fruits are harvested and cooked green that are relished equally. The active ingredient compound-Q is known to have therapeutic effect against the human immuno deficiency virus (HIV) (Robinson and Deckerwalter, 1997). Every 100 g edible portion of fruit

contains 94.6 g moisture, 0.5 g protein, 0.3 g fat, 0.5 g minerals, 0.8 g fibre, 3.3 g carbohydrates and 160.01 IU vitamin-A (Gopalan *et al.*, 1982).

The snake gourd seeds characterized by the presence of hard seed coat exhibit dormancy, resulting in both poor and staggered germination. Breakdown of dormancy in natural course is a gradual process, which extends for a period of five to six months (Agrawal, 1995). Seed dormancy is nature's way of setting a time clock that allows seeds to germinate when conditions become normally favourable. The effects of dormancy on emergence and field establishment can be critical, where delayed emergence or missing plants may reduce yield and necessitate alterations in cultural practices for crop plants that are directly sown in the field.

Seed invigoration implies on improvement in seed performance by any post harvest treatment - physical, chemical or physiological, which results in improved germinability, greater storability and better field stand. Thus, invigoration allows 'slow' and 'fast' seeds in a population to attain the same stage of readiness.

In order to improve the seed quality in terms of reduced time for germination of freshly extracted seeds and to ensure a uniform stand of vigorous plants, seed invigoration treatment might be a practicable proposition in a crop like snake gourd.

By studying the storability of invigorated seeds, it would be possible to know whether the initial advantage gained through invigoration is retained even after storage. If so, this will play a significant role in the seed industry where seed supply and distribution can be managed with a lot of flexibility. The information on field performance of plants derived from invigorated seeds will throw light further on the retention of this initial advantage of invigoration till its logical end.

A major constraint to the commercial application of invigoration treatment is the variability among the seed lots and specificity, concentration and duration of the treatment. Research findings on the effect of different invigoration treatments on germination rate, vigour, seedling establishment and subsequent yield attributes are rather limited in a tropical crop like snake gourd.

It is in this backdrop, the present investigation was carried out at the Department of Olericulture, College of Horticulture, Vellanikkara, during 2003-05 with the following focused objectives:

1) To study the seed invigoration techniques in snake gourd to over come dormancy.
2) To study the effect of selected invigoration treatments on storability and on different seed quality attributes and
3) To compare the effects of selected invigoration treatments on field performance.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

High degree of mechanization in today's agriculture and horticulture demands fast, uniform and complete germination of seeds. As the seed production and supply become more and more sophisticated and result oriented the importance of seed characters influencing crop stand and uniformity is being immensely realized by seed producers as well as researchers.

Dormancy, reduced germinability and low vigour of seeds affect the seedling emergence and subsequent performance in the field. Hence, the use of viable seed is of critical importance both for seed producers and farmers.

In order to provide a context for subsequent discussion, the relevant available literature on seed dormancy in vegetables, seed vigour, seed deterioration, seed invigoration studies, storage potential and field performance of invigorated seeds are reviewed here under.

2.1 Seed dormancy in vegetables

Seed is an incubator with an immune covering (the seed coat) and a nutritive insurance (the endosperm) for the continuum of the species (the embryo). The eventual function of the surviving seed is its germination. A dormant seed is one that does not have a capacity to germinate in a specified period of time under any combination of normal physical environmental factors, that otherwise is favorable for its germination. Seeds are not always able to germinate and produce healthy vigorous seedlings in the field. A viable seed goes from a dormant, quiescent state to one of active growth, allowing the embryo to break through its seed coat in the process of germination (Baskin and Baskin, 2004).

For germination to occur, a seed requires moisture, suitable temperature, and in most cases an aerobic atmosphere. If one or more of these requirements are

not met, germination will fail to take place, and in this condition the seeds may be regarded as being in a state of imposed dormancy (Roberts, 1972).

Villiers (1972) defined dormancy as a developmental arrest resulting from structural or compositional factors within the seed and quiescence as a state of arrested development imposed by unfavorable environmental conditions.

Causes of seed dormancy are many and varied. Impermeability of seed coat to water and gases, immaturity of the embryo, special requirement for temperature and light, presence of inhibitors and mechanical restriction to embryo growth are the major reasons (Tran and Cavanagh, 1984). Primary dormancy was proposed for dormancies occurring due to pre-harvest or pre-dispersal changes in seeds and the secondary dormancy is the one induced following harvest or dispersal, by natural or artificial means (Khan and Karssen, 1980).

Stier (1938) stated that the seed coat is responsible for restricting the oxygen supply to the embryos of potato. The nucellar membrane is reported to contribute to impermeability to gases in *Cucurbita pepo* (Brown, 1940) and thus causing dormancy. Shifriss and George (1965) reported dormancy in cucumber (*Cucumis sativus*) cv. Baroda, for a period of 6 to 12 months. Roberts and Smith (1977) stated that breaking of dormancy often requires easy availability of oxygen, which was provided by oxidants like KNO_3. Ednapesis and Ng (1986) reported seed coat imposed dormancy in muskmelon, where the seed coat inhibits germination by decreasing oxygen uptake.

The dormancy also induced in response to abrupt dehydration and the state of endosperm surrounding the embryo seems to determine dormancy in pepper, tomato and carrot (Khan, 1994). Quagliotti *et al.* (1994) reported that okra seeds exhibit dormancy resulting from a hard, water resistant seed coat and a chalazal plug, causing very slow water uptake.

Suryawanshi *et al.* (1996) revealed that the impermeability of nucellar membrane to oxygen and water intake contributed to the dormancy in *Cucumis sativus* cv. Himangi to the extent of 66 per cent and was maintained up to 49 days.

Katiyar *et al.* (1998) found that freshly harvested seeds of bittergourd *(Momordica charantia* L.) from rainy season crop of variety Kalyanpur Baramasi did not germinate in Northern India due to inherent seed dormancy. Lan-fu-sheng *et al.* (1998) observed that sea kale (*Crambe maritima*) seeds germinate very slowly with a low germination percentage due to seed dormancy and slow water imbibition as a result of a thick and hard seed integument.

Pandita *et al.* (1999) found that hard seededness is a serious problem in the multicut leafy vegetable *Trigonella corniculata*, resulting in dormancy. Welbaum (1999) reported primary dormancy in *Cucumis melo*. Sreenivasulu and Amritphale (2000) revealed secondary dormancy in cucumber cv. Poinsett-76 as a result of intracellular membrane of the embryonic axis and cotyledons. Yogeesha *et al.* (2002) observed 96 per cent dormancy in fresh seeds of brinjal var. Arka Neelkant due to the presence of ABA.

Ganar (2003) revealed that seeds extracted from fresh ash gourd fruits exhibited dormancy and showed a very low germination of five percent during *kharif* season and 10 percent during spring summer. Unnikrishnan (2005) also revealed endogenous dormancy in ash gourd, which is due to certain chemical blocks, caused either by the presence of growth inhibiting factors or due to deficiency of some essential compounds.

2.2 Seed vigour concept

Seed vigour is a multiple concept (Perry, 1987) and an important seed quality component (Hampton and Coolbear, 1990). Seed vigour may be defined as

a potential for rapid and uniform germination and fast seedling growth under general field conditions (Singh *et al.*, 1973).

International Seed Testing Association (ISTA) defined seed vigour as the sum of those properties, which determine the potential level of activity and performance of seed or seed lot during germination and seedling emergence (Anonymous, 1985).

Delouche and Baskin (1973) stated that loss of viability is preceded by the loss of vigour and suggested that deterioration of seed vigour precedes loss of germinability. Ellis and Roberts (1980) have shown close correlation between initial viability and other aspects of seed vigour. A complex of environmental factors acting during development and maturation of seed has been found to relate to subsequent germination and vigour. Rapid uniform emergence of germinable seeds is said to reflect high seed vigour, as low vigour seeds emerge, slowly and poorly (Mathews, 1980).

2.2.1 Relationship of seed vigour and emergence

Willey and Heath (1969) stated that total emergence determines plant density and there is a strong relationship between density and yield .The effect of seed vigour on emergence and stand can be especially critical since delayed emergence or inagequacy of plant population may adversely affect yield and plant uniformity at harvest.

The effects of seed vigour on emergence and stand establishment are well documented (Roberts, 1972 and Heydecker, 1977). Effects have been reported on total emergence, rate of emergence and the uniformity of emergence. All of these factors can potentially influence dry matter accumulation by the plant and thus potentially affect crop yield. The slower rate of emergence frequently associated

with low vigour seed will result in smaller plants, if measurements are made relatively to the planting date instead of date of emergence (Ellis, 1989).

Jagadeesh (1998) found out that seed vigour might have a direct effect on the ability of the plant to carry out physiological processes and accumulate dry matter.

2.2.2 Seed vigour and crop yield

Seed viability and vigour directly affect the performance of seeds planted to regenerate the crop. The objective of this review is to examine the relationship of seed vigour to crop yield, one of the major aspects of crop performance.

Earlier workers have related seed viability (Roberts, 1972) and seed vigour (Burris, 1976) to various facets of field performance. The concept of seed vigour implies that two seed lots having similar standard germination level under ideal laboratory conditions may perform quite differently under poor field conditions due to differences in vigour potential (AOSA, 1988).

Reduction in yield can be indirectly related to low seed vigour (Perry, 1987) if plant populations are below a critical level. Seed vigour affects vegetative growth and is frequently related to crop yield. However, there is usually no such relationship in crop harvested at full reproductive maturity, because seed yield at full reproductive maturity is usually not closely associated with vegetative growth (Tekrony and Egli, 1991).

2.2.3 Seed vigour and storability

Seed vigour denotes rapid and uniform germination and fast seedling growth under general field conditions (Ching, 1973). Any loss in vigour or

reduced germination is a reflection on storability of seeds, which has a considerable economic impact.

The storability of a seed lot of a given kind is primarily determined by the vigour of the seed at maturity and level of deterioration at the time it enters storage. Loss of storage potential is one of the specific consequences of seed deterioration, as the germination rate decreases, the seedling abnormalities increases (Delhoche and Baskin, 1973). Poor storage conditions reduced the respiration and seedling size (Ching, 1973). Immaturity is likely to be a more important cause than faulty storage of the wide differences in vigour of seeds (Roberts, 1983).

Ellis and Roberts (1981) suggested that there is continuity between loss of potential seed quality and ultimately loss of seed vigour and viability during storage. However, physical, biochemical and physiological factors affecting seed storability have been reasonably well established as seed moisture content and storage temperature are crucial factors determining seed quality in storage (Harrington, 1973 and Chin, 1988).

2.3. Seed deterioration

Delouche and Baskin (1973) defined seed deterioration as summation of all physical, physiological, biochemical changes occurring in a seed, which ultimately lead to its death.

The process of seed deterioration is a matrix of interrelated events (Priestley, 1986). As seed deteriorates, there will be loss of vigour and viability during storage with much change such as slower growth rate of normal growth, increased leachates and susceptibility to stress (Roberts, 1983). However, it is still difficult to realize which are the causes and consequences of deterioration.

Generally, seed viability and vigour are at its maximum at the time of physiological maturity stage. Seed begins to deteriorate at varying rates depending on the condition of storage environment. Loss of germinabilty and increase in incidence of seedling abnormality are the specific consequences of seed deterioration in tomato (Gayathri, 2000).

2.3.1 Membrane degradation and seed deterioration

One of the fundamental factors highlighted for loss in viability is disruption of the membrane system. An increase in membrane permeability will result in greater leakage of sugars, amino acids and inorganic solutes from the seed (Abdul-Baki and Anderson, 1970).

Saha *et al.* (1990) revealed that damage to cellular membrane and other essential organelles by auto-oxidation can be put forward as a possible reason for seed deterioration.

2.3.2 Free radical damage

Free radical damage is an important aspect of seed deterioration and has a close relationship between the loss of vigour and viability (Basu *et al.*, 1975).

Rudrapal and Basu (1982) stated that free radicals formed due to lipid peroxidation act on the membrane leading to its rupture and loss of viability and expect severe losses of polyunsaturated fatty acids like linolic, palmetic and oleic acids in tomato.

2.3.3. Impaired enzymatic activity

Several workers have attempted to correlate loss of viability and vigour with decreased activity of certain enzymes.

Chauhan *et al.* (1984) observed that marked changes in the content and activity of certain respiratory enzymes such as catalase, peroxidase, dehydrogenase and cytochrome oxidases were noticed with seed deterioration.

Zuo *et al.* (1988) noticed decreased activities of amylase in peas, tomato and spinach seeds and peroxidase in tomato and spinach.

2.3.3 Respiration changes

Decline in oxygen uptake and increase in respiratory quotients were observed with increase in the seed deterioration (Harrington, 1973).

Loss of ability to produce ATP's was found to be highly correlated with loss of viability in cauliflower, rape and soybean seeds (Lunn and Madsen, 1981).

2.3.5 Accumulation of toxicants

Toxic metabolites are the cause of many secondary events in the deteriorating seeds. The presence of ethanol, aldehydes, short chain fatty acids and phenols are mainly responsible for the loss of quality (Zhang *et al.*, 1993).

2.4 Seed invigoration

The invigoration implies on improvement in seed performance by any post harvest treatments (physical, chemical and physiological) resulting in improved germinability, greater storability and better field stand than the corresponding untreated seeds (Basu, 1990).

Recently, infusion of bioingredients, agrochemicals, nutrients etc. in to the seed is reported to invigorate the seeds. The invigoration process was found to be independent of the cultivar, but seems to be best expressed in highly viable but low vigour seed lots (Perl and Feder, 1981).

2.4.1 Physiological basis of seed invigoration

Seed invigoration treatment is a technique accomplished by imbibing the seed in an osmotic solution that allows the seed to imbibe water to a level that permits some of the initial steps of germination (Heydecker, 1975).

The key basis of all pre-sowing treatments is to hydrate the seeds under controlled condition, so that they become physiologically active. Thus they are able to initiate repair and detoxify the system. The time from planting to seedling establishment is a crucial phase in the production cycle. The period of imbibition is extremely sensitive to changes in the environment and slight or sudden changes appear to profoundly affect seedling emergence (Khan, 1977).

Bradford (1986) stated that percent emergence and uniformity of direct seeded crop have a major impact on stand establishment, yield and quality.

Generally, any invigoration treatment which aims to reduce the period between sowing and emergence will mean that seeds are more likely to escape from a hostile environment and this results in better crop establishment (Gayathri, 2000).

2.4.2 Leaching of inhibitors

Abdul-Baki and Anderson (1970) found that an increase in membrane permeability due to hydration results in greater leakage of sugars, aminoacids and inorganic solutes from the seed.

Hot water soaking has benefited in leaching out of autotoxin metabolites from the seeds (Basu, 1976).

2.4.3 Enzymatic and metabolic activities

Enhancement in enzyme and metabolic activities are common features during germination through seed invigoration.

Mazor *et al.* (1984) observed an increase in the respiratory activities and the formation of ATP needed for synthesis of macromolecules, during or following osmo-conditioning in seeds of knol-khol, spinach, eggplant and pepper.

Dey and Mukherjee (1986) revealed that increased activity of dehydrogenase, peroxidase and lowering of free fatty acids formation were the contributing factors for higher germinability of invigorated seeds.

Groot *et al.* (1988) reported that enzymes such as endo-β-mannase, α-galactosidase and mannase are involved in hydrolysis of cell walls of the endosperm.

The effect of invigoration treatments was reported on increased activities of dehydrogenase, isocitrate lyases in pepper (Smith and Cobb, 1988) and amylase and peroxidase in tomato and spinach (Zuo *et al.*, 1988).

According to Simbula (1993), endo-β-mannase, a marker of germination has enhanced activities in embryos after 12 hours or more of imbibition.

2.4.4 Free radical damage

Rudrapal and Nakamura (1988) reported lower electrical conductivity values following priming of eggplant and radish.

The electrical conductivity of the leachete of treated seeds was found to be significantly lower in onion and cabbage (Taylor *et al.*, 1995) and in tomato (Coolbear *et al.*, 1984).

Several workers have ascribed seed invigoration to phenomenon of repair of membrane system by providing a source of electrons, thus the free radical damage could be significantly reduced.

The mode of action of seed invigoration treatments is still unclear but prevention of damaging oxidative reactions especially free radical induced lipid peroxidation reaction and repair of age induced damage to vital bio-organelles by the cellular repair system, appear to be the primary reason for invigoration (Basu, 1990).

2.5 Dormancy breaking treatments

Several workers have reviewed the beneficial effects of seed invigoration or priming or pre-soaking treatments wherein bioingrediants such as growth regulators, nutrients, antioxidants, osmoticums etc. are incorporated into the seed in order to improve its performance.

In general, invigoration treatments can be divided in to wet and dry treatments. Wet treatments comprise of chemical action (acids, alcohols, growth regulators, oxidizing agents or osmoticum treatments) and thermal action (hot water treatment, liquefied gases). In contrast, dry treatments comprise of

mechanical action either manual or mechanical using different instruments and thermal (dry heat, radiation, electromagnetic waves) treatments.

Since the subject of interest here is coat imposed (physical) dormancy, the invigoration treatments should aim at softening the hard endocarp, reducing the defects of embryo and shortening the dormancy period.

2.5.1 Hydration treatments

When a seed is hydrated, physiological and biochemical changes begin to take place. A prolonged seed hydration particularly at low water potential profoundly influences the rapidity, synchrony and percentage of seeds that germinate.

Kidd and West (1918) demonstrated that short period of presoaking in water had a favorable effect on subsequent percentage germination and seedling growth.

According to Abdul-Baki and Anderson (1972) the differential germinability of hydration-dehydration treated and control seeds has been related to dehydrogenase activity, membrane functions and lipid peroxidation.

Muninov (1973) stated that soaking of melon seeds in water for 24 to 36 hours enhanced germination. According to Singh *et al.* (1973) seed soaking for 24 hours in distilled water increased the percentage germination in bottle gourd, bitter gourd, watermelon and okra. Nagy (1974) found that seed soaking in water at 30^0 C for four hours is necessary to increase germination percentage in watermelon.

Heydecker and Coolbear (1977) suggested that allowing the capsicum seeds to imbibe water at 30^0 C is sufficient for commencing initial germinative metabolism and have promotive effect on the germination.

Ma and Liu (1986) reported that forestry species with hard seed coat germinate better when they were previously soaked in water for 15 to 25 hours.

Pandita and Nagarajan (2002) found that wrapping seeds in moist muslin cloth for 48 hours at 25^0 C improved field emergence and seedling quality in bitter gourd.

2.5.2 Use of growth regulators

Pisani (1959), Chatterjee (1960), Voldin (1960) and Bhatt (1963) have demonstrated increased germination and seedling growth of carrot and brinjal by treating seeds with various growth regulators.

Sadawarte and Gupta (1968) observed increased percentage of germination in brinjal seeds by pre-sowing soaking with IAA and NAA each at five and ten ppm. Srivastava and Singh (1968) reported the beneficial effects of GA_3 and NAA on okra seed germination.

Srivastava and Sachan (1971) observed that soaking of seeds in GA_3 enhanced the emergence of okra seedlings in the nursery.

According to Singh *et al.* (1973) seed soaking for 24 hours in GA_3, IBA, NAA, 24-D at 25-100 ppm and distilled water increased the per cent germination in bottle gourd, bitter gourd, watermelon and okra.

Suryanarayana and Afrijuddin (1980) investigated the effect of pre-treatment in okra seed with GA_3 at 50, 100 and 150 ppm and NAA at 10, 20 and

40 ppm. Treatment with GA_3 at 150 ppm concentration resulted in the highest percentage of seed germination.

Katiyar *et al.* (1998) reported that GA_3 150 ppm was effective in improving germination of bitter gourd.

Singhvi and Chaturvedi (1990) reported that pre-soaking in distilled water for 12 hours or solutions containing 10, 25 or 50 mg of GA_3 per litre or 10, 25 or 50 mg of morphactin per litre promoted radicle length and hypocotyl extension in radish.

Agrawal (1995) reported that germination process of freshly harvested seeds of snake gourd was improved when treated with 500 ppm GA_3 for 24 hours.

According to Suryawanshi *et al.* (1996) the dormancy in *Cucumis sativus* cv. Himangi was overcome by treating the seeds with 100 ppm GA_3.

Yogeesha *et al.* (2002) stated that dormancy in fresh seed of brinjal variety Arka Neelkant could be overcome by treating with GA_3 200 ppm for two hours.

Unnikrishnan (2005) revealed that GA_3 at 25, 50 and 100 ppm and NAA at 25 and 50 ppm were effective in breaking dormancy of ash gourd seeds.

2.5.3 Scarification treatments

The simple observation or assumption of dormancy breaking through scarification without comprehensive anatomical investigation may often lead to false conclusion being drawn. A wide gap in the knowledge on the seed coat anatomy, effect of seed coat on imbibition and different treatments aroused a

renewed interest in many researchers. Some of the reviews on these topics are presented below.

2.5.3.1 Seed coat anatomy

Dormancy imposed by the seed coat had been a subject of interest since third century B.C. Then, the Greek writer Theophrastus stated that the seeds of certain pulses were 'hard' and require soaking in 'nitre' for proper germination (Evenari, 1981).

The seed coat (often refer to as testa) is the outer covering of every mature seed, which acts as a modulator between seed and external environment. The seed coat structure and function has been the subject of special interest each reflecting specific reviews by many workers (Ballard, 1973; Rolston, 1978; Peske and Pereira, 1983; Swanson *et al.*, 1985 and Woodstock, 1988).

Tran and Cavanagh (1984) showed that seed coat is one of the main determinants of seed germination, vigour and storage potential. Understanding of its properties and thickness characteristics may explain, anticipate or even allow the modification of seed performance under certain environmental conditions.

During seed ontogeny, the outer integument gives rise to several distinct layers transforming itself into the testa, while in many species the inner integument disappears (Esau, 1977 and Miller *et al.*, 1999). Inwards from the surface they are: the waxy cuticle layer, the epidermis, the hypodermis, and the interior stellate parenchyma (Swanson *et al.*, 1985). The outermost layer is the waxy cuticle of variable thickness, which represents the first barrier to imbibition. The epidermis, a layer of thick-walled palisade cells called macro-sclereids and hypodermal pillar cells constitute the next layer. In mature seed

coat, the interior parenchyma is often crushed or partially so (Miller *et al.*, 1999).

Different regions of the seed coat present different levels of thickness (Pereira and Andrews, 1985; Noodén *et al.*, 1985) and water uptake varies accordingly (Ballard, 1973). The hilum is a particularly important structure controlling embryo external environment relationship (Saio, 1976).

Bhojwani and Bhatnagar (1979) stated that the structure which is most implicated in impermeability is the palisade layer of seed coat. This was strongly supported by another experiment done by Egley and Paul (1982). Baskin *et al.* (2000) reported that physical dormancy is caused due to one or more water impermeable layers of palisade cells in the seed coat. The cuticle layer will become gelatinous or mucilaginous when wet and thus forms the first barrier for water imbibition. Palisade layer consists mainly of pectin and hemi-cellulose and is very hard and hydrophobic during the later stages of seed maturation (Werker, 1981).

2.5.3.2 Effect of seed coat on imbibition

Water imbibition is the first step in seed germination and is positively associated with size of the seed coat. The coat of impermeable seeds is mechanically hard and was held responsible for water exclusion to begin initial process of germination. Hence, there arose the practice of boiling hard seed to soften them (Agrawal and Menon, 1974).

The experimental evidence by Tran and Cavanagh (1984) showed that during storage, coat imposed dormancy breaks down and if given sufficient time most seeds will eventually take up water rapidly.

Egli (1990) viewed that longer seed storage may result in reduced seed coat size as well as seed moisture content and stored seeds may imbibe water more rapidly causing rapid germination.

Evans and Cabin (1995) found no obvious relationship between seed coat thickness and degree of impermeability. On the other hand, Tran and Cavanagh (1984) in an experiment showed the inverse relationship between the seed coat thickness and degree of impermeability in case of several *Acacia* species.

Werker *et al.* (1979) and Baskin and Baskin (1998) individually opined that both the outer and inner layers have been considered to be the cause of impermeability. However, this view was not supported by the findings of Ballard (1973) and Tran and Cavanagh (1984) where shallow scratches, which penetrate the cuticle, do not break impermeability.

Mckee *et al.* (1977) in a piercing experiment with seeds of *Coronalla viria* claimed that both the osteoscleroid and mesophyll layers needed to be punctured or made permeable, for seeds to imbibe thereby suggesting that water absorption was positively associated with the size of the seed coat.

Egley and Paul (1982) provided the information on the development of impermeability as a function of the stage of maturation. In seeds of *Sida spinosa* at stage three (15-16 days post-anthesis), the seed coat was pale brown and soft. Afterwards, the seeds lost water rapidly and became fully impermeable, mechanically hard and dark brown in colour.

Comprehensive review on region of permeability shows that water reaches the embryo mainly through the testa (Noodén *et al.*, 1985 and Chachalis and Smith 2000), or through the hilar area (Mcdonald *et al.*, 1988a).

Mcdonald *et al.* (1988b) in another experiment showed that the seeds absorbed nearly 60 per cent of water in the first three hours and it was concluded

that thickness of the seed coat was the most important factor conferred by the hydrophobic nature of the testa.

Bewley and Black (1994) in an experiment of soaking seeds showed that at five hours of soaking, water enters the seed in relatively higher and steady rate and at the following stage (after five hours) the imbibition process slows down and seed reaches almost full capacity of hydration.

