GERMINATION AND EMERGENCE OF SELECTED AFRICAN LEAFY VEGETABLES

by

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DECLARATION

“I hereby declare that the dissertation submitted for the degree, Magister Technologiae: Agriculture, at the Tshwane University of Technology, is my own original work and has not previously been submitted to any other institution of higher education. I further declare that all sources cited or quoted are indicated and acknowledged by means of a comprehensive list of references”.

M M Motsa
DEDICATION

This study is dedicated to:

My late father and mother Zephaniah Mconyiswa Motsa and Caroline Baphumzile Mabotjo Leafe, for being the vessels that God used to create me, the individual who administered the accomplishment of this project.

My brothers, sisters and grandmother Sibongile Dlamini, for their continued support and encouragement. In addition, I would also dedicate this to my entire Motsa and the Leafe family for standing by me. Special dedication to my brother Mbusi Motsa for all his financial assistance during my study period.

Youth For Christ and Living Waters Church of the Nazarene for moulding, developing and directing me in a path that allowed me to witness the power of God being manifested in my life.

And lastly, to all my friends, especially high school and tertiary friends who demonstrated belief in me, relaxed my mind when the going was tough and were always there during the daunting times when all seemed to fade away with each day.
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ABSTRACT

Using laboratory incubation, the response of seed germination and seedling emergence to variability in temperature, pre-sowing dormancy treatments and light was examined for eight African leafy vegetables, namely, spider flower (*Cleome gynandra* L.), amaranth (*Amaranthus cruentus* L.), non-heading Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*), nightshade (*Solanum retroflexum* Dun.), pumpkin (*Cucurbita maxima* Duchesne), tsamma melon (*Citrillus lanatus* L.), Jew’s mallow (*Corchorus olitorius* L.) and cowpea (*Vigna unguiculata* (L.) Walp.). Generally, optimum germination occurred at temperatures ranging between 29 °C and 32 °C but cowpea (36 °C) and Jew’s mallow (35 °C) had higher optima. Maximum temperature for germination ranged between 36 °C and 40 °C but Jew’s mallow seed still germinated at 44 °C. Minimum temperature for germination ranged between 8 °C and 20 °C. The optimum temperature for seedling emergence ranged between 25 °C and 33 °C, the maximum temperature between 36 °C and 40 °C and the minimum temperature between 8 °C and 20 °C. Improved onset and final germination percentage was observed when the seeds of amaranth and Chinese cabbage were scarified and when the seeds of nightshade and Chinese cabbage were treated with KNO₃. Pre-chilling only improved onset and final germination of amaranth. Exposure of the seed to light improved onset of germination of amaranth, Chinese cabbage, and Jew’s mallow but delayed onset of germination of tsamma melon and cowpea. Exposure to light improved final germination percentage of the seed of Chinese cabbage, nightshade and tsamma melon.
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CHAPTER 1

1 INTRODUCTION

Leafy vegetables are plant species of which the leafy parts, which may include young succulent stems, flowers and fruits, are used as vegetables (Jansen van Rensburg et al., 2007:317). Consumption of leafy vegetables is a traditional practice in many African communities (Coertze, Jefthas & Reinten, 1999:160-163; Mwangi & Mumbi, 2006:1; Abukutsa-Onyango, 2007:3; Odhav et al., 2007:434). In cereal-based and nutrient-poor human diets, which are characteristic of many poor rural communities across the globe (Faber et al., 2010:30), leafy vegetables can make an important contribution to the nutritional balance, because they are rich in minerals, such as iron, calcium and magnesium; amino acids, such as thiamin, riboflavin and nicotinic acid; and vitamins A and C (National Research Council, 2006:13; Maunder & Meaker, 2007:403; Van Wyk & Gericke, 2007:63).

In Africa, a wide range of plant species are used as vegetables (Attere, 1995:4; Schippers, 2002:iii). Among these, many are leafy vegetables. For example, in South Africa, Wehmeyer and Rose (1983:1) recorded more than 100 plant species that were consumed as leafy vegetables. The range of plant species used as leafy vegetables differs among communities, depending on the local ecology and culinary traditions. Typically the range includes indigenous, indigenised and recently introduced plant species (Jansen van Rensburg et al., 2007:317; Faber et al., 2010:35). In order to capture this variability, Jansen van Rensburg et al. (2007:317) introduced the dynamic concept of African leafy
vegetables, which they defined as “the collective of leafy vegetable species that form part of the culinary repertoire of particular contemporary African communities”. People in Africa, including South Africa, obtain leafy vegetables in various ways, including collection from the wild, collection from cropped land where some of these species grow as weeds and in some cases by means of cultivation (Gockowski et al., 2003:222; Adebooye et al., 2005:1480; Abukutsa-Onyango, 2007:2; Odhav et al., 2007:430; Faber et al., 2010:35). In some parts of Africa, cultivation and commercialisation of particular traditional African leafy vegetable species has occurred and this has resulted in their increased consumption (Schippers, 2006:9-10; Diouf et al., 2007:346-347), but in other parts their use has been declining (Coertze, Jefthas & Reinten, 1999:160-163; Mwangi & Mumbi, 2006:1). These opposing trends have also been observed in South Africa (Jansen van Rensburg et al., 2007:318). For example, in the Vhembe District, local varieties of non-heading Chinese cabbage (Brassica rapa L. subsp. chinensis) and the indigenous nightshade species Solanum retroflexum Dun. have been commoditised successfully during the past few decades (Van Averbeke, Tshikalange & Juma, 2007:352), but in other parts of the country the use of traditional African leafy vegetables has declined (Jansen van Rensburg et al., 2007:318-319). Decline in the consumption of vegetables, including leafy vegetables, has been linked to increases in nutrient deficiency disorders and related diseases, including birth defects, mental and physical retardation, weakened immune systems, blindness and even death (Mwangi & Mumbi, 2006:1; Odhav et al., 2007:430). Regular intake of vegetables, including leafy vegetables, has been recommended as part of a dietary diversification strategy to combat human micronutrient malnutrition (Faber & Wenhold, 2007:397). Leafy vegetables that grow as weeds in the wild or on cropped land are highly seasonal (Jansen van Rensburg et al., 2007:318). Cultivation of a diverse range of leafy vegetable species, especially in home gardens, has the potential to enhance their
availability, both in terms of quantity and over time. Moreover, evidence from elsewhere in Africa (Schippers, 2002:iii) and also from South Africa (Van Averbeke, Tshikalange & Juma, 2007:353) has shown that once a particular traditional vegetable is being cultivated, the likelihood of it becoming commercialised is increased. This, in turn, creates opportunities for rural households to derive income from the cultivation of this vegetable.

The transformation of an edible weed into a cultivated crop generates the need for agronomic knowledge of the plant concerned. Generally, there is a dearth of agronomic information on many of the plant species that are traditionally used as leafy vegetables in Africa and South Africa. Attere (1995:4) pointed out that, “traditional (African) vegetables are being displaced in many areas, partly because of their neglect by the scientific community relative to some recently introduced species - on which there is much more scientific information - and improved varieties, which are more easily available. This trend is to the detriment of local people's health and income, and has been exacerbated by urban migration. Not enough of these valuable plants are being moved into the specialized micro-environments of urban and peri-urban agriculture.” Considering that many of these traditional vegetable species might be well adapted to particular resource-poor growing conditions in terms of soil water or plant nutrient availability, the development of agronomic information for these crops should be considered a priority for African research systems (Schippers, 2002:4; Gockowski et al., 2007:222).

The current study aimed to contribute to the development of agronomic information on a selection of African leafy vegetables commonly used in South Africa. The particular focus of the study was on the processes of germination and seedling emergence. Knowledge of these processes is a critical component of the agronomy of crop species, because it affects
both yield and monetary value of crops (Wang, 2005:2). Modelling of these processes assists in the assessment of the suitability of climatic conditions and the scheduling of sequential planting in order to meet market demand and continuity of supply. It also enables prediction of the optimum planting date (Böhringer, Lourens & Jansen van Vuuren, 1999:21).

Many factors affect the processes of germination and seedling emergence, including light, water, temperature, dormancy, soil physical conditions and oxygen availability (Bewley & Black, 1994:2; Mayer & Poljakoff-Mayber, 1989:44; Hemmat, Khashoei & Ranjbar, 2003:87; Manoto, Ferreira & Agenbag, 2004:214; Ghaderi, Soltani & Sadeghipour, 2008:574). Among these factors, temperature, light and dormancy are arguably cardinal (Garcia-Huidobro, Monteith & Squire, 1982:288; Bruin, 1994:5; Craufurd et al., 1996:2; Bewley, 1997:1055; Benech-Arnold & Sánchez, 2004:4; Koger, Reddy & Poston, 2004:989; Fenner & Thompson, 2005:99; Mpati, 2006:15), and for this reason they were selected for investigation in this study. Temperature is one of the main environmental factors governing the germination of seed in moist soils and its effect varies among plant species (Garcia-Huidobro, Monteith & Squire, 1982:288; Bruin, 1994:5). The prevailing temperature regime determines both the proportion of the seeds in a population that will germinate and the rate at which they will germinate (Garcia-Huidobro, Monteith & Squire, 1982:288). Consequently, temperature is an important determinant of the rate and uniformity of germination of seeds, the emergence of seedlings, seedling vigour, and the initial growth rate of seedlings.

Light can either promote or inhibit germination, depending on its spectral composition and irradiance, the physiological status of the seeds and the environmental factors of
temperature and water potential (Benech-Arnold & Sánchez, 2004:222). According to Pons (2000:237), “the light response of seeds can control the timing of germination in the field, a crucial factor in the survival of the resulting seedlings and growth and fitness in subsequent stages”. Responses of seeds to light are important for preventing the occurrence of germination in places or at times that are not favourable to seedling establishment. This ability of seeds to detect different aspects of light enables the seed to have some form of control over where and when germination takes place (Fenner & Thompson, 2005:116).

Another important mechanism employed by nature to reduce the high mortality rate among germinating seeds is seed dormancy. Seed dormancy can be defined as the failure of seeds to germinate under optimal environmental conditions favouring germination (Bradford & Nonogaki, 2007:55). Seed dormancy can delay seed germination or spread germination over a longer time, thereby ensuring better seedling survival and establishment (Fenner & Thompson 2005:99). In weedy species, dormancy secures long-term survival by allowing the seeds to germinate over a long period (Ochuodho & Modi, 2005:49). Seeds that fail to germinate can be induced to germinate by various special artificial treatments under specific external conditions (Mayer & Poljakoff-Mayber, 1989:71).

The current study formed part of the Water Research Commission (WRC) project K5/1579//4, which was aimed at determining the nutritional content of a selection of African leafy vegetables, as well as their water and plant nutrient requirements. The project team selected spider flower (Cleome gynandra L.), amaranth (Amaranthus cruentus L.), non-heading Chinese cabbage (Brassica rapa L. subsp. chinensis), nightshade (Solanum retroflexum Dun.), pumpkin (Cucurbita maxima Duchesne), tsamma melon (Citrillus lanatus L.), Jew’s mallow (Corchorus olitorius L.) and cowpea (Vigna
*unguiculata* (L.) Walp.) for investigation. Swiss chard (*Beta vulgaris* L. var. *cicla*) was selected as the reference crop because it is a popular conventional vegetable in South Africa.

The research questions that guided the study were:

- What are the effects of temperature on the germination and emergence of the selected African leafy vegetables?
- Is germination of the selected African leafy vegetables affected by dormancy?
- Is germination of the selected African leafy vegetables affected by light?

The specific objectives of the current study were:

- to determine the cardinal temperatures for germination and emergence of the selected African leafy vegetable seeds at different controlled temperatures;
- to determine whether the seeds of the selected African leafy vegetables possessed any form of dormancy and to investigate whether particular pre-sowing treatments were able to break dormancy where applicable;
- to determine the effect of light on the germination of the seed of the selected African leafy vegetable species.

The hypotheses tested in the study were:

- Temperature affects the rate of seed germination and emergence of the selected African leafy vegetables.
- Dormancy affects the germination of the seed of the selected African leafy vegetables.
- Light affects germination of the seed of the selected African leafy vegetables.
In natural environments, seeds germinate in soils. The temperature of soils is subject to diurnal and seasonal fluctuations. In this study, the experiments were conducted in a laboratory using environmental controlled low-temperature incubators fitted with Lasec® pencil merc thermometer. Seed samples were subjected to a constant temperature selected for each independent variable (temperature, light and dormancy) for 14 days (336 h). In the specified temperature treatments that were applied in the experiments, the temperature was kept constant throughout the duration of the experiments.

The dissertation is divided into seven chapters. The first chapter presents the background to the study and existing knowledge on the selected African leafy vegetables and also explains the objectives. The second chapter reviews existing knowledge of the selected African leafy vegetables in terms of their seed germination, seedling emergence and factors that affect these two processes. The third chapter reports on the effect of temperature on seed germination of the selected African leafy vegetables. The fourth chapter reports on the effect of temperature on seedling emergence of the selected African leafy vegetables. Chapter 5 reports on the effect of dormancy on germination of the selected African leafy vegetables. In Chapter 6 the effect of light on germination of the selected African leafy vegetables is investigated. The general conclusion of the dissertation is presented in Chapter 7.
CHAPTER 2

2 LITERATURE REVIEW

This review consists of two parts. In the first part, existing knowledge of the eight African leafy vegetable species featuring in this study is reviewed. Aspects covered include the background, description, growth conditions and uses of the African leafy vegetable species. In the second part, existing knowledge on seed germination and seedling emergence is reviewed. Aspects covered include selected factors affecting seed germination, factors affecting dormancy of seeds and how to overcome dormancy in seeds, light as a factor on seed germination and temperature as a fundamental factor in seedling emergence.

2.1 AFRICAN LEAFY VEGETABLES

2.1.1 Amaranth (*Amaranthus cruentus* L.)

2.1.1.1 Background

According to Schippers (2002:9) and Grubben (2004:67), *Amaranthus* was domesticated as grain amaranth from the weed *Amaranthus hybridus* in Central American 6000 years ago. The vegetable form of amaranth was probably introduced in the tropics and subtropics during the old-world colonial times (Mposi, 1999:1; Grubben, 2004:67). *A. cruentus* is an important leafy vegetable crop for many subsistence farmers in Africa (Schippers, 2002:10; Faber *et al.*, 2010:37). *A. cruentus* is one of three *Amaranthus* species that are
cultivated, the other two being *A. hypochondriacus* and *A. caudatus*. *Amaranthus* spp. are most commonly grown in the lowland tropics of Africa including Benin, Togo, and Sierra Leone amongst others (Schippers, 2002:9; Grubben, 2004:67).

According to Modi (2007:369), amaranth species are the most widely occurring leafy vegetable in South Africa. This is probably due to the ability of this genus to adapt to new environments, and its competitive ability, which permits its cultivation with minimum crop management (Van den Heever & Coertze, 1996:1). According to Van den Heever and Coertze (1996:1), there are six *Amaranthus* species that are important edible weeds in South Africa, namely *A. cruentus*, *A. caudatus*, *A. deflexus*, *A. blitum*, *A. thunbergii* and *A. spinosus*.

*A. cruentus* is known as “misbredie”, “hanekam”, “varkbossie” (Afrikaans); pigweed, cockscob and hell’s curse (English); “unomdlomboyi”, “imbuya”, “imifino”, “utyuthu” (isiXhosa); “imbuya”, ”isheke”, “indwabaza” (isiZulu); “theepe” (isiPedi, Sesotho and Setswana); “imbuya”, “isheke” (isiSwati); “vowa”, “thebe” (Tshivenda); “cheke”, “theyke” (Xitsonga); “mohwa” (Shona); and “tyutu” (Pondo) (Jansen van Rensburg *et al*., 2007:319).

### 2.1.1.2 Description

*Amaranthus cruentus* is a common flowering plant species belonging to the Amaranthaceae. *A. cruentus* is an annual herb with a variable, erect to spreading growth habit with large and complex inflorescences (Grubben, 2004:69; Jansen van Rensburg *et al*., 2007:319; Van Wyk & Gericke, 2007:64). According to Grubben (2004:69) and Van
Wyk (2005:55) mature plants can grow up to 2 m in height, depending on growth habit and environment. This amaranth species is best recognized by its leaf, of which the length measures twice or three times the width and often has a pointed tip (Schippers, 2002:10) (Fig. 2.1).

The leaves are variable in shape, green or purple in colour and normally alternate in arrangement. Petiole and tip are often obtuse. The flowers are small, numerous, regular and unisexual, with at least four times as many female flowers as male flowers. *Amaranthus* plants are cross pollinated although some self-pollinating occurs (Van den Heever & Coertze, 1996:2). Seeds of leafy amaranth are usually small, very shiny and have a dark brown to black colour (Van Wyk & Gericke, 2007:64). Domesticated forms characteristically have white seeds, while wild forms have glossy black seeds (Van Wyk, 2005:55).
2.1.1.3 Growth conditions

Amaranthus cruentus grows optimally under warm conditions, with day temperatures of 25 °C and night temperatures not lower than 15 °C, bright light and adequate availability of plant nutrients. It is a short day plant that prefers fertile, well-drained soils, high organic matter content, with adequate mineral reserves and a loose structure (Mposi, 1999:2; Grubben, 2004:70; Jansen van Rensburg et al., 2007:319). The optimum pH ranges between 5.5 and 7.5 (Van den Heever & Coertze, 1996:3). Most amaranth species that grow on marginal lands are tolerant to adverse conditions and drought once fully established (Mnkeni, Masika & Maphaha, 2007:377) but prolonged dry spells induce flowering and decrease leaf yield (Grubben, 2004:70).

The optimal spacing for amaranth plants to be harvested by uprooting is 10 cm x 10 cm, whereas for cutting fresh shoots (to encourage successive harvesting) the optimal spacing is about 20 cm x 20 cm. Frequent irrigation is essential for a fast growing crop that will flower late (Schippers, 2002:14). Application of nitrogen has been identified as a major factor influencing yield and an application rate of at least 80 kg N ha\(^{-1}\) has been recommended (Van den Heever & Coertze, 1996:3).

Amaranthus grows rapidly and may be harvested 30 to 50 days from sowing when they are about 15 cm to 20 cm high (Tindall, 1983:39; Grubben, 2004:71). However, the National Research Council (2006:36) contended that plants of amaranth produced seeds so abundantly, with rapidly emerging seedlings that sprouted with such vigour, that the first crop of leaves could be harvested within three weeks of planting. For harvesting, either the whole plant is uprooted, or established plants are cut back to within 15 cm of the soil.
surface, every 10 days, to encourage lateral growth, providing successive harvests (Van Wyk, 2005:64). When the entire plant is harvested, the yield is 20 to 25 t ha$^{-1}$, and when harvesting shoots successively, yields of up to 30 to 60 t ha$^{-1}$ are obtained (Tindall, 1983:39; Van den Heever & Coertze, 1996:3-4; Grubben, 2004:71).

2.1.1.4 Usage

The main use of leafy amaranth is as a cooked vegetable (Brenner et al., 2000:267). The young leaves, the growth points or the whole seedling of the amaranth plant are harvested and cooked as a potherb, relish, stew or side dish. The cooked leaves are added to different dishes depending on local tradition and availability of other food stuffs (Grubben, 2004:67). The leaves have a fine and smooth texture and taste similar to spinach when cooked (Brenner et al., 2000:267; Jansen van Rensburg et al., 2007:319). The leaves may also be fried or ground for use as snuff (Grubben, 2004:67; Jansen van Rensburg et al., 2007:320).

*Amaranthus* is a nutritious vegetable (Schippers, 2002:15). The leaves contain high levels of essential micro-nutrients, such as B-carotene, vitamin C, iron and calcium (Van Wyk, 2005:55). *A. cruentus* also contains large amounts of high quality protein in the leaves and provides essential amino acids that are lacking in diets based on cereals and tubers (Schippers, 2002:15; Van Wyk, 2005:55). This latter statement is supported by the National Research Council (2006:37) who reported *A. cruentus* to have a protein content of about 25% whilst Mnkeni, Masika and Maphaha (2007:377) reported a protein content of 17.5 % to 38.3%.
2.1.2 Tsamma melon (*Citrillus lanatus* L.)

2.1.2.1 Background

*Citrillus lanatus* originated in the western Kalahari region of Namibia and Botswana where it can be still found in the wild in a diversity of forms together with other *Citrillus* species (Schippers, 2002:63; Van der Vossen, Denton & El Tahir, 2004:185). *Citrillus lanatus* was domesticated during prehistoric times in Southern Africa, and its cultivation became widespread in Mediterranean Africa, West Asia and the Middle East 3000 years ago. *Citrillus lanatus* is now widespread in tropical, subtropical and warm temperate (hot summers) regions of the world (Van der Vossen, Denton & El Tahir, 2004:185).

The leaves of *Citrillus lanatus* are known as “maketaanblare” (Afrikaans); “ibotola” (isiNdebele); “umxoxozi” (isiXhosa); “ikhabe” (isiZulu); “mogapu” (isiPedi); “thoomo” (Sesotho); “makopuntji” (Setswana); “gwadi” (Tshivenda); and “bawora” (Shona) (Jansen van Rensburg *et al.*, 2007:323).

2.1.2.2 Description

*Citrillus lanatus* belongs to the Cucurbitaceae and is a creeping annual herb with hairy stems, forked tendrils and three-lobed hairy leaves (Van der Vossen, Denton & El Tahir, 2004:187; Van Wyk & Gericke, 2007:38) (Fig. 2.2a). Both the male and female flowers are borne on the same plant (monoecious) and are bright yellow or white in colour (Jansen van Rensburg *et al.*, 2007:323). The plant may grow up to 10 m long, climbing by 1 to 4 tendrils (Van der Vossen, Denton & El Tahir, 2004:187). The fruits of this plant taste
bitter thus the name “bitter melon” (Fig. 2.2b). *Citrillus lanatus* is rich in iron and lowers the blood sugar (hypoglycemic) and some of its proteins have shown the ability to inhibit the AIDS virus (Schippers, 2002:65; Van der Vossen, Denton & El Tahir, 2004:185).

**FIGURE 2.2**: (a) *Citrillus lanatus* L. and (b) harvested fruits

### 2.1.2.3 Growth conditions

*Citrillus lanatus* can grow on a wide variety of soils but prefers deep, sandy, free draining soils (Schippers, 2002:66). In the wild it often occurs in dry watercourses and on sandy flats (Van der Vossen, Denton & El Tahir, 2004:188). *Citrillus lanatus* is also found naturally in disturbed lands or as weeds in cultivated lands. *Citrillus lanatus* is drought-tolerant because of its deep root system (Schippers, 2002:66). *Citrillus lanatus* is a day length neutral plant and grows well in soils with pH 6 to 7. Seeds of *Citrillus lanatus* will typically germinate four to seven days after planting. The fruits ripen between three to four months after sowing, depending on the temperatures (Schippers, 2002:66; Van der Vossen, Denton & El Tahir, 2004:188).
An annual rainfall of about 600 mm to 1200 mm is ideal for *Citrillus lanatus* but the crop is very sensitive to the combination of high humidity and low temperatures (20 °C). High yield can be obtained under irrigation provided no wetting of leaves takes place (Schippers, 2002:66). Reportedly, the crop responds particularly well to manure applications, and application of nitrogen helps to improve photosynthetic activity, vigorous vegetative growth and a dark green colour of the leaves (Dauda, Ajayi & Ndor, 2008:3109).

2.1.2.4 Usage

According to Van Wyk and Gericke (2007:38), *C. lanatus* is one of the most important summer fruits in southern Africa. Both leaves and young fruits are used as a cooked vegetable (Van der Vossen, Denton & El Tahir, 2004:185-186). At times this crop is used as a minor crop in mixed cropping systems, with maize as the major crop. In these mixed cropping systems, it covers the soil surface, which helps to control weeds (Schippers, 2002:66; Jansen van Rensburg *et al.*, 2007:323). In the Kalahari Desert region of southern Africa, the San people use wild watermelon (known as *tsamma*) as an important water source during the dry season (Van Wyk, 2005:136).

2.1.3 Cowpea (*Vigna unguiculata* (L.) Walp.)

2.1.3.1 Background

*Vigna unguiculata* originated in Africa, where a large genetic diversity of wild types still occurs; Southern Africa being the richest (Madamba *et al.*, 2006:221; Gazendam & Oelofse, 2007:387). According to Madamba and Grubben (2004:550), *V. unguiculata* was
introduced in Madagascar and other Indian Ocean islands where it can still be found. *V. unguiculata* is one of the most important food legume crops in the semi-arid tropics, covering Asia, Africa, southern Europe and Central and South America. The crop is among the most widely distributed legumes and among the top three or four leafy vegetables in most parts of Africa (Barret, 1990:391).

*V. unguiculata* has a number of common names, including cowpea, crowder pea, black eye pea, southern pea, and is also known as lubia, niebe, coupe or frijole. In the past *V. unguiculata* L., was referred to as *Vigna sinensis* (L.) (Faye, 2005:1). In South Africa, *V. unguiculata* is known as “koertjie” (Afrikaans); “dinawa” (isiNdebele and Setswana); “iimbotyi” (isiXhosa); “isinhlumaya” (isiZulu); “monawa” (Sepedi and Sesotho); “nawa” (Tshivenda); “tinyawa” (Xitsonga); and “murowi we nyemba” (Shona) (De Ronde & Spreeth, 2007:381; Van Wyk & Gericke, 2007:30).

*V. unguiculata* is an important component of traditional intercropping systems in the complex smallholder farming systems of the dry savannas in sub-Saharan Africa (Schippers, 2002:155; De Ronde & Spreeth, 2007:381; Gazendam & Oelofse, 2007:387). The spreading, prostrate types are the varieties that are mainly used as a leafy vegetable (Jansen van Rensburg *et al*., 2007:323).

**2.1.3.2 Description**

*V. unguiculata* is an annual or perennial herb (Fig. 2.3) that is cultivated as an annual crop (Madamba *et al*., 2006:223). It has a strong taproot and many spreading lateral roots in the surface soil (Madamba *et al*., 2006:223). The plant is drought tolerant and prefers warm
weather (Madamba et al., 2006:225). It belongs to the Leguminosae or Fabaceae (Van Vuuren, 2005:24; Gazendam & Oelofse, 2007:387). Growth forms vary and may be erect, trailing, climbing or bushy. The plant is usually indeterminate (Jansen van Rensburg et al., 2007:323). *V. unguiculata* can be a short day plant or a day neutral plant (Bubenheim, Mitchell & Nielsen, 1990:535; Madamba et al., 2006:225). In dry climates, *V. unguiculata* is almost entirely self-pollinated, but in areas with high air humidity, cross pollination by insects often occurs (Madamba et al., 2006:224; National, Research Council, 2006:115).

Stems of *V. unguiculata* are striate, smooth or slightly hairy and sometimes tinged with purple (Madamba et al., 2006:223-224). Leaves are dark green, alternate and trifoliate (Van Wyk, 2005:383; Madamba et al., 2006:223). The first pair of leaves is simple and opposite, and the leaf petiole is 5 cm to 25 cm long. Flowers are arranged in intermediate inflorescences at the distal ends of 5 cm to 60 cm long peduncles. Flowers are borne in alternate pairs, with usually only a few flowers per inflorescence. The fruit are pods that vary in size, shape, colour and texture. The fruit may be erect, crescent-shaped or coiled, and is usually yellow coloured when ripe, but may also be brown or purple in colour. The seeds are reniform to oblong in shape and variable in colour but white with a black spot (hence “black eye pea”) is the most common colour pattern (Van Wyk, 2005:383).
The *V. unguiculata* plant has no particular preference as far as soil texture is concerned, as long as the soil is well-drained (Madamba *et al.*, 2006:225; Plants For A Future, 2008:1). *V. unguiculata* has a deep tap root and can extract soil water from depths exceeding 120 cm, contributing to its drought tolerance (Schippers, 2002:155). *V. unguiculata* is heat-loving and well adapted to hot cropping areas, but also yields well in cooler areas (Coertze & Venter, 1996:1-2).

The water requirements of *Vigna* species with a determinate growth habit decline rapidly after flowering but species with an indeterminate growth use soil water over a longer period of time (Madamba *et al.*, 2006:225). *V. unguiculata* is considered a drought tolerant crop, which can be produced successfully in areas with a rainfall of 300 mm per year.
(Coertze & Venter, 1996:2). A temperature of 8.5 °C is considered the lower threshold for successful germination. Temperatures above 21 °C are conducive for vegetative growth, but temperatures above 33 °C advance flowering time and can promote flower abscission if they coincide with water stress (Coertze & Venter, 1996:1; Jansen van Rensburg et al., 2007:324).

The best planting time for *V. unguiculata* is middle November in cooler areas and middle December, in warmer areas. The crop can also be planted at the beginning of the rain season (early October) or late in January, but this increases the risk of crop failure. Early planting can lead to poor germination of the seed because of low temperature and can also increase the risk of flower abortion because flowering will occur in December and January, when temperature peaks. Planting late in summer can lead to low yield as a result of weaker growth and early frost. Low temperatures also results in the plants not forming pods, resulting in very low grain yield (Coertze & Venter, 1996:2). Leaves can be harvested by cutting the entire plant before flowering or by means of partial defoliation. When the entire shoot is cut, the plant is allowed to regrow for harvest of the grain (Bubenheim, Mitchell & Nielsen, 1990:1).

### 2.1.3.4 Usage

*V. unguiculata* is an important food crop for small-scale farmers, who use both leaves and grain (Schippers, 2002:155). During the vegetative stages, the leaves and growth points serve as an important component in human diets throughout Africa, being consumed as cooked greens (Bubenheim, Mitchell & Nielsen, 1990:535; Coertze & Venter, 1996:1; Van Wyk, 2005:383; Madamba et al., 2006:222; De Ronde & Spreeth, 2007:381). The leaves
can also be sun dried for storage and use during the dry season. Dried cooked leaves are less prone to insect damage than grain (Barret, 1990:5; Madamba et al., 2006:222).

2.1.4 Jew’s mallow (*Corchorus olitorius* L.)

2.1.4.1 Background

*Corchorus olitorius* has been cultivated for centuries in Africa and Asia, and occurs in the wild on both continents. Africa has more wild species and larger genetic diversity than Asia (Fondio & Grubben, 2004:218). *Corchorus olitorius* is a popular vegetable in semi-arid and humid topic regions of Africa (Schippers, 2002), and is said to be the leading leafy vegetable in Côte d’Ivoire, Benin, Nigeria, Zimbabwe, Cameroon, Sudan, Uganda and Kenya (Fondio & Grubben, 2004:218). *Corchorus olitorius* is known as Jute (English); “wilde jute” (Afrikaans); “ligusha” (Sepedi, Sesotho, Setswana and siSwati); “delele” (Tshivenda) and “ligushe” (Xitsonga and Shangaan) (Jansen van Rensburg et al., 2007:322).