The electrical conductivity test consists of measuring electrical conductivity of electrolytes leached from imbibed seeds. Conductivity readings and degree of seed deterioration are positively correlated (Vieira *et al.*, 1999). Since water imbibition and electrolyte leaching are reverses of a same coin, the conductivity test estimates seed coat permeability as well (Kuo, 1989).

Ragus (1987) suggested that thick seed coat is slower in absorbing water than thinner one and old age seed has higher speed of water absorption than the newly harvested seed due to deterioration of its seed coat and loss of turgor pressure of cell.

The work reviewed in this chapter reveals gaps in our knowledge on several aspects of coat-imposed dormancy. It is not clearly evident that impermeability is due to mechanical barrier or due to chemical effects or combination of both.

2.5.3.3 Effect of scarification treatments in breaking dormancy

Seed coat or external dormancy results from a hard seed coat, which is impervious to water and gas. The seed will not germinate until the seed coat is altered physically. Any process of breaking, scratching or mechanically nicking of seed coat to make it permeable to water and gases is known as scarification.

The role of birds and animals in distributing seed and enhancing its germination has been known for many years. The grinding effects on the seed coat

passing through the digestive tract of birds are equivalent to mechanical scarification. Also, stomach acids are thought to corrode the coat and allow fluid penetration (Ragus, 1987 and Yaklich *et al.*, 1986).

Hard seededness increases the survival rate of seeds in its passage through the digestive tract of many animal species (Neto *et al.*, 1987). Hard seededness may also be artificially overcome by a variety of thermal, chemical and physical treatments (Argel and Paton, 1999).

Grey (1962) noticed hot water soaking as superior to sulphuric acid treatment and seeds treated with hot water retained full viability in *Leucaena glauca* L. seeds.

Singh and Singh (1969) reported that dormancy in bitter gourd could be broken by acid scarification of seeds, with dilute H_2SO_4, HNO_3 or HCl for 30-60 minutes.

Anithakumari and Kohli (1984) noticed that seeds of *Cassia occidentalis* L. have impermeability to water and gas exchange. They further noticed that scarification of seeds with sulphuric acid was the best treatment for breaking seed dormancy.

Ali *et al.* (1991) found that in cucumber cv. Baroda, dormancy was broken when seeds were subjected to puncturing, removal or cutting of the inner integument.

According to Krishnaswamy (1991), bitter gourd seeds with seed coat removed imbibed water faster and emerged earlier. But total emergence and seedling vigour were significantly lower than the intact seeds.

Maithani *et al.* (1991) showed that immersing the seed in luke warm water for 18 hours gave better germination.

Weston *et al.* (1992) observed that after ripening increases the growth potential of embryo by allowing radical penetration of the seed coat, which presents a significant physical barrier in dormant seeds of cucumber.

Latha (1992) reported low germination percentage in CM 214 (*Cucurbita moschata*) due to the presence of hard seed coat. Various seed treatments like mechanical scarification, hot water treatment, dipping in GA_3 etc. did not improve the germination percentage considerably. But when the seed coat was removed, the germination percentage got increased up to 71.4 per cent.

Katiyar *et al.* (1998) reported that hot water (40^0 C for two minutes) treatment was effective in improving germination and overcoming seed dormancy in rainy season crop of bitter gourd variety Kalyanpur Baramasi.

2.5.4 Osmotic treatments

The osmoticums such as glycerol, KH_2PO_4, NaH_2PO_4, KNO_3 and NaCl have been used successfully for invigoration in a wide variety of crop species (Heydecker and Coolbear, 1977).

According to Sachs (1977), seed priming using two per cent or three per cent KNO_3 for 6 days improved germination though NH_4NO_3, $NaNO_3$, $Ca(NO_3)_2$ and KCl had similar effect on field emergence under low temperature in winter grown watermelon.

Solanki and Joshi (1984) invigorated the seeds of onion (*Allium cepa* L.) and carrot (*Daucus carota* L.) using KH_2PO_4, KNO_3 and GA_3 at different concentrations along with hot water treatment. The maximum germination was

recorded in case of onion seeds soaked in three per cent KNO_3 solution, whereas hot water soaking for 12 hours resulted in maximum germination of carrot.

Renugadevi (1992) found that treatment with one per cent KNO_3 recorded a significant increase in seed germination, speed of germination, dry matter production and vigour index of seedling in ash gourd.

Renugadevi and Selvaraj (1994) reported that for achieving cent per cent viability and enhanced vigour in bittergourd cv. CO.1, pre-treatment of seeds with one per cent KNO_3 is beneficial.

Manoharan (1999) observed remarkable improvement in germination percentage by osmo-priming of chilli seeds with chemicals like sodium chloride during the tenth month of storage.

Singh *et al.* (1999) revealed that osmo-conditioning of seeds of muskmelon c.v. Punjab Hybrid and Punjab Sunehri with PEG-6000 (-8 bars) and KNO_3 (0.35 M) containing 0.2 per cent thiram as fungicide at 15^0 C for three, five and seven days increased per cent germination, speed of germination and vigour. KNO_3 recorded more pronounced effect in all the above-mentioned parameters.

Bhuyar *et al.* (2000) studied the effect of growth regulators like GA_3, thiourea and NAA on seed germination in spine gourd (*Momordica dioica* Roxb.). Amongst the three growth regulators GA_3 200 ppm was superior to all the other treatments with respect to early germination percent and shoot and root growth.

Germination percent of onion variety Kalyanpur Red Round was improved significantly by seed treatment with GA_3 100 ppm and NAA 10 ppm (Tewari *et al.*, 2001).

Osmo-conditioning with PEG (-8 bars) containing two per cent thiram for three days recorded good germination and higher speed of germination (Singh *et al.*, 2001) in muskmelon cv. Punjab Sunehri

Malarkodi *et al.* (2002) reported that treating cowpea seeds with KH_2PO_4 at 0.5 per cent improved germination and seedling growth followed by NaH_2PO_4 at 0.5 per cent concentration.

2.6 Storage potential of invigorated seeds

The storability of a seed of a given kind is primarily determined by the vigour of the seeds at maturity and level of deterioration at the time it enters storage. Loss of storage potential after invigoration of seed therefore, must be broadened to encompass the complex subject of seed deterioration (Ching and Craft, 1968).

Young (1949) recorded an increased germination of 98.4 per cent in butternut squash after four months of storage.

Vicek (1963) reported that pre-sowing soaking of seeds in water for 48 hours and storing for one to five days at 6^0 C increased the yield of tomato by 19.04 per cent.

Berjak and Villiers (1972) found definite increase in electrical conductivity values with increase in storage period. This increase in electrical conductivity values with increase in period of storage was attributed to membrane aberrations of seeds.

Basu *et al.* (1975) reported the usefulness of seed storage correction treatments in controlling the seed deterioration in wheat, jute, rice, sunflower,

pulses and vegetables during storage. They also suggested second time invigoration of seeds for prolonging the viability of the seeds.

Basu *et al.* (1979) reported that dry permeation of potassium iodide (10^{-4} M), p-hydroxy benzoic acid (10^{-4} M) and tannic acid by employing acetone as infusing solvent effectively controlled the deterioration in the stored seeds of lettuce and attributed that the concentration of free radical damage might be the possible reason for the maintenance of viability.

Suryanarayana and Afrijuddin (1980) treated the seeds of okra variety Pusa Sawani with GA_3 and NAA at different concentrations and stored for a period of 30 days. Results revealed that storage of treated seeds for 15 to 30 days did not have much deleterious effect on growth and yield of plants.

Yadav *et al.* (1981) related increased membrane integrity of Sal seeds during storage and solute leakage to decreased germination.

Araujo *et al.* (1982) reported increased seed germination with increasing fruit age and storage length in cucurbits.

Woodstock *et al.* (1983) found that treatments of onion, pepper and parsley seeds with several concentrations of tocopherol and butylated hydroxytoluene improved storability in some storage conditions but increased deterioration in others.

Chauhan *et al.* (1984) found that leaching of toxic metabolites, germination advancement, antipathogenic effect, repair of biochemical lesions, quinching and counter action of free radicals, prevention of lipid peroxidation etc. could be the probable reasons to reduce the rate of deterioration of invigorated seeds during storage.

According to Metha and Ramkrishnan (1986) hydration treatments with sodium phosphate (dibasic) for three hours and drying back to its original weight slowed down the rate of deterioration of both large and small seeds of CO-1 chilli subjected to less than 12 months of storage.

Chin (1988) opined that seed moisture content and storage temperature are crucial factors determining seed quality once in store.

New (1988) reported that oxygen pressure and seed treating chemicals are other important factors, which affect seed storability, and many seed treating chemicals have an oxidizing effect.

Gayathri and Kalappa (2002) invigorated the seed lots of tomato hybrid, Akash differing in germination percentage using different methods. Invigoration with selected chemicals, humidification (24 hours at 95% RH) and hydration-dehydration for two hours at 1:1 (wt/vol.) seed to water ratio followed by shade drying (43 hours) was tried before storing at room temperature (25^0 C) for four months period. Seed invigoration with one per cent KNO_3 showed enhanced performance even after storage.

2.7 Studies on field performance of invigorated seed

Seed viability and vigour directly affect the performance of seeds planted to regenerate the crop. Thus, the effect of seed vigour on emergence and stand can be especially critical where delayed emergence or missing plants may reduce yield and plant uniformity at harvest. The effects of seed vigour on emergence and field establishment are well documented by many workers.

Adulka and Verma (1965) reported early flowering and increased yield from invigorated tomato seeds compared to control. Similar results were reported in brinjal (Sadawarte and Gupta, 1968) and okra (Nandpuri *et al.*, 1969) as well.

Willey and Heath (1969) reported that total emergence determines plant density and there is a strong relationship between density and yield.

Effects have been reported on total emergence, rate of emergence, uniformity of emergence and their effect on yield and other economic characters. All of these factors can potentially influence dry matter accumulation by the plant and thus potentially affect crop yield (Roberts, 1972).

Heydecker (1977) stated that reduction in yield could be indirectly related to low seed vigour if plant populations are below critical level.

Pre-sowing soaking in one percent potassium nitrate or 1.5 per cent potassium phosphate for three hours and periodical wetting over 69 hours and drying to 10-11 per cent moisture content gave better plant stand and yield per unit area in tomato and capsicum (Dimov *et al.*, 1978).

Pre-sowing seed treatment gave better seedling performance, field establishment and increased yield in *Beta vulgaris* (Basu and Dhar, 1979), tomato (Mitra and Basu, 1979) and carrot (Kundu and Basu, 1981).

Singh *et al.* (2002) stated that vegetable quality, yield, seed yield and quality are directly dependant on the quality of seedlings raised.

Ganar (2003) reported that seed invigoration treatment with two per cent KNO_3 for two days improved field emergence in ash gourd during adverse climatic conditions of spring - summer seasons.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation "Seed invigoration and dormancy studies in snake gourd (*Trichosanthes anguina* L.)" was carried out at the Department of Olericulture, College of Horticulture, Vellanikkara during 2003-2005.

The experimental site was located at an altitude of 22.5m above M.S.L between 10^0 32' N latitude and 75^0 16' longitude. The location experiences a warm humid tropical climate. The soil of the experimental site comes under the textural class of sandy clay loam and is acidic in reaction. The average monthly values of the meteorological parameters viz., rainfall, maximum and minimum temperatures and relative humidity were collected from the observatory attached to College of Horticulture and are presented in Appendix-I

The study consisted of following three experiments:

1. Seed invigoration to break dormancy
2. Storage potential of invigorated seeds
3. Field performance of plants derived from invigorated seeds

The materials used and the methods adopted for the studies are briefly described below.

3.1 SEED INVIGORATION TO BREAK DORMANCY

Snake gourd variety 'Baby' was grown in the research fields of Department of Olericulture during November 2003 to February 2004, adopting the recommended cultural operations. Fully matured uniform fruits were harvested and seeds were extracted manually immediately after harvest.

All the extracted seeds were dried to a moisture content of eight per cent, cleaned, sealed in 700 gauge polythene cover and stored at ambient room

temperature. A total number of 5 x 50 samples of seeds were drawn at random and evaluated at monthly intervals under laboratory conditions. The following invigoration treatments were given before sowing in sterilized sand medium for germination under ambient conditions, starting from the month of harvest up to five months.

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4 : Water soaking for 12 hours
T_5 : Hot water (40^0 C) soaking for 5 minutes
T_6 : Mechanical scarification by way of seed rupturing
T_7 : GA_3 (250 ppm) for 24 hours
T_8 : GA_3 (500 ppm) for 24 hours
T_9 : NAA (100ppm) for 24 hours
T_{10}: 1% KNO_3 for 12 hours
T_{11}: 0.5% NaH_2PO_4 for 1 hour
T_{12}: 0.5% KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

Design	- CRD
Number of treatments	- 13
Number of replications	- 5
Seeds per treatment	- 50

The following physiological and biochemical parameters were recorded during each month.

3.1.1 Germination percentage

From the samples sown for seed evaluation, the seedlings were evaluated on the 14^{th} day from the date of sowing (final count day) and the total number of normal seedlings was recorded. The mean number of normal seedlings produced to the total number of seeds sown was expressed as germination percentage.

3.1.2 Intensity of dormancy

The number of non germinated seeds in the test at seven days after sowing (NGS_7) and at 14 days after sowing (NGS_{14}) was calculated from the number of germinated seeds and the mean number of non germinated seeds to the total number sown was expressed as intensity of dormancy in percentage (Swain *et al.*, 2001).

3.1.3 Dormancy index

The speed of release of dormancy was estimated by counting number of seeds showing dormancy release on each day after sowing until the 14^{th} day. From this data the dormancy index was calculated using the formula,

Dormancy index $=\Sigma$ (Ni / Di)

Where, Ni =Number of seeds showing dormancy release on the i^{th} day

Di =Days after harvest

3.1.4 Duration of dormancy

The number of days taken from the day of sowing to achieve 60 per cent germination was noted and expressed as DG_{60} (Swain *et al.*, 2001).

3.1.5 Speed of germination

From the samples sown for seed evaluation, number of seedlings emerged was recorded daily until the 14^{th} day of the emergence of first seedling. The conditions wherein cotyledons slipping out of the seed coat was taken as the criteria for emergence of normal seedling. From the mean germination percentage

recorded on each counting date, speed of germination was calculated employing the following formula suggested by Maguire (1962).

$$\text{Speed of germination} = \frac{X_1}{Y_1} + \frac{X_2 - X_1}{Y_2} + \ldots\ldots\ldots\ldots \frac{Xn - Xn_{-1}}{Yn}$$

Where, Xn = Per cent germination on n^{th} day

Yn = number of days from sowing to n^{th} count.

3.1.6 Root length of seedling

At the end of the germination test period i.e. on the 14^{th} day, five normal seedlings were carefully uprooted at random from the test sample, root length was measured and the mean was computed. The length between collar region and tip of the root was measured as root length and expressed in cm.

3.1.7 Shoot length of seedling

From the sample, after measuring root length, the length between collar region and tip of the leaf was measured in cm and the mean value was recorded as shoot length.

3.1.8 Vigour index-I of seedling

Vigour index-I was computed adopting the formula suggested by Abdul-Baki and Anderson (1972) and expressed as whole number.

Vigour index-I = Percent germination × Mean length of root and shoot

3.1.9 Seedling dry weight

Five normal seedlings were air dried initially for six hours and then in hot air oven maintained at 105^0 C for 24 hours. Dried seedlings were cooled for 45 minutes and the dry weight of a single seedling was calculated in g.

3.1.10 Vigour index –II

Vigour index-II was computed, adopting the formula suggested by Bewley and Black (1994).

Vigour index-II = Percent germination × Seedlings dry weight in g.

3.1.11 Pooled analysis for selection of best five treatments

Based on the pooled analysis involving most important seed quality parameters like germination percentage, speed of germination, vigour index-I and vigour index-II, best five invigoration treatments were selected for further studies.

3.1.12 Determination of seed coat thickness

The effect of scarification treatments on seed coat thickness of five selected invigoration treatments from 3.1.11 was compared with the untreated stored seeds and untreated fresh seeds. The freshly extracted seeds from summer season crop of snake gourd were subjected to seed scarification treatments and were dried at room temperature to a safe moisture content of 8-10 per cent. The following treatments were included in the study.

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated fresh seeds)

T_7: Stored seeds from previous *kharif* crop

From each treatment uniform, bold, undamaged and healthy seeds were selected. Further, seed fresh weight, length, width and girth of selected seeds were determined using absolute digimatic caliper and 20 uniform (± 0.5mm) seeds were selected for further studies.

The selected seeds were soaked in water for 10 minutes. Thin horizontal sections of seed coat, opposite to hilum and middle of the seeds were taken with the help of microtome instrument. Such thin sections of seed coat were stained using acetocarmine and images were viewed at 4X and 10X magnifications, using image analyzer stereoscopic microscope, equipped with a computerized micrometer. Appropriate titles and scales were added and measurement of seed coat thickness was taken using the software 'Labomed Digipro-2' at 10X magnification. For every field, 25 counts were taken randomly and mean was worked out to know the seed coat thickness, expressed in microns.

3.1.13 Water imbibition rate

Water imbibition rate of seeds was determined using 'modified ISTA (International Seed Testing Association) low constant temperature oven method', which is an indirect method of determination of seed moisture retention rate (ISTA, 1993).

The freshly extracted seeds from summer season crop of snake gourd were invigorated with best five treatments selected from 3.1.11.

Treatments - 7

Replication - 3

Number of seeds / treatment - 50

The seed lots containing sufficient seeds were invigorated with above treatments and seeds were air dried for 24 hours. Then the seeds were oven dried (24 hours at $101^0 \pm 3^0$ C) along with untreated fresh seeds and stored seeds. Next day morning seeds were taken out from the oven and cooled for 10-15 minutes at room temperature. Seeds, which were bold, firm and undamaged, were considered for the study. The precession of seed uniformity is obtained by measuring length, width and girth of selected seeds using absolute digimatic caliper and 50 uniform (± 0.5mm) seeds were selected for further study.

Mean weight of seed was recorded to a four decimal point accurately using electronic balance and readings were noted as initial seed weight (mg). Then seeds were soaked in distilled water. After one hour, the seeds were taken out, the surfaces of the seeds were blotted dried in between two whatman No.1 filter paper to remove surface adsorbed water and seed weight was recorded accurately. The seeds were kept back in the beaker containing water and process was repeated after 3, 6, 12 and 24 hours. The amount of water imbibition was determined as actual increase in seed weights and converted to percentage using formula

$$\text{Per cent water imbibition} = [(W_i - W_d)/W_d] \times 100$$

Where, Wi and W_d are masses of imbibed and dry seeds respectively

3.2 STORAGE POTENTIAL OF INVIGORATED SEEDS

Fully matured uniform fruits were selected from the seed crop of snake gourd var. Baby, raised during June-October, 2004 as a rainy season crop and the seeds extracted from them were used for storage studies. The extracted seeds were

invigorated with the selected five treatments from 3.1.11 along with control (untreated seeds) and dried to moisture content of 8-10 per cent. They were stored in 700 gauge polythene covers under ordinary room temperature. The treatments selected were,

T_1: Mechanical scarification by way of seed rupturing
T_2: Hot water (40^0 C) soaking for 5 minutes
T_3: 5N HCl for 20 minutes
T_4: 5N H_2SO_4 for 10 minutes
T_5: 1% KNO_3 for 12 hours
T_6: Control (untreated seeds)

Treatments	- 6
Replication	- 5
Design	- CRD
Number of seeds / treatment	- 50

The treated and dried samples were drawn at monthly intervals and sown in a sterilized sand medium for germination under ambient conditions. Starting from one month after treatment, the following seed quality parameters were recorded under laboratory conditions for six months.

3.2.1 *Germination percentage* - *recorded as detailed* under item 3.1.1

3.2.2 Intensity of dormancy - recorded as detailed under item 3.1.2

3.2.3 Dormancy index - recorded as detailed under item 3.1.3

3.2.4 Duration of dormancy - recorded as detailed under item 3.1.4

3.2.5 Speed of germination - recorded as detailed under item 3.1.5

3.2.6 Root length of seedling - recorded as detailed under item 3.1.6

3.2.7 Shoot length of seedling - recorded as detailed under item 3.1.7

3.2.8 Vigour index - I of the seedling- recorded as detailed under item 3.1.8

3.2.9 Seedling dry weight - recorded as detailed under item 3.1.9.

3.2.10 Vigour index- II of the seedling - recorded as detailed under item 3.1.10

3.2.11 Electrical conductivity of seed leachate

Two replications of 50 invigorated seeds were placed in beakers and washed in distilled water to remove all adhering dirt, soil or chemicals. The seeds were then soaked in 50 ml of distilled water for 24 hours by occasionally stirring the contents. The beakers containing the soaked seeds were covered to reduce evaporation and contamination by dust. The seed leachate was decanted and collected in a 100 ml beaker. Then seed leachate was filtered and made up to 50 ml. The electrical conductivity of seed leachate was measured in a digital conductivity meter (Type CM 180) with cell constant of electrode, one. The electrical conductivity of seed leachate was expressed as μ mhos/cm (Presley, 1958).

3.3 FIELD PERFORMANCE OF PLANTS DERIVED FROM INVIGORATED SEEDS

Seeds invigorated by the five selected methods from 3.1.11 were compared for field performance with the seeds whose dormancy has been broken naturally by storage.

The experiment was conducted during February-May 2005. The crop was raised as summer season crop, adopting the recommended cultural operations and plant protection measures. The treatments were:

T_1- Seeds from previous summer season crop, which were stored till sowing (12 months).

T_2- Seeds from previous *kharif* crop, which were stored till sowing (six months)

T_3 - Fresh seeds subjected to mechanical scarification by way of seed rupturing

T_4 - Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_5 - Fresh seeds treated with 5N HCl for 20 minutes

T_6 - Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_7 - Fresh seeds treated with 1% KNO_3 for 12 hours

T_8 - Control (untreated fresh seeds)

Number of treatments	- 8
Design	- RBD
Replication	- 3
Individual plot size	- 4 m^2

The following observations were recorded.

3.3.1 Field emergence

The number of normal seedlings produced was recorded and its ratio to the total number of seeds sown was computed and expressed in percentage.

3.3.2 Length of the main vine

The length of the main vine was recorded from collar region to tip of the vine in m. at the time of final harvest.

3.3.3 Primary branches per plant

The number of primary branches emerging from the main vine was counted.

3.3.4 Days to first female flower opening

The number of days taken to the opening of the first female flower from the date of sowing was recorded.

3.3.5 Node at which first female flower appeared

The node at which the first female flower appeared was counted from the cotyledon node and recorded.

3.3.6 Per cent fruit set

The number of flowers produced and fruits set were noted and the percentage was calculated.

From each plot, half of the plants were retained for seed purpose and the remaining half was harvested at vegetable stage. The following observations were recorded from plants retained for vegetable harvest.

3.3.7 Days to first harvest for vegetable purpose

The number of days taken by the plants for first harvest at vegetable maturity from the date of sowing was recorded.

3.3.8 Days to last harvest

The number of days taken by the plants for last harvest at vegetable maturity from the date of sowing was recorded.

3.3.9 Average fruit weight

Weight of immature fruits was recorded individually and the average was worked out and expressed in g.

3.3.10 Fruits per plant

The number of fruits produced on the five observational plants was recorded and the mean was computed to arrive at the fruits per plant.

3.3.11 Circumference of fruit

The circumference of fruits at vegetable harvest was measured at the middle of the fruit and recorded in cm.

3.3.12 Length of fruit

Length of the fruit from the stalk end to the tip was recorded in cm.

3.3.13 Fruit shape index

Ratio of the fruit length to fruit diameter was computed.

3.3.14 Fruit yield per plot

Total weight of the fruits harvested from each plot was recorded in kg.

3.3.15 Fruit yield per hectare

Fruit yield per hectare was calculated from the net plant yield and expressed in kg.

The following observations were recorded from the plants retained for seed purpose.

3.3.16 Average fruit weight

The weight of fully mature fruits, which are turning red, was recorded and the average was worked out and expressed in g.

3.3.17 Fruits per plant

The number of fully matured fruits produced on the observational plants was recorded and the mean was computed to arrive at the fruits per plant.

3.3.18 Seeds per fruit

The number of seeds extracted from each fully mature fruit was counted and average recorded.

3.3.19 Weight of seeds per fruit

The seeds extracted and dried from each fully mature fruit were weighed and the average was worked out and expressed in g.

3.3.20 Hundred seed weight

Seeds extracted from the mature fruits of uniform size were washed, cleaned and dried to a moisture content of eight per cent. Hundred bold seeds were selected and the weight recorded in g

3.3.21 Seed yield per plant

Total weight of seeds collected from individual plant was recorded in g.

3.3.22 Seed yield per hectare

Seed yield per hectare was calculated from net seed yield per plant and expressed in kg.

3.4 Statistical analysis

Statistical analysis of the data was performed using MSTAT-C programme in CRD for laboratory studies and in RBD for field performance. The data were subjected to analysis of variance (ANOVA) and in cases where analysis of variance indicated a significant treatment effect, Dunken's Multiple Range Test (DMRT) was used to identify homogenous treatments as described by Panse and Sukhatme (1978).

RESULTS

4. RESULTS

The present investigation was carried out to standardize seed invigoration treatments to break dormancy in snake gourd and to study the storage potential as well as field performance of invigorated seeds. The experimental data collected were tabulated and analyzed statistically for significant difference and the results are presented in this chapter.

4.1 SEED INVIGORATION TO BREAK DORMANCY

The seed invigoration treatments showed significant difference among themselves with respect to all the physiological and biochemical parameters studied.

4.1.1 Germination percentage

The effect of invigoration treatments on germination percentage is given in table 1. The freshly extracted seeds (0 MAE), subjected to mechanical scarification showed the maximum germination percentage (77.00) and seeds soaked in NAA showed the minimum (8.00). The germination percentage of untreated control seeds was 34.00 at this stage. At 1 MAE, the maximum germination percentage was shown by seeds treated with H_2SO_4 (81.00) and the seeds soaked in KH_2PO_4 recorded the minimum (11.00) germination percentage. At 2 MAE, the maximum germination was again recorded in seeds treated with H_2SO_4 (89.00) and minimum was shown by untreated seeds (17.00). At 3 MAE maximum germination percentage was exhibited by seeds treated with HCl (91.00) and minimum germination percent by KH_2PO_4 treated seeds (5.00). At 4 MAE and 5 MAE, seeds subjected to mechanical scarification recorded the highest (93.00 and 92.00 respectively) germination percent. GA_3 250 ppm treatment could result in seeds with minimum germination percentage (7.00 and 20.00 respectively).

Table 1. Effect of invigoration treatments on germination percent of snake gourd seeds at monthly intervals

	Germination per cent					
Treatments	**0 MAE**	**1 MAE**	**2 MAE**	**3 MAE**	**4 MAE**	**5 MAE**
T_1	49^{bcd}	81^{a}	89^{a}	74^{bc}	61^{b}	83^{bc}
T_2	59^{bc}	75^{ab}	84^{ab}	91^{a}	66^{b}	79^{cd}
T_3	40^{cde}	62^{bc}	46^{f}	66^{cd}	89^{a}	67^{de}
T_4	51^{bcd}	52^{cd}	82^{bc}	31^{e}	38^{c}	42^{gh}
T_5	68^{ab}	57^{bc}	35^{g}	54^{d}	57^{b}	47^{gh}
T_6	77^{a}	75^{ab}	72^{c}	86^{ab}	93^{a}	92^{a}
T_7	21^{efg}	33^{e}	59^{de}	9^{gh}	7^{e}	20^{hi}
T_8	20^{fg}	28^{ef}	64^{cd}	20^{efg}	32^{cd}	28^{h}
T_9	8^{g}	32^{e}	41^{fg}	61^{cd}	24^{d}	45^{gh}
T_{10}	52^{bcd}	38^{de}	81^{bc}	52^{d}	56^{b}	55^{f}
T_{11}	36^{def}	21^{ef}	22^{h}	14^{fgh}	62^{b}	52^{fg}
T_{12}	48^{cd}	11^{f}	21^{h}	5^{h}	63^{b}	48^{fgh}
T_{13}	34^{def}	23^{ef}	17^{h}	26^{ef}	89^{a}	85^{ab}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1% KNO_3 for 12 hours
T_{11}: 0.5% NaH_2PO_4 for 1 hour
T_{12}: 0.5% KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.

4.1.2.a Intensity of dormancy at seven days after sowing (NGS_7)

Table 2.a shows the effect of seed invigoration on the intensity of dormancy at seven days after sowing (NGS_7).

At 0 MAE, the intensity of dormancy was significantly lower in case of seeds subjected to mechanical scarification (72.00 %) than rest of the treatments. At 1 MAE, seeds treated with both KH_2PO_4 and NAA had the maximum intensity of dormancy (NGS_7, 96.00) at seven days after sowing, while minimum NGS_7 (53.00) was shown by seeds treated with H_2SO_4. At 2 MAE, seeds treated with GA_3 500 ppm and untreated seeds exhibited highest NGS_7 (98.00) value and minimum (33.00) was by H_2SO_4 treated seeds. At 3 MAE, seeds treated with both KH_2PO_4 and untreated seeds recorded highest NGS_7 (100.0) and minimum value was exhibited by seeds subjected to mechanical scarification (60.00). At 4 MAE, seeds treated with KH_2PO_4, NaH_2PO_4, NAA and untreated seeds recorded the maximum value (100.0) and the seeds subjected to mechanical scarification had the minimum (16.00). At 5 MAE, seeds treated with NaH_2PO_4 and GA_3 250 ppm showed highest intensity of dormancy (97.00) and untreated seeds (96.00) were on par. The lowest intensity of dormancy was recorded by mechanically scarified seeds (32.00).

4.1.2.b Intensity of dormancy at 14 days after sowing (NGS_{14})

The intensity of dormancy at fourteen days after sowing (NGS_{14}) at monthly intervals is shown in Table 2.b

NGS_{14} was highly significant ($P \leq 0.05$) at all the months. Immediately after extraction (0 MAE) seeds treated with NAA and GA_3 500 ppm had maximum intensity of dormancy (92.00 and 88.00 respectively), while seeds subjected to mechanical scarification had minimum (22.67) NGS_{14}. At 1 MAE, seeds treated with KH_2PO_4 had the highest value (89.00) and seeds treated with

Table 2.a. Effect of invigoration treatments on intensity of dormancy (NGS_7) at monthly intervals

Treatments	Intensity of dormancy (%)					
	0 MAE	1 MAE	2 MAE	3 MAE	4 MAE	5 MAE
T_1	100^{a}	53^{d}	33^{e}	72^{d}	75^{b}	78^{de}
T_2	100^{a}	59^{cd}	69^{cd}	73^{d}	72^{b}	72^{e}
T_3	100^{a}	60^{cd}	92^{ab}	77^{cd}	77^{b}	88^{abcd}
T_4	92^{a}	72^{bc}	67^{d}	97^{a}	79^{b}	82^{cde}
T_5	92^{a}	79^{ab}	79^{bcd}	83^{bc}	75^{b}	83^{bcde}
T_6	72^{b}	75^{bc}	80^{bc}	60^{e}	16^{c}	32^{f}
T_7	97^{a}	90^{ab}	89^{ab}	92^{ad}	98^{a}	97^{a}
T_8	100^{a}	87^{ab}	98^{a}	98^{a}	97^{a}	94^{abc}
T_9	100^{a}	96^{a}	85^{ab}	96^{a}	100^{a}	89^{abcd}
T_{10}	100^{a}	74^{bc}	39^{e}	94^{a}	70^{b}	77^{de}
T_{11}	100^{a}	87^{ab}	86^{ab}	99^{a}	100^{a}	97^{a}
T_{12}	100^{a}	96^{a}	97^{a}	100^{a}	100^{a}	95^{ab}
T_{13}	100^{a}	95^{a}	98^{a}	100^{a}	100^{a}	96^{a}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1% KNO_3 for 12 hours
T_{11}: 0.5% NaH_2PO_4 for 1 hour
T_{12}: 0.5% KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Month after extraction
Values having common superscript are not significantly different from one another.
NGS_7: Percentage non-germinated seeds at seven days after sowing

Table 2.b. Effect of invigoration treatments on intensity of dormancy (NGS_{14}) at monthly intervals

	Intensity of dormancy (%)					
Treatments	**0 MAE**	**1 MAE**	**2 MAE**	**3 MAE**	**4 MAE**	**5 MAE**
T_1	50^{cd}	19^{f}	15^{bc}	26^{gh}	39^{d}	17^{e}
T_2	41^{de}	25^{ef}	20^{bc}	9^{i}	34^{d}	21^{de}
T_3	60^{cd}	38^{de}	15^{bc}	34^{fg}	11^{e}	33^{cd}
T_4	49^{cde}	48^{cd}	5^{c}	69^{d}	62^{c}	58^{b}
T_5	32^{ef}	43^{d}	5^{c}	46^{f}	43^{d}	53^{d}
T_6	22^{f}	25^{ef}	5^{c}	14^{hi}	7^{e}	8^{e}
T_7	78^{ab}	67^{b}	10^{bc}	91^{ab}	93^{a}	80^{a}
T_8	88^{a}	72^{ab}	20^{bc}	80^{bcd}	68^{bc}	72^{a}
T_9	92^{a}	68^{b}	25^{b}	39^{efg}	76^{b}	55^{b}
T_{10}	48^{cde}	62^{bc}	25^{b}	50^{e}	44^{d}	45^{bc}
T_{11}	64^{b}	79^{ab}	70^{a}	86^{abc}	38^{d}	48^{b}
T_{12}	52^{cd}	89^{a}	70^{a}	95^{a}	37^{d}	52^{b}
T_{13}	65^{bc}	77^{ab}	80^{a}	74^{cd}	11^{e}	15^{e}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1% KNO_3 for 12 hours
T_{11}: 0.5% NaH_2PO_4 for 1 hour
T_{12}: 0.5% KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Month after extraction
NGS_{14}: Percentage non-germinated seeds at 14 days after sowing
Values having common superscript are not significantly different from one another.

H_2SO_4 have lowest intensity of dormancy (19.00). At 2 MAE, untreated seeds had the highest NGS_{14} (80.00). Seeds subjected to mechanical scarification and water soaking exhibited lowest intensity of dormancy (5.00). At 3 MAE, seeds treated with KH_2PO_4 had the highest NGS_{14} (95.00) and seeds treated with HCl with minimum (9.00). At 4 and 5 MAE, seeds treated with GA_3 250 ppm had the highest NGS_{14} (93.00 and 80.00 respectively). The minimum NGS_{14} at 4 MAE and 5 MAE was recorded by seeds subjected to mechanical scarification (7.00 and 8.00 respectively).

4.1.3 Duration of dormancy (DG_{60})

The number of days to achieve sixty per cent germination (DG_{60}) is shown in Table 3.

At 0 MAE, seeds subjected to mechanical scarification required minimum number of days to achieve 60 per cent germination (7.33 days). At 1 MAE, seeds treated with H_2SO_4 had the minimum duration of dormancy (6.20 days) days. At 2 MAE, mechanically scarified seeds recorded minimum duration of dormancy (6.25 days) while the maximum duration of 12.33 days was recorded by seeds treated with GA_3 500 ppm. At 3 MAE seeds treated with mechanical scarification recorded lowest intensity of dormancy (6.20 days). HCl and HNO_3 showed 9.00 days of dormancy. At 4 MAE and 5 MAE mechanically scarified seeds showed minimum days to achieve sixty per cent germination (6.20), whereas maximum duration was shown by seeds treated with hot water soaking (11.00 days) at 4 MAE and KH_2PO_4 (12.00) at 5 MAE. Untreated seeds gave 60 per cent or more germination only after 4 MAE.

4.1.4 Dormancy index

The effects of invigoration treatments on mean speed of release of dormancy i.e. dormancy index are shown in the table 4.

Table 3. Effect of invigoration treatments on number of days to achieve 60 per cent germination (DG_{60})

Treatments	Duration of dormancy (days)					
	0 MAE	1 MAE	2 MAE	3 MAE	4 MAE	5 MAE
T_1	9.0	6.2	7.2	10.2	8.0	8.6
T_2	8.67	7.20	10.2	9.0	8.5	8.8
T_3	-	7.80	11.5	9.0	8.0	8.7
T_4	9.0	9.0	8.6	-	-	-
T_5	7.66	8.6	-	12.5	11.0	-
T_6	7.33	6.6	6.25	6.2	6.2	6.7
T_7	-	-	12.0	-	-	-
T_8	-	-	12.3	-	-	-
T_9	-	-	-	10.33	-	-
T_{10}	14.50	-	7.6	12.5	8.75	10.5
T_{11}	-	-	-	-	10.24	-
T_{12}	9.0	-	-	-	9.33	12.0
T_{13}	-	-	-	-	8.2	8.8

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1% KNO_3 for 12 hours
T_{11}: 0.5% NaH_2PO_4 for 1 hour
T_{12}: 0.5% KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

- : Indicate the treatments, which did not gave 60 per cent germination
MAE: Month after extraction

The effect of seed treatment on speed of release of dormancy was highly significant ($P \leq 0.001$) during the period of study. At 0 MAE, seeds subjected to mechanical scarification showed the maximum (3.64) speed of release of dormancy, where as seeds treated with NAA100 ppm showed the minimum (0.37) speed of release of dormancy. The seeds treated with hot water and HCl were the next best treatments with dormancy indeces of 2.70 and 2.61 respectively. At 1 MAE, seeds subjected to mechanical scarification could result in the highest (2.64) speed of release of dormancy, where as KH_2PO_4 treated seeds showed the minimum (0.44) speed. At 2 MAE, the maximum speed of release of dormancy was recorded in GA_3 250ppm treated seeds (1.33) and lowest by untreated seeds (0.23). However from 3 MAE to 5MAE consistent results were observed in the seeds subjected to mechanical scarification, which recorded the highest dormancy index. Minimum dormancy index (0.08) was shown by seeds soaked in a solution of KH_2PO_4 at 3 MAE. GA_3 250 ppm treated seeds recorded the lowest (0.05 and 0.11) dormancy index during 4 and 5 MAE respectively.

The over all mean dormancy indices were significantly different for different treatments during the period of study. The highest mean dormancy index was recorded with seeds subjected to mechanical scarification (1.56) that was followed by seeds treated with HCl (1.18), H_2SO_4 (1.14) and KNO_3 (1.0). Seeds treated with NAA (0.42) recorded the mean minimum dormancy index.

4.1.5 Speed of germination

Results of the statistical analysis of the data on speed of germination are shown in Table 5.

The effect of seed treatment on speed of germination was significant for all the months. At 0 MAE, seeds subjected to mechanical scarification showed the maximum (9.73) speed of germination, where as seeds treated with NAA100 ppm showed the minimum (0.95) speed. At 1 MAE, seed treatment with H_2SO_4 could result in the highest (11.79) speed of germination, where as KH_2PO_4 treated seeds

Table 4. Effect of invigoration treatments on dormancy index at monthly intervals

Dormancy Index							
Treatments	**0 MAE**	**1 MAE**	**2 MAE**	**3 MAE**	**4 MAE**	**5 MAE**	**Mean**
T_1	2.23^{bcd}	1.83^{b}	1.19^{bc}	0.69^{ab}	0.46^{b}	0.49^{ab}	1.14^{bc}
T_2	2.61^{b}	1.70^{bc}	0.99^{c}	0.85^{a}	0.48^{b}	0.46^{b}	1.18^{b}
T_3	1.86^{cde}	1.39^{bc}	0.55^{d}	0.63^{abc}	0.67^{a}	0.40^{b}	0.92^{d}
T_4	2.11^{bcd}	1.24^{c}	1.06^{c}	0.28^{abcd}	0.29^{c}	0.25^{cd}	0.87^{d}
T_5	2.70^{b}	1.35^{c}	0.46^{d}	0.47^{abcd}	0.44^{b}	0.28^{c}	0.95^{d}
T_6	3.64^{a}	2.64^{a}	0.98^{c}	0.81^{a}	0.71^{a}	0.56^{a}	1.56^{a}
T_7	0.89^{gh}	0.62^{d}	1.33^{a}	0.09^{d}	0.05^{e}	0.11^{e}	0.51^{e}
T_8	0.95^{gh}	0.66^{d}	1.31^{ab}	0.13^{cd}	0.24^{cd}	0.17^{d}	0.58^{e}
T_9	0.37^{h}	0.74^{d}	0.53^{d}	0.51^{abcd}	0.16^{d}	0.23^{cd}	0.42^{e}
T_{10}	2.48^{bc}	1.31^{c}	1.10^{c}	0.37^{abcd}	0.43^{b}	0.30^{c}	1.00^{cd}
T_{11}	1.32^{efg}	0.50^{d}	0.30^{e}	0.12^{cd}	0.47^{b}	0.31^{c}	0.50^{e}
T_{12}	1.71^{def}	0.44^{d}	0.28^{e}	0.08^{d}	0.48^{b}	0.29^{c}	0.54^{e}
T_{13}	1.10^{fg}	0.46^{d}	0.23^{e}	0.23^{bcd}	0.67^{a}	0.49^{ab}	0.53^{e}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1% KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

Values having common superscript are not significantly different from one another.

MAE: Month after extraction

Table 5. Effect of invigoration treatments on speed of germination of snake gourd at monthly intervals

	Speed of germination					
Treatments	**0 MAE**	**1 MAE**	**2 MAE**	**3 MAE**	**4 MAE**	**5 MAE**
T_1	5.68^{cd}	11.79^{a}	13.77^{abc}	9.79^{b}	9.24^{c}	9.87^{b}
T_2	6.81^{bc}	10.82^{ab}	11.3^{bcd}	12.09^{a}	9.54^{c}	9.53^{b}
T_3	4.55^{cde}	9.03^{abc}	13.6^{abc}	9.22^{b}	12.97^{ab}	8.06^{b}
T_4	6.00^{bcd}	7.71^{cd}	14.43^{ad}	3.63^{ef}	5.56^{d}	5.30^{cd}
T_5	8.02^{ab}	8.06^{bcd}	15.67^{a}	6.68^{e}	8.67^{c}	5.70^{cd}
T_6	9.73^{a}	10.04^{abc}	14.39^{ab}	11.99^{a}	14.38^{a}	12.56^{a}
T_7	2.39^{efg}	3.94^{ef}	10.88^{cde}	1.33^{gh}	0.86^{f}	2.21^{f}
T_8	2.06^{fg}	4.19^{ef}	9.57^{de}	1.77^{fgh}	4.19^{d}	3.20^{ef}
T_9	0.95^{g}	3.97^{ef}	8.01^{e}	6.48^{cd}	2.39^{e}	4.38^{de}
T_{10}	5.84^{bcd}	5.95^{de}	9.26^{de}	4.75^{de}	9.31^{c}	6.30^{c}
T_{11}	3.85^{def}	3.13^{ef}	2.26^{f}	1.54^{gh}	8.50^{c}	9.40^{cd}
T_{12}	5.59^{cd}	1.53^{f}	2.03^{f}	0.65^{h}	9.17^{c}	5.37^{cd}
T_{13}	3.91^{def}	2.57^{f}	0.98^{f}	2.84^{fg}	11.89^{b}	9.30^{b}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1% KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.

showed the minimum (1.53) speed. At 2 MAE the maximum speed of germination was recorded in seeds subjected to hot water soaking (15.67) and minimum speed of germination was shown by untreated seeds (0.98). The seeds subjected to mechanical scarification recorded the highest (14.38 and 12.56) speed of germination at 4 and 5 MAE respectively. The minimum speed of germination (0.65) was shown by seeds soaked in a solution of KH_2PO_4 at 3 MAE. GA_3 250 ppm treated seeds recorded the lowest (0.86 and 2.21) speed of germination during 4 and 5 MAE respectively.

4.1.6 Root length of seedling

The effect of seed invigoration treatments on the root length of seedlings was significant as shown in Table 6.

At 0 MAE, untreated seeds recorded the maximum root length of 11.74 cm and HNO_3 had the minimum length of 8.62 cm. At 1 MAE the highest root length was recorded by H_2SO_4 treated seeds (12.52). The lowest root length (9.26) was recorded by KNO_3 treated seeds. At 2 MAE, the maximum root length (12.46) was recorded in GA_3 500 ppm treated seeds and KNO_3 treated seeds showed minimum root length (8.74). At 3MAE, both GA_3 250 ppm and HCl treated seeds showed maximum (14.40) root length and minimum root length was exhibited by seeds treated with KH_2PO_4 (11.10). At 4 MAE, KNO_3 treated seeds showed maximum length of root (16.20) and untreated seed showed minimum (12.00) root length. At 5 MAE, seeds subjected to water soaking had maximum (15.40) root length and seeds treated with NaH_2PO_4 exhibited minimum root length of 11.20 cm.

4.1.7 Shoot length of seedling

Result of the statistical analysis of the data on shoot length of seedlings is given in Table 7.

Table 6. Effect of invigoration treatments on root length of snake gourd (cm) at *monthly intervals*

Treatments	Root length (cm)					
	0 MAE	1 MAE	2 MAE	3 MAE	4 MAE	5 MAE
T_1	8.8^{c}	12.52^{a}	10.14^{defg}	14.0^{ab}	15.2^{abc}	14.4^{b}
T_2	10.6^{b}	10.68^{abcd}	9.76^{defg}	14.4^{a}	14.2^{bcde}	14.2^{b}
T_3	8.62^{c}	10.44^{abcd}	8.98^{fg}	12.6^{ab}	14.0^{bcde}	13.0^{c}
T_4	10.02^{b}	11.88^{ab}	9.32^{efg}	12.60^{ab}	13.6^{cdef}	15.4^{a}
T_5	9.46^{bc}	11.72^{abc}	11.86^{abc}	13.10^{ab}	15.4^{ab}	13.2^{c}
T_6	9.58^{bc}	9.7^{bcd}	8.76^{g}	14.2^{ab}	12.6^{ef}	12.8^{cd}
T_7	9.52^{bc}	9.4^{cd}	11.08^{abcd}	14.4^{a}	14.4^{bcd}	12.2^{cde}
T_8	10.0^{b}	11.44^{abcd}	12.46^{a}	13.2^{ab}	13.0^{def}	12.6^{cd}
T_9	9.72^{bc}	10.44^{abcd}	10.42^{cdef}	11.2^{ab}	14.8^{abcd}	12.4^{cd}
T_{10}	9.78^{bc}	9.26^{cd}	8.74^{g}	12.2^{ab}	16.2^{a}	11.8^{de}
T_{11}	10.26^{b}	12.4^{a}	10.62^{bcde}	12.4^{ab}	12.2^{f}	11.2^{e}
T_{12}	9.80^{bc}	11.72^{abc}	10.84^{bcd}	11.1^{b}	12.2^{f}	11.8^{de}
T_{13}	11.74^{a}	11.90^{ab}	12.06^{ab}	11.7^{b}	12.0^{f}	11.8^{de}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: *Hot water (40^0 C) soaking for 5 minutes*
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1 % KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.

Table 7. Effect of invigoration treatments on shoot length (cm) of snake gourd at monthly intervals

	Shoot length (cm)					
Treatments	**0 MAE**	**1 MAE**	**2 MAE**	**3 MAE**	**4 MAE**	**5 MAE**
T_1	13.33^{a}	28.30^{a}	26.34^{c}	29.30^{a}	26.80^{a}	30.00^{abc}
T_2	13.48^{a}	27.94^{a}	26.96^{c}	29.90^{a}	26.60^{a}	29.00^{cd}
T_3	12.38^{a}	28.62^{a}	26.20^{c}	28.20^{a}	26.40^{ab}	27.80^{de}
T_4	14.09^{a}	28.80^{a}	27.75^{bc}	27.80^{a}	26.40^{ab}	30.80^{a}
T_5	13.09^{a}	31.06^{a}	26.18^{c}	29.00^{a}	26.40^{ab}	29.20^{bcd}
T_6	13.23^{a}	27.80^{a}	27.92^{abc}	30.00^{a}	25.00^{ab}	30.40^{ab}
T_7	12.21^{a}	29.04^{a}	29.10^{ab}	29.40^{a}	26.00^{ab}	27.00^{ef}
T_8	12.90^{a}	30.28^{a}	30.02^{a}	27.60^{a}	25.40^{ab}	28.80^{cd}
T_9	12.81^{a}	28.80^{a}	29.34^{ab}	26.60^{a}	25.80^{ab}	29.00^{cd}
T_{10}	12.72^{a}	27.30^{a}	27.25^{bc}	27.40^{a}	26.80^{a}	29.20^{bcd}
T_{11}	11.94^{a}	27.30^{a}	28.12^{abc}	28.60^{a}	24.60^{b}	26.20^{f}
T_{12}	11.92^{a}	30.10^{a}	29.28^{ab}	27.20^{a}	24.60^{b}	26.00^{f}
T_{13}	12.37^{a}	30.36^{a}	26.94^{c}	26.60^{a}	25.80^{ab}	25.80^{f}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1 % KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.

Plate 1. General view of laboratory studies

The effect of treatments on shoot length was significant only at 2, 4 and 5 MAE. At 2 MAE, GA_3 500 ppm treatment resulted in seedlings with maximum shoot length (30.02 cm). The hot water soaked seeds recorded the minimum value of 26.18 cm. At 4 MAE, both H_2SO_4 and KNO_3 treatment resulted in seedlings with maximum shoot length (26.80 cm). Treatments with NaH_2PO_4 and KH_2PO_4 resulted in seedlings with minimum shoot length of 24.60 cm. Water soaked seeds produced seedlings with a maximum value of 30.80 cm at 5 MAE and the minimum shoot length (25.80 cm) was recorded in untreated seeds.

4.1.8 Vigour index-I of seedling

In Table 8, the results of the statistical analysis of the data on vigour index-I of seedling are furnished.