2.1.4.2 Description

*Corchorus olitorius* belongs to the Tiliaceae and is an erect, annual or perennial herb that grows up to 1.5 m tall (Nkomo & Kambizi, 2009:1078). *Corchorus olitorius* stems are angular and well developed with abundant fibres in the phloem tissue. The leaves are simple to lacerolate and have serrated margins and distinct hair-like teeth at the base (Fig 2.4) (Schippers, 2002:221; Fondio & Grubben, 2004:219). Inflorescences have a one to four flowered axillary fascicle, with bisexual flowers and cylindrical fruits (Fondio &
The flowers of *Corchorus olitorius* are bright yellow, small and usually self-pollinating, but cross pollination of up to 10% commonly occurs (Fondio & Grubben, 2004:219).

**FIGURE 2.4:** *Corchorus olitorius* L.

**2.1.4.3 Growth conditions**

Wild plants of this species grow in grasslands and fallowed or abandoned fields, usually close to marshes, rivers or lakes (Schippers, 2002:223). This short-day plant thrives under hot and humid conditions and prefers sandy loam soils rich in organic matter. It grows poorly on heavy clay (Fondio & Grubben, 2004:219; Jansen van Rensburg *et al.*, 2007:322). Natural germination of this species occurs towards the end of spring and the plant grows throughout summer (Nkomo & Kambizi, 2009:1079). *Corchorus olitorius*
performs well in areas with a high rainfall (600 mm – 2000 mm), high temperatures (30 °C day and 25 °C night), with optimum temperature being 25 °C to 32 °C (Schippers, 2002:225). However, the crop can tolerate an annual precipitation between 400 mm and 429 mm, and a mean annual average temperature range of 16.8 °C to 27.5 °C. In addition, *Corchorus olitorius* can tolerate soil pH in the range of 4.5 to 8.2. Growth is negatively affected by temperatures below 15 °C and long periods of water deficit (Schippers, 2002:225; Fondio & Grubben, 2004:219; Plants For A Future, 2008:2).

Sowing is done in lines 30 cm to 50 cm apart using a row spacing of 10 cm to 15 cm (Schippers, 2002:225). Once the seedlings are 5 cm to 10 cm tall, they are transplanted 10 cm to 20 cm apart in rows spaced 30 cm to 50 cm apart. It is reported that a spacing of 10 cm x 45 cm can yield 29 kg of leaves per 10 m². Organic fertiliser may be applied up to 20 t ha⁻¹. A basal application with nitrogen, phosphorus and potassium (NPK) and a side dressing with nitrogen is recommended for optimal yield. Nitrate fertilisers give better results than ammonium fertilisers. Nitrogen fertiliser greatly improves the micronutrient content of the plant (Fondio & Grubben, 2004:220).

### 2.1.4.4 Usage

*Corchorus olitorius* is used as a leafy mucilaginous vegetable (Fondio & Grubben, 2004:218). The cooked leaves form a sticky sauce that aids consumption of starchy balls made from yam or cassava. Leaves of *Corchorus olitorius* are seasonal and highly perishable. Different ways of preserving leaves of this specie have been developed in order to extend the period during which they are available. These include drying of fresh, blanched or cooked leaves in the sun. These techniques transform the leaves into dry
products that have a prolonged shelf life. However, some nutrients may be lost during this preservation process (Nkomo & Kambizi, 2009:1079).

2.1.5 Nightshade \((Solanum retroflexum\) Dun.)

2.1.5.1 Background

\(Solanum retroflexum\) is one of the species that form part of the \(S. nigrum\) complex. In Africa, species belonging to the \(Solanum nigrum\) complex are probably the second most popular traditional leafy vegetables after amaranth (Schippers, 2002:199). The species are widely distributed and grow in various habitats from tropical to temperate regions and from sea level to altitudes exceeding 3500 m. They are generally found in disturbed habitats, such as roadsides, arable lands, railway cuttings, rubbish tips, around buildings, under trees, and along forest and grassland margins (Edmonds & Chweya, 1997:78). In South Africa, \(S. nigrum\) spp. which include \(S. retroflexum\), are known as “nastergal” (Afrikaans); “ixabaxa” (isiNdebele); “umsobo” (isiXhosa); “umgwaba” (isiZulu); “lethotho” (isisPedi); “momoli” (Sesotho); “umsobo” (isiSwati); “muxe” (Tshivenda); “kophe” (Xitsonga) and “musaka” (Shona) (Jansen van Rensburg et al., 2007:321).

2.1.5.2 Description

\(S. retroflexum\) is an erect, branched annual or biannual herbaceous plant belonging to the Solanaceae. Plants are sparsely hairy and can reach a height of about 75 cm (Van Wyk & Gericke, 2007:56). The leaves are alternate and bright green in colour but purple pigmentation may occur (Fig. 2.5). The plant has white flowers with a yellow centre and
green berries that turn dark purple when ripe (Van Averbeke, Tshikalange & Juma, 2007:349). The small flowers are about 4 mm to 10 mm long, and consist of white petals and conspicuous yellow anthers that are arranged in a drooping umbel-like inflorescence (Jansen van Rensburg et al., 2007:322). *S. retroflexum* is self-pollinating but natural out- and cross-breeding can occur (Edmonds & Chweya, 1997:73).

![Solanum retroflexum](image)

**FIGURE 2.5:** *Solanum retroflexum* Dun.

### 2.1.5.3 Growth conditions

The *S. retroflexum* species is commonly found in fairly humid environments with at least 500 mm of rain per year. It prefers fertile soils with high nitrogen and phosphorus contents. Optimum growth temperature of *S. nigrum* and related species ranges between 20 °C and 30 °C, but the majority of *S. nigrum* species will tolerate a temperature range of 15 °C to 35 °C (Edmonds & Chweya, 1997:82). When grown during winter, maximum growth and
biomass production are attained when plants are exposed to full sunlight, whilst during summer, shading of up to 60% is beneficial (Jansen van Rensburg et al., 2007:322).

*S. retroflexum* yields best at a spacing of 15 cm to 50 cm between plants and 30 cm to 60 cm between rows. High soil fertility and top-dressing with nitrogenous fertiliser up to the flowering stage encourages vigorous growth and leaf production (Edmonds & Chweya, 1997:82). Reportedly, *S. retroflexum* is not sensitive to differences in soil pH (Plants For A Future, 2008:1).

### 2.1.5.4 Usage

The leaves and tender shoots of species belonging to the *S. nigrum* complex are widely used as vegetables throughout the world and have provided a food source since early times (Edmonds & Chweya, 1997:56). They are harvested and cooked (boiled) as pot-herbs. The leaves may also be eaten raw or used in soups and sauces. The leaves taste bitter and are often mixed with *Amaranthus* spp., *Corchorus* spp. or other green leafy vegetables to reduce bitterness. The leaves can also be sun dried and stored. The leaves provide appreciable amounts of protein and amino acids, minerals (calcium, iron and phosphorus) and vitamin A and C (Edmonds & Chweya, 1997:57). The berries of *S. retroflexum* are poisonous when green, but edible and used for jam once they turn black upon ripening (Van Wyk & Gericke, 2007:56).
2.1.6 Non-Heading Chinese cabbage (*Brassica rapa* L. subsp. *chinensis*)

2.1.6.1 Background

*Brassica rapa* subsp. *chinensis* is one of the most economically important vegetable crops, and was probably introduced into China thousands of years ago. *Brassica rapa* subsp. *chinensis* is one of the most important vegetable crops in China and Taiwan and accounts for 12% of total cultivated area planted to leafy vegetables (Chuang *et al*., 2004:331; Jansen van Rensburg *et al*., 2007:321). Chinese farmers developed two main types of Chinese cabbage, namely heading (*Brassica rapa* L. subsp. *pekinensis*) and non-heading (*Brassica rapa* L. subsp *chinensis*). In tropical Africa, *Brassica rapa* subsp. *chinensis* is cultivated in many countries, such as Cameroon, Democratic Republic of Congo, Sierra Leone, Kenya, Uganda, Tanzania, Eritrea, Ethiopia, Mozambique and Zimbabwe (Schippers, 2002:41; Toxopeus & Baas, 2004:146).

2.1.6.2 Description

*Brassica rapa* subsp. *chinensis* is an annual to biennial flowering vegetable that belongs to the Crucifereae. Plants may grow to about 15 cm to 30 cm high at the end of the vegetative season (Fig. 2.6). *Brassica rapa* subsp. *chinensis* has dark green leaves supported by light green to white petioles. The stem is branched and the flowers are bisexual and pollinated by bees. *B. rapa* subsp. *chinensis* has an inflorescence that is a terminal umbel-like raceme, which can be up to 60 cm long, with stout taproot which is sometimes partly swollen (Toxopeus & Baas, 2004:147; Jansen van Rensburg *et al*., 2007:321). The *Brassica rapa* subsp. *chinensis* is a flowering vegetable that takes 6 to 11
weeks from sowing to the end of the vegetative stage (Van Averbeke, Tshikalange & Juma, 2007:349).

**FIGURE 2.6: Brassica rapa subsp. chinensis**

**2.1.6.3 Growth conditions**

*Brassica rapa* subsp. *chinensis* is a cool season crop that requires adequate availability of soil water and plant nutrients for optimum growth (Jansen van Rensburg *et al.*, 2007:321). The plant is not sensitive to differences in soil texture, requires well-drained soils and does not tolerate poorly drained conditions. It grows well in soils with a pH of 5.5 to 6.5 (Toxopeus & Baas, 2004:148). Seeds germinate optimally at the 20 °C to 25 °C range but germination is also known to occur at temperatures far below this optimum (5 °C). Seedlings are transplanted 20 to 30 days after sowing in rows 30 cm to 50 cm apart and 50 cm between rows (Toxopeus & Baas, 2004:148).
The mineral uptake in *Brassica rapa* subsp. *chinensis* is high. A *Brassica rapa* subsp. *chinensis* crop that yields 25 t ha\(^{-1}\) requires 150 – 200 kg N, 15 – 20 kg P and 100 – 150 kg K ha\(^{-1}\) and application of 3.5 kg ha\(^{-1}\) of boron (Borax) before planting is beneficial. Crops in the tropics may suffer from lack of micronutrients resulting in yield loss and increased disease incidence. Watering should be done as required to keep the rooting zone at 65 to 85% of field capacity (Toxopeus & Baas, 2004:149).

### 2.1.6.4 Usage

*Brassica rapa* subsp. *chinensis* leaves can be eaten at any stage from seedling to mature stage, raw in salads or cooked in soups (Toxopeus & Baas, 2004:146). Immature inflorescences can be cooked like broccoli. Edible oil can be extracted from the seed (Schippers, 2002:41). Young plants are boiled as green vegetables or they are used as an ingredient in stir-fries, noodle dishes and soups (Van Wyk, 2005:107). *Brassica rapa* subsp. *chinensis* has a nutritional value similar to that of cabbage but with lower caloric value of only 12 kcal per 100 g (Van Wyk, 2005:107). Fresh leaf yield typically ranges between 5 t h\(^{-1}\) and 30 t ha\(^{-1}\), with date of planting being an important factor (Jansen van Rensburg *et al*., 2007:321). However, Toxopeus and Baas (2004:150) stated that the yield varied widely according to crop and maturity period, and reported 30 to 50 t ha\(^{-1}\) of fresh product being the range for well-grown crops.
2.1.7 Pumpkin (*Cucurbita maxima* Duchesne)

2.1.7.1 Background

*Cucurbita maxima* is one of the most diverse domesticated species. *Cucurbita maxima* originated from the wild *Cucurbita maxima* subsp. *andreana* over 400 years ago in temperate South America (Chingumira Ngwerume & Grubben, 2004:263). *Cucurbita maxima* is native to the warm temperate zone of the South America. *Cucurbita maxima* has been reported in many countries of Africa and probably occurs in all countries. It is most important in the cooler parts of southern Africa and the Sahel region and less important in more humid West and East Africa (Chingumira Ngwerume & Grubben, 2004:263; Ndoro *et al*., 2007:649).

The leaves of *Cucurbita maxima* are called “pampoenblare” (Afrikaans); “ibobola” (isNdebele); “cetshana” (isiXhosa); “intanga” (isiZulu); “mphodi” (isiPedi); “mekopu” and “maphutse” (Sestwana and Sesotho); “thanga” (Tshivenda); and “tinwembe” (Xitsonga) (Jansen van Rensburg *et al*., 2007:323).

2.1.7.2 Description

*Cucurbita maxima* is a spreading, annual, climbing herb belonging to the Cucurbitaceae. It is widely grown in Southern Africa for its leaves, flowers, fruits and seeds (Ndoro *et al*., 2007:649). The leaves are alternate, simple and palmately lobed (Fig. 2.7). Stems are rounded with alteral branched tendrils. The stems are long running, softly pubescent and often root at the nodes. The leaves and stems are covered in sharp, translucent hairs that
can irritate the human skin (Chingumira Ngwerume & Grubben, 2004:264; Jansen van Rensburg et al., 2007:323). Male and female flowers are yellow, with rounded lobes that flare out. The ripe fruits of *Cucurbita maxima* are often yellow or orange, but dark green, pale green, orange-yellow, white, red and gray fruits also occur. They vary greatly in shape, ranging from oblate to oblong. The rind is smooth and usually lightly ribbed (Chingumira Ngwerume & Grubben, 2004:263).

**FIGURE 2.7:** *Cucurbita maxima* Duschene

### 2.1.7.3 Growth conditions

*Cucurbita maxima* is a warm season plant that is tolerant to drought and shade and grows best under warm and humid conditions. *Cucurbita maxima* is sensitive to frost and water logging. It can be cultivated on well drained soil with neutral or slightly acid reaction (pH 5.5 to 6.8), and grows best on soils rich in organic matter. The recommended plant spacing
is 2 m x 2 m with one to four seeds per planting station (Chingumira Ngwerume & Grubben, 2004:265; Jansen van Rensburg et al., 2007:323; Ndoro et al., 2007:649; Biesiada et al., 2009:204).

The optimum soil temperature for rapid seed germination is 18 °C to 30 °C and 20 °C to 27 °C for growth. Poor or no growth occurs at air temperatures below 15 °C. Optimum root growth occurs at a soil temperature of 20 °C. Below 16 °C, germination is unsatisfactory low. The total nitrogen recommendation for *Cucurbita maxima* amounts to between 150 and 200 kg N ha\(^{-1}\), where one third to half of the total N application should be applied before sowing and the rest as a top dressing when the first flowers occur on the plants (Chingumira Ngwerume & Grubben, 2004:265; Biesiada et al., 2009:204).