At 0 MAE, seeds invigorated with mechanical scarification and hot water soaking recorded the maximum vigour index-I of 1934 and 1736 respectively. NAA treatment could result in seeds with minimum (133) vigour index I at 0 MAE. At 1 MAE, both H_2SO_4 and mechanically scarified seeds recorded maximum vigour index I (3280 and 3274 respectively) and minimum (280) was recorded in KH_2PO_4 treated seeds. At 2 MAE seeds subjected to hot water soaking resulted in production of seedlings with the highest vigour index (3804), whereas KH_2PO_4 (1204) and NaH_2PO_4 (1162) treated seeds were poor in performance along with the untreated seeds (1560). At 3 MAE, HCl treatment resulted in seeds having the maximum vigour index-I (3765) and the seeds soaked in a solution of KH_2PO_4 could induce the lowest (191) vigour index. At 4 MAE, mechanically scarified seeds recorded the maximum vigour index-I (3634) that was on par with untreated seeds (3583) and HNO_3 (3321) treated seeds. GA_3 250 ppm produced seeds with minimum (215) vigour index. At 5 MAE, mechanically scarified seeds recorded maximum vigour index-I (4070) and GA_3 250 ppm soaked seeds resulted in minimum vigour index I (680) at the end of the experiment.

Table 8. Effect of invigoration treatments on vigour index-I of snake gourd seeds at monthly intervals

Treatments	Vigour index-I					
	0 MAE	1 MAE	2 MAE	3 MAE	4 MAE	5 MAE
T_1	1060^{b}	3280^{a}	3101^{abcd}	3123^{b}	2495^{b}	3595^{ab}
T_2	1275^{b}	2915^{ab}	2938^{de}	3765^{a}	2650^{b}	3254^{b}
T_3	860^{b}	2526^{ab}	2992^{cde}	2528^{c}	3321^{a}	2529^{c}
T_4	1110^{b}	2276^{b}	3521^{abcd}	1240^{d}	1519^{c}	1619^{d}
T_5	1736^{a}	2314^{b}	3804^{a}	2170^{c}	2267^{b}	1802^{d}
T_6	1934^{a}	3274^{a}	3668^{ab}	3520^{ab}	3634^{a}	4070^{a}
T_7	366^{c}	1170^{cd}	3616^{abc}	312^{ef}	215^{e}	680^{e}
T_8	193^{c}	1135^{cd}	3398^{abcd}	605^{ef}	1275^{c}	988^{e}
T_9	133^{c}	1374^{cd}	2982^{cde}	2135^{c}	805^{d}	1719^{d}
T_{10}	1187^{b}	1546^{c}	2699^{e}	2113^{c}	2251^{b}	2218^{cd}
T_{11}	796^{b}	755^{de}	1162^{f}	556^{ef}	2457^{b}	2003^{cd}
T_{12}	1092^{b}	280^{e}	1204^{f}	191^{f}	2597^{b}	1862^{d}
T_{13}	822^{b}	636^{de}	1560^{f}	880^{de}	3583^{a}	3545^{ab}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1 % KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.

4.1.9 Seedling dry weight

Table 9 shows the effect of seed invigoration on seedling dry weight at monthly intervals.

The effect of the treatment was significant only at 0 and 5 MAE. At 0 MAE, invigoration with KNO_3 resulted in the highest seedling dry weight of 0.249 g. Seeds subjected to water soaking treatment recorded the lowest (0.170 g) seedling dry weight. At 5 MAE, GA_3 500 ppm treated seeds recorded maximum (0.156 g) seedling dry weight, which was on par with seeds treated with water soaking (0.152 g) and hot water soaking (0.150 g). The seeds treated with both KH_2PO_4 and NaH_2PO_4 resulted in lowest seedling dry weight of 0.098 g and 0.090 g respectively.

4.1.10 Vigour index –II

Results of the statistical analysis of the data revealed that the invigoration treatments were significant in influencing the vigour index-II of the seedling during all the months (Table 10).

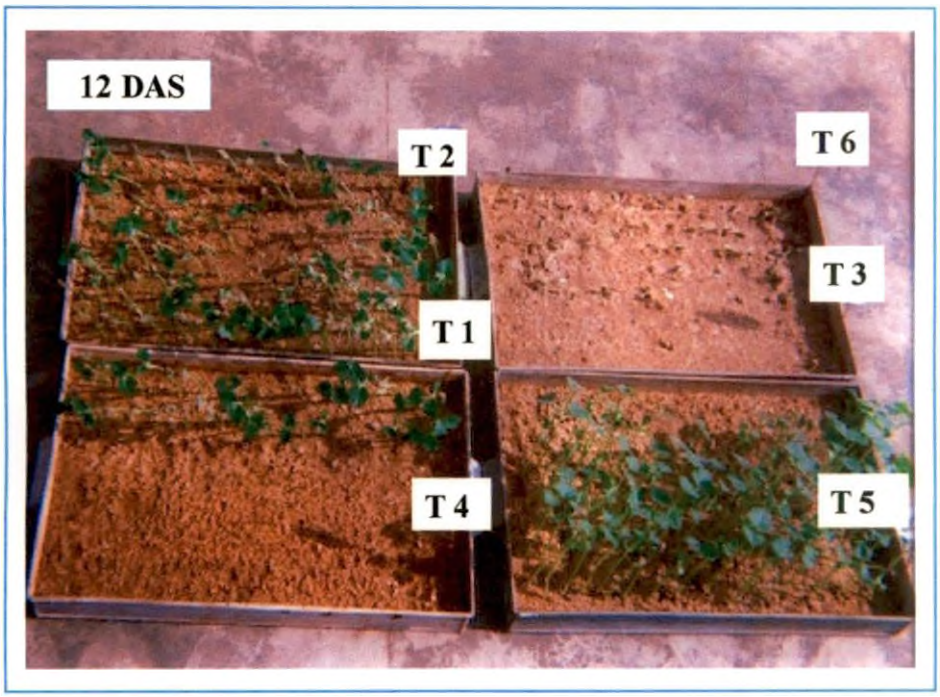
At 0 MAE, both mechanically scarified and hot water soaked seeds exhibited the maximum (3.39 and 3.30 respectively) vigour index-II and minimum vigour was recorded in NAA treated seeds (0.20). Seeds subjected to mechanical scarification induced maximum vigour index-II at 1 MAE (8.69), which was on par with HCl (8.35) and H_2SO_4 (7.38). The KH_2PO_4 treated seeds recorded the lowest vigour index-II (1.91) at 1 MAE. At 2 MAE, seeds invigorated with KNO_3 produced seedlings with maximum vigour index-II (11.19) and minimum was recorded in untreated seeds (2.41). At 3 MAE, seeds subjected to HCl treatment showed maximum vigour index-II (11.48). At 4 MAE, seeds subjected to mechanical scarification was having maximum vigour index-II (11.68) that was on par with untreated seeds (11.47) and HNO_3 treated seeds

Table 9. Effect of invigoration treatments on seedling dry weight (g) of snake gourd at monthly intervals

	Seedling dry weight (g)					
Treatments	**0 MAE**	**1 MAE**	**2 MAE**	**3 MAE**	**4 MAE**	**5 MAE**
T_1	0.188^{ab}	0.091^{a}	0.100^{a}	0.136^{a}	0.149^{a}	0.114^{ab}
T_2	0.196^{ab}	0.109^{a}	0.110^{a}	0.133^{a}	0.140^{a}	0.122^{ab}
T_3	0.181^{b}	0.086^{a}	0.105^{a}	0.126^{a}	0.133^{a}	0.115^{ab}
T_4	0.170^{b}	0.083^{a}	0.120^{a}	0.131^{a}	0.137^{a}	0.152^{a}
T_5	0.198^{ab}	0.090^{a}	0.113^{a}	0.132^{a}	0.138^{a}	0.150^{a}
T_6	0.210^{ab}	0.114^{a}	0.103^{a}	0.123^{a}	0.115^{a}	0.128^{ab}
T_7	0.193^{ab}	0.090^{a}	0.128^{a}	0.116^{a}	0.149^{a}	0.124^{ab}
T_8	0.189^{ab}	0.110^{a}	0.120^{a}	0.130^{a}	0.129^{a}	0.156^{a}
T_9	0.197^{ab}	0.116^{a}	0.105^{a}	0.132^{a}	0.127^{a}	0.126^{ab}
T_{10}	0.249^{a}	0.115^{a}	0.107^{a}	0.128^{a}	0.133^{a}	0.126^{ab}
T_{11}	0.232^{ab}	0.104^{a}	0.110^{a}	0.128^{a}	0.101^{a}	0.09^{b}
T_{12}	0.208^{ab}	0.116^{a}	0.122^{a}	0.111^{a}	0.111^{a}	0.098^{b}
T_{13}	0.200^{ab}	0.102^{a}	0.091^{a}	0.118^{a}	0.123^{a}	0.133^{ab}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1 % KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.



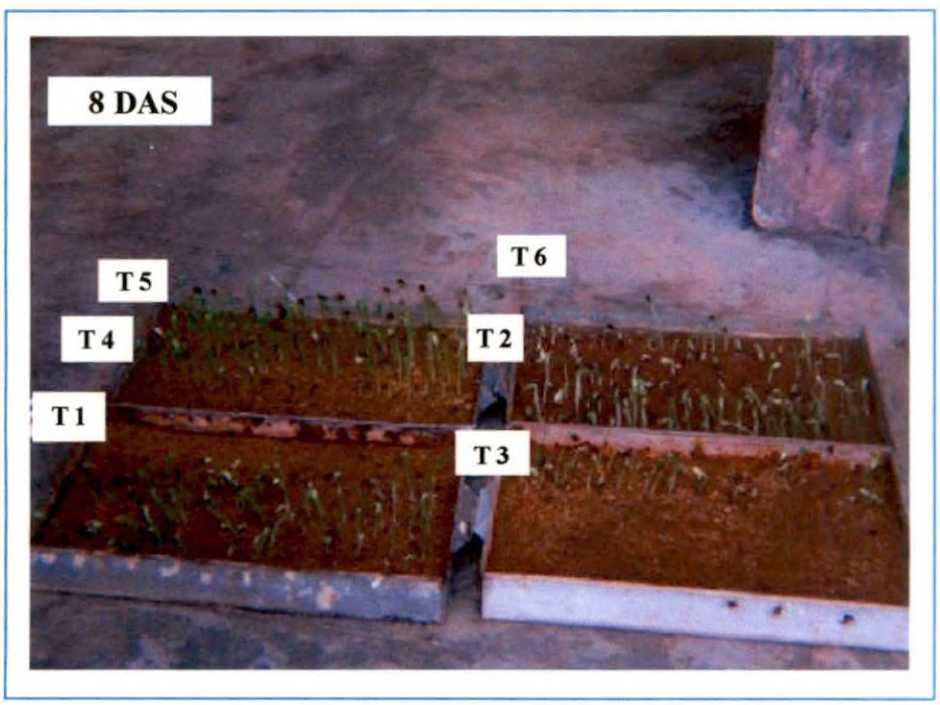


Plate 2. Performance of invigorated and stored seeds

Table 10. Effect of invigoration treatments on vigour index-II of snake gourd at monthly intervals

	Vigour index-II					
Treatments	**0 MAE**	**1 MAE**	**2 MAE**	**3 MAE**	**4 MAE**	**5 MAE**
T_1	2.32^{bc}	7.38^{a}	9.60^{a}	9.51^{bc}	8.33^{bc}	10.80^{a}
T_2	2.87^{ab}	8.35^{a}	9.47^{b}	11.48^{a}	8.51^{bc}	10.37^{a}
T_3	1.94^{bcd}	6.93^{ab}	4.76^{c}	7.55^{d}	10.33^{a}	7.84^{b}
T_4	2.86^{ab}	5.15^{bcd}	10.42^{a}	3.53^{f}	4.87^{d}	5.72^{bcd}
T_5	3.30^{a}	5.34^{bc}	4.13^{cd}	6.53^{def}	7.61^{bc}	6.49^{bc}
T_6	3.39^{a}	8.69^{a}	9.92^{a}	10.32^{ab}	11.68^{a}	10.51^{a}
T_7	1.09^{de}	3.48^{cde}	6.84^{b}	0.85^{gh}	0.59^{f}	1.82^{e}
T_8	0.48^{e}	3.20^{de}	7.09^{b}	2.05^{fg}	4.15^{d}	3.73^{de}
T_9	0.20^{e}	3.54^{cde}	4.53^{c}	6.08^{def}	2.19^{e}	5.14^{cd}
T_{10}	2.69^{abc}	3.82^{cde}	11.19^{a}	6.16^{def}	6.91^{c}	7.41^{bc}
T_{11}	1.77^{cd}	2.08^{e}	2.49^{de}	1.40^{gh}	7.92^{bc}	6.89^{bc}
T_{12}	2.52^{abc}	1.91^{e}	2.41^{de}	0.98^{gh}	8.56^{b}	5.92^{bcd}
T_{13}	1.75^{cd}	2.39^{e}	1.84^{e}	2.47^{fg}	11.47^{a}	11.58^{a}

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1 % KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.

(10.33). Minimum vigour index-II was recorded in GA_3 250 ppm treated seeds (0.59) at the end of the experiment. At 5 MAE, untreated seeds recorded the highest vigour index-II (11.58) that was on par with mechanical scarification, H2SO4 and HCl.

4.1.11 Pooled analysis for selection of best five treatments

Pooled analysis of various invigoration treatments over a period of six months showed significant variation among treatments with respect to different seed quality parameters (Table 11).

The most important seed quality parameters like germination percentage, speed of germination, vigour index-I, vigour index-II and mean performance of these four characters were considered for the pooled analysis.

Considering the germination percentage, seeds subjected to mechanical scarification were superior in performance (82.55) followed by HCl (75.61), H_2SO_4 (72.88), HNO_3 (61.66), KNO_3 (55.66) and hot water soaking (53.00). Seed treatment with GA_3 250 ppm resulted in poor germination per cent (24.88).

The seeds subjected to mechanical scarification gave the highest speed of germination (12.18) followed by H_2SO_4 (10.02), HCl (10.02), HNO_3 (9.57), hot water soaking (8.79) and water soaking (7.11). GA_3 250 ppm recorded the lowest speed of germination (3.60).

Seeds subjected to mechanical scarification recorded maximum vigour index-I (3350), which was followed by HCl (2799), H_2SO_4 (2777), HNO_3 (2459), hot water soaking (2349) and KNO_3 (2003).

The overall analysis of vigour index-II of seedlings revealed that the seeds subjected to mechanical scarification recorded maximum vigour index-II (9.09),

Table 11. Analysis of overall performance of invigoration treatments over a period of six months

Treatments	Germination per cent	Speed of germination	Vigour index-I	Vigour index-II	Mean performance	Ranked order
T_1	72.88^{abc}	10.02^{ab}	2777^{ab}	7.99^{abc}	717.06	**3**
T_2	75.61^{ab}	10.02^{ab}	2799^{ab}	8.51^{ab}	723.41	**2**
T_3	61.66^{bcd}	9.57^{ab}	2459^{abc}	6.56^{abcd}	634.28	**4**
T_4	49.77^{def}	7.11^{bc}	1880^{cd}	5.43^{bcd}	485.79	**7**
T_5	53.00^{de}	8.79^{b}	2349^{abc}	5.57^{abcd}	604.09	**5**
T_6	82.55^{a}	12.18^{a}	3350^{a}	9.09^{a}	863.49	**1**
T_7	24.88^{g}	3.60^{d}	1061^{d}	4.51^{cd}	273.62	**13**
T_8	32.00^{fg}	4.16^{cd}	1266^{d}	4.05^{d}	326.64	**11**
T_9	35.00^{efg}	4.36^{cd}	1524^{cd}	4.44^{cd}	392.16	**9**
T_{10}	55.66^{cd}	6.90^{bcd}	2003^{bcd}	6.36^{abcd}	517.81	**6**
T_{11}	34.50^{efg}	4.11^{cd}	1288^{d}	4.48^{cd}	332.81	**10**
T_{12}	32.66^{gh}	4.06^{cd}	1204^{d}	4.13^{d}	311.31	**12**
T_{13}	45.66^{def}	5.25^{cd}	1884^{bcd}	5.27^{bcd}	485.24	**8**

T_1: 5N H_2SO_4 for 10 minutes
T_2: 5N HCl for 20 minutes
T_3: 5N HNO_3 for 10 minutes
T_4: Water soaking for 12 hours
T_5: Hot water (40^0 C) soaking for 5 minutes
T_6: Mechanical scarification by way of seed rupturing
T_7: GA_3 (250 ppm) for 24 hours
T_8: GA_3 (500 ppm) for 24 hours
T_9: NAA (100ppm) for 24 hours
T_{10}: 1 % KNO_3 for 12 hours
T_{11}: 0.5 % NaH_2PO_4 for 1 hour
T_{12}: 0.5 % KH_2PO_4 for 1 hour
T_{13}: Control (untreated seeds)

MAE: Months after extraction.
Values having common superscript are not significantly different from one another.

followed by HCl (8.51), H_2SO_4 (7.99), HNO_3 (6.56), KNO_3 (6.36) and hot water soaking (5.57).

Finally, considering all these seed quality parameters together, statistical analysis was done for mean performance or true worthiness of the treatments. The treatments were ranked according to their mean performance. Out of the thirteen treatments, mechanical scarification was the best (863.49) followed by HCl (723.41), H_2SO_4 (717.06), HNO_3 (634.28), hot water soaking (604.09) and KNO_3 (517.81). Since HNO_3 being an acid is having similar action like HCl and H_2SO_4, an osmoticum, KNO_3 was selected as fifth treatment for further studies.

4.1.12 Seed coat thickness

The effect of selected invigoration treatments on seed coat thickness exhibited high degree of variation ($P \leq 0.01$) at the different seed coat regions like hilum end and middle of seed (Table 12 and Table13).

The treatments had significant effect on seed coat thickness measured at hilum end (Table 12). The freshly extracted untreated seeds showed high coat thickness (647.60 microns) and the thickness was significantly high for all regions (inner osteosclerides layer: 194.03 microns; middle stellate parenchyma layer: 113.42 microns; and outer parenchyma layer: 307.45 microns). On the other hand, seeds that were stored from previous *Kharif* crop showed minimum seed coat thickness (393.60 microns) and the thickness of inner osteosclerides layer (128.48 microns), middle stellate parenchyma layer (60.99 microns) and outer parenchyma layer (189.47 microns) was also lower. However, there was no significant difference between seeds subjected to HCl (404.70 microns), H_2SO_4 (424.40 microns) and hot water treatment (429.70 microns). The seeds subjected to KNO_3 showed a thickness of 503.80 microns. Since mechanical scarification is done manually by rupturing, the coat thickness was on the higher side (591.80 microns) as in the case of freshly extracted seeds

Table 12. Seed coat thickness (microns) at hilum end of snake gourd seed

Treatments	Inner layer (Osteosclerides)	Middle layer (Stellate parenchyma)	Outer layer (Parenchyma)	Total thickness
T1	163.53	111.84	275.37	591[b]
T2	160.2	56.31	216.51	429[d]
T3	158.49	48.48	206.97	404[d]
T4	159.22	82.77	241.99	424[d]
T5	146.31	73.51	219.82	503[c]
T6	194.03	113.42	307.45	647[a]
T7	128.48	60.99	189.47	393[d]

T1 - Fresh seeds subjected to Mechanical scarification by way of seed rupturing

T_2. Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_3. Fresh seeds treated with 5N HCl for 20 minutes

T_4. Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_5. Fresh seeds treated with 1% KNO_3 for 12 hours

T_6.Control (untreated fresh seeds)

T_7-Stored seeds from previous *kharif* crop

Values having common superscript are not significantly different from one another

Table 13. Seed coat thickness (microns) at middle portion of snake gourd seed

Treatments	Inner layer (Osteosclerides)	Middle layer (Stellate parenchyma)	Outer layer (Parenchyma)	Total thickness
T1	165.09	467.37	500.52	1133^{b}
T2	165.78	254.98	477.24	898^{d}
T3	175.65	203.42	385.91	765^{e}
T4	183.07	189.20	479.72	852^{d}
T5	183.00	392.82	427.17	1003^{c}
T6	184.66	507.76	588.57	1281^{a}
T7	122.03	241.34	547.62	911^{d}

T1 - Fresh seeds subjected to Mechanical scarification by way of seed rupturing

T_2- Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_3- Fresh seeds treated with 5N HCl for 20 minutes

T_4- Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_5- Fresh seeds treated with 1% KNO_3 for 12 hours

T_6-Control (untreated fresh seeds)

T_7-Stored seeds from previous *kharif* crop

Values having common superscript are not significantly different from one another

Table 14. Length, width and girth of snake gourd seeds selected for seed coat thickness and moisture imbibition studies

Treatments	Length (mm)	Width (mm)	Girth (mm)
T1	15.74[a]	10.57[a]	4.432[a]
T2	15.61[a]	10.29[a]	4.485[a]
T3	15.58[a]	10.24[a]	4.445[a]
T4	15.83[a]	10.47[a]	4.377[a]
T5	15.64[a]	10.36[a]	4.525[a]
T6	15.49[a]	10.51[a]	4.385[a]
T7	15.70[a]	10.27[a]	4.303[a]

T1 - Fresh seeds subjected to Mechanical scarification by way of seed rupturing

T_2. Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_3. Fresh seeds treated with 5N HCl for 20 minutes

T_4. Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_5. Fresh seeds treated with 1% KNO_3 for 12 hours

T_6.Control (untreated fresh seeds)

T_7-Stored seeds from previous *kharif* crop

Values having common superscript are not significantly different from one another

The effect of invigoration treatments on seed coat thickness at the middle of seed (Table 13) was also highly significant ($P \leq 0.01$). Seeds that were stored from previous *Kharif* crop showed lesser thickness (911 microns) compared to fresh seeds (1281 microns). No significant difference was observed between hot water soaked (898 microns) and H_2SO_4 (852 microns) treated seeds. However, the thickness was minimum (765 microns) in the seeds treated with HCl when compared to all others. Again KNO_3 treated seeds showed intermediate coat thickness (1003 microns) and mechanically scarified seeds had higher thickness (1133 microns) similar to fresh untreated seeds.

4.1.13 Water imbibition rate

The effect of invigoration treatments on moisture imbibition rate is given in table15.

The seeds that are stored from previous *kharif* crop resulted in the highest mass increase (42.52 %) after one hour of soaking, whereas the mass of untreated seeds increased by only 9.46 per cent. Of the seeds treated, the seeds subjected to hot water soaking showed the maximum mass increase by 41.79 per cent after one hour of soaking. At three hours of soaking seeds subjected to hot water treatment had the maximum mass increase (49.38 %) followed by stored seeds (47.86 %). The seeds treated with HCl, H_2SO_4 and KNO_3 showed moderate response to treatment while the untreated seeds had the lowest mass increase (10.52 %). At six hours after soaking, water entered the seeds in relatively high and steady rate in the seeds subjected to mechanical scarification (81.98 %) followed by stored seeds (75.14 %). The seeds treated with H_2SO_4 (61.83 %), HCl (54.72 %), hot water (54.40 %) and KNO_3 (46.41 %) had moderate imbibition rates while the moisture imbibition was minimum (22.11 %) in case of untreated seeds. At 12 hours after soaking, stored seeds and the seeds subjected to mechanical scarification showed higher increase in mass (87.26 and 85.74 respectively). Seeds treated with HCl, H_2SO_4, hot water and KNO_3 recorded moderate increase

Table 15. Increase in weight of individual seeds subjected to invigoration treatments at different time intervals

Weight of individual seed						
Treatments	Initial weight	1 hours	3 hours	6 hours	12 hours	24 hours
T1	24.5955	33.4575	36.3895	44.76	45.68525	46.3935
T2	26.3795	37.406	39.408	40.7325	43.13	49.869
T3	25.926	30.764	34.4965	40.1135	43.5125	46.418
T4	26.88	34.3925	38.4695	43.5005	44.3775	46.802
T5	26.4695	31.3345	34.989	38.755	40.3345	44.8805
T6	31.724	34.726	35.064	38.739	44.3125	47.205
T7	25.0885	35.7565	37.098	43.941	46.983	49.349

Per cent imbibition rate

	Initial weight	1 hours	3 hours	6 hours	12 hours	24 hours
T1	-	36.03	47.95	81.98	85.74	88.62
T2	-	41.79	49.38	54.40	63.49	89.04
T3	-	18.66	33.05	54.72	67.83	79.04
T4	-	27.94	43.11	61.83	65.09	74.11
T5	-	18.37	32.18	46.41	52.38	69.55
T6	-	9.46	10.52	22.11	39.68	48.79
T7	-	42.52	47.86	75.14	87.26	96.69

T_1 - Fresh seeds subjected to Mechanical scarification by way of seed rupturing

T_2. Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_3. Fresh seeds treated with 5N HCl for 20 minutes

T_4. Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_5. Fresh seeds treated with 1% KNO_3 for 12 hours

T_6.Control (untreated fresh seeds)

T_7-Stored seeds from previous *kharif* crop

in mass of the seed compared to untreated control seeds. Finally, at 24 hours after soaking the stored seeds showed almost full capacity (96.69 %) followed by hot water soaking (89.04 %) and mechanically scarified seeds (88.62 %). The seed treated with HCl, H_2SO_4 and KNO_3 had moderate moisture absorption and untreated seeds recorded lowest mass increase of 48.79 per cent.

4.2. STORAGE POTENTIAL OF INVIGORATED SEEDS

4.2.1 Germination percentage

Table 16 shows the effect of storage on germination percent of invigorated seeds.

The overall mean germination percent of invigorated seeds within each month was highly significant. At 1 MAS, HCl treated seeds recorded the maximum (80 %) germination percent which was superior to all other treatments as well as untreated seeds which showed a germination of only 23.00 per cent. At 2 MAS, seeds subjected to mechanical scarification recorded maximum germination (75.00 %) that was on par with H_2SO_4 (74.00 %) and KNO_3 (73.00 %). However, the HCl treated seeds did not germinateat all. The untreated seeds showed 38.00 per cent germination. At 3 MAS the seeds subjected to hot water soaking gave maximum germination of 78.00 per cent. HCl treated seeds again failed to germinate and untreated seeds had minimum (44.00 %) germination. From 4 to 6 MAS untreated seeds recorded maximum germination per cent (55.00, 89.00 and 88.00 respectively) and other treatments resulted in poor germination.

There was a drastic reduction in mean germination percent of treated seeds during the period of storage. However, untreated seeds recorded gradual increase in germination percent during the period of storage from 23.00 per cent to 88.00 per cent. HCl treated seeds gave germination only during 1 MAS and did not

Table 16. Effect of storage on germination percent of invigorated seeds

Germination percent							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	69.0	75.0	53.0	43.0	41.0	46.0	54.5^{ab}
T_2	64.0	48.0	78.0	31.0	52.0	49.0	53.67^{ab}
T_3	80.0	00	00	00	00	00	13.33^{c}
T_4	65.0	74.0	59.0	40.0	31.0	00	44.83^{b}
T_5	76.0	73.0	60.0	47.0	53.0	55.0	60.67^{a}
T_6	23.0	38.0	44.0	55.0	89.0	88.0	56.17^{ab}
Mean	62.83	51.33	49.00	36.00	44.33	39.66	
C.D for months: 5.54 C.D for treatments: 5.54 C.D for treatment within months: 13.57							

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS: months after storage

germinate in all other months. H_2SO_4 treated seeds showed gradual reduction in germination percent from 65.00 per cent at 1 MAS to 31.00 per cent at 5 MAS and did not germinate at 6 MAS.

4.2.2.a Intensity of dormancy at seven days after sowing (NGS_7)

The effect of storage on intensity of dormancy at five days after sowing of invigorated seeds is presented in Table 17a.

It is evident from the table that, the intensity of dormancy between treatments within each month showed significant variation. At 1 MAS, untreated seeds recorded maximum intensity (94.00 %) of dormancy while minimum (66.00 %) was recorded in mechanically scarified seeds. At 2 MAS, the highest intensity of dormancy was exhibited by seeds treated with HCl (100 %), which was on par with untreated and hot water soaked seeds (93.00 %) and the lowest intensity was noticed in seeds treated with KNO_3 (67.00 %). From 2 MAS onwards, the HCl treatment had the maximum intensity of dormancy at seven days of sowing (100 %). At 6 MAS, HCl and H_2SO_4 showed maximum intensity and untreated seeds recorded minimum intensity (57.00 % and 54.00 %) of dormancy at 5 MAS and 6 MAS respectively.

The mean intensity of dormancy recorded over the period of storage showed significant difference. The maximum intensity was recorded at 4 MAS (88.33 %). The NGS_7 value was minimum at 1 MAS (81.83 %).

4.2.2.b Intensity of dormancy at 14 days of sowing (NGS_{14})

Table 17.b shows the effect of storage on the intensity of dormancy of invigorated seeds at 14 days of sowing.

Table 17a. Effect of storage on intensity of dormancy (NGS_7) of invigorated seeds.

Intensity of dormancy (%)							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	66	68	89	78	93	80	79.00
T_2	87	93	67	86	79	93	84.50
T_3	89	100	100	100	100	100	98.00
T_4	87	91	91	90	89	100	91.33
T_5	68	67	84	88	74	79	76.67
T_6	94	93	85	88	57	54	78.50
Mean	81.83	85.33	86.00	88.33	82.00	84.30	

C.D for months= 3.72
C.D. for treatments= 3.72
C.D. for treatment within months=9.12

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS: months after storage

Table 17b. Effect of storage on the intensity of dormancy (NGS_{14}) of invigorated seeds.

Intensity of dormancy (%)							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	31.0	25.0	47.0	57.0	59.0	54.0	45.50
T_2	36.0	52.0	22.0	69.0	48.0	51.0	46.33
T_3	20.0	100.0	100.0	100.0	100.0	100.0	86.66
T_4	35.0	26.0	41.0	60.0	69.0	100.0	55.17
T_5	24.0	27.0	40.0	53.0	47.0	45.0	39.33
T_6	77.0	62.0	56.0	45.0	11.0	12.0	43.83
Mean	37.167	48.66	51.00	64.0	55.667	60.33	

C.D. for months: 5.54
C.D. for treatments: 5.54
C.D. for treatments within months: 13.57

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS-Months after storage

The NGS_{14} values among different treatments within each month showed significant difference. At 1 MAS untreated seeds recorded the maximum (77.00 %) NGS_{14} value. However, HCl treatment recorded the minimum value (20.00 %). From two months after storage onwards the NGS_{14} value was maximum for seeds treated with HCl (100 %) and minimum value (27.00 %) was recorded in KNO_3 treated seeds. At 3 MAS, the lowest NGS_{14} (22.00 %) value was recorded by hot water soaked seeds. The intensity was minimum in untreated seeds (45.00, 11.00 and 12.00 %) during 4, 5 and 6 MAS respectively.

The NGS_{14} showed a gradual increase during the period of storage from 37.16 at 1 MAS to 64.00 per cent at 4 MAS. Thereafter, there was decline in mean intensity of dormancy. Maximum NGS_{14} was recorded at 4 MAS (64.00 %), which was on par with 6 MAS (60.63 %). Minimum NGS_{14} was recorded at 1 MAS (37.16 %).

Among the different treatments, the HCl treated seeds recorded highest value (86.66 %) of NGS_{14} that was followed by H_2SO_4 treated seeds (55.17 %). The seeds treated with KNO_3 recorded the minimum NGS_{14} value (39.33 %) that was on par with untreated seeds (43.85 %) and seeds subjected to mechanical scarification (45.50 %).

4.2.3 Duration of dormancy

The effect of storage on the duration of dormancy i.e. the number of days to achieve 60 per cent germination was significant (Table 18).

At 1 MAS, the minimum number of days (9.00) to achieve 60 per cent germination was noticed in seeds subjected to mechanical scarification followed by KNO_3 treatment (9.20 days). The maximum days were taken by the seeds treated with H_2SO_4 (12.00 days). The untreated seeds even failed to achieve 60 per cent germination.

Table 18. Effect of storage on number of days to achieve 60 per cent germination (DG_{60})

Days to achieve 60 percent germination							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	9.0	9.0	-	-	-	-	-
T_2	10.0	-	8.0	-	-	-	-
T_3	10.6	-	-	-	-	-	-
T_4	12.0	11.0	11.0	-	-	-	-
T_5	9.2	8.0	7.0	-	-	-	-
T_6	-	-	-	-	8.0	8.0	-
Mean	-	-	-	-	-	-	

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS - Months after storage

- : Treatments without 60 per cent germination

. At 2 MAS untreated seeds, hot water soaked seeds and HCl treated seeds did not give 60 per cent germination. The seeds treated with KNO_3 have recorded the minimum days (8.00) to achieve DG_{60} and maximum days (11.00) by H_2SO_4 treated seeds.

At 3 MAS, seeds treated with hot water soaking, KNO_3 and H_2SO_4 had resulted in 60 per cent germination and other treatments failed to achieve 60 per cent germination. The seeds treated with KNO_3 achieved early DG_{60} at seven days after sowing and maximum number of days (11.00) was taken by H_2SO_4 treated seeds.

DG_{60} was non-significant for remaining months. However, the untreated seeds gave 60 per cent germination at 5 MAS (8.00 days) and 6 MAS (8.00 days).

4.2.4 Dormancy index

The effect of storage on dormancy index of invigorated seeds is shown in Table 19.

The speed of release of dormancy of different treatments within each month was found to be significant. The seeds treated with HCl were found to have highest (4.67) dormancy index during 1 MAS compared to other treatments. Minimum dormancy index was noticed in untreated seeds (1.35).

From 2 MAS onwards, HCl treated seeds did not germinate. Out of the remaining, seeds treated with KNO_3 had higher speed of release of dormancy (2.92). The untreated seeds recorded the minimum (0.95) dormancy index. At 3 MAS, seeds subjected to hot water soaking showed the maximum performance (1.19) over untreated seeds (0.66). At 4, 5 and 6 MAS untreated seeds recorded maximum dormancy index, which was on par with all other treatment except HCl.

Table 19. Effect of storage on dormancy index of invigorated seeds

Dormancy index							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	4.24	1.96	0.79	0.41	0.30	0.32	1.34
T_2	3.76	1.25	1.19	0.29	0.39	0.34	1.20
T_3	4.67	00	00	00	00	00	0.78
T_4	3.85	1.86	0.88	0.38	0.23	00	1.20
T_5	4.67	2.92	0.89	0.45	0.39	0.38	1.62
T_6	1.35	0.95	0.66	0.52	0.66	0.62	0.79
Mean	3.78	1.49	0.74	0.34	0.33	0.28	
C.D for months: 0.27 C.D for treatments: 0.27 C.D for treatment within months: 0.65							

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS: months after storage

The mean dormancy index during different months was significant. The higher speed of release of dormancy was recorded during 1 MAS (3.78) and the least dormancy index during 6 MAS. In general, the mean dormancy indexes showed a decreasing trend over the months of storage.

The overall speed of release of dormancy was significantly different for treatments when averaged over months. The highest speed of release of dormancy was recorded from KNO_3 (1.62) treatment that was on par with seeds subjected to mechanical scarification (1.34) and H_2SO_4 treatment (1.20). The mean minimum speed of release of dormancy was recorded by HCl treated seeds (0.78).

4.2.5 Speed of germination

The effect of storage on speed of germination of invigorated seeds is shown in Table 20.

The speed of germination of treatments within each month was found to be significant. The seeds treated with KNO_3 have recorded maximum speed of germination (9.33) during 1 MAS, which was on par with HCl treated seeds (8.93) and mechanically scarified (8.50) seeds. At 2 MAS, again KNO_3 had higher speed of germination (9.31), which was on par with mechanical scarification (9.24) and H_2SO_4 treatment (8.23). The untreated seeds recorded the minimum (3.68) speed and HCl treated seeds failed to germinate. At 3 MAS, seeds subjected to hot water soaking showed the highest speed (10.17) that was superior to all other treatments. HCl treated seeds did not germinate and untreated seeds gave minimum speed of germination (5.42). At 4, 5 and 6 MAS, untreated seeds recorded maximum speed (6.34, 11.84 and 11.61 respectively), which was on par with mechanical scarification and KNO_3 treatment.

The overall speed of germination was significantly different for treatments when averaged over months. The highest speed of germination was

Table 20. Effect of storage on speed of germination of invigorated seeds

Speed of germination							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T1	8.50	9.24	6.36	5.44	4.84	5.64	6.69
T2	7.21	5.69	10.17	3.65	6.57	5.44	6.47
T3	8.93	-	-	-	-	-	8.93*
T4	7.44	8.23	6.84	4.66	3.91	-	5.18**
T5	9.33	9.31	6.69	5.59	6.89	6.79	7.29
T6	2.59	3.68	5.42	6.34	11.84	11.61	6.98
Mean	7.33	7.23**	7.09**	5.14**	6.81**	7.37#	

C.D for months: 0. 66
C.D for treatments: 0. 66
C.D. for treatment within months: 1.61

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS: Months after storage

* : reading from one month

** : mean from five observations

: mean from four observation

recorded from KNO_3 (7.29) treatment that was on par with untreated seeds (6.98) and seeds subjected to mechanical scarification (6.69). The minimum speed was recorded by H_2SO_4 treatment.

4.2.6 Root length of seedling

The effect of storage on the root length of seedlings raised from invigorated seeds is presented in Table 21.

The root length of seedling showed significant difference between treatments within each month. At 1 MAS the seeds subjected to mechanical scarification recorded the maximum root length (10.88 cm) that was on par with HCl (10.80 cm) and hot water soaked seeds (10.76 cm). The minimum root length was recorded in untreated seeds (5.30 cm). From 2 MAS to 4 MAS, the seeds treated with KNO_3 recorded the maximum root length (12.68 cm, 11.28 cm and 10.88 cm respectively) and was superior to rest of treatments. HCl treated seeds did not germinate and untreated seeds recorded the minimum root length of 8.06 cm at 2 MAS and 7.72 cm at 3 MAS. At 4 MAS, the hot water soaked seeds recorded minimum root length (5.08 cm). At 5 MAS and 6 MAS maximum root length was recorded in untreated seeds (11.10 cm and 10.34 cm respectively), which were on par with KNO_3 treatment. H_2SO_4 and HCl treated seeds failed to germinate at 6 MAS.

The overall mean root length of seedlings pooled over months showed significant difference between treatments. The maximum root length was recorded for seeds treated with KNO_3 (10.49 cm), which was superior to the rest of treatments. The seeds treated with HCl displayed higher root length (10.80 cm) at 1 MAS. The minimum root length was recorded from H_2SO_4 treated seeds (7.04 cm) followed by untreated seeds (8.42 cm).

Table 21. Effect of storage on root length of invigorated seeds

Root length (cm)							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	10.88	9.90	9.20	8.50	9.44	7.60	9.26
T_2	10.76	10.92	8.70	5.08	8.76	8.36	8.77
T_3	10.80	-	-	-	-	-	10.80*
T_4	7.40	8.32	8.68	9.12	8.72	-	7.04**
T_5	8.60	12.68	11.28	10.88	10.92	8.60	10.49
T_6	5.30	8.06	7.72	6.60	11.10	10.34	8.42
Mean	8.96	9.71**	8.86**	7.81**	9.79**	8.14#	

C.D. for months= 0.51
C.D. for treatments= 0.51
C.D. for treatment within months= 1.25

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS - Months after storage

* : reading from one month

** : mean from five observations

\# : mean from four observation

4.2.7 Shoot length of seedling

Table 22 shows the data on the effect of storage on shoot length of seedlings produced from invigorated seeds.

The effect of storage on shoot length showed significant difference between treatments within each month. At 1 MAS, the seeds treated with KNO_3 exhibited highest shoot length (31.04 cm) and untreated (20.48 cm) seeds had the minimum shoot length. At 2 MAS, again seeds treated with KNO_3 (32.24 cm) as well as seeds subjected to mechanical scarification (32.02 cm) showed the longest shoot. Shoot length was less (26.28 cm) for untreated seeds. At 3 MAS to 5 MAS, KNO_3 has given maximum shoot length (31.52, 30.72 and 31.48 cm respectively) and minimum shoot length was in untreated seeds (26.96 cm) at 3 MAS, hot water soaked seeds (20.88 cm) at 4 MAS and H_2SO_4 treated seeds at 5 MAS. At 6 MAS, untreated seeds resulted in maximum shoot length (30.98 cm).

The overall mean shoot length was significantly different between each treatment. The seeds treated with KNO_3 (30.88 cm) had the highest mean shoot length (30.88 cm) followed by mechanical scarification (28.65 cm). However, seeds treated with HCl germinated only at 1 MAS and mean is calculated on the basis of reading at one month. The minimum shoot length was recorded by the untreated seeds (26.22 cm).

The overall mean performance at different months after storage was significant throughout storage. The highest mean shoot length was recorded at 5 MAS (29.21cm) and mean shoot length was same at 1 MAS and 6 MAS. The minimum shoot length was recorded after 3 MAS.

Table 22. Effect of storage on shoot length of invigorated seeds.

Shoot length (cm)							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	29.24	32.02	28.52	28.48	27.56	26.12	28.65
T_2	30.52	28.72	26.88	20.88	27.04	28.92	27.16
T_3	29.24	-	-	-	-	-	29.24*
T_4	26.16	26.82	26.80	27.72	26.12	-	26.72**
T_5	31.04	32.24	31.52	30.72	31.48	28.28	30.88
T_6	20.48	26.28	26.96	23.68	30.32	30.98	26.22
Mean	28.43	27.35**	25.56**	27.71**	29.21**	28.43#	

C.D. for months = 0.77
C.D. for treatments= 0.77
C.D. for treatment within months= 1.90

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 30 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS -Months after storage

*: reading from one month

**: mean from five observations

#: mean from four observation

4.2.8 Vigour index - I

Table 23 shows the effect of storage on vigour index-I of invigorated seeds.

Seeds treated with HCl recorded maximum vigour index-I (3218) at 1 MAS that was on par with KNO_3 treatment (3006) and mechanical scarification (2761). The untreated seeds recorded the minimum vigour index (706). At 2 MAS, seeds treated with KNO_3 had the maximum vigour index I (3290) which was on par with seeds subjected to mechanical scarification (3144) and the untreated seeds recorded minimum (1376) vigour index. At 3 MAS, seeds subjected to hot water soaking resulted in maximum (2787) vigour and minimum vigour index-I was exhibited by untreated seeds (1782). At 4 MAS, KNO_3 treated seeds gave maximum (1948) vigour index. At 5 and 6 MAS, untreated seeds had maximum vigour index values (3689 and 3635 respectively) and HCl treated seeds did not germinate after second month of storage and H_2SO_4 during 6 MAS.

The mean performance of treatments differed significantly from each other, the maximum mean vigour index being recorded by KNO_3 treated seeds (2512) and minimum by H_2SO_4 treated seeds (1570).

The mean performance during storage was significantly different between each month. The maximum (2460) vigour index was observed during 2 MAS and minimum (1535) was recorded at 4 MAS.

4.2.9 Seedling dry weight

The Table 24 shows the effect of storage on seedling dry weight of invigorated seeds.

Table 23. Effect of storage on vigour index-I of invigorated seeds

Vigour index-I							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	2761	3144	1996	1602	1517	1605	2104
T_2	2628	1929	2787	871	1863	1833	1985
T_3	3218	-	-	-	-	-	3218*
T_4	2161	2562	2095	1471	1130	-	1570**
T_5	3006	3290	2561	1948	2240	2030	2512
T_6	706	1376	1535	1782	3689	3635	2120
Mean	2413	2460**	2194**	1535**	2088**	2275#	

C.D. for months: 217
C.D. for treatment: 217
C.D. for treatment within months: 533

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: *Control (untreated seeds)*

MAS : months after storage

* : reading from one month

** : *mean from five observations*

\# : mean from four observation

The seedling dry weight of treatments within each month showed significant variation. At 1 MAS, the maximum dry weight was recorded in KNO_3 treatment (0.138 g) and minimum by untreated seeds (0.086 g). At 2 MAS, both KNO_3 and mechanical scarified seeds had maximum dry weight of 0.141 g. Minimum seedling dry weight was recorded in untreated seeds (0.080 g) and HCl treatment failed to germinate from two months onwards. At 3 MAS, again KNO_3 had maximum dry weight of 0.143 g and minimum was by untreated seeds (0.090 g). From 4 MAS to 6 MAS, untreated seeds gave maximum seedling dry weight (0.125 g, 0.142 g and 0.136 g respectively).

The mean seedling dry weight pooled over months showed significant difference among the treatments. The KNO_3 treatment recorded maximum mean dry weight of 0.133 g. The minimum dry weight was recorded in H_2SO_4 treated seeds (0.102 g) while HCl treated seeds failed to germinate from 2 MAS.

The variation of mean seedling dry weight between different months of storage remained non significant.

4.2.10 Vigour index- II

The effect of storage on vigour index-II of invigorated seeds is shown in Table 25.

The vigour index-II for different treatments with in each month showed significant difference. At 1 MAS, KNO_3 treated seeds recorded maximum (10.50) vigour index-II and minimum vigour index was noticed in untreated seed (1.94). At 2 MAS, seeds subjected to mechanical scarification had maximum (10.67) vigour which was on par with KNO_3 (10.32) and untreated seeds showed minimum vigour (3.07) of seedlings. At 3 MAS, hot water soaked seeds recorded maximum vigour of 9.17 and minimum vigour index-II was recorded from

Table 24. Effect of storage on the seedling dry weight of invigorated seeds

Seedling dry weight (g)							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	0.115	0.141	0.122	0.118	0.095	0.110	0.117
T_2	0.123	0.113	0.118	0.089	0.100	0.105	0.108
T_3	0.104	-	-	-	-	-	0.104*
T_4	0.098	0.100	0.102	0.107	0.106	-	0.102**
T_5	0.138	0.141	0.143	0.123	0.134	0.120	0.133
T_6	0.086	0.080	0.096	0.125	0.142	0.136	0.110
Mean	0.110	0.115**	0.116**	0.112**	0.108**	0.117#	

C.D. for months= 0.005
C.D. for treatments= 0.005
C.D. for treatment within months= 0.011

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS -Months after storage

* : reading from one month

** : mean from five observations

: mean from four observation

Table 25. Effect of storage on vigour index-II of invigorated seeds.

Vigour index-II							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	8.10	10.67	6.41	5.03	3.87	5.05	6.52
T_2	7.81	5.44	9.17	2.81	5.25	5.19	5.95
T_3	8.33	-	-	-	-	-	8.33*
T_4	6.31	7.40	6.00	4.27	3.31	-	5.46**
T_5	10.50	10.32	8.61	5.85	7.05	6.62	8.16
T_6	1.94	3.07	4.26	6.8	12.63	11.93	6.78
Mean	7.16	7.38**	6.89**	4.96**	6.42**	7.20#	

C.D. for months=0.72
C.D. for treatments=0.72
C.D. for treatments within months=1.75

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS : months after storage

* : reading from one month

** : mean from five observations

\# : mean from four observation

untreated seeds (4.26). From 4 MAS, to 6 MAS untreated seeds recorded maximum vigour index-II (6.83, 12.63 and 11.93 respectively).

The mean vigour index-II was significantly different for different treatments. The maximum vigour was noticed in KNO_3 treatment (8.16) and minimum vigour by H_2SO_4 treatment (5.46). Although, HCl treatment recorded the highest vigour index-II (8.33) at 1 MAS the seeds failed to germinate from 2 MAS.

The mean vigour index-II between each month of storage differed significantly from each other. The maximum vigour index (7.38) was recorded at 2 MAS and minimum vigour index-II at 4 MAS (4.96).

4.2.11 Electrical conductivity of seed leachate

The effect of storage on the electrical conductivity of invigorated seeds is shown in Table 26.

Electrical conductivity showed significant difference between different treatments with in a month. At 1 MAS, the EC value was maximum for seeds treated with HCl (198.22) while the seeds subjected to hot water soaking recorded minimum EC values. From 2 MAS to 6 MAS, HCl treated seeds showed maximum electrical conductivity values. At 2 MAS, the hot water soaked seeds recorded minimum electrical conductivity value (42.62) while minimum EC values of 54.36, 56.77, 48.53 and 76.29 was recorded in untreated seeds after 3, 4, 5 and 6 MAS respectively.

The overall mean electrical conductivity of treatments showed significant difference when averaged over the period of storage. The seeds treated with HCl showed maximum mean electrical conductivity value (440.33) and minimum

Table 26. Effect of storage on electrical conductivity of invigorated seeds

Electrical conductivity (μ mhos/cm)							
Months / Treatments	1MAS	2MAS	3MAS	4MAS	5MAS	6MAS	Mean
T_1	96.32	80.94	121.40	179.94	97.75	149.07	120.90
T_2	56.86	42.62	86.67	96.58	115.52	174.57	95.47
T_3	198.22	386.30	436.59	527.83	539.83	553.23	440.33
T_4	71.92	121.95	292.58	465.19	384.86	403.96	290.07
T_5	69.40	60.75	81.70	75.99	83.73	93.55	77.52
T_6	71.00	62.29	54.36	56.77	48.53	76.29	61.54
Mean	93.95	125.88	178.88	233.71	211.70	241.77	

C.D. for months= 42.81
C.D. for treatments= 42.81
C.D. for treatments within months=104.85

T_1: Mechanical scarification by way of seed rupturing

T_2: Hot water (40^0 C) soaking for 5 minutes

T_3: 5N HCl for 20 minutes

T_4: 5N H_2SO_4 for 10 minutes

T_5: 1% KNO_3 for 12 hours

T_6: Control (untreated seeds)

MAS - months after storage

mean electrical conductivity was observed in untreated seeds (61.54), which was on par with KNO_3 and hot water soaked seeds.

The mean observations between different months showed significant variations. The minimum electrical conductivity value was recorded during first month of storage (93.95) which showed a steady progressive trend during the period of storage up to 6 MAS and the EC value was maximum at 6 MAS (241.77).

4.3 FIELD PERFORMANCE OF INVIGORATED SEEDS

The seeds invigorated with the selected five methods and seeds whose dormancy has been broken naturally by storage, were evaluated for field performance and the results are presented below.

4.3.1 Field emergence

The field emergence of the seeds was significantly influenced by different treatments (Table 27) during field study.

Seeds subjected to mechanical scarification recorded maximum field emergence (91.50 per cent) which was on par with seeds treated with KNO_3 (89.50 per cent) and seeds extracted from previous rainy season crop, which was stored till next sowing (84.00 per cent). Minimum field emergence was recorded by untreated seeds (46.17 per cent) which was on par with seeds of previous summer season crop (53.50 per cent).

4.3.2 Length of the main vine

The length of the main vine was found to be non-significant between different treatments (Table 27).