### 2.1.7.4 Usage

The leaves, fruits, flowers and seeds of *Cucurbita maxima* are edible. The fruits are boiled or steamed, the seeds are roasted and the leaves and flowers boiled to make a green vegetable stew (Ndoro et al., 2007:649). The yellow or orange flesh of the fruit is also cooked as a sweet vegetable or enjoyed as a soup. The fruits have a low energy value of 300 kcal kg\(^{-1}\), but are a good source of minerals and B-carotene, and also contain moderate quantities of vitamins B and C (Van Wyk, 2005:161). Leaf yields of *Cucurbita maxima* are highly variable and data are limited. Under extensive low input management, the leaf yield is low, around 5 t ha\(^{-1}\). However, with good care, a yield of 15 t ha\(^{-1}\) can be achieved and with improved cultivars, a yield of 30 t ha\(^{-1}\) is possible. The leaves are usually harvested using partial defoliation. Excessive picking of young leaves and shoots reduces fruit yield (Chingumira Ngwerume & Grubben, 2004:266).
2.1.8 Spider flower (*Cleome gynandra* L.)

2.1.8.1 Background

The origin of *Cleome gynandra* is not known. There are claims that it has a Southern Asian origin, whilst others suggest that it originates from Africa or Central America (Mnzava & Chigumira Ngwerume, 2004:191; Silué, 2009:1). According to Chweya and Mnzava, (1997:8) and Ochuodho and Modi, (2005:50), *Cleome* is probably a native of Africa (Egypt, Cameroon, Mali, Nigeria, Ethiopia, Madagascar, and Tanzania) but now it is widely distributed in tropical and subtropical regions throughout the world, including Southern Africa. According to Schippers (2002:53), *Cleome gynandra* is growing in popularity in Uganda, Zimbabwe and Zambia, where a change from a tolerant weed through a phase of backyard gardening into a fully-fledged cultivated crop has been seen. *Cleome gynandra* is known as “palmbossie” (Afrikaans); African cabbage or cat’s whiskers (English); “ulude” (isiNdebele); “amazonde” (isiZulu); “lerotho” (Sepedi and Sesotho); “murudi” (Tshivenda); “bangala” (Xitsonga) and “nyere” (Shona) (Jansen van Rensburg et al., 2007:320).

2.1.8.2 Description

*Cleome gynandra* is an erect herbaceous annual herb belonging to the Capparaceae (Schippers, 2002:54). It can grow up to 1.5 m tall, but is strongly branched. It has a long tap root with few secondary roots and rarely glabrous stem (Chweya & Mnzava, 1997:11). The leaves are compound and have several leaflets that radiate from the tip of the leaf stalk (Fig. 2.8) (Van Wyk & Gericke, 2007:68). *Cleome* follows the C4 photosynthetic
pathway, an adaptation that enables it to survive in dry and hot environments (Fletcher, 1999:3; Mnzava & Chigumira Ngwerume, 2004:193; Silué, 2009:1). The leaves exhibit a strong circadian movement, following the direction of the sun, and the species grow in areas with short periods of rains, (Chweya & Mnzava, 1997:16; Schippers, 2002:55). Both the leaves and stems are covered with glandular hair (Fletcher, 1999:3). Pigmentation of the stems varies. It can either be green, pink, violet or purple (Chweya & Mnzava, 1997:11; Jansen van Rensburg et al., 2007:320; Silué, 2009:1). The terminal inflorescence carries bisexual, erect spider-like clusters of flowers, which are white and at times tinged with purple. The fruit capsules are elongated, usually green or yellow in colour (Mnzava & Chigumira Ngwerume, 2004:193). Plants are predominantly self-pollinating but a relatively high percentage of cross pollination may occur (Chweya & Mnzava, 1997:11; Fletcher, 1999:2; Schippers, 2002:55; Mnzava & Chigumira Ngwerume, 2004:193; Jansen van Rensburg et al., 2007:320).

FIGURE 2.8: Cleome gynandra L.
2.1.8.3 Growth conditions

*Cleome gynandra* grows well in fertile soils that are enriched with animal manure. The soil should be deep, well drained and have a pH that ranges between 5.5 and 7.0. Preferred soil textures are sandy loam to clay loam with high organic matter contents and adequate mineral reserves (Fletcher, 1999:3). Growth of *Cleome gynandra* is inhibited by shade and temperatures below 15 °C (Schippers, 2002:57; Mnzava & Chigumira Ngwerume, 2004:193). Growth is also inhibited in poorly drained and heavy soils. *Cleome gynandra* requires adequate soil water availability and high light intensity for optimum growth (Jansen van Rensburg *et al.*, 2007:320). *Cleome gynandra* can grow in areas with short rainy seasons and requires temperatures of 18 to 25 °C (Fletcher, 1999:3; Schippers, 2002:53). *Cleome gynandra* tolerates mild water stress, but prolonged water stress hastens flowering and senescence (Jansen van Rensburg *et al.*, 2007:320).

Due to their small size, the seeds are usually mixed with dry sand at a ratio of 1:10, before being drilled or broadcast in rows spaced 30 cm to 60 cm apart. After 3 weeks, plants are thinned to a final spacing of 10 cm to 20 cm between plants when sown in rows, or 25 cm to 30 cm in each direction when broadcast. Transplanting is virtually impossible due to the taproot (Schippers, 2002:57; Mnzava & Chigumira Ngwerume, 2004:193). After thinning at three to four weeks, a top dressing of up to 100 kg ha\(^{-1}\) ammonium nitrate is recommended. Applications of 30 t ha\(^{-1}\) of animal manure are said to result in delayed flowering and, therefore, longer harvest periods and significantly higher yields of leaves and shoots (Schippers, 2002:57; Mnzava & Chigumira Ngwerume, 2004:194).
2.1.8.4 Usage

*Cleome* is commonly used as a leafy vegetable (Denari, S.a.:2; Fletcher, 1999:4). The nutritional composition of raw leaves varies, depending on soil fertility, environment, plant type, plant age and production techniques used (Fletcher, 1999:3). In Africa, the tender leaves, young shoots, and sometimes the flowers are eaten boiled as a potherb, relish, stew or side dish. The leaves are bitter and to reduce their bitterness, they are cooked with milk (and left overnight) or together with other leafy vegetables, such a *Vigna unguiculata, Amaranthus cruentus* or *Solanum* spp. (Mnzava & Chigumira Ngwerume, 2004:191). The leaves are harvested by picking the top shoot, allowing new side shoots to develop, or by picking the tender leaves and young shoots. Cumulative leaf yields of up to 30 t ha\(^{-1}\) can be attained (Fletcher, 1999:5; Mnzava & Chigumira Ngwerume, 2004:194; Jansen van Rensburg et al., 2007:320; Silué, 2009:1).

*Cleome* is rich in magnesium and iron and also has a relatively high level of nicotinic acid (Van Wyk & Gericke, 2007:68). The leaves also contain appreciable amounts of vitamin A and C and the minerals calcium, magnesium and iron (Ekpong, 2009:236; Silué, 2009:1). The crude protein composition varies from 17.9% in green-stemmed plants to 31.4% in purple-stemmed plants. The lipid content varies from 25.1% in green-stemmed plants to 29.6% in purple-stemmed plants. Oleic and linoleic acids account for about 81% of the total fatty acids, with linoleic acid accounting for about 59% (Fletcher, 1999:3).
2.1.9 Swiss chard (*Beta vulgaris* var. *cicla*)

2.1.9.1 Background

*Beta vulgaris* var. *cicla* is quite closely related to the garden beet (*Beta vulgaris* var. *esculenta*) and sugar beet (*Beta vulgaris* var. *vulgáris*) (Oyen, 2004:110; Van Wyk, 2005:87). Wild forms of *Beta vulgaris* var. *cicla* occur along the shores of the Mediterranean, extending eastwards as far as Indonesia, and westwards along the coasts of the Atlantic up to the Canary Islands and southern Norway. *Beta vulgaris* var. *cicla*, which is grown for its leaves, was taken into cultivation in the eastern Mediterranean or the Middle East and was first mentioned in the literature in Mesopotamia in the 9th century BC (Oyen, 2004:110). Around 400 B.C. *Beta vulgaris* var. *cicla* was being cultivated as a leafy vegetable in Greece. *Beta vulgaris* var. *cicla* can be found in all African countries, but is more common in the cooler parts of East and Southern Africa than in the tropical lowlands. In Africa, it mostly serves as a relatively minor market vegetable around the big cities (Oyen, 2004:110).

2.1.9.2 Description

*Beta vulgaris* var. *cicla* belongs to the Chenopodiaceae. *Beta vulgaris* var. *cicla* is a tall annual or biennial green leafy vegetable (Fig. 2.9a). It has a thick, crunchy stalk that can be white, red or yellow in colour, and fleshy dark green leaves (Fig. 2.9b). The leaves are curly, with lighter-coloured ribs running throughout. *Beta* spp. are very variable and adaptable, with branched taproots and varying sugar content. The greenish flowers are borne in slender clusters and turn into small, dry, spiny fruits (Van Wyk, 2005:87).
2.1.9.3 Growth conditions

Although *Beta vulgaris* var. *cicla* grows well during warm weather, seedlings are better established under cool, moist conditions (Swiss chard, S.a.; The Owlcroft Company, 2010). Good plant stands are achieved when planting is delayed until the average daytime soil temperature at seeding depth is 10 °C or higher. However, according to Drost (2005:1-2), *Beta vulgaris* var. *cicla* seeds can be sown as soon as the soil temperature has reached 4 °C. Seeds germinate best at 12 to 23 °C and require about one to two weeks to emerge. Temperatures above 26 °C can reduce seed germination. Higher temperatures tend to reduce growth and quality, and can cause bitter or off-flavours to develop (Oyen, 2004:112). *Beta vulgaris* var. *cicla* is a half-hardy plant, which can withstand light frost, but growth is retarded by low temperatures. Prolonged exposure to temperatures below 5 °C may induce seed production (bolting) (Swiss chard, S.a.).

Planting *Beta vulgaris* var. *cicla* too deep, or when soil crusts develop after sowing due to heavy rains, can result in poor stands. *Beta vulgaris* var. *cicla* is tolerant to soil salinity, because it accumulates higher levels of sodium in its tissues than most other leafy
vegetables, but extreme salinity causes a quality and yield decrease (Pokluda & Kuben, 2002:114). The *Beta vulgaris* var. *cicla* plant prefers well-drained soils, but is not particular about soil texture. For good growth, the plant requires the soil to be reasonable fertile and amply supplied with water. The water requirements of *Beta vulgaris* var. *cicla* depend on soil type and temperature, but the plant typically requires 25 mm to 50 mm of water per week. *Beta vulgaris* var. *cicla* is usually drilled directly into the soil in rows spaced 45 cm to 60 cm apart. Later on, plants are thinned to a spacing of 25 cm to 30 cm in the row (Oyen, 2004:112; Swiss chard, S.a.).

The crop responds well to organic manuring and periodic side-dressings of nitrogen, which ensure continuous, rapid growth. A general rule is to apply the fertiliser mixture 2:3:4 (30) at rates of 500 to 1000 kg per hectare, depending on the nutrient status of the soil at planting, followed by 175 to 225 kg limestone ammonium nitrate (LAN) ha\(^{-1}\) at 4 weeks and again at 8 weeks after planting (Swiss chard, S.a.).

### 2.1.9.4 Usage

The leaves of *Beta vulgaris* var. *cicla* are the main parts used. These are prepared and eaten as spinach (potherb). In Africa, the leaves and leaf stalks are usually prepared with the midribs in one dish (Oyen, 2004:110). They are also used as an ingredient in soups, pastries and savoury tarts. Cooked leaves are very nutritious and contain about 200 kcal per kg. The leaves are also fairly rich in minerals (calcium, iron, phosphorus, potassium and especially magnesium), and vitamins, especially vitamin A. One kg of fresh stalks contains approximately 3.790 mg potassium, 510 mg calcium, 81 mg magnesium, 2130 mg sodium, and 460 mg phosphorus (Pokluda & Kuben, 2002:114).
Beta vulgaris var. cicla is harvested by successive removal of the outer leaves as soon as these are large enough (about 18 cm). Leaves are usually cut with a sharp knife about 5 cm above the ground, taking care not to harm the younger leaves, or are wrenched off the plant with a sideways twist. Over-harvesting at one picking can weaken growth and affect the size of the later picks, as well as reduce total yield. Yield potential is approximately 40 t ha\(^{-1}\), but normally yield varies between 20 and 30 t ha\(^{-1}\) (Swiss chard, S.a). Oyen (2004:113) reported yields of 15 to 25 kg ha\(^{-1}\) with good cultivation techniques in the tropics.

2.2 SEED GERMINATION

The stages of seed germination and seedling establishment are the most vulnerable stages in the life cycle of a plant (Benech-Arnold & Sánchez, 2004:3). Manoto, Ferreira and Agenbag (2004:214) defined germination as "the resumption of the growth of a dormant seed that is sufficient for the embryo to extend beyond the coverings surrounding it". Germination involves numerous events, such as protein hydration, subcellular structural changes, respiration, macromolecular syntheses and cell elongation, of which none are unique to germination. The combined effect of these metabolic processes is to trigger a dehydrated, resting embryo into initiating growth. The process of germination proceeds only when favourable environmental conditions in terms of temperature, water, oxygen and light, prevail (Bewley & Black, 1994:2).

According to Benech-Arnold and Sánchez (2004:4) germination of seeds and seedling emergence and establishment are critical processes in the survival and growth cycle of plant species. They determine uniformity, crop stand density, degree of weed infestation
and efficient use of nutrients and water resources available to the crop, and they affect yield and quality of the crop.

Germination begins with the imbibing of water by the dry seed, but oxygen and favourable temperatures are necessary for the metabolic processes to begin. This is followed by embryo expansion (Mayer & Poljakoff-Mayber, 1989:19; Wang, 2005:6). Germination is completed once the radicle protrudes from the testa of the seed, and depends on embryo growth driven by water uptake (Meidema, 1982:105; Manoto, Ferreira & Agenbag, 2004:214). In many seeds, the radicle penetrates the surrounding structures once growth commences. However, in others considerable radicle growth is attained before the testa ruptures (Bewley & Black, 1994:191).

Sometimes seeds do not exhibit the above germination processes. Such seeds are said to be in a quiescent phase (Bewley & Black, 1994:191). Quiescent seeds are resting organs, with low moisture contents of about 5 to 15% and metabolic activity that is more or less at standstill. Such seeds need to be hydrated under conditions that enable metabolism to occur. For example, a suitable temperature and the presence of oxygen are factors that are required for germination to occur (Bewley & Black, 1994:191). The quiescent phase is different from the dormancy phase. Seed dormancy is the failure of a viable seed to germinate under favourable conditions (Bradford & Nonogaki, 2007:55).

Two types of germination can occur, namely, epigeal or hypogeal. In epigeal germination, the hypocotyl elongates and pushes the cotyledons and apical meristem through the soil, as in the case of Phaseolus vulgaris seed germination (Thomson, 1979:41; Bewley & Black, 1994:193). In hypogeal germination, the hypocotyls remain short and compact and the
cotyledons stay underground where they eventually decompose. The epicotyls expand to raise the first true leaves out of the soil, as in the case of *Zea mays* seed germination (Thomson, 1979:41; Bewley & Black, 1994:193).

Mayer and Poljakoff-Mayber (1989:44) stated that the process of germination depends on both internal and external factors surrounding the seed. These factors represent the fundamental conditions that must exist before germination can occur. These conditions are:

- the embryo must be viable;
- any dormancy requirements that prevent germination must be overcome; and
- the proper environmental conditions (water, oxygen and temperature) must exist for germination.