Table 27. Effect of invigoration treatments on growth component of snake gourd

Treatments	Field emergence	Length of the main vine (cm)	Primary Branches per plant	Days to first female flower opening	Node at first female flower appearance	Per cent fruit set	Days to first harvest	Days to last harvest
T_1	53.50^{d}	573.30^{a}	6.02^{b}	53.79^{c}	15.98^{b}	20.41^{ab}	73.04^{bc}	107.80^{a}
T_2	84.0^{a}	581.70^{a}	7.97^{a}	57.54^{ab}	16.40^{b}	25.48^{a}	76.66^{abc}	107.30^{a}
T_3	91.50^{a}	599.20^{a}	4.52^{bc}	55.46^{bc}	15.77^{b}	20.89^{ab}	74.56^{abc}	102.50^{a}
T_4	62.50^{cd}	527.40^{a}	3.83^{c}	55.13^{bc}	16.23^{b}	16.57^{b}	72.67^{bc}	105.80^{a}
T_5	72.25^{b}	551.70^{a}	5.50^{bc}	55.55^{bc}	18.87^{a}	21.23^{ab}	73.94^{bc}	108.70^{a}
T_6	75.45^{b}	500.00^{a}	5.42^{bc}	58.12^{ab}	16.39^{b}	19.68^{ab}	77.85^{ab}	108.60^{a}
T_7	89.50^{a}	528.30^{a}	5.45^{bc}	57.09^{ab}	16.19^{b}	25.54^{a}	70.66^{c}	104.60^{a}
T_8	46.17^{d}	526.70^{a}	4.58^{bc}	58.85^{a}	18.75^{a}	15.39^{b}	80.26^{a}	98.53^{a}

T_1 - Extracted seeds from previous summer season crop, which were stored till sowing

T_2 - Extracted seeds from previous *kharif* crop, which were stored till sowing

T_3 - Fresh seeds subjected to Mechanical scarification by way of seed rupturing

T_4 - Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_5 - Fresh seeds treated with 5N HCl for 20 minutes

T_6 - Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_7 - Fresh seeds treated with 1% KNO_3 for 12 hours

T_8 -Control (untreated fresh seeds)

Values having common superscript are not significantly different from one another

Plate 3. Field views of the experimental plot

The first female flower appeared on the earlier node (15.77) in seeds subjected to mechanical scarification and in the plants raised from HCl treated seeds and untreated seeds, first female flowers appeared on later (18.87 and 18.75 respectively) nodes only.

4.3.6 Per cent fruit set

Table 27 shows the effect of different treatments on percentage of fruit set. Percentage of fruit set was found to be significantly influenced by different treatments. The seeds that are stored from previous rainy season recorded the highest per cent fruit set (25.48) while the minimum fruit set was recorded by plants raised from untreated seeds (15.39) followed by hot water soaking (16.57).

4.3.7 Days to first harvest

There was significant difference among the treatments in the case of days to first harvest (Table 27).

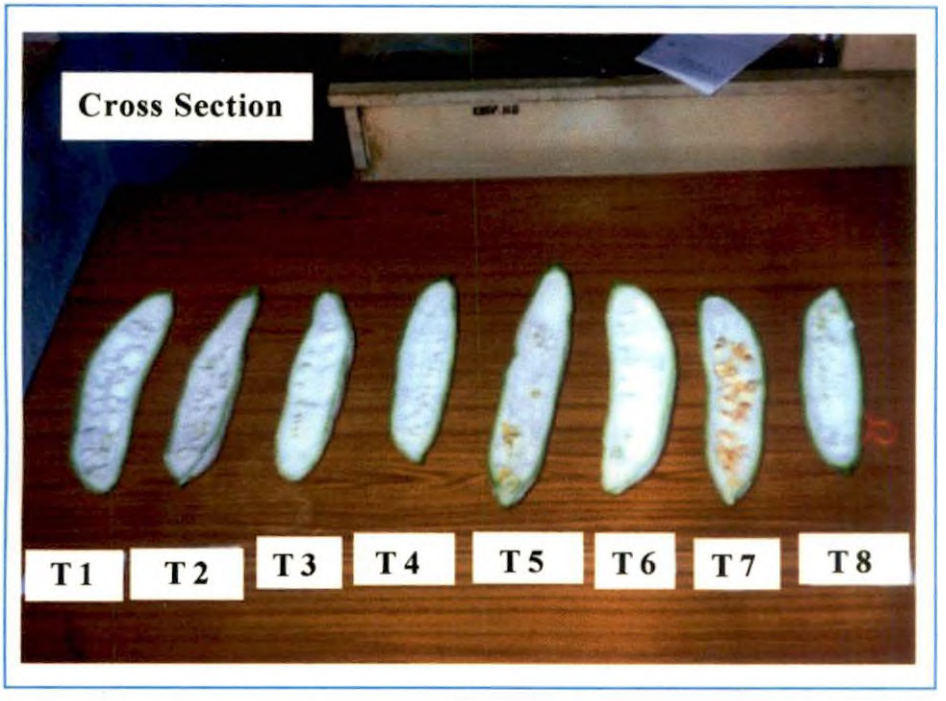
The seeds treated with KNO_3 recorded the minimum days for the first vegetable harvest (70.66 days). The maximum days (80.26 days) were recorded by plants raised from untreated seeds.

4.3.8 Days to last harvest

There was no significant difference among the treatments in the case of days to last harvest (Table 27).

4.3.9 Average fruit weight

Average fruit weight was significantly influenced by different treatments (Table 28). The maximum single fruit weight (455.80 g) was recorded by the



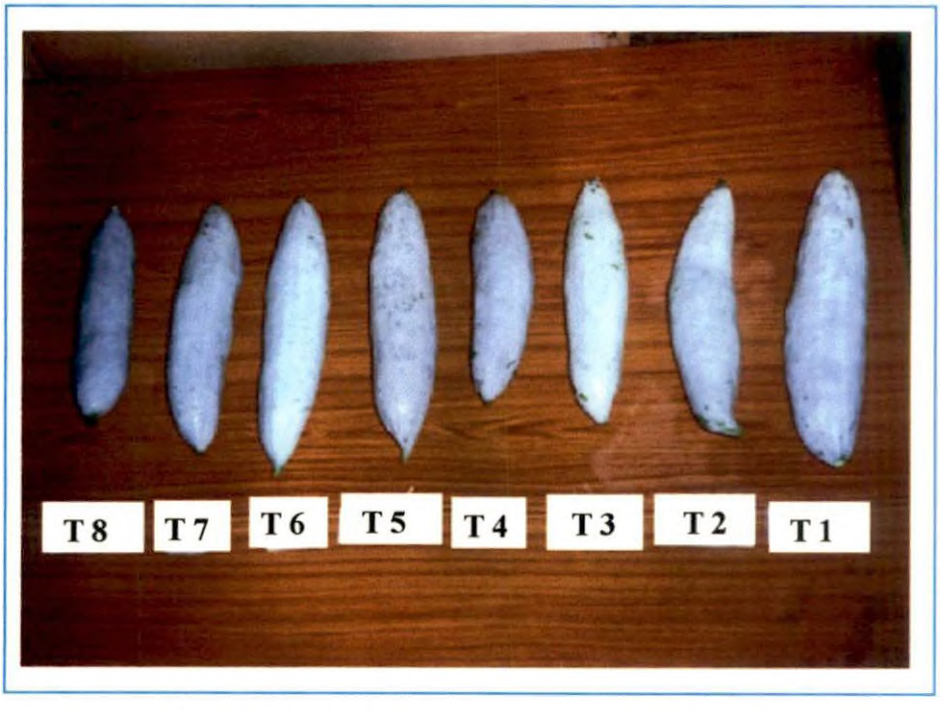


Plate 4. Fruits produced by invigorated seeds

seeds treated with KNO_3. The untreated seeds recorded minimum fruit weight (350.30 g).

4.3.10 Fruits per plant

The number of fruits obtained per plant when harvested at vegetable stage was significantly different among different treatments (Table 28).

The plants raised from seeds treated with KNO_3 produced the maximum number of fruits (4.49) which was on par with seeds that were extracted and stored, from previous rainy season (4.46). The minimum number of fruits per plant (3.38) was recorded from plants raised from untreated seeds.

4.3.11 Circumference of fruit

The data on the effect of treatments on circumference of fruit at vegetable harvest is presented in Table 28.

The treatments had significant influence on the circumference of fruit harvested at vegetable maturity stage. The seeds subjected to mechanical scarification produced fruits with maximum circumference (25.14 cm) while seeds treated with HCl produced fruits with minimum circumference (22.98 cm).

4.3.12 Length of fruit

Length of fruit at vegetable harvest was not significantly influenced by different treatments (Table 28).

However, maximum fruit length (35.67 cm) was recorded by seeds subjected to mechanical scarification while minimum fruit length (31.99 cm) was recorded in plants raised from seeds treated with HCl.

Table 28. Effect of invigoration treatments on yield component of snake gourd for vegetable purpose

Treatments	Average fruit weight (g)	Fruits per plant	Circumference of fruit	Length of fruit (cm)	Fruit shape index	Fruit yield / Plot (Kg)	Yield per ha. (Kg)
T_1	418.30^{ab}	3.78^{ab}	23.57^{ab}	35.49^{a}	4.72^{a}	26.02^{abc}	16260^{abc}
T_2	431.00^{ab}	4.45^{a}	24.71^{ab}	35.60^{a}	4.52^{a}	30.77^{ab}	19230^{ab}
T_3	447.90^{ab}	3.91^{ab}	25.14^{a}	35.67^{a}	4.46^{a}	28.37^{abc}	17730^{abc}
T_4	371.60^{ab}	3.54^{ab}	23.65^{ab}	32.25^{a}	4.28^{a}	21.80^{bc}	13630^{bc}
T_5	413.00^{ab}	3.80^{ab}	22.98^{b}	31.99^{a}	4.37^{a}	25.67^{abc}	16040^{abc}
T_6	443.80^{ab}	3.83^{ab}	23.64^{ab}	33.85^{a}	4.49^{a}	28.73^{abc}	17960^{abc}
T_7	455.80^{a}	4.49^{a}	23.85^{ab}	34.18^{a}	4.49^{a}	33.47^{a}	20920^{a}
T_8	350.30^{b}	3.37^{b}	24.01^{ab}	35.59^{a}	4.66^{a}	20.09^{c}	12550^{c}

T_1 - Extracted seeds from previous summer season crop, which were stored till sowing

T_2 - Extracted seeds from previous *kharif* crop, which were stored till sowing

T_3 - Fresh seeds subjected to Mechanical scarification by way of seed rupturing

T_4 - Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_5 - Fresh seeds treated with 5N HCl for 20 minutes

T_6 - Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_7 - Fresh seeds treated with 1% KNO_3 for 12 hours

T_8 -Control (untreated fresh seeds)

Values having common superscript are not significantly different from one another

4.3.13 Fruit shape index

Fruit shape index at vegetable harvest was not significantly influenced by different treatments (Table 28).

However, maximum fruit shape index (4.73) was recorded by plants raised from seeds collected from previous summer season crop and the minimum fruit shape index (4.29) was recorded by plants raised from seeds subjected to hot water soaking.

4.3.14 Fruit yield per plot

The vegetable yield per plot was significantly influenced by different treatments (Table 28).

The yield per plot was higher (33.47 Kg) for the seeds invigorated with KNO_3, which was superior to rest of treatments. This was followed by seeds extracted from previous rainy season crop (30.77 Kg). The minimum yield per plot (20.09 Kg) was recorded by untreated seeds.

4.3.15 Fruit yield per hectare

The effect of different treatments on fruit yield per hectare is presented in Table 28.

The variation in vegetable yield per hectare was highly significant between different treatments. The yield per hectare was maximum (20920 Kg) from seeds invigorated with KNO_3, which was superior to seeds of previous rainy season crop (19230 Kg). This was followed by H_2SO_4 treated seeds with 17960 Kg yield per hectare. The minimum yield per hectare (12550 Kg) was recorded by seeds extracted from plants raised from untreated seeds.

4.3.16 Average fruit weight

Average weight of the fruit harvested for seed purpose was significantly influenced by different treatments (Table 29).

The maximum average fruit weight (474.99 g) was recorded by plants raised from seeds subjected to mechanical scarification followed by KNO_3 (414.3 g). The minimum fruit weight (328.5 g) was recorded by plants raised from seeds treated with HCl.

4.3.17 *Fruits per plant at seed harvest*

The number of fruits obtained per plant, retained for seed purpose was not significantly influenced by different treatments (Table 29). However, plants raised from seeds of previous summer season crop produced maximum number of fruits per plant (1.71).

4.3.18 Seeds per fruit

The number of seeds per fruit was not significantly influenced by different treatments (Table 29).

However, maximum seeds (45.00) were present in fruits produced from plants subjected to mechanical scarification followed by hot water soaking (42.87) and KNO_3 (42.80) treatment, where as the minimum seeds (35.15) were recorded in fruits of plants raised from seeds treated with HCl.

4.3.19 Weight of seeds per fruit

The effect of different treatments on weight of seeds per fruit is highly significant (Table 29). Maximum weight of seeds per fruit was recorded by H_2SO_4 treatment (18.20) and minimum by HCl treatment (13.15).

Table 29. Effect of invigoration treatments on yield component of snake gourd for seed purpose

Treatments	Average fruit weight (g)	Fruits per plant	Seeds per fruit	Weight (g) of seeds/fruit	Hundred seed weight (g)	Seed yield / Plant (g)	Seed yield / ha. (kg)
T_1	333.3^{b}	1.708^{a}	41.42^{a}	13.66^{cd}	27.93^{cd}	23.75^{a}	237.5^{a}
T_2	373.1^{ab}	1.608^{a}	41.92^{a}	17.51^{ab}	31.00^{a}	24.04^{a}	240.4^{a}
T_3	474.9^{a}	1.158^{a}	45.00^{a}	14.87^{bcd}	29.23^{bc}	21.79^{a}	217.9^{a}
T_4	385.9^{ab}	1.350^{a}	42.87^{a}	16.78^{abc}	27.80^{cd}	21.50^{a}	215.0^{a}
T_5	328.5^{b}	1.318^{a}	35.15^{a}	13.15^{d}	27.47^{d}	21.06^{a}	210.6^{a}
T_6	371.5^{ab}	1.333^{a}	40.58^{a}	18.20^{a}	28.30^{bcd}	24.13^{a}	241.3^{a}
T_7	414.3^{ab}	1.542^{a}	42.80^{a}	13.90^{cd}	27.13^{d}	22.71^{a}	227.1^{a}
T_8	410.0^{ab}	1.167^{a}	40.88^{a}	16.28^{abcd}	29.70^{ab}	18.71^{a}	187.1^{a}

T_1 - Extracted seeds from previous summer season crop, which were stored till sowing

T_2 - Extracted seeds from previous *kharif* crop, which were stored till sowing

T_3 - Fresh seeds subjected to Mechanical scarification by way of seed rupturing

T_4 - Fresh seeds subjected to hot water (40^0 C) soaking for 5 minutes

T_5 - Fresh seeds treated with 5N HCl for 20 minutes

T_6 - Fresh seeds treated with 5N H_2SO_4 for 10 minutes

T_7 - Fresh seeds treated with 1% KNO_3 for 12 hours

T_8 -Control (untreated fresh seeds)

Values having common superscript are not significantly different from one another

4.3.20 Hundred seed weight

The data on the effect of different treatments on hundred seed weight is presented in Table 29.

The hundred seed weight was significantly influenced by different treatments. The plants raised from stored seeds of previous rainy season crop recorded the highest hundred seed weight (31.00 g). The minimum value (27.13 g) was recorded by plants raised from seeds treated with KNO_3.

4.3.21 Seed yield per plant

The seed yield per plant was not significantly influenced by the treatments (Table 29).

However, seeds extracted from fruits raised from treated seeds with H_2SO_4 had maximum seed yield (24.14 g). This was followed by seeds extracted from previous rainy season crop (24.04 g) that was on par with all other treatments. The minimum seed yield was recorded from untreated seeds (18.72 g).

4.3.22 Seed yield per hectare

Seed yield per hectare was not significantly influenced by treatments as shown in table 29. However, seeds extracted from fruits, raised from H_2SO_4 treated seeds had the maximum seed yield (241.30 Kg). The minimum seed yield was recovered from untreated plants (187.10 Kg).

DISCUSSION

5. DISCUSSION

Seed unquestionably occupies a pivotal place in any agricultural system. Seed quality is hence a deciding factor in the success of all agricultural enterprises particularly the multi-crore seed and nursery business. Obviously, seed dormancy, uneven germination, excessively low germinative energy and low seed vigour can all lead to greater economic losses in agriculture and allied industries.

Snake gourd (*Trichosanthes anguina* L.) seeds characterized by the presence of hard seed coat exhibit delayed and uneven germination for a period of five to six months and attendant adverse consequences. Specific information on the dormancy and germination behavior of this species and on the techniques to improve the germinability and vigour is presently very limited. Hence, the present investigation was carried out at the Department of Olericulture, College of Horticulture, Vellanikkara to standardize seed invigoration techniques in snake gourd that can break dormancy and improve seed vigour and to study the impact of invigoration techniques on storability and field performance. The results of the present study are discussed below.

5.1 SEED INVIGORATION TO BREAK DORMANCY

Freshly extracted snake gourd seeds show varying degrees of dormancy probably due to their hard coat and consequently fail to achieve the mandatory minimum germination requirement of 60 per cent. The influence of various invigoration treatments on the freshly extracted snake gourd seed was studied at monthly intervals up to five months. Thirteen treatments used for the study were scarification treatments (mechanical scarification, acid scarification using H_2SO_4, HCl and HNO_3), growth regulators (GA_3 250 / 500 ppm and NAA 100 ppm), hot water soaking, hydration treatment (water soaking), osmoticum treatments (KNO_3, NaH_2PO_4 and KH_2PO_4) and untreated control.

To evaluate the dormancy behavior in fresh seeds, the parameters like germination percent, intensity of dormancy, days to achieve 60 per cent germination, and dormancy index were assessed for a period of five months. Along with these, other seed quality parameters like speed of germination, root length, shoot length, seedling dry weight, vigour index-I and vigour index-II were also studied.

The data presented on germination per cent (Table 1) demonstrates that none of the invigoration treatments showed gradual increase in germination per cent over a period of five months. Although germination percent varied significantly among the treatments ($P \leq 0.05$), the germination showed varying values at different months even with the same treatments. Thus, it seems that differences in germination percentage is attributed to differences in some of the environmental factors such as atmospheric temperature, oxygen, light and moisture as well as differences in vigour among seed lots that are present during seed development, which have a profound influence on germination phenotype.

In a recent study this assumption was strongly supported by Kornmeef *et al.* (2002) in which they suggested that seed dormancy is a typical quantitative trait, since it is controlled by multiple loci and highly influenced by genotypes versus environment interactions. Further, it seems reasonable that seed dormancy is a physiological adaptation to environmental heterogeneity during seed maturation and consequently seed lots differ in their performance even under identical conditions.

Comparing the effects of treatments on germination or breaking dormancy among the thirteen treatments, germination was rapid in seeds subjected to mechanical scarification even from 0 MAE. The seeds subjected to mechanical scarification exhibited a steady performance during the entire period of study, suggesting that the mechanical scarification by way of seed rupturing was the

most effective treatment in breaking seed dormancy in snake gourd. The beneficial effect of seed invigoration using mechanical scarification was reported earlier by Ali *et al.* (1991) in cucumber cv. Baroda, where dormancy was broken when seeds were subjected to puncturing, nicking or removal of the integument. Latha (1992) and Kousalya (2005) also reported high germination percentage in *Cucurbita moschata* var. Nigerian Local (71.40 per cent) and *Abelmoschus caillei* var. Susthira (65.7) respectively as a result of mechanical scarification.

Seeds subjected to mechanical scarification gave a higher germination per cent of 77.00 at 0 MAE compared to untreated control (34.00 %), indicating that the embryo is non-dormant. Thus, seeds of *Trichosanthes anguina* L. have a physical dormancy only and not physical plus physiological dormancy. Subsequently, mechanically scarified seeds showed variation in germination from 72.00 to 93.00 per cent over a period of five months. This significant increase ($P \leq 0.001$) in germination of mechanically scarified seeds compared to untreated seeds under the experimental condition indicates that seed coat dormancy is present in snake gourd and that dormancy can be overcome by mechanical scarification.

It is quite evident that the seeds subjected to other scarification methods like HCl, H_2SO_4 and HNO_3 treatment attained high germination of more than 60 per cent which is the minimum mandatory germination requirement except at 0MAE. The data presented in table 1 suggest that, these were the next best treatments resulting in better germination. The effect of acid scarification in breaking dormancy may be due to disruption of seed coat or softening of seed coat or decreased coat thickness thus allowing easier penetration of the radicle through it. Another assumption is that the scarification with acids and hot water might have opened the cracks or water gaps in the seed coat through which rapid entry of water is being facilitated. The beneficial effects of acid and hot water scarification in improving seed germination were also confirmed by the findings

of Grey (1962); Singh and Singh (1969); Anithakumari and Kohli (1984); Maithani *et al.* (1991) and Katiyar *et al.* (1998).

It is evident from the present study that dormancy in seeds of snake gourd is due to water impermeable seeds coat, allowing mechanically scarified seeds to imbibe water rapidly and consequently result in higher germination. On the other hand, acid treatment and boiling imbibed water at relatively much slower rate than mechanically scarified seeds. Therefore, it can be presumed that the difference in germination per cent between mechanical scarification, acid and hot water treatments might be due to differences in the rates of imbibition achieved by the invigoration techniques.

It is the quite clear from the study that the opening in the seed created by rupturing at hilum end via mechanical scarification would be larger than that formed by opening of the water gaps and reduced coat thickness via acid and hot water treatment (Fig. 2). When larger area of seed is made permeable, obviously, the rate of water entry into the seed is much faster and this might be the main reason behind the superiority of mechanical scarification over other scarification methods. This view was corroborated by the findings of Krishnaswamy (1991) who reported that bitter gourd seeds with coat removed imbibed water much faster and resulted in higher germination.

Among the osmoticums tried, KNO_3 treatment gave a comparatively better performance. This treatment gave a higher germination per cent of 81 at 2 MAE and 55 ± 5 per cent during other months except 1 MAE. Similar findings of relatively good germination percentage using 1% KNO_3 were reported by Renukadevi and Selvaraj (1994) in bitter gourd; Heydecker and Coolbear (1977) and Basu *et al.* (1978) in rice and Ganar (2003) in ash gourd and bitter gourd. The superiority of KNO_3 may be ascribed to its role in making oxygen available for citric acid cycle and thereby enhancing the ambient oxygen level. This view was supported by the findings of Roberts and Smith (1977) who suggested that

breaking of dormancy often requires easy availability of oxygen, which is provided by oxidants like KNO_3.

Further, beneficial effect of water soaking treatment due to prolonged seed hydration, particularly at low water potential increases the rapidity, synchrony and percentage of seeds that germinate. Kidd and West (1918) had demonstrated the favorable effect of water soaking using either cold or hot water on subsequent germination and seedling growth. Similar results were also obtained by Singh *et al.* (1973) in bottle gourd, bitter gourd, watermelon and okra; Nagy (1974) in watermelon; Ma and Liu (1986) in certain forest tree species and Pandita and Nagarajan (2002) in bitter gourd. However, in the present study water soaking was not found to be highly effective in snake gourd. No promotion of germination of seeds was detected with the application of GA_3, NAA, NaH_2PO_4 and KH_2PO_4 and these treatments were ranked poor with respect to germination percentage.

The present finding on germinability parameter suggest that mechanical scarification was the best treatment. The acid scarification, KNO_3 and hot water treatments were superior to untreated control till 3 MAE. From the fourth month onwards, untreated seeds gave better germination, which was on par with mechanical scarification. This result indicates that most seeds break up impermeability barrier naturally four months after extraction.

Considering the intensity of dormancy, none of the treatments could give a gradual release of dormancy during the period of study. Intensity of dormancy at seven days after sowing showed varying values at different months (Table 2.a). If any treatment is to be effective in breaking dormancy, it should have a decreased intensity of dormancy than the control. The seeds subjected to mechanical scarification were always superior to control in this respect, while HCl, H_2SO_4, HNO_3, hot water and KNO_3 were superior except at 0 months after extraction. These results suggest that some invigoration treatment is essential for the release of dormancy in snake gourd.

When intensity was recorded at 14 days after sowing, there was a significant difference ($P \leq 0.01$) in treated seeds compared to untreated fresh seeds. All the treatments that were effective during the initial days were also superior in performance after 14 days of sowing (Table 2.b). Of the treated seeds, mechanical scarification was consistent in results and recorded lowest intensity of dormancy during the entire study period. The treatments such as HCl, H_2SO_4, hot water, HNO_3 and KNO_3 exhibited lowest intensity of dormancy compared to control up to three months. The untreated seeds, though ineffective in the initial three months gave lower intensity of dormancy at four and five months after extraction. From the fourth month onwards, acid, KNO_3 and hot water treatments were inferior to untreated seeds and only mechanical scarification retained its supremacy over control. This result scientifically validates the view that seed dormancy in snake gourd is naturally broken only four to five months after extraction and if the seeds are to be used immediately after extraction or till three months afterwards, an invigoration treatment is inevitable.

Of the days taken for 60 per cent germination, seeds subjected to mechanical scarification attained the fastest germination and results were consistent through out the study period (Table 3). In contrast, the untreated seeds did not give 60 per cent germination up to four months after extraction. From the data presented in table 3, the effects of treatments on 60 per cent germination can be categorized into three groups as fast, medium and slow germination category. Mechanical scarification falls under first group with lower number of days to achieve 60 per cent germination while treatments with medium response are HCl, H_2SO_4, hot water, HNO_3 and KNO_3. The remaining treatments namely water soaking, GA_3 250/500 ppm, NAA 100 ppm, NaH_2PO_4 and KH_2PO_4 alongwith control can be classified into slow category. Thus invigoration allows slow category germination seeds to attain the early initiation of physiological processes leading to early days for 60 per cent germination. This was strongly supported by the dormancy index i.e. speed of release of dormancy as well. The dormancy

index can also be similarly classified as high, medium and low. The seeds subjected to mechanical scarification showed high speed of release of dormancy compared to other treatments. The seeds treated with HCl, H_2SO_4, HNO_3, KNO_3 and hot water belonged to the medium category and all others came under the category of low dormancy index (Table 4).

The present study on dormancy parameters suggests that there is a general positive association between impermeability and dormancy in the case of fresh seeds while such correlation exists between permeability and germination in case of invigorated seeds. Thus it seems likely that the dormancy parameters like germination per cent, intensity of dormancy, days to achieve 60 per cent germination and dormancy index may be used as fast and effective indicators to identify the best techniques for dormancy release. Further, these parameters provide a useful hint as regards the mechanism of dormancy and the possible measures to overcome this phenomenon.

Different seed quality parameters were significantly influenced by seed invigoration treatments. Though speed of germination could be improved by different invigoration treatments, none of the treatments exhibited a steady superior performance during the entire period of study. Seeds subjected to mechanical scarification recorded higher and consistent speed of germination during the period of study followed by treatments such as HCl, H_2SO_4, HNO_3, KNO_3 and hot water in which seeds were made water permeable by scarification treatment (Table 5). Hence, it can be hypothesized that these differences in speed of germination might be due to differences in rates of imbibition among the treatments and due to the increased supplement of oxygen by osmotic treatment.

The seeds subjected to mechanical scarification exhibited maximum vigour index-I in freshly extracted seeds and vigour was consistent during the period of study. The difference between HCl, H_2SO_4 and HNO_3 treatments was not significant and they were moderate in performance. Other treatments like hot

water soaking and KNO_3 also had reasonably good speed of germination. But none of the treatments displayed consistent increase in vigour during the period of study. However, the seeds subjected to mechanical scarification, HCl, H_2SO_4 and HNO_3 and hot water maintained the superiority over control up to four months after extraction (Table 8).

Seedling dry weight was significantly influenced by invigoration treatments (Table 9) up to five months after extraction. Maximum seedling dry weight was recorded from KNO_3 treated seeds as well as seeds subjected to mechanical scarification. This may possibly be due to the better biomass partitioning as a result of increased supply of oxygen as well as water in these invigoration treatments. There is also a tendency of greater vigour index-II in seeds subjected to mechanical scarification, HCl, H_2SO_4, hot water, HNO_3 and KNO_3 (Table10). Expectedly, treatments like scarification and KNO_3 had larger seedling growth and dry weight.

None of the treatments except mechanical scarification could maintain the superiority and consistency in results throughout the entire period of experimentation. It seems likely that the differential performance of the treatments may be due to the differences in seed lot, seed coat thickness, water imbibition rate as well as environmental influence. While the seeds subjected to mechanical scarification were always superior to control, those treated with HCl, H_2SO_4, HNO_3, hot water and KNO_3 were superior upto 3 months after extraction. All these findings point towards the inevitability of one of the afore-mentioned invigoration treatments for attaining an appreciable germinability in snake gourd seeds during the first three months after extraction.

Overall performance was analyzed to select the best five invigoration treatments, which could result in better performance with respect to germinability as well as vigour. Important seed quality parameters like germination per cent, speed of germination, vigour index-I and vigour index-II were considered for the

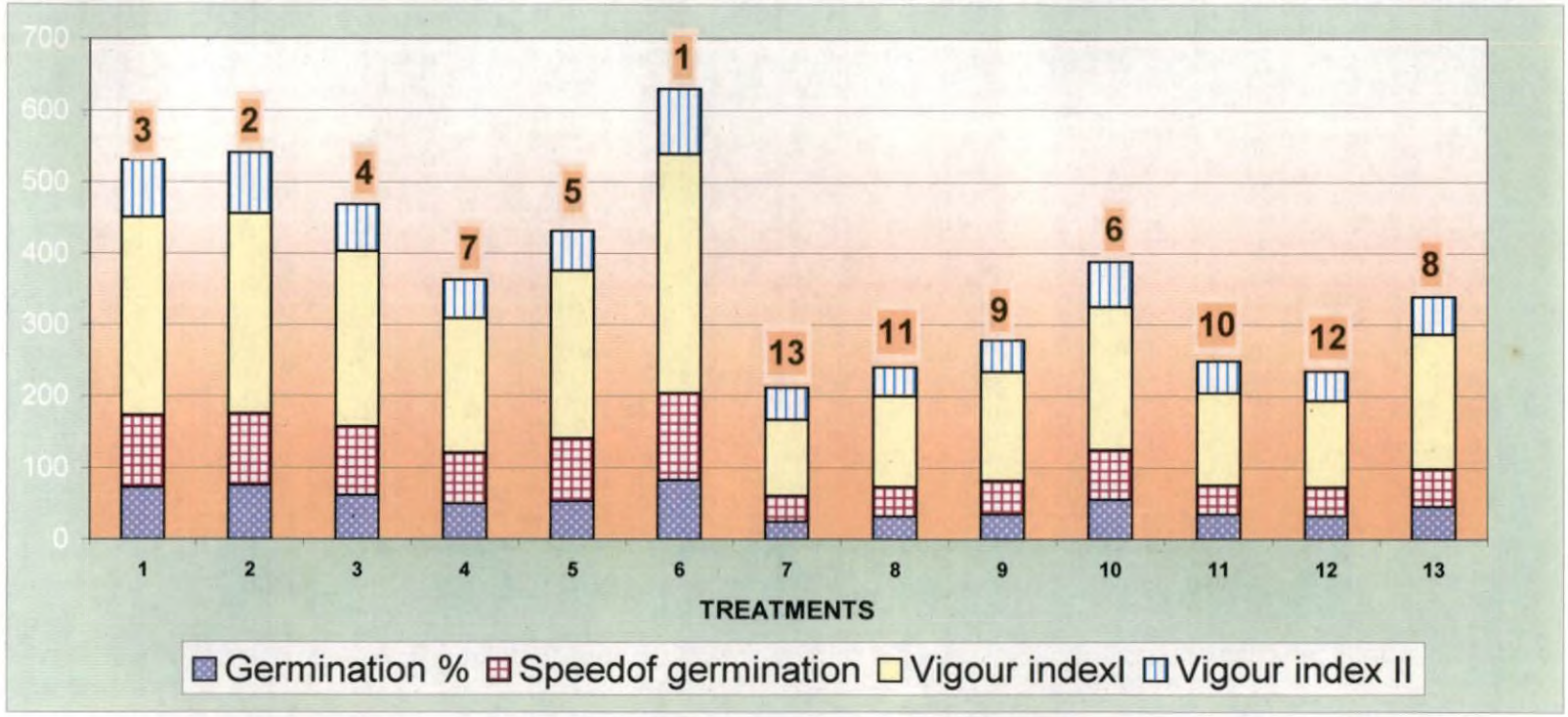


Figure 1. Mean performance of invigoration treatments

T1: 5N H_2SO_4 **T2: 5N HCl** **T3: 5N HNO_3** **T4 : Water soaking** **T5 : Hot water soaking**

T6 : Mechanical scarification **T7 : GA3 (250 ppm)** **T8 : GA3 (500 ppm)** **T9 : NAA (100ppm)**

T10: 1% KNO_3 **T11: 0.5% NaH_2PO_4** **T12: 0.5% KH2Po4** **T13: Control**

study. Seeds subjected to mechanical scarification resulted in maximum germination per cent, speed of germination, vigour index-I and vigour index-II and higher mean performance (863.496). Similar results were reported by Krishnaswamy (1991) and Latha (1992) who found that removal of seed coat gave superior germination and vigour in bitter gourd and pumpkin respectively. The next best treatment identified was HCl which showed higher mean germination per cent, speed of germination, vigour indices as well as mean performance. The third best treatment was the seeds treated with H_2S0_4 with a mean performance of 717.05, followed by HNO_3 treatment (634.28), hot water treatment (604.08) and KNO_3 treatment (517.15) (Fig.1). Similar results on effect of acid scarification on increasing germination per cent, speed and vigour indices were reported by Singh and Singh (1969) in bitter gourd, that of hot water treatment by Grey (1962) and that of KNO_3 by Solanki and Joshi (1984) and Renugadevi (1992).

Outcome of the present study clearly shows that the dormancy in seeds of snake gourd is probably due to a water impermeable seed coat (physical dormancy) and requires scarification treatment for good germination. Most of the research efforts hitherto carried out were focussed on improvement of germinability rather than unravelling the basic mechanism involved in breaking dormancy. Against this backdrop, an image analysis of the layer-wise seed coat thickness as well as study of moisture imbibition rate were attempted to get an insight into the changes rendered by the different seed invigoration techniques on seed ontogeny.

The results obtained provided strong positive correlation between seed coat differences, kinetics of water imbibition and seed germination parameters (Fig. 3). The seed coat thickness and imbibition rate of the treated, stored and untreated seeds differed significantly. The seeds that were stored for six months showed lesser seed coat thickness (393.6 microns) at hilum end and higher imbibition rate after 24 hours. The seeds subjected to the invigoration treatments also had lesser coat thickness and higher imbibition rate. In contrast, untreated

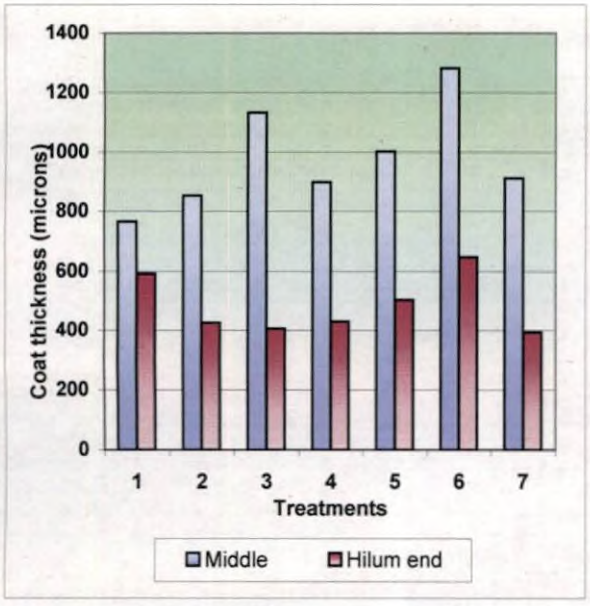


Figure 2. Seed coat thickness

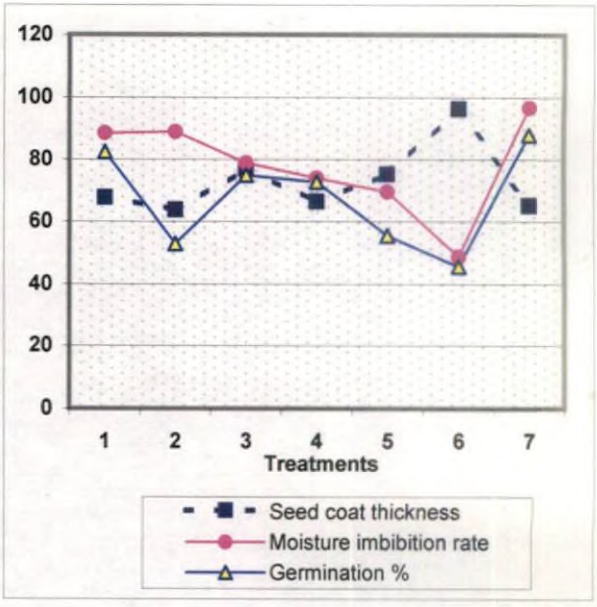


Figure 3. Effect of seed coat thickness on imbibition rate and germination %

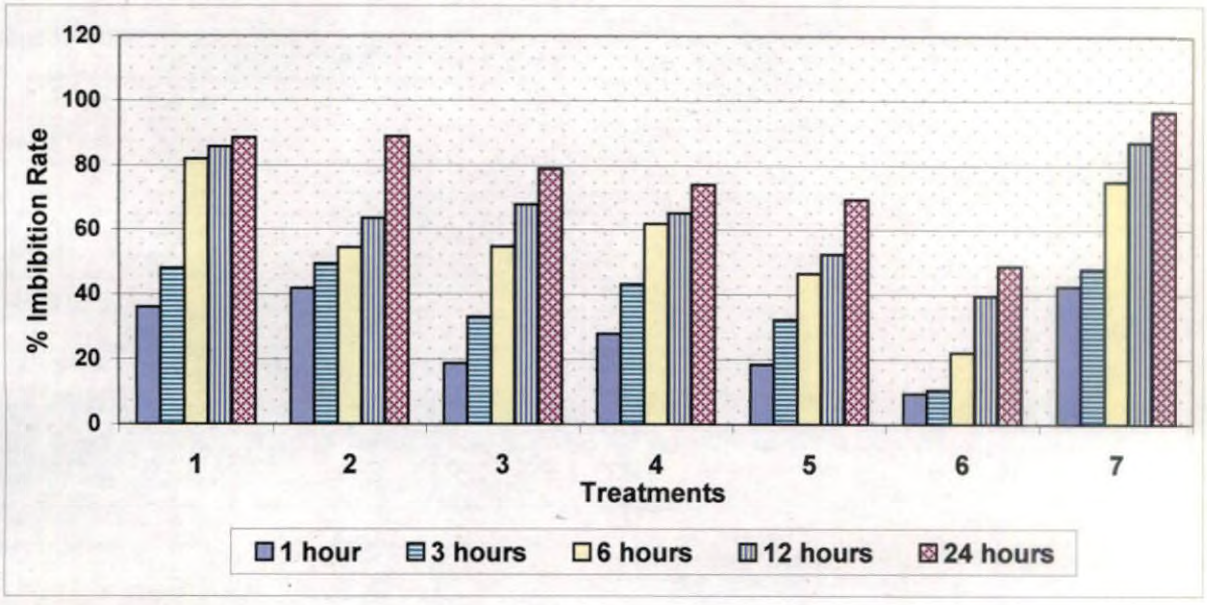


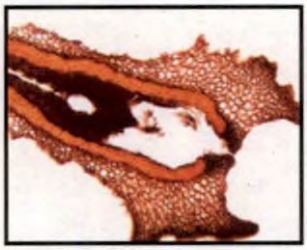
Figure 4. Effect of invigoration treatments on moisture imbibition rate at time intervals

fresh seeds had higher coat thickness (647.6 microns) and very low imbibition rate (Fig. 3 and 4). Thus it can be concluded that fresh seeds have higher seed coat thickness and this acts as a mechanical barrier for water imbibition. The seeds become permeable naturally after storage and this pattern of loss of impermeability and reduced coat thickness are due to opening of specialized cracks in seed coat and general deterioration of its seed coat due to loss of turgour pressure in cells. Such suggestions were consistent with findings of Ragus (1987) and Tran and Cavanagh (1984) who suggested that thick seed coat is slower in absorbing water than thinner ones and old age seed has higher speed than the freshly harvested seeds and coat imposed dormancy breaks down during storage resulting in rapid water uptake. Figure 3 demonstrates the relatively rapid germination per cent of stored seeds due to reduced seed coat thickness and increased imbibition rate.

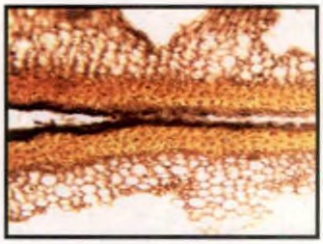
The seeds subjected to mechanical scarification imbibed water more rapidly after 24 hours (88.62 %) and resulted in higher and early germination. On the other hand, percentage mass increase in untreated soaked seeds is only 48.79 per cent and had the lowest germination per cent. The fact that all the mechanically scarified seeds imbibed water due to removal of seed coat in contrast with the non-scarified seeds indicates that mechanical scarification results in complete loss of coat impermeability.

Seeds rendered water permeable by boiling and acid treatments imbibed water and thus germinated at a relatively much faster rate than untreated fresh seeds. The reason for this may be that boiling and acid scarification opened the cracks or water gaps in the seed coat and water entered the seed only through this opening. Thus it can be safely deduced that reduced seed coat thickness due to scarification accounted for the rapid moisture imbibition and higher germination per cent. Similar findings were reported by Agrawal and Menon (1974) who observed that practice of boiling of hard seed resulted in softening of its seed coat thereby improving the permeability.

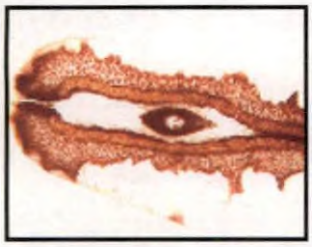
Plate 5 Ultrastructure of seed coat at hilum portion of snake gourd seed



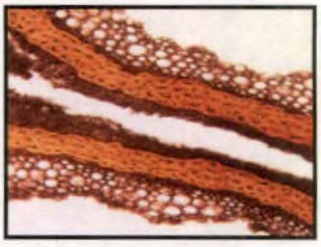
a) Mechanical scatification



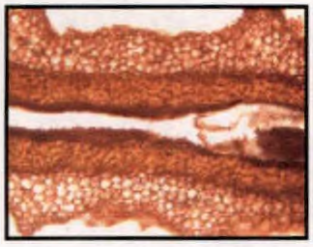
b) Hot water treatment



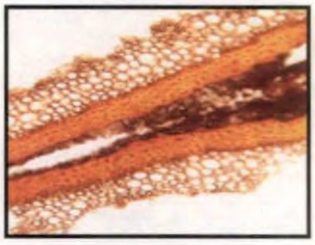
c) HCl treatment



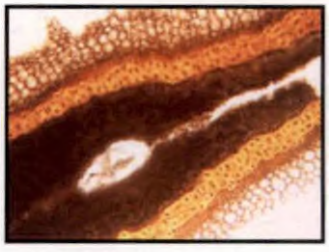
d) H2SO4 treatment



e) KNO3 treatment



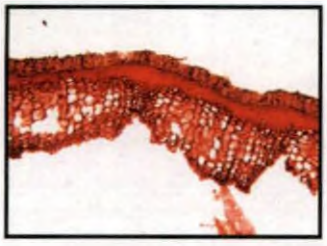
f) Untreated stored seeds



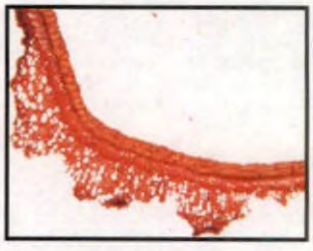
g) Untreated fresh seeds

a) Mechanical scatification

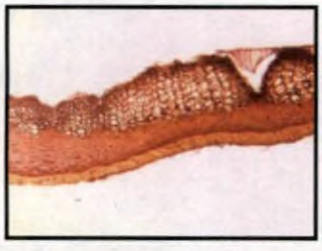
b) Hot water treatment



c) HCl treatment

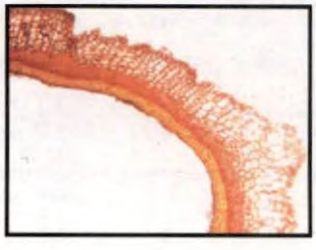


d) H2SO4 treatment



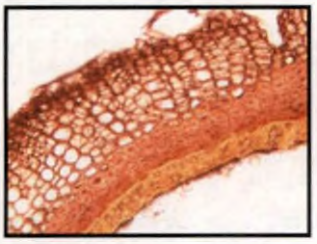
e) KNO3 treatment

f) Untreated stored seeds

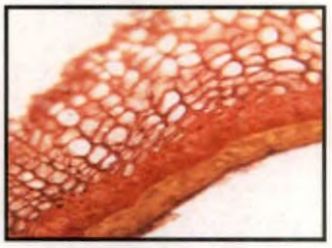


g) Untreated fresh seeds

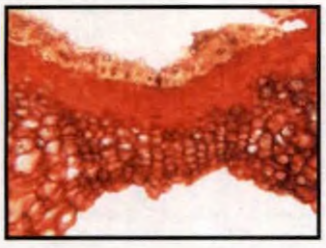
Plate 6 Ultrastructure of seed coat at middle portion of snake gourd seed at 10X magnification



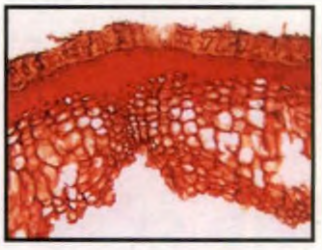
a) Mechanical scatification



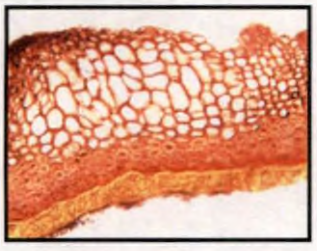
b) Hot water treatment



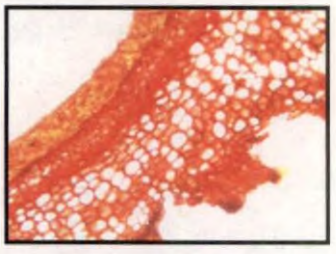
c) HCl treatment



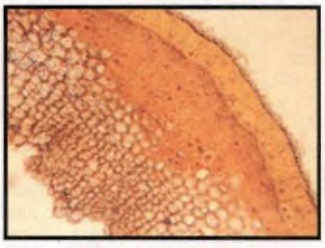
d) H2SO4 treatment



e) KNO3 treatment



f) Untreated stored seeds



g) Untreated fresh seeds

Plate 7 Ultrastructure of seed coat at middle portion of snake gourd seed at 4X magnification

The measurement of moisture imbibition rate has been found associated with germinability of seeds, days to achieve 60 per cent germination and intensity of dormancy. Twenty four hours after the beginning of the imbibition experiment, more than 90 per cent of the stored seeds and 70-90 per cent of scarified seeds have imbibed water. On the other hand, untreated seeds imbibed only 48.79 per cent (Fig. 4). Consequently those treatments, which showed higher permeability and mass increase of seeds exhibited higher mean germination percentage and expressed lowest intensity of dormancy when compared to untreated seeds. This kind of inverse relationship between the seed coat thickness and degree of impermeability was shown by Tran and Cavanagh (1984) in several *Acacia* spp.

Thus it seems likely that unraveling the ontogeny of physical dormancy in seeds of snake gourd could be a major step in overcoming the problem of dormancy. From the findings of the present study as well as literature cited, it is quite clear that the mandatory minimum germination requirement of seeds could be achieved with minimum efforts in seeds with physical dormancy like those of snake gourd by the use of simple invigoration techniques.

An analysis of the practicability and economic feasibility of the seed invigoration treatments seems to be very pertinent. Mechanical scarification by way of seeds rupturing is the simplest and cheapest method especially when the quantum of seeds involved is not very excessive. However, when large quantities of seeds are to be invigorated, treatments with acids, KNO_3 and hot water will be more practically feasible. In case of acid treatments, soaking for longer duration and improper concentration may cause deformity or even mortality of the seeds and hence utmost care has to be bestowed. The cost incurred in preparation of 250 ml treatment solution of 5N HCl and 5N HNO_3 is comparatively on the higher side (Rs. 27.95 and Rs. 20.98 respectively) while the cost involved in case of 5N H_2SO_4 is lesser (Rs. 9.10). KNO_3 treatment which costs only Rs. 0.65 per 250 ml of treatment solution and hot water soaking are still cheaper propositions though

their ability to break dormancy is not as good as mechanical scarification and acid treatments.

5.2 STORAGE POTENTIAL OF INVIGORATED SEEDS

In this study, the focus was on the impact of seed invigoration techniques on the storability of seeds. Freshly extracted snake gourd seeds were invigorated with selected five treatments and subjected to storage study after drying. Starting from one month after storage the seed quality parameters like germination per cent, intensity of dormancy, dormancy index, speed of germination, root length, shoot length, vigour index-I, vigour index-II and electrical conductivity were recorded up to a period of six months.

Germination percentage showed a declining trend during storage. The overall germination per cent was 62.83 at one month after storage which reached 39.66 per cent after six months (Fig. 6). Considering the individual treatments means the germination per cent varied significantly during each month. In general, the seeds subjected to mechanical scarification, H_2SO_4, hot water and KNO_3 could be stored safely for a period of 2-3 months, up to which the mandatory minimum germination requirement of 60 per cent could be maintained. However, the seeds treated with HCl did not germinate after two months showing the adverse impact of this particular treatment on storability. Considering the effect of invigoration treatments when averaged over months, all the treatments except KNO_3 showed decreased germination per cent when compared to untreated seeds (Fig. 6). Thus it is seen that the invigorated snake gourd seeds can be stored only for a period of one to two months without loss of viability. This finding is consistent with the results obtained by Suryanarayana and Arifuddin (1980) in okra seeds.