### 2.2.1 Seed viability

The length of time that a seed is capable of producing a seedling varies widely with different conditions and kinds of seeds (Klingman & Ashton, 1982:44). Viability determines the percentage of seed germination that can occur (ISTA, 1995:4) and is affected by different conditions during storage, which can include moisture content, temperature, cultivar and harvest variability, oxygen pressure, and fluctuating storage conditions (Bewley & Black, 1994:391-397).

Pathogens and predators can damage seed while still in the fruit or after dispersal, and environmental conditions like heat and flooding can kill seed before or during germination. Some plants produce seeds with no embryo or the embryo might be non-functional. In addition, seed age affects the health and germination ability of seeds, because over time as
cells degenerate or die. High quality seed has a high viability measured by high germination percentage and germination rate (Thomson, 1979:38).

### 2.2.2 Dormancy

Germination occurs when the growth potential of the embryo can overcome the constraints imposed by the covering structures (Bradford & Nonogaki, 2007:29). When an intact, viable seed fails to germinate as a result of an inherent inadequacy, even when conditions are favourable for germination to take place, such as adequate supply of water and oxygen and optimum temperatures, it is deemed dormant (Bewley & Black, 1994:199; Ochuodho & Modi; 2005:49; Bradford & Nonogaki, 2007:29). Dormancy is a complex quantitative character controlled by several genes, some of which are regulated by environmental factors (Salisbury & Ross, 1978:322).

In weedy species, dormancy contributes to long-term survival by allowing germination to occur over a long period. It allows time for dispersal, safeguards seeds or seedlings from bad weather periods and prevents germination of seeds even when conditions appear favourable (Salisbury & Ross, 1978:322). Travlos, Economou and Karamanos (2007:505) pointed out that the germination of many leguminous species is spread over time, which increases the chance that some seeds will germinate, establish and complete the life cycle successfully. The failure of a dormant seed to germinate may be attributed to many factors, such as hard seed coats, growth inhibitors, immature embryos and the absence of light. In some seeds exposure to light breaks the dormancy, and germination is induced. This is as a result of light penetrating the dormant embryo.
2.2.2.1 Physical dormancy

According to Bewley and Black (1994:201) the seed is dormant because the enclosing tissues (hard seed coat) exert a constraint that cannot be overcome by the developing embryo (physical dormancy). This protects the embryo against adverse environmental conditions, but also imposes dormancy through impermeability to water, resistance to radicle protrusion and gaseous exchange (Ochuodho & Modi, 2005:49; Salisbury & Ross, 1978:323). Seeds with extremely hard seed coats not only prevent water entry but can also delay germination for many years (Bewley & Black, 1994:206). Tissues surrounding the embryo also limit the capacity for gaseous exchange by the embryo through impeding oxygen entry and hindering the escape of carbon dioxide, thus inhibiting respiration (Bewley & Black, 1994:208).

2.2.2.2 Physiological dormancy

Physiological dormancy may be brought about by growth inhibitors, such as abscisic acid and phenolic compounds, which may be present in the embryo or the seed coat (Bewley & Black, 1994:213). The presence of these inhibitors does not necessarily lead to dormancy (Bewley & Black, 1994:222). Dormancy may be due to an increase in abscisic acid in the cotyledons at about the time when the embryo begins to move into dormancy (Bewley & Black, 1994:203). Abscisic acid is produced by the embryo itself and prevents radical cell loosening, thereby preventing radical extension to complete germination (Bewley, 1997:1059-1060). Physiological dormancy prevents germination until a chemical change occurs within the seed (Fenner & Thompson, 2005:97).
2.2.2.3 Morphological dormancy

Morphological dormancy may occur due to unfavourable environmental conditions, such as too hot, too cold, or too dry, and by immature embryos that either have not fully differentiated, or need to develop more before germination (Leubner, 2000; Fenner & Thompson, 2005:97; Ochuodho & Modi, 2005:49). In the latter case, germination is delayed until embryo differentiation is completed. Some species may possess embryos that are differentiated when the seed is dispersed but when imbibed with water; the embryo continues growth before germination takes place (Villiers, 1972:225). In other cases, the seed remains dormant until it is exposed to low temperature conditions for several months even though the embryo is fully grown (Villiers, 1972:225-26).

2.2.3 Breaking Dormancy

Seed in a dormant state may be induced to germinate by various special artificial treatments under specific external conditions (Mayer & Poljakoff-Mayber, 1989:71). A combination of dormancy breaking treatments does not only shift the seed from dormancy to a quiescence state, but also induces germination (Ochuodho & Modi, 2005:49). Such treatments may include scarification, stratification, prechilling, and predrying, daily alternating of temperatures, light exposure, treatment with potassium nitrate, and the use of plant growth regulators, such as gibberellins, cytokinins, ethylene (Bekaardt et al., 2004:114) and warm water treatment (Erasmus & Pieterse, 2001:85).
2.2.3.1 Scarification

Bradbeer (1988:71) stated that dormancy caused by hard seed coats may be broken by damaging the seed coverings. This dormancy-breaking mechanism is called scarification, and is defined as the process of nicking thick seed coats to initiate germination (Salisbury & Ross, 1978:323). Chemical scarification may also be done by softening hard seed coats using chemicals, such as acids (Materechera & Materechera, 2001:143; Ochuodho & Modi, 2005:50). Other means of scarification include soaking in hot water or poking holes in the seed coat with a pin.

Examples are the abrasion of seed by sand particles blown against the seed by wind or the seed being rubbed against rocks whilst it is being transported by water (Travlos, Economou & Karamanos, 2007:502). Animals can also be responsible for scarification of seed. This can be when seed is consumed and passes through the digestive tract as in the case of ruminants. Whereas the hard seed coat protects the embryo against damage when passing through the digestive tract of animals, it gets sufficiently weakened by this passage to allow germination to occur when the seed is deposited in an environment that is conducive for germination (Thompson & Morgan, S.a; Bradbeer, 1988:71). Soil microorganisms can also be used to break down hard seed coats, and by storing the seed in moist warm sandy soils for months under non-sterile conditions (Klingman & Ashton, 1982:52; Bewley & Black, 994:246).

Fire is another natural means of scarification and particularly explains why after forest fires there is a relatively rapid recovery of the vegetation (Salisbury & Ross, 1978:324). During exposure to high temperature, cracks appear in the seed coat of some species,
especially in the region of the micropyle through which water can enter (Bewley & Black, 1994:246). Klingman and Ashton (1982:53) explained fire as a means to terminate dormancy as an effect of the five factors which normally follow a fire. These include greater diurnal temperatures differences in the upper soil layers, more light reaching the soil surface, removal of litter, reduced competition from other plants and removal of other plants previously living in the area that produce substances that prevent germination of other species (allelopathic effect). In agriculture, scarification is usually done using alcohol or other fat solvents or by using concentrated acids, which dissolve away the waxy materials that inhibit imbibition of water (Salisbury & Ross, 1978:323).

2.2.3.2 Stratification

Moist-chilling or cold treatment refers to breaking down physiological dormancy by imbibing at low temperatures, or by drying seeds at high temperatures, followed by subjecting the seeds to a period of moist chilling to after-ripen the embryo (Bewley & Black, 1994:232). In nature, the low temperature requirement protects the seed from precocious germination during unfavourable conditions. During this period, the embryo continues to grow (Salisbury & Ross, 1978:324).

Exposure to cold temperatures under moist conditions can break seed dormancy, particularly in seeds of temperate regions adapted to spring emergence (Bradford & Nonogaki, 2007:79). This dormancy-breaking treatment mostly applies when dormancy is controlled by an inhibitor-promoter balance (Ochuodho & Modi, 2005:49). Although inhibitors are often present in seed coats, direct evidence that they inhibit radicle protrusion seems to be lacking. It is thought that inhibitors disappear during cold treatment and
growth promoters, such as gibberellins or cytokinins, accumulate in amounts that overcome dormancy (Salisbury & Ross, 1978:325).

According to Bewley and Black (1994:233), low temperatures reduce the rate of enzymatic reactions within the seed. As a result, all dormancy imposing processes are retarded by a chilling treatment. When these processes are retarded, certain steps in the germination are thought to proceed slowly. By increasing the duration of pre-chilling, rate of germination and germination percentage, are both increased (Bradbeer, 1988:57; Thompson & Morgan, S.a).

2.2.3.3 Leaching and soaking

The soaking of seeds in water or leaching with water removes chemical inhibitors such as phenolic compounds, which prevent germination in some seeds. This can be accomplished naturally through rainwater and melting snow, resulting in the soil becoming sufficiently wet for survival of new seedlings (Salisbury & Ross, 1978:324). The use of running water and frequent changes in water are an effective way of removing chemical inhibitors. The effectiveness of leaching depends on the rate of diffusion of the inhibitors from the seed and the volume and rate of flow of the surrounding water (Bradbeer, 1988:70).

Soaking of seeds for periods of 12 to 24 hours is used to induce germination in some seeds, but care should be taken not to soak seeds for long periods in stagnant water to avoid fermentation and seed death (Thompson & Morgan, S.a). Seeds with hard seed coats can be soaked in hot water to break open the impermeable seed coats that prevent imbibition (Erasmus & Pieterse, 20001:85).
### 2.2.4 Environmental conditions

For successful seed germination, plants require a set of conditions to be met. Among the requirements, are adequate supply of water, a suitable temperature and gas composition of the air, light, as well as the presence or absence of certain other soil conditions (Manoto, Ferreira & Agenbag, 2004:214).

#### 2.2.4.1 Temperature

Germination is a complex process composed of many steps that are highly dependant on temperature (Garcia-Huidobro, Monteith & Squire, 1982:288; Bruin, 1994:5). Temperature affects the capacity and rate of germination (Manoto, Ferreira & Agenbag, 2004:214). It increases or decreases the period of time needed for initial radicle elongation to occur. Temperature regulates various aspects of germination that are important in crop production. For instance, it determines the speed and uniformity of germination of seeds, the emergence of seedlings and the vigour and initial growth of seedlings (Bahler, Hill & Bayers, 1989:142; Wang, 2005:7).

Temperature is said to have an effect on embryo water uptake. Respiration and mitochondrial phosphorylation proceed at a normal rate in seeds imbibing water at high temperatures and adenosine-5 triphosphate (ATP) levels are adequate for germination (Riley, 1981:68). However, at low temperatures activities of specific enzymes are lower, and the rate of protein synthesis in the embryo is severely reduced compared to when seeds are imbibing at warmer temperatures.
As temperature increases, germination rate increases (Wang, 2005:7). This could be due to increased imbibitional rates. Metabolic processes accelerate as temperature is increased until the optimum temperature is reached (Bruin, 1994:5), but seeds have the capacity to germinate over a wide range of temperatures. Hence, the concept of cardinal temperatures, characterized by the minimum and maximum temperature and in between these extremes, the optimum, which usually consists of a fairly wide temperature range (Bewley & Black, 1994:147; Benech-Arnold & Sánchez, 2004:6). In order to predict the response of the seed of a particular crop to temperature, the cardinal temperatures need to be determined (Böhringer, Lourens & Jansen van Vuuren, 1999:21).

**Minimum temperature**

Minimum temperature, also known as the base temperature, is the lowest temperature (or narrow range of temperatures) at which germination of seed of a particular crop will occur, regardless of how long the seeds are incubated (Bradford & Nonogaki, 2007:83). At this given temperature or temperature range, the duration of germination will be much longer than at optimum temperature, thus enhancing the probability of infection, drought or damage by water logging. This, in turn, results in non-uniform emergence of the seeds and seedling mortality, which reduces germination percentage (Wagenvoort & Bierhuizen, 1977:260).

**Maximum temperature**

The maximum or ceiling temperature is the highest temperature or narrow temperature range at which seed germination of a plant takes place (Bradford & Nonogaki, 2007:83).
Both maximum germination percentage and rate of germination increase as temperature rises above the base temperature until the optimum temperature range is reached. Maximum germination percentage and rate of germination decline as temperature rises above the optimum (Dumur, Pilbeam & Craigon, 1990:1423). Supra-optimum temperatures cause a reduction in maximum germination percentage by inducing seed dormancy or death. Seeds that do germinate at temperatures higher than the maximum temperature face the possibility of seedling death by soil temperature being too high for seedling survival. In high temperature regimes, poor seedling establishment can occur due to the loss of seed viability during imbibitions or by carbohydrate starvation and mobilization and poor carbohydrate translocation to the developing seedling (Riley, 1981:72).

Optimum temperature

Optimum temperature is the range at which the maximum proportion of plant seeds will germinate in the shortest period of time (Mayer & Poljakoff-Mayber, 1989:53). Below or above the optimum temperature range, germination percentage of seeds declines and the length of time taken for seeds to germinate, increases. The optimum temperature differs among plant species, but according to Bruin (1994:5), it normally falls within the 25 to 30 °C range. In most cases, there is an optimal temperature range rather than a single optimum temperature (Bradford & Nonogaki, 2007:84). This becomes evident when time to germination is plotted as a function of temperature. When temperature deviates from the optimum during germination, poor seedling establishment typically occurs due to a loss of seed viability during imbibition and initial growth (Wagenvoort & Bierhuizen, 1977:260).
2.2.4.2 Moisture

Water uptake (imbibition) is the first process that occurs when seeds are set to germinate (Meidema, 1982:105). According to Bewley and Black (1994:153), the success of germination is inversely proportional to the rate of water penetration into the seed. Penetration of water in the seed triggers metabolic reactions or cell activity of the seed necessary for germination to occur (Klingman & Ashton, 1982:47).

Seed imbibition is dependent on composition of the seed, seed coat permeability to water, the availability of water in liquid or gaseous form, and the relative difference in water potential between soil water and seed (Fenner & Thompson, 2005:121). The pressure caused by imbibing water helps in cracking the seed coat for germination to take place and makes room in the soil for the developing seedling to grow non-photosynthetically until it reaches light (Bewley & Black, 1994:147; Bradford & Nonogaki, 2007:267).

Germination of seeds requires moist conditions and dry, mature seeds need to imbibe fairly large amounts of water before metabolism can resume (Bradford & Nonogaki, 2007:264). Once a dry, mature seed has imbibed water, it swells (Meidema, 1982:105), which is the result of starches and proteins, the chief components of the seed, being broken down by hydrolytic enzymes to allow radical protrusion from the seed coat (Riley, 1981:71-72; Bradford & Nonogaki, 2007:265). Germination percentage is reduced when water uptake is too slow, because seeds can deteriorate when the moisture content of the seed is reduced. This deterioration results from the slowing down of the activity of enzymes and in turn, metabolism, because the amount of moisture determines respiratory rate (Klingman &
Ashton, 1982:48). Seeds can also suffer imbibitional damage when water uptake is too rapid (Benech-Arnold & Sánchez, 2004:55).

Under optimal conditions, water uptake of a dry, mature seed is triphasic. It starts with the rapid uptake of water by the seed regardless of seed condition. The second stage is a lag phase characterised by metabolic preparation of germination. Dormant seeds are also metabolically active during this phase. Although dormant seeds enter the second phase, only germinating seeds enter the third and last stage, which is characterised by an increase in water uptake, related to changes in the cells of the radicle as they expand and this marks the completion of germination. The last stage of water uptake causes hydraulic growth of the embryo and the emerging seedling (Bewley & Black, 1994:149-153; Benech-Arnold & Sánchez, 2004:54-56; Fenner & Thompson, 2005:121; Bradford & Nonogaki, 2007:265). According to Benech-Arnold and Sánchez (2004:24) the triphasic process of germination of seeds is controlled by:

- The seed properties with respect to water, such as seed water potential and diffusivity to water.
- The physical properties of the soil that effects soil water status, such as diffusivity and conductivity, as well as the water potential in the soil.
- The hydraulic properties of the seed-soil interface.

2.2.4.3 Oxygen

When oxygen is readily available, seeds germinate well. However, when the oxygen concentration is less than in the air, seed germination of the majority of plant species is
delayed (Bewley & Black, 1994:147). This may be attributed to the difference in oxygen and carbon dioxide concentrations in air and soil, which is the result of biological activities in the soil, particularly by microorganisms and plant roots, which lead to the depletion of oxygen and raised carbon dioxide levels (Fenner & Thompson, 2005:124). Oxygen is the terminal electron acceptor in respiration and other oxidative processes (Benech-Arnold & Sánchez, 2004:7). Absence or insufficient oxygen supply inhibits the respiration that is necessary for the germination of most seeds and results in the accumulation of potentially toxic products of anaerobic respiration, such as acetaldehyde, ethanol and lactate (Bradbeer, 1988:28).

When seed germinates in moist soils, a conflict between water and oxygen availability can develop because of the very low solubility and diffusivity of oxygen in water (Benech-Arnold & Sánchez, 2004:7). Water logging soils reduce the availability of oxygen, thus inhibiting germination of seed, which can lead to rotting of the seed. In crops that are cultivated under flooded conditions, such as rice, anaerobic conditions can lead to the formation of abnormal seedlings (Mayer & Poljakoff-Mayber 1989:51) because aerobic respiration of seeds, which is the main source for a seedling’s energy, is prevented until photosynthesis begins. It is believed that low germination in waterlogged soils is as a result of the reduced supply of oxygen rather than excess water (Klingman & Ashton, 1982:49).

2.2.4.4 Soil physical condition

Soil provides the physical medium in which germination of most seeds takes place (Benech-Arnold & Sánchez, 2004:9) except in the case of epiphytes, which germinate in
branches of trees, and some mangrove species, which germinate while attached to the parent plant (Fenner & Thompson, 2005:124). Koller (1972:11) stated that soil physical conditions are of importance in germination because they determine soil-plant-water relationships, soil aeration, and the mechanical impedance to root and shoot growth. Structure and texture of the soil have an influence on the germination of seeds. Soils with a high clay percentage (heavy soils) slow down the germination process, while those with a low clay percentage (light soils) speed up the process (Fenner & Thompson, 2005:123). The process of germination begins earlier and faster in sandy soils than in loams and clays. Roots from seedlings penetrate the soil faster in sandy soils than in heavier soils, but this could be attributed to sandy soils warming up faster in spring, having a better supply of oxygen, besides exerting less resistance to the germinating seed (Schütz, Milberg & Lamont, 2002:23).

2.2.4.5 Light

Where favourable environmental conditions prevail, other factors such as seed sensitivity to light, can determine the success or failure of a crop (Benech-Arnold & Sánchez, 2004:4). Light can either promote or inhibit germination, depending on its spectral composition and irradiance, the physiological status of the seeds, and other environmental conditions, such as temperature and soil water potential (Benech-Arnold & Sánchez, 2004:222). According to Pons (2000:237), the light response of seeds can control the timing of germination in the field, a crucial factor in the survival of the resulting seedlings, and also the growth and fitness of the seedlings during subsequent stages.
Depending on the plant species, light can be an important factor in releasing seed from dormancy (Bewley & Black, 1994:237; Mpati, 2006:39). In such species, dormancy is terminated when the hydrated seed is exposed to light. This is particularly common among weed species (Benech-Arnold & Sánchez, 2004:251). Fenner and Thompson (2005:116) pointed out that the light requirement of the seed of certain plant species may prevent germination in places and times not favourable for seedling establishment. The light requirement of such seed acts as a mechanism that determines where and when germination takes place. This mechanism is important for survival of the plant species as it prevents stored seed reserves from being depleted.

The effect of light on seeds depends on genotype and on the environmental factors during ripening of the seeds, dormancy and germination itself, and light factors such as photon flux density, spectral composition and duration of exposure. Exposure to light depends on the position of the seed in the soil and the presence of shade (Pons, 2000:237-238).

Some seeds germinate better when exposed to light, others better in darkness, and still others germinate readily in either light or darkness (Klingman & Ashton, 1982:50; Kettenring, Gardner & Galatowitsch, 2006:869). Almost all light-requiring seeds have coat-imposed dormancy (Bewley & Black, 1994:237). Exposing seed of selected plant species to light can help to break their dormancy and induce germination (Khan & Gulzar, 2003:134; Ochuodho & Modi, 2005:49). This can occur, for instance, when the seed is brought to the surface when soil is turned over during soil disturbance (Pons, 2000:237), although this process can also induce germination by improving aeration and oxygen supply (Klingman & Ashton, 1982:49).
It must be noted that many of the species that emerge as a consequence of soil disturbance and accompanying illumination do not disperse light-requiring seeds. Instead these seeds develop a light requirement after their dispersal, i.e. during burial (Bewley & Black, 1994:274; Fenner & Thompson, 2005:117). The responses of seeds to the effect of the surrounding light are facilitated by a pigment located in the embryo of the seed, called phytochrome (Bewley & Black, 1994:238; Pons, 2000:239; Benech-Arnold & Sánchez, 2004:223; Fenner & Thompson, 2005:112; Bradford & Nonogaki, 2007:81). The term phytochrome refers to the family of chromoproteins with molecular mass of about 125 kilodaltons (KDa) (Takaki, 2001:105).

In plants phytochrome exists in two forms, an inactive form of phytochrome (Pr) synthesized in dark-grown seedlings, which absorbs light of 665 nm, and an active form (Pf) which absorbs light of 735 nm and promotes several processes. These two forms are photoreversible (Benech-Arnold & Sánchez, 2004:251; Bradford & Nonogaki, 2007:81). When Pr absorbs red light, it is converted to the Pf form and when Pf absorbs far red light, it is converted to the Pr form. Pf can also revert spontaneously to the Pr form in the dark over time. This process is called dark reversions (Pons, 2000:240).

Takaki (2001:105), Benech-Arnold and Sánchez (2004:251), and Bradford and Nonogaki (2007:81) classified the physiological effects of phytochrome into three distinct mechanism, namely:

- Low fluence responses, which represents the red/far-red reversible responses, in which the production of Pf promotes responses by plants and removal of Pf reverses the response.
• Very low fluence responses, which represents the saturation of responses by very low fluencies with reciprocity but without reversibility.

• High irradiance responses, which represents the responses produced by prolonged high irradiance, and does not show reciprocity or reversibility.

According to Benech-Arnold and Sánchez (2004:223), a millisecond of exposure to sunlight can be sufficient to induce germination in seeds characterised by very low fluence responses.

Different types of phytochromes have been discovered and these are encoded with different genes (Pons, 2000:242). Phytochrome A is responsible for very low fluence responses, permitting seeds to perceive light of very low fluencies. It accumulates at very high levels in darkness. Phytochrome A is also responsible for high irradiance responses. Phytochrome B is responsible for changes in the red:far-red ratio of canopy filtered light (shade detection and avoidance) and controls germination by low fluence responses. This is the response that allows many species to increase their stem extension rate when they become shaded. The relative amount of Pfr is reduced strongly by the presence of chlorophyll-bearing leaves that filter-out red light but not far-red (Takaki, 2001:105; Benech-Arnold & Sánchez, 2004:223).

When soil is disturbed by agricultural practices, seed germinates via the very low fluence responses while reductions in canopy densities promote germination by low fluence responses of many weed seeds on the soil surface (Benech-Arnold & Sánchez, 2004:252; Bradford & Nonogaki, 2007:81). The presence or absence of light may trigger or inhibit germination in seeds that are buried too deeply or not buried at all (Mpati, 2006:16).
Fenner and Thompson (2005:116) stated that the response of seeds to light was important to prevent the occurrence of germination in places and at times that are not favourable to seedling establishment. The ability of seeds to detect different aspects of light enables them to have some form of control over where and when to germinate. The degree of shade from the surrounding vegetation plays a decisive role when the seed is on the soil surface (Benech-Arnold & Sánchez, 2004:252). This explains why seeds in forests do not germinate until an opening in the canopy allows them to receive sufficient light.

2.2.5 Seed germination rate

According to Garcia-Huidobro, Monteith and Squire (1982:288), germination rate can be defined as the reciprocal of time taken for half the population of seeds to germinate. Germination rate is usually expressed as a percentage, and is determined at time intervals over the full duration of the germination period (Bewley & Black, 1994:3). Seed viability, dormancy and environmental conditions affect rate of germination and final germination percentage. In a population of seeds, a minority germinates early, then the majority germinates and finally, a minority germinates late. Germination rate is usually positively skewed because a greater proportion of seeds germinate in the first half of the germination period than in the second half (Bewley & Black, 1994:3).

2.3 SEEDLING EMERGENCE

According to Fenner and Thompson (2005:148), the start of the seedling phase can be defined as the completion of germination. It is the appearance of the first parts of the seedling above the soil surface (Wang, 2005:9). This is marked by the extension of the
radicle, which anchors the seedling in the soil or growth medium, followed by the plumule, which grows towards the light. In cases where the seed is buried, the plumule has to push its way through the soil to the surface, a process that expends energy from the seed’s reserve. Germination to emergence from the soil is amongst the crucial steps in crop production (Benech-Arnold & Sánchez, 2004:51; Wang, 2005:9).

According to Benech-Arnold and Sánchez (2004:51), a wide range environmental factors interact with the potential performance of the seed lot to determine the success of seedling establishment. Many of the factors influencing seed germination, such as temperature, moisture, light and soil conditions, also influence seedling emergence, but the emerging seedling also faces new hazards. Factors such as lack of water and light have little or no effect on seed survival, but become major causes of death in seedlings. Predators and pathogens that threatened seed are replaced by different organisms that threaten the seedlings (Fenner & Thompson, 2005:147). New factors, such as competition amongst seedlings or with the surrounding vegetation, seed size and depth of burial affect the emerging seedling (Fenner & Thompson, 2005:155).

Temperature affects the physiological characteristics of seedlings, including soluble sugar content and hormonal level, and these ultimately determine seedling emergence percentages and times (Huang et al., 2008:184). Temperature effects on seedling emergence tend to be positive and linear. Tobe, Zhang and Omasa (2005:649), stated that seed germination determines when and where seedling growth begins. The success of seedling establishment may, therefore, depend largely on seed germination responses to the environment (Awal & Ikeda, 2002:102). Plants whose seedlings emerge fast and develop
rapidly may out-compete slower emerging and growing seedlings (Chopra & Chaudhary, 1980:125).
CHAPTER 3

3 EFFECT OF TEMPERATURE ON SEED GERMINATION OF SELECTED AFRICAN LEAFY VEGETABLES

3.1 INTRODUCTION

Seed germination is crucial in successful crop production (Ghaderi, Soltani & Sadeghipour, 2008:574). Mpati (2006:13) defined seed germination as the protrusion of the radicle through the surrounding seed covering. The process by which germination occurs in a non-dormant seed is affected by the age and quality of the seed and by environmental factors, such as temperature, light, moisture and oxygen (Hemmat, Khashoei & Ranjbar, 2003:87; Ghaderi, Soltani & Sadeghipour, 2008:574).

Temperature is one of the prominent environmental factors regulating growth and development of plants (Garcia-Huidobro, Monteith & Squire, 1982:288; Bruin, 1994:5; Craufurd et al., 1996:2; Koger, Reddy & Poston, 2004:989; Mpati, 2006:15). The rate at which germination occurs usually increases linearly with temperature, over a well-defined range and then declines sharply at high temperatures. Minimum temperature is the lowest temperature at which germination occurs, regardless of how long the seeds are incubated. At the minimum temperature, germination proceeds but at a very slow rate. The optimum temperature is the temperature giving the greatest percentage of germination within the shortest time. The maximum temperature is the highest temperature at which germination still occurs (Bradford & Nonogaki, 2007:82-83). The minimum, maximum and optimum
temperatures for germination are referred to as the cardinal temperatures (Ghaderi, Soltani & Sadeghipour, 2008:574).

Onset and rate of germination are enhanced as temperature increases from minimum to optimum and are slowed down as temperature increases from optimum to maximum (Obroucheva, 1999:109). Germination percentage is also dependent on temperature and is typically reduced by extreme temperatures. The temperature (optimum) at which maximum germination percentage occurs tends to differ among crops (Bewley & Black, 1994:262; Fessehazion, Marais & Robbertse, 2008:1).

Clear understanding of the germination response of seeds of different crops to temperature, obtained by determining cardinal temperatures, is important. It enables the identification of tolerance to low and high temperatures and the climates where the crop can germinate and establish successfully. It also assists the construction of models that predict the crop development process (Craufurd et al., 1996:3; Ghaderi, Soltani & Sadeghipour, 2008:574). Furthermore, estimation of the cardinal temperatures helps in defining the range of temperatures at which germination is accelerated (Roché, Thill & Shahfi, 1997:529).

Existing knowledge on the cardinal temperatures and the effect of temperature on seed germination of the eight selected African leafy vegetables featuring in this study appears to be limited. Therefore, it was decided to investigate the effect of temperature on the germination of the seed of these crops and determine their cardinal temperatures.
3.2 MATERIALS AND METHODS

3.2.1 Seed source

Seeds of *A. cruentus, Cleome gynandra, Citrillus lanatus* (tsamma melon), *Cucurbita maxima, Corchorus olitorius* and *V. unguiculata* were supplied by the Vegetable and Ornamental Plant Institute of the Agricultural Research Council at Roodeplaat. The seed of *Brassica rapa* subsp. *chinensis* (*dabadaba* land race) and *S. retroflexum* were obtained by the Department of Crop Sciences, Tshwane University of Technology from farmers in the Vhembe District (Venda), where these two species are cultivated. The seed of *Beta vulgaris* cv. Ford Hook Giant var. *cicla* was obtained from Hygrotech (Pyramid, Pretoria North).

3.2.2 Seed pre-treatment and sanitation

To avoid contamination of seed during *in vitro* germination studies, which can result in the loss of seed, the recommendations of Miller and Ivey (S.a:1) and Department of Agriculture and Food, (2005:1) were followed. These involved the use of hot water treatment, a standard practice used to reduce a range of fungal and bacterial contaminations during germination tests.

The hot water treatment involved wrapping the seed in cheesecloth (Fig. 3.1a and 3.1b) (the cheesecloth was surface sterilized for 15 minutes in 1% sodium hypochlorite) and soaking in a warm water bath (LABCON® shaking water bath, 5070 U, model WBM-SPL 25) for 20 minutes at 50 °C. Immediately after hot water bath pre-treatment, seeds were
soaked in cold distilled water to rapidly reduce the seed temperature (Fig. 3.1c). The seeds were then evenly spread on a piece of germination paper and dried overnight at 20 °C (Fig. 3.1d). Thereafter, seeds were used for the conduct of standard germination tests described by Miller and Ivey (S.a). In order to prevent secondary contamination, the surfaces of the temperature incubators were sterilized by wiping them clean with 1% sodium hypochlorite before use and the containers used for germination, as well as the bench surfaces in the laboratory were sterilized with 90% alcohol.