In the case of intensity of dormancy at seven days, all invigorated seeds exhibited highest intensity of more than 70 per cent (Table 17a). However,

Performance of invigorated seeds during storage

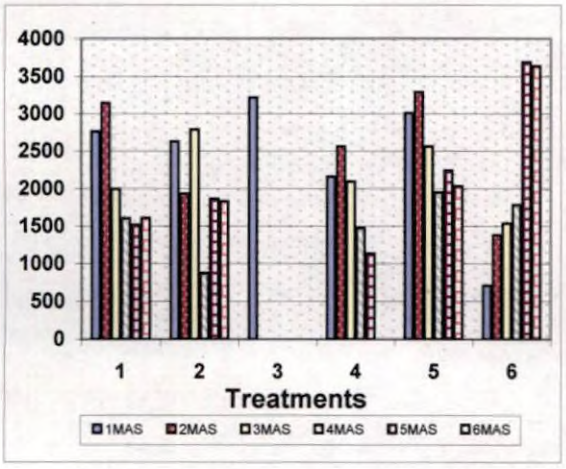


Fig 5. Effect of treatments on germination per cent

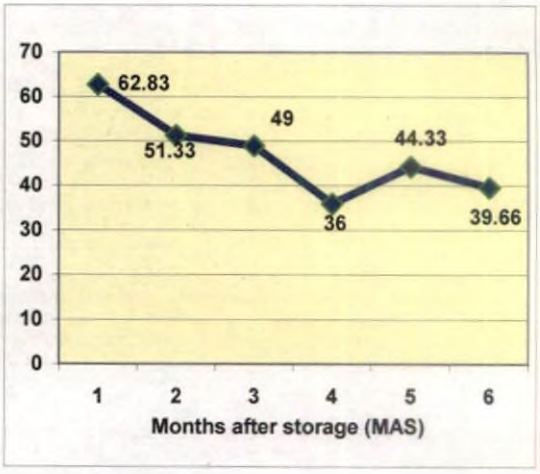


Fig 6. Germination percent at monthly intervals

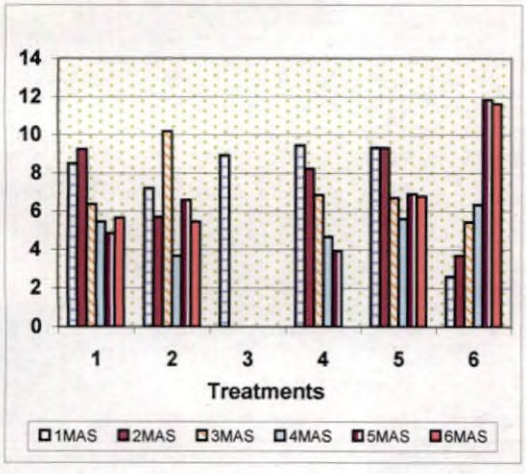


Fig 7. Effect of treatments on speed of germination

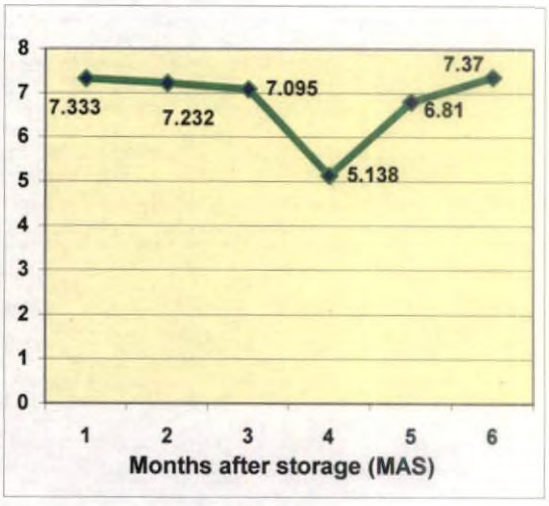


Fig 8. Speed of germination at monthly intervals

intensity of dormancy at 14 days showed varying results during different months of storage. In general, the mean intensity was lower than 40 per cent only at one month after storage and in all other months the intensity of dormancy was more than 40 per cent showing non-storability of invigorated seeds (Table 17b) beyond one to two months.

Of the individual treatment means, the seeds subjected to mechanical scarification, hot water, H_2SO_4 and KNO_3 recorded comparatively lower intensity up to two months and HCl treatment for only one month. In the case of mean intensity of treatments over months, all the treatments except KNO_3 showed more than 40 per cent NSG_{14} values. This again corroborates the results obtained with respect to NSG_7.

Other seed quality parameters like speed of germination, vigour index-I and vigour index-II also had shown a general decline during the period of storage (Figs. 7-12). However, KNO_3 was the only treatment which performed comparatively better during the entire period of storage. This significant decrease in seed quality parameters of invigorated treatments in the storage can possibly attributed to either one or a combination of the factors like accumulation of toxicants and corrosive action caused by acids (Zhang *et al.*, 1993), membrane degradation which resulted in greater leakage of sugars, amino acids and inorganic solutes from the seed (Abdul-Baki and Anderson, 1970), free radical damage formed due to lipid peroxidation (Rudrapal and Basu, 1982), impaired enzymatic activity (Chauhan *et al.*, 1984; Zuo *et al.*, 1988) and increase in respiratory quotients (Harrington, 1973).

Electrical Conductivity (EC) of seed leachates was significantly influenced by the invigoration treatments during the period of storage. There was an explicit increase in EC values with increase in the duration of storage (Fig.13). This increase in EC values with increase in duration of storage may probably be due to membrane aberration of seeds. Yadav *et al.* (1981) related increased EC

Performance of invigorated seeds during storage

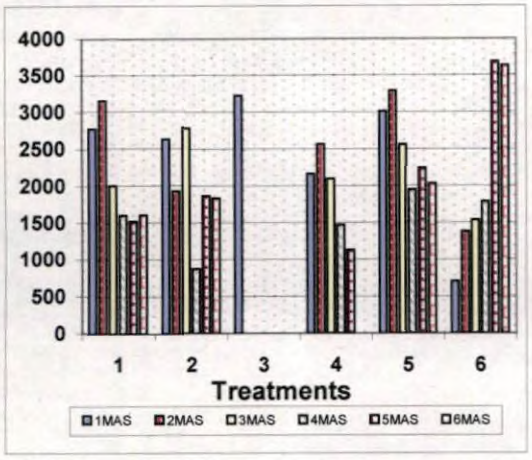


Fig 9. Effect of treatments on vigour index-I

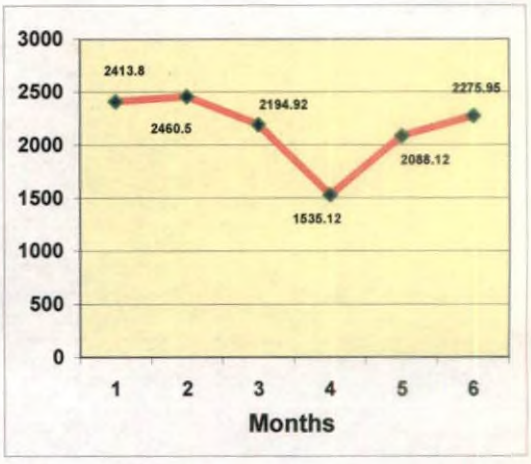


Fig 10. Vigour index-I at monthly intervals

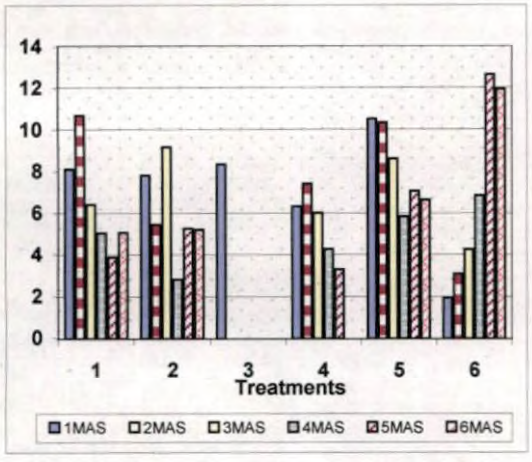


Fig 11. Effect of treatment on vigour index-II

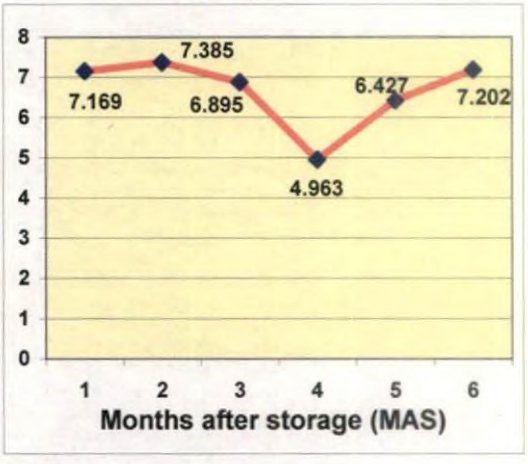


Fig 12. Vigour index-II at monthly intervals

Performance of invigorated seeds during storage

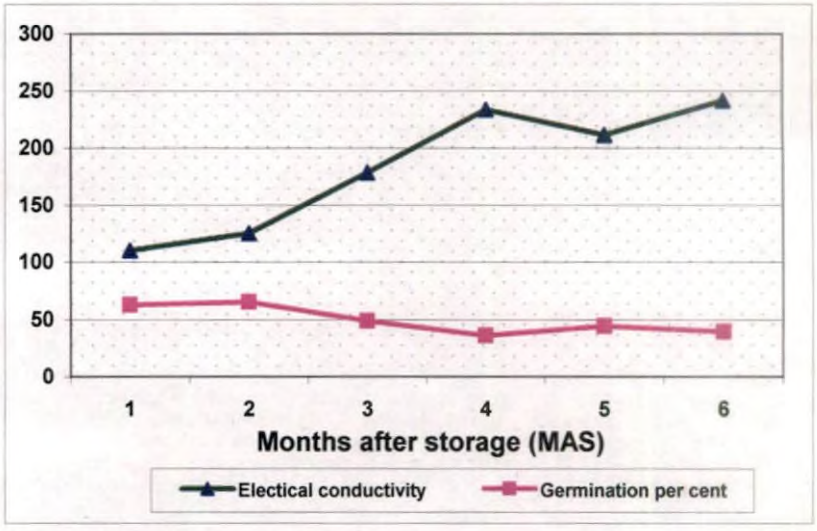


Fig. 13. Electrical conductivity and germination per cent at monthly intervals

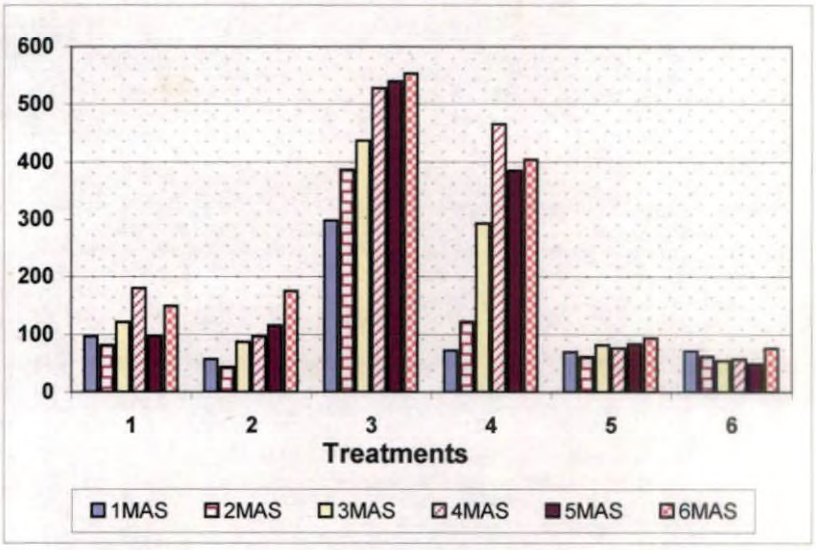


Fig 14. Effects of treatment on electrical conductivity

values with weakening of cell membrane integrity in case of sal seeds and they opined that solute leakage would decrease germinability of seeds.

A high correlation was obtained between the content of total leachates of invigorated seeds and seed quality parameters during the period of storage. The seeds treated with HCl and H_2SO_4 recorded higher EC values and all other seed quality parameters were found to be low during all the months (Fig.14). These results clearly support the assumption that if a seed is being deteriorated in storage, it will have low germinability, low vigour and high EC values. The seeds treated with KNO_3 recorded lower EC values and all other seed quality parameters were also found to be reasonably good. This result was in accordance with the reports of Taylor *et al.* (1995) in onion and cabbage as well as Gayathri and Kalappa (2002) in tomato. But Pesis (1983) reported that electrolytic leakage test is an indirect method of examining changes in membrane permeability and this alone cannot be considered as an ultimate test for seed quality in musk melon. However, in a later study, Vieira *et al.* (1999) gave sufficient experimental evidence to the effect that EC reading and degree of seed deterioration are positively correlated. Thus it can be deduced that during the storage of invigorated seeds, the total leachates increased and there was a high negative correlation between EC values and percentage of germination (Fig.13). The present study establishes that invigorated seeds of snake gourd are not amenable to storage beyond one to two months. It also confirms the usefulness of electrical conductivity study as a rapid and effective indicator of seed deterioration during storage.

5.3 FIELD PERFORMANCE OF INVIGORATED SEEDS

The freshly extracted seeds of snake gourd were invigorated with the best five treatments selected during the initial study and their field performance as both vegetable and seed crops was compared with the untreated and stored seeds

from the previous summer and rainy season crops whose dormancy might have been broken naturally by storage.

The growth characters of snake gourd plants like field emergence, length of the main vine, primary branches per plant, days to first female flower opening, node at first female flower appeared, per cent fruit set, days to first harvest and days to last harvest were significantly influenced by the different invigoration treatments (Table 27).

The seeds subjected to mechanical scarification showed maximum field emergence (91.50 per cent). The seeds stored from previous *Kharif* crop and fresh seeds treated with KNO_3 recorded relatively higher percentage of emergence in the field. The period of storage might have been beneficial in the case of seeds stored from previous *Kharif* crop for release of dormancy and enhancement of field emergence while mechanical scarification and other invigoration treatments had the similar effect in fresh seeds. Similar results have been reported by Odland (1937) in cucurbits, Holmes (1953) in squashes, Nagy (1974) in *Cucurbita pepo*, Quagliotli *et al.* (1981) in chilli, Krishnaswamy (1991) in bitter gourd and Mini *et al.* (2002) and Unnikrishnan (2005) in ash gourd.

The seeds extracted from previous *kharif* season crop produced maximum number of primary branches (7.96), which was closely followed by seeds stored from previous summer season crop (6.10). The seeds that are stored from previous summer season crop showed early flowering (53.79 days) and untreated seeds had taken maximum number of days for flowering. There was no significant difference between the treatments with respect to the node at first female flower appearance. However, the untreated seeds produced female flower at higher nodes (18.75) compared to other treatments. The effect of seed invigoration on per cent fruit set differed significantly among the treatments. The highest fruit set percentage and earliness as regards vegetable harvest were noticed in seeds treated with 1 % KNO_3 (25.54) and seeds stored from previous

kharif crop (25.48 %) (Table 27). Increased fruit set and yield from invigorated seeds was also reported by Adulka and Verma (1965) in tomato and Sadawarte and Gupta (1968) in brinjal.

The seeds treated with 1 % KNO_3 recorded the maximum fruit weight and fruits per plant compared to other treatments. Fruit yield per plot for vegetable purpose was high for seeds treated with KNO_3 (33.47 Kg) followed by seeds extracted and stored from previous *kharif* crop. Since the yield of the crop per hectare was calculated from yield per plot, the significant difference between treatments remained same. Thus the highest fruit yield per hectare was obtained from seeds treated with 1 % KNO_3 (20920 Kg) (Table 28). The positive influence of KNO_3 on crop yield was reported earlier by Dimov *et al.* (1978) in tomato and capsicum and Ganar (2003) in ash gourd.

Though not significant, circumference, length and fruit shape index when harvested for vegetable purpose were maximum for seeds subjected to mechanical scarification (Table 28), which was closely followed by seeds stored from previous *kharif* crop.

The over all results for fruits harvested for vegetable purpose revealed the superiority of KNO_3 treatment in influencing the yield of the crop. In addition to this KNO_3 treatment had significant positive influence on single fruit weight, fruits per plant, per cent fruit set, early flowering and early fruiting. Among the invigoration treatments, KNO_3 was found to be the most effective one as far as field performance is concerned, though it recorded only a moderate performance in the laboratory studies.

When harvesting was done for seed purpose, the seeds subjected to mechanical scarification recorded the maximum average fruit weight and highest number of seeds. There was no significant difference in case of fruits per plant, seeds per fruit and seed yield per plant. The H_2SO_4 treatment has resulted in the

maximum weight of seeds per fruit while highest hundred seed weight was observed in the crop raised from stored seeds of previous *Kharif* season. The crop raised from seeds treated with H_2SO_4 again gave the highest seed yield per plant (Table 29).

The present investigation could thus bring out that the initial advantage gained with respect to germinability and seed vigour through invigoration techniques could be sustained to a larger extent in the field performance both as vegetable and seed crops.

Future line of work

The future works in this line should focus on the possible residual impact of the seed invigoration techniques on the seed and plant characteristics in the ensuing generations.

SUMMARY

6. SUMMARY

The present investigation on "Seed invigoration and dormancy studies in snake gourd (*Trichosanthes anguina* L.)" was undertaken at the Department of Olericulture, College of Horticulture, Vellanikkara during 2003-2005. The salient findings of the experiment intended to study the impact of seed invigoration techniques on breaking dormancy, seed vigour, seed storability and crop performance in snake gourd are summarized here under.

1. Snake gourd seeds exhibit delayed and uneven germination for a period of four months due to the presence of hard seed coat that restricts water imbibition. In other words, the dormancy of snake gourd seeds is coat-imposed or physical dormancy.

2. Analysis of physiological and biochemical parameters revealed that seeds subjected to mechanical scarification resulted in maximum germination per cent (82.55), speed of germination (12.18), vigour index-I (3350) and vigour index-II (9.09) and higher overall performance (863). This was followed by HCl, H_2SO_4, HNO_3, hot water soaking and KNO_3 treatments. Seed treatments with water soaking, growth regulators and osmoticums like NaH_2PO_4 and KH_2PO_4 along with control were found to be less effective.

3. Among the invigoration treatments tried, mechanical scarification was the best throughout the entire period of the study. The treatments such as HCl, H_2SO_4, HNO_3, KNO_3 and hot water soaking were superior to untreated seeds till 3 MAE and thereafter, untreated control seeds performed better. This result scientifically validates the view that seed dormancy in snake gourd is naturally broken only four to five months after extraction.

4. The present study revealed that the failure of fresh snake gourd seeds to germinate is due to the thick impermeable seed coat and scarification treatments resulted in its softening thus allowing easier penetration of radicle.

5. An investigation on the changes in the anatomy of seed coat thickness revealed the differences in invigorated seeds, stored seeds and fresh seeds. The stored seeds had lesser coat thickness (393.60 microns) as in the case of invigorated seeds. In contrast, untreated fresh seeds had higher coat thickness (647.60 microns) and this acts as a mechanical barrier for water imbibition.

6. The evidences from the present study showed association between seed coat thickness and kinetics of water imbibition. The seeds subjected to mechanical scarification imbibed water more rapidly after 24 hours and resulted in higher and early germination and high speed of release of dormancy. The stored seeds as well as seeds invigorated with acids and hot water also displayed high imbibition rate due to reduced seed coat thickness and opening of specialized cracks in seed coat. On the other hand, untreated seeds showed lesser water imbibition.

7. From the findings of the present study it is evident that the mandatory minimum germination requirement could be achieved in seeds with physical dormancy like those of snake gourd with minimum efforts by the use of simple invigoration techniques. The outcome of this study also points towards the inevitability of an invigoration treatment for attaining an appreciable germinability in snake gourd seeds during the first four months after extraction.

8 The study on storability of invigorated seeds revealed that the germination percentage showed a declining trend during storage. The overall

germination per cent was 62.83 at one month after storage which reached 39.66 per cent after six months. There was also a significant decrease in other seed quality parameters during the storage. This significant decrease in seed quality parameters of invigorated treatments in the storage can possibly attributed to either one or a combination of the factors like accumulation of toxicants and corrosive action caused by acids, membrane degradation which resulted in greater leakage of sugars, amino acids and inorganic solutes from the seed, free radical damage formed due to lipid peroxidation, impaired enzymatic activity and increase in respiratory quotients.

9. Electrical conductivity (EC) of seed leachates was significantly influenced by the invigoration treatments during the period of storage. A high correlation was obtained between the content of total leachates of invigorated seeds and seed quality parameters during the period of storage. This increase in EC values with increase in duration of storage may probably be due to membrane aberration of seeds and weakening of cell membrane integrity.

10. The present study establishes that invigorated seeds of snake gourd are not amenable to storage beyond one to two months. It also confirms the usefulness of electrical conductivity study as a rapid and effective indicator of seed deterioration during storage.

11. The field performance of invigorated seeds was compared with seeds collected from previous summer and rainy season crop along with untreated fresh seeds. The seeds subjected to mechanical scarification and seeds from previous *Kharif* crop were found to have maximum field emergence and more number of primary branches. The seeds treated with 1 % KNO_3 recorded highest fruit set, earliness, higher yield, maximum fruit weight as well as higher seed yield followed by stored seeds from

previous *Kharif* crop. All other treatments were also superior in field performance when compared to untreated fresh seeds.

12. The present investigation could thus bring out that the initial advantage gained with respect to germinability and seed vigour through invigoration techniques could be sustained to a larger extent in the field performance as well.

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* Originals not seen

APPENDIX

APPENDICES-I

Weather parameters during period of study (May 2004 - June 2005)

	Temperature (^{0}C)		Relative humidity (%)	Total rainfall (mm)	Total sunshine hours	Rainy days
	Maximum	Minimum				
May-04	34.4	22.0	84	578.3	104.3	21
Jun-04	31.3	21.6	85	786.0	98.9	24
Jul-04	31.8	21.6	85	369.6	66.4	24
Aug-04	31.3	21.5	83	386.9	137.1	14
Sep-04	32.8	22.6	80	208.8	154	10
Oct-04	33.8	20.8	73	493.2	185.3	11
Nov-04	32.8	21.4	65	71.7	211.9	3
Dec-04	33.6	18.6	55	0.0	279.9	0
Jan-05	35.0	19.8	56	7.6	264	1
Feb-05	37.6	17.4	53	00.0	280.7	0
Mar-05	38.2	22.0	42	00.0	193.2	0
Apr-05	36.7	22.8	74	171.4	208.2	10
May-05	35.5	21.5	72	89.2	217.5	5
Jun-05	33.2	21.8	86	711.4	94.3	23

SEED INVIGORATION AND DORMANCY STUDIES IN SNAKE GOURD *(Trichosanthes anguina* L.*)*

By

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ABSTRACT OF THE THESIS

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ABSTRACT

"Seed invigoration and dormancy studies in snake gourd (*Trichosanthes anguina* L.)" were carried out at Department of Olericulture, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur during 2004-2005. This study aimed at standardizing seed invigoration techniques in snake gourd that can break dormancy and improve seed vigour and studying the impact of invigoration techniques on storability as well as field performance.

Among the different invigoration treatments tried, mechanical scarification by way of seed rupturing was the most effective one followed by acid treatments (5N H_2SO_4, 5N HCl and 5N HNO_3 for 10-20 minutes), hot water soaking (40^0 C for 5 minutes) and treatment with 1 % KNO_3 for 12 hours. These treatments could break the dormancy of snake gourd seeds from the freshly extracted state onwards and improve the seed vigour. From the fourth month onwards, untreated seeds also showed higher germination. Treatments such as water soaking, GA_3 250 / 500 ppm, NAA 100 ppm, 0.5 % NaH_2PO_4 and 0.5 % KH_2PO_4 did not show any positive influence on dormancy release.

It is evident from the present study that dormancy in seeds of snake gourd is due to water impermeable seed coat and this is naturally broken only four months after extraction and if the seeds are to be used immediately after extraction or till three months afterwards, an invigoration treatment is inevitable.

An insight in to the changes in the anatomy of seed coat thickness revealed the differences in the layer wise coat thickness of invigorated seeds, stored seeds and fresh seeds. The stored seeds had lesser coat thickness as in the case of invigorated seeds. In contrast, untreated fresh seeds had higher coat thickness and this acts as a mechanical barrier for water imbibition.

The study on moisture imbibition rate revealed that the seeds subjected to mechanical scarification imbibed water more rapidly after 24 hours and resulted in higher and early germination and high speed of release of dormancy. The stored seeds as well as seeds invigorated with acids and hot water also displayed high imbibition rate due to reduced seed coat thickness and opening of specialized cracks in seed coat. On the other hand, untreated seeds showed lesser water imbibition.

There was a gradual reduction in quality parameters like germination percentage, speed of germination and vigour indices during storage of invigorated seeds. This indicates that the invigorated seeds can be supplied to farmers only for immediate use and they are not amenable to storage beyond one to two months.

Electrical conductivity of seed leachates was significantly influenced by the invigoration treatments during the period of storage. The EC values showed increasing trend with increase in duration of storage. This confirms the usefulness of electrical conductivity study as a rapid and effective indicator of seed deterioration during storage.

The seeds subjected to mechanical scarification and seeds from previous *Kharif* crop were found to have maximum field emergence and the seeds treated with 1 % KNO_3 recorded highest fruit set, earliness, higher yield, maximum fruit weight as well as higher seed yield followed by stored seeds from previous *Kharif* crop. All other treatments were also superior in field performance when compared to untreated fresh seeds. Thus it can be seen that the initial advantage gained through seed invigoration has been sustained to a larger extent in the field performance as well.