FIGURE 3.1: Warm water treatment of seeds prior to standard germination tests, a) *Corchorus olitorius* seed spread on cheesecloth, b) seeds wrapped in cheesecloth with a rubber band, c) cooling seeds in cold distilled water and d) seeds spread on germination paper for overnight drying
3.2.3 Seed germination

The experiments were conducted in a laboratory using environmental controlled low-temperature incubators (Labcon™ 220v, 50 Hz), fitted with Lasec® thermometers (GLAA504.110IMTJ, -10/110 °C) (Fig. 3.2a). Incubators were allowed to run at the desired temperatures for 48 h before samples were incubated.

Each treatment consisted of 50 seeds per vegetable specie and was replicated four times, totaling 200 seeds per treatment. Germination experiments were conducted by sowing small seeds on top of four layers (115 mm x 125 mm) of pre-cut, brown, anchor germination paper (top paper) moistened with 10 ml distilled water in a plastic container (Fig. 3.2b), or into 160 mm x 100 mm rectangular transparent plastic containers (Fig. 3.2c), moistened with 20 ml distilled water. Large seeds were sown on four layers of rolled germination paper (260 mm x 380 mm) moistened with 50 ml distilled water (Fig. 3.2d) (ISTA, 2008:13). Treatments were arranged using a completely randomized design for all experiments.
The effect of temperature on seed germination was investigated by monitoring germination under specified constant temperatures ranging from 4 °C to 44 °C using 4 °C increments, under continuous darkness over a period of 14 days (336 h), but seeds were exposed to normal light during observation of germination. Observation of germination was done every 6 h during the first 10 days (240 h), and every 12 h thereafter, because by then the majority of seeds had already germinated. Seeds were sampled using the tail sampling procedure (Ntuli, 2008) under a magnifier lamp (model no.:8066D, AC 230v, 50 Hz, 22w, bulb type 22w G10Q). A pair of stainless steel tweezers was used for picking seeds and a
spatula for moving seeds during sampling. Any contaminated, broken or alien seeds were removed and discarded.

Seeds were considered to have germinated once the radicle has protruded at least 2 mm from the testa. When a seed had germinated, it was counted and removed, and was expressed as a percentage of the total number of tested seeds. A Nikon microscope (model, C-LEDS, 100-240v, 0.2A, 50/60 Hz) was used to determine the length of the radicle if not clearly visible to the naked eye.

### 3.2.4 Data analysis

The following parameters were determined:

- **Germination percentage**
  
  The germination percentage referred to the average number of seeds that germinated as a percentage of the total number of seeds used per temperature treatment per incubation time.

  \[
  \text{Germination \%} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds incubated}} \times 100
  \]

  The final germination percentage was determined after 336 h and was expressed as a percentage of the total number of seeds incubated.
• **Germination rate**

The rate of germination was calculated according to the formula of Ellis and Roberts as quoted by Bruin (1994:8), i.e.:

Germination rate (seeds/hour) = Mean germination duration (MGD), with

\[ MGD = \frac{\sum n h n}{\sum n} \]

Where \( n \) = number of seeds germinated at hour \( h \)

\( h \) = incubation duration, in hours

• **Germination coefficient**

The germination coefficient is the final germination percentage divided by the mean germination duration and is expressed in percentage/h (% h\(^{-1}\)). It is an indicator of the duration of incubation needed to obtain the final germination percentage.

• **Time to 50% germination**

Time to 50% germination refers to the time taken for half of the total number of seeds incubated to germinate (Jami Al-Ahmadi & Kafi, 2007:309).

The non-intercept sigmoid function as described in TableCurve\textsuperscript{®} 2D (2002) was fitted to determine the time to 50% germination:

\[ y = \frac{a}{1 + e^{\left(\frac{x-b}{c}\right)}} \]
Where \( a \) = maximum germination percentage

\[ b = \text{turning point} \]

\[ c = \text{slope of the line} \]

\[ x = \text{time (h)} \]

\[ y = \text{germination } \% \]

- **Cardinal temperatures (minimum, optimum and maximum)**

The optimum temperature was determined by fitting two straight lines using a non-linear (NLIN) procedure with SAS between temperature and the inverse of the time to 50\% germination for each species separately. The temperature extremes at which 50\% germination was recorded were used as the minimum and maximum temperatures for that species.

### 3.2.5 Statistical analysis

Analysis of variance (ANOVA) was used to test for treatment effects. Treatment means were separated using Fisher’s protected least significant difference test at the 1\% level of significance (Snedecor & Cochran, 1980), because of heterogeneity of variances. All data were analysed using the statistical program GenStat® (Payne et al., 2007). The Sigmoid function as described in TableCurve® 2D was fitted with SAS/NLIN (Non-Linear procedure) and the time to 50\% germination was calculated and subjected to an appropriate analysis of variance (ANOVA) using SAS® statistical software version 9.2 (SAS, 1999).
3.3 RESULTS

3.3.1 Germination percentage

The effect of temperature on cumulative percentage of germinated African leafy vegetable seed is shown in Figures 3.3 to 3.19, and the statistical analysis of the data is presented in Annexures A to I. For all crops species studied, temperature affected commencement of germination, rate at which germination proceeded, time required to attain final germination, and final germination percentage.

3.3.1.1 *Amaranthus cruentus* L.

Germination percentage of *A. cruentus* is shown in Figure 3.3 and the statistical analysis is presented in Annexure A.
FIGURE 3.3: Cumulative percentage of germinated *Amaranthus cruentus* seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C.

It is clear from the cumulative germination of *A. cruentus* that seeds germinated in nearly all temperature treatments although the germination percentage varied with time to germination. Commencement of germination of the seed of *A. cruentus* occurred after 12 h of incubation in the 28 °C, 32 °C, and 36 °C temperature treatments, after 18 h in the 40 °C treatment, after 24 h in the 24 °C treatment and after 30 h in the 20 °C treatment. All other temperature treatments substantially delayed commencement of germination.

Within the first 36 h at 20 to 40 °C, approximately 60% of seeds germinated, and differences between these treatments were statistically not significant ($p\leq0.01$). Thereafter, germination percentage remained unchanged at 20 and 24 °C, but at 28 to 40 °C, germination percentage significantly increased ($p\leq0.01$) up to more than 90% after about 96 h. Below 20 °C and above 40 °C, germination was slow and germination percentage
remained below 50%. At 16 °C, germination only started after 48 h and reached a level of only 30% after 96 h, while at 12 °C and 44 °C, germination started after 120 h reaching a level of 3% and 1.5%, respectively. No germination was observed at 4 °C. At 8 °C, germination started after 66 h and was very low (0.5%).

Time to final germination percentage was shortest at 40 °C (120 h) followed by 126 h in the 28 °C and 36 °C treatments. At 24 °C, time to final germination percentage was 156 h and at 20 °C it was 174 h. Time to final germination percentage at 32 °C was 192 h, while at 12 °C and 44 °C it was substantially delayed to 204 h and 264 h, respectively. Final germination percentage was significantly higher \((p\leq0.01)\) in the 28 °C to 40 °C temperature treatments than in the other temperature treatments. At 28 °C, final germination was 95%, which was not significantly different from the 99% attained in the 32 °C to 40 °C treatments. Final germination at 20 °C and 24 °C was 64.5% and 62.5%, respectively. It was 12% at 12 °C and 10.5% at 44 °C.

3.3.1.2 Beta vulgaris L. var. cicla

Germination percentage of Beta vulgaris var cicla is shown in Figure 3.4 and the statistical analysis is presented in Annexure B.
Cumulative germination of *Beta vulgaris* var. *cicla* was affected by temperature. Germination of *Beta vulgaris* var. *cicla* seed commenced after 24 h in the 28 °C to 40 °C treatments, after 30 h in the 24 °C treatment and after 36 h in the 20 °C treatment. Commencement of germination in all the other temperature treatments was delayed substantially. Seeds incubated at 20 °C to 40 °C germinated rapidly and reached maximum germination after 24 h to 48 h. Significantly fewer (*p*≤0.01) seeds germinated during the same period at lower (4 °C to 16 °C) and higher temperatures (44 °C). Although onset of germination was delayed to 60 h at 16 °C and 108 h at 12 °C, final germination percentage in these two treatments was similar to that at 20 °C to 36 °C. Germination commenced only after 216 h at 8 °C and final germination was 53.0%, whilst at 40 °C it was 52.0% after 288 h. At 44 °C, final germination percentage (4%) was reached after 288 h and was
significantly lower ($p \leq 0.01$) than that obtained at 40 °C (52.0%). No germination of *Beta vulgaris* var. *cicla* seed was observed at 4 °C.

Final germination percentage was attained earliest in the 36 °C and 32 °C treatments, being after 114 h and 126 h, respectively. At 24 °C and 28 °C, time to final germination percentage was extended to 186 h and 192 h, respectively. Final germination percentage was reached after 264 h in the 40 °C treatment, after 276 h in the 20 °C treatment and after 282 h in the 12 °C and 16 °C treatments. Final germination percentage was highest (87.5%) in the 20 °C, but not different statistically ($p \leq 0.01$) from the 85% achieved at 12 °C, the 80% at 16 °C, the 81% at 24 °C and the 76% at 32 °C.

3.3.1.3 *Brassica rapa* L. subsp. *chinensis*

Germination percentage of *Brassica rapa* subsp. *chinensis* is shown in Figure 3.5 and the statistical analysis is presented in Annexure C.
Commencement of germination of the seed of *Brassica rapa* subsp. *chinensis* occurred after 18 h in the 28 °C and 32 °C temperature treatments, after 24 h in the 24 °C and 36 °C treatments and after 30 h in the 20 °C treatment. Commencement of germination was delayed to 36 h in the 16 °C treatment, 42 h in the 40 °C treatment, 60 h in the 12 °C treatment and 114 h in the 8 °C treatment. No germination of *Brassica rapa* subsp. *chinensis* seed was observed at 44 °C, while at 4 °C commencement of germination was delayed to 288 h. During the first 48 h, germination percentage was highest in the 20 °C to 36 °C constant temperature treatments.

Germination after 18 h was similar in the 28 °C and 32 °C treatments and remained similar throughout the incubation period. After 144 h and 156 h, germination percentage at 36 °C and at 20 °C was statistically not different from the germination percentage in the

**FIGURE 3.5:** Cumulative percentage of germinated *Brassica rapa* subsp. *chinensis* seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C
28 °C to 32 °C treatment. Germination percentage at 24 °C, though relatively high, was significantly lower \( (p \leq 0.01) \) than that attained at 32 °C but statistically not different from that at 20 °C, 28 °C and 36 °C. *Brassica rapa* subsp. *chinensis* seed germination in the 4 °C and 44 °C proceeded slowly. The onset of germination at 16 °C was delayed to after 48 h, but germination proceeded rapidly thereafter, reaching levels in excess of 60% after 60 h.

Final germination percentage was reached earliest (after 78 h) at 28 °C and 32 °C. In all other treatments, time to final germination percentage was delayed. Final germination percentage was reached after 114 h in the 36 °C treatment, 144 h in the 24 °C treatment, 276 h in the 20 °C treatment and after more than 300 h in all treatments below 20 °C. Final germination percentage was 92.5% at 32 °C, 88.5% at 28 °C, 81.5% at 36 °C, 78% at 24 °C and 82.5% at 20 °C. Relative to the final germination percentage in the 20 °C to 36 °C treatments, final germination percentage of *Brassica rapa* subsp. *chinensis* seeds was significantly lower \( (p \leq 0.01) \) at temperatures below 20 °C and above 36 °C. Final germination percentage was 71.5% at 16 °C, 58.5% at 12 °C, 29% at 8 °C, 15% at 40 °C and 5.5% at 4 °C.

### 3.3.1.4 *Citrullus lanatus* L.

Germination percentage of *Citrullus lanatus* is shown in Figure 3.6 and the statistical analysis is presented in Annexure D.
FIGURE 3.6: Cumulative percentage of germinated *Citrillus lanatus* seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C.

Generally, germination of *Citrillus lanatus* seed occurred at temperatures ranging between 20 °C and 40 °C. At the other temperatures, germination was either completely inhibited or extremely poor. Germination commenced after 36 h in the 32 °C to 40 °C treatments, after 42 h in the 24 °C treatment, after 48 h in the 28 °C treatment and after 54 h in the 20 °C treatment. Germination at 16 °C commenced after 312 h. No germination of *Citrillus lanatus* seed was observed below 16 °C and above 44 °C.

Although germination started after 36 h in the 32 °C to 40 °C treatments, germination percentage after 36 h was significantly higher ($p \leq 0.01$) at 36 °C (8.5%) than at 32 °C (2.5%) and 40 °C (1.5%). During the first 72 h, germination percentage varied among the 24 °C to 36 °C treatments, but after 72 h differences in germination percentage among these temperature treatments were no longer statistically significant. After 78 h to 144 h,
germination percentage varied significantly \((p \leq 0.01)\) among the 24 °C to 36 °C treatments. After 150 h, germination percentage in the 20 °C to 28 °C treatments was significantly higher than that at 32 °C and 36 °C. However, the germination percentage of 82.5% at 32 °C was not significantly different from that at 20 °C (88%), 24 °C (88.5%) and 36 °C (77.5%). This trend in germination percentage remained the same until final germination was recorded after 336 h.

Final germination percentage was reached after 126 h in the 24 °C to 32 °C treatments. Final germination percentage was attained after 132 h at 36 °C, after 186 h in the 20 °C treatment and after 210 h in the 40 °C treatment. Final germination percentage of *Citrullus lanatus* was highest (93%) in the 24 °C treatment, but statistically, this final germination percentage did not differ from that at 20 °C (89%) and 28 °C (88.5%). The final germination percentage of 82.5% attained at 32 °C was significantly lower than that at 24 °C. A final germination percentage of 77.5% was attained in the 36 °C treatment, while only 53.5% was attained in the 40 °C treatment.

3.3.1.5 *Cleome gynandra* L.

Germination percentage for *Cleome gynandra* seeds is shown in Figure 3.7 and the statistical analysis is presented in Annexure E.
Onset of germination of *Cleome gynandra* was recorded after 18 h in the 28 °C to 40 °C temperature treatments, after 24 h in the 24 °C treatment, after 30 h in the 44 °C treatment and after 42 h in the 20 °C treatment. Below 20 °C, commencement of germination was substantially delayed, and no germination was observed in the 4 °C and 8 °C temperature treatments. After 18 h of incubation, the germination percentage of 19% at 36 °C was significantly higher (*p*≤0.01) than that at 28 °C (1%), 32 °C (4.5%) and 40 °C (7.5%). After 24 h, germination percentage in the 28 °C to 36 °C treatments still differed significantly (*p*≤0.01) from that in the 40 °C treatment. Thereafter, germination percentage was significantly higher (*p*≤0.01) in the 28 °C and 32 °C treatments than in the other temperature treatments, and this trend was maintained for the remainder of the incubation period.
Final germination percentage was attained after 192 h at 40 °C but was very low (34.5%). At 36 °C, final germination percentage (56.5%) was attained after 216 h, while at 24 °C, final germination percentage (40%) was reached after 228 h. Time to final germination in the 28 °C and 32 °C treatments was delayed to 294 h. Final germination percentage (30.5%) was attained after 270 h at 20 °C, after 300 h (3.5%) at 12 °C and after 306 h (20%) at 16 °C. The final germination percentage in the 28 °C (66%) and 32 °C (78%) treatments was significantly higher ($p \leq 0.01$) than in all other treatments.

### 3.3.1.6 Corchorus olitorius L.

Germination percentage of *Corchorus olitorius* is shown in Figure 3.8 and the statistical analysis is presented in Annexure F.

**FIGURE 3.8:** Cumulative percentage of germinated *Corchorus olitorius* seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C
Germination commenced after 12 h in the 28 °C to 40 °C temperature treatments, after 18 h in the 24 °C and 44 °C treatments, after 24 h at 20 °C and after 36 h in the 16 °C treatment. Germination of *Corchorus olitorius* seeds was observed after 168 h in the 12 °C treatment and after 324 h in the 8 °C treatment. No germination was observed in the 4 °C treatment.

After 12 h, germination percentage was significantly higher (*p*≤0.01) in the 28 °C, 32 °C and 36 °C treatments than in all other temperature treatments. After 24 h, germination percentage rose to above 90% in the 28 °C to 40 °C treatments. After 72 h of incubation differences in germination percentage among the 28 °C to 44 °C treatments were no longer statistically different (*p*≤0.01). After 234 h, the germination percentage of seed incubated at 16 °C was statistically (*p*≤0.01) not different from that in the 20 °C to 44 °C treatment.

Final germination percentage was attained after 24 h in the 32 °C treatment, after 36 h in the 36 °C treatment, after 42 h in the 40 °C treatment and after 54 h in the 28 °C treatment. Final germination percentage was attained after 84 h in the 20 °C , 24 °C and 44 °C treatments and after 186 h in the 16 °C treatment. Below 16 °C, attainment of final germination percentage was substantially delayed. Statistically, final germination percentage did not differ significantly (*p*≤0.01) among the 16 °C to 44 °C temperature treatments. In these treatments, final germination percentage ranged between 93% and 99%. 
3.3.1.7 *Cucurbita maxima* Duchesne

Germination percentage of *Cucurbita maxima* is shown in Figure 3.9 and the statistical analysis is presented in Annexure G.

![Cumulative percentage of germinated Cucurbita maxima seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C](image)

**FIGURE 3.9:** Cumulative percentage of germinated *Cucurbita maxima* seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C

Seed germination of *Cucurbita maxima* seed started after 24 h at 32 °C and 36 °C, after 30 h at 24 °C and 40 °C, after 42 h at 20 °C and after 96 h in the 16 °C treatment. No seeds of *C. maxima* germinated below 16 °C or above 40 °C during the 336 h of incubation. Although germination was observed earliest in both the 32 °C and 36 °C treatments, after 24 h, the germination percentage of 56% in the 36 °C was significantly higher \((p \leq 0.01)\) than the 34.5% in the 32 °C treatment. During the 36 h to 72 h period, germination percentage varied significantly \((p \leq 0.01)\) among seed incubated in the 20 °C to 40 °C range.
of treatments but after 78 h, there were no longer significant differences ($p \leq 0.01$) in germination percentage among these treatments.

Final germination percentage was attained after 48 h in the 32 °C treatment, after 54 h in the 28 °C and 36 °C treatments, after 60 h in the 24 °C treatment and after 96 h in the 40 °C treatment. Temperature substantially delayed time to final germination percentage in the 20 °C (108 h) and 16 °C (189 h) treatments. Final germination percentage of more than 95% attained in the 20 to 40 °C treatments was significantly higher ($p \leq 0.01$) than the 45.5% in the 16 °C treatment.

3.3.1.8 *Solanum retroflexum* Dun.

Germination percentage of *S. retroflexum* is shown in Figure 3.10 and the statistical analysis is presented in Annexure H.
Germination of *S. retroflexum* seed was characterised by very low germination percentage across all temperature treatments over the entire incubation period. Germination was only recorded in the 12 °C to 36 °C temperature treatments. Germination of *S. retroflexum* commenced after 54 h in the 28 °C, after 60 h in the 24 °C treatment and after 78 h in the 32 °C treatment. All other temperature treatments substantially delayed commencement of germination. No germination of *S. retroflexum* was observed below 12 °C and above 36 °C.

After 78 h, the germination percentage of 3.5% in the 28 °C treatment was significantly higher (*p*≤0.01) than that in all other temperature treatments. Thereafter, germination percentage remained significantly higher in the 28 °C treatment than in the other treatments until 180 h, when differences between the 24 °C and 28 °C treatments were no

**FIGURE 3.10:** Cumulative percentage of germinated *Solanum retroflexum* seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C
longer significant. After 204 h, differences among the 20 °C to 28 °C temperature treatments were no longer significant (p≤0.01). Although the onset of germination at 12 °C was delayed to 282 h, final germination percentage was significantly higher than that in the 16 °C, 20 °C, 24 °C and 32 °C treatments.

Time to final germination percentage was attained after 144 h in the 28 °C treatment, after 168 h in the 32 °C treatment, after 186 h in the 24 °C treatment, after 204 h in the 16 °C treatment, after 234 h in the 20 °C treatment and after 330 h in the 12 °C treatment. Final germination percentage was highest in the 12 °C (11%), 20 °C (4%), 24 °C (4%) and 28 °C (9.5%) temperature treatments. Final germination percentage was 3% in the 32 °C treatment and 2% in the 16 °C treatment.

3.3.1.9 Vigna unguiculata (L.) Walp.

Germination percentage of V. unguiculata is shown in Figure 3.11 and the statistical analysis is presented in Annexure I.
FIGURE 3.11: Cumulative percentage of germinated *Vigna unguiculata* seed over 336 h at different constant temperatures within the range of 4 °C and 44 °C

Germination of *V. unguiculata* seed occurred after 12 h in the 24 °C to 40 °C temperature treatments, after 18 h in the 20 °C treatment and after 24 h in the 44 °C treatment. Germination commenced after 36 h in the 16 °C treatment and after 102 h in the 12 °C treatment. No germination of *V. unguiculata* seed was observed below 12 °C.

The cumulative germination curve in the 20 °C to 44 °C temperature range showed a sharp increase in germination percentage during the first 36 h. After 12 h, germination percentage was 28.5% at 32 °C and 41% at 36 °C. These values were significantly higher \((p \leq 0.01)\) than the 20.5% and 16.5% observed in the 28 °C and 40 °C treatments, respectively. After 30 h, differences in germination percentage among the 20 °C to 36 °C temperature treatments were no longer significant. After 102 h, germination percentage in the 16 °C treatment also no longer differed significantly \((p \leq 0.01)\) from those in the 20 °C...
to 36 °C temperature treatments, and after 282 h, the germination percentage attained in the 12 °C treatment was also no longer different statistically from that in the 16 °C to 36 °C treatments.

Final germination percentage was reached after 30 h in the 36 °C treatment but took longer in all other treatments, being attained after 42 h in the 32 °C and 40 °C treatments, after 48 h in the 44 °C treatment, after 72 h in the 24 °C treatment and after 96 h in the 20 °C treatment. Final germination percentage was substantially delayed to 186 h and 288 h in the 16 °C and 12 °C temperature treatments, respectively. Final germination percentage (72.5% to 89%) was significantly higher ($p\leq0.01$) in the 12 °C to 36 °C treatments than in the 40 °C (59.5%) and 44 °C (14%) treatments.

### 3.3.2 Time to 50% germination

#### 3.3.2.1 *Amaranthus cruentus* L.

The effect of temperature on time to 50% germination of *Amaranthus cruentus* seed is shown in Figure 3.12.
FIGURE 3.12: Effect of temperature on time taken to achieve 50% germination of Amaranthus cruentus seed incubated at different constant temperatures within the range of 4 °C and 44 °C over 336 h (values with the same letter are not significantly different \( p \leq 0.01 \)).

The minimum time required for 50% germination of A. cruentus was 14 h at 32 °C. Higher and lower temperatures tended to increase time to 50% germination, but statistically time to 50% germination was only increased significantly \( (p \leq 0.01) \) at 16 °C.

3.3.2.2 Beta vulgaris L. var. cicla

The effect of temperature on time to 50% germination of Beta vulgaris var. cicla is shown in Figure 3.13.
Time to 50% germination of *Beta vulgaris* var. *cicla* was shortest ($p \leq 0.01$) in the 24 °C to 36 °C treatments. At temperatures below 24 °C and above 36 °C, time to 50% germination was significantly increased ($p \leq 0.01$).

### 3.3.2.3 *Brassica rapa* L. subsp. *chinensis*

Figure 3.14 shows the effect of temperature on time to 50% germination of *Brassica rapa* subsp. *chinensis* seed.
FIGURE 3.14: Effect of temperature on time taken to achieve 50% germination of *Brassica rapa* subsp. *chinensis* seed incubated at different constant temperatures within the range of 4 °C and 44 °C over 336 h (values with the same letter are not significantly different \( p \leq 0.01 \)).

The shortest time to 50% germination of *Brassica rapa* subsp. *chinensis* was 23 h at 28 °C, but this did not differ significantly \( (p \leq 0.01) \) from the 31 h at 24 °C, 25 h at 32 °C and 31 h at 36 °C. At 16 °C and 12 °C, time to 50% germination was increased to 61 h and 128 h, respectively.

3.3.2.4 *Citrullus lanatus* L.

The effect of temperature on time to 50% germination of *Citrullus lanatus* seed is presented in Figure 3.15.
The time to 50% germination of *Citrullus lanatus* was shorter in the 24 °C to 36 °C treatment than in the 20 °C and 40 °C treatments. Time to 50% germination was 63 h at 24 °C, 65 h at 28 °C, 60 h at 32 °C and 58 h at 36 °C. At 20 °C, time to 50% germination was increased to 112 h and at 40 °C temperature; it was increased to 80 h.

**3.3.2.5 Cleome gynandra** L.

The effect of temperature on time to 50% germination of *Cleome gynandra* is presented in Figure 3.16.
FIGURE 3.16: Effect of temperature on time taken to achieve 50% germination of *Cleome gynandra* seed incubated at different constant temperatures within the range of 4 °C and 44 °C over 336 h (values with the same letter are not significantly different \([p \leq 0.01]\))

Seeds incubated at temperatures higher than 36 °C or lower than 28 °C did not reach 50% germination. Only in the 28 °C, 32 °C and 36 °C temperature treatments was 50% germination attained. Statistically \((p \leq 0.01)\), differences in incubation time needed to obtain 50% germination among these three treatments were not significant. Time required to reach 50% germination was 38 h at 28 °C, 30 h at 32 °C and 33 h at 36 °C.

3.3.2.6 *Cucurbita maxima* Duchesne

The effect of temperature on time to 50% germination of *Cucurbita maxima* seed is shown in Figure 3.17.
FIGURE 3.17: Effect of temperature on time taken to achieve 50% germination of *Cucurbita maxima* seed incubated at different constant temperatures within the range of 4 °C and 44 °C over 336 h (values with the same letter are not significantly different \([p \leq 0.01]\))

Time to 50% germination was 25 h in the 32 °C treatment and 30 h in the 28 °C treatment, but the difference in time between these two treatments and the 36 °C treatment was statistically not significant \((p \leq 0.01)\). Reducing the incubation temperature to 24 °C or lower, significantly \((p \leq 0.01)\) increased incubation time to 50% germination when compared with the 32 °C and 36 °C treatments. Increasing the incubation temperature to 40 °C increased time to 50% germination from 24 h in the 36 °C to 33 h in the 40 °C treatment, an increase that was statistically significant \((p \leq 0.01)\).
3.3.2.7 *Corchorus olitorius* L.

The effect of temperature on time to 50% germination of *Corchorus olitorius* seed is shown in Figure 3.18.

**FIGURE 3.18**: Effect of temperature on time taken to achieve 50% germination of *Corchorus olitorius* seed incubated at different constant temperatures within the range of 4 °C and 44 °C over 336 h (values with the same letter are not significantly different \([p \leq 0.01]\)).

Minimum time to 50% germination of *Corchorus olitorius* was 12 h in the 28 °C to 40 °C treatments. Below and above this temperature range, time to 50% germination was significantly increased \((p \leq 0.01)\). Time to 50% germination was 299 h at 12 °C, 54 h at 16 °C, 27 h at 20 °C and 50 h at 44 °C.
3.3.2.8 *Vigna unguiculata* (L.) Walp.

The effect of temperature on time to 50% germination of *V. unguiculata* seed is presented in Figure 3.19.

**FIGURE 3.19**: Effect of temperature on time taken to achieve 50% germination of *Vigna unguiculata* seed incubated at different constant temperatures within the range of 4 °C and 44 °C over 336 h (values with the same letter are not significantly different \([p\leq0.01]\))

The minimum time to 50% germination of *V. unguiculata* was 14 h at 36 °C, although this did not differ significantly \((p\leq0.01)\) from the time to 50% germination recorded in the 20 °C to 40 °C treatments, which ranged from 14 h to 27 h. At temperatures of 12 °C and 16 °C, time to 50% germination was increased significantly to 192 h and 66 h, respectively.
3.3.3 Cardinal temperatures

The cardinal temperatures for the selected African leafy vegetables are summarized in Table 3.1.

**TABLE 3.1:** Cardinal temperatures for 50% germination of selected African leafy vegetables

<table>
<thead>
<tr>
<th>African leafy vegetables</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td><em>Amaranthus cruentus</em> L.</td>
<td>16</td>
</tr>
<tr>
<td><em>Beta vulgaris</em> var. <em>cicla</em></td>
<td>8</td>
</tr>
<tr>
<td><em>Brassica rapa</em> subsp. <em>chinensis</em></td>
<td>12</td>
</tr>
<tr>
<td><em>Cleome gynandra</em> L.</td>
<td>12</td>
</tr>
<tr>
<td><em>Citrillus lanatus</em> L.</td>
<td>20</td>
</tr>
<tr>
<td><em>Corchorus olitorius</em> L.</td>
<td>12</td>
</tr>
<tr>
<td><em>Cucurbita maxima</em> Duchesne</td>
<td>16</td>
</tr>
<tr>
<td><em>Vigna unguiculata</em> (L.) Walp.</td>
<td>12</td>
</tr>
<tr>
<td><em>Solanum retroflexum</em> Dun.</td>
<td>Did not reach 50% germination</td>
</tr>
</tbody>
</table>

3.4 DISCUSSION

The results showed that germination of the seed of the selected African leafy vegetables was affected by temperature. The general trend was for germination percentage to increase
from low temperatures towards a maximum achieved at an optimum temperature range, followed by a rapid decline at temperatures higher than the optimum, which is in line with the pattern that applies for most plants. High temperatures had a negative effect on final germination percentage and germination decreased for all eight plant species tested or failed completely at temperatures of 40 °C to 44 °C. These high temperatures are known to cause denaturing of proteins, membrane dysfunction and termination of metabolic activity (Kurtar, 2010:1347-1348), and this probably explains why the majority of seeds failed to germinate. Low temperatures delayed germination, which is known to increase the probability of fungal growth on seed (Singh & Dhaliwal, 1972:443).

In *A. cruentus*, germination in excess of 90% was obtained at temperatures ranging from 28 °C to 40 °C. Time to 50% germination was shortest in the 20 °C to 40 °C temperature range and final germination percentage of *A. cruentus* decreased at temperatures below 28 °C and above 40 °C. This is in agreement with the results of Gutterman, Corbineau and Côme (1992:115), who recorded 65% germination at temperatures ranging between 12 °C and 24 °C and 10% germination at temperatures ranging between 40 °C and 44 °C. The relationship between temperature and germination in *A. cruentus* underlines the importance of temperatures above 16 °C for rapid germination and high germination percentage (Aufhammer *et al*., 1998:133).

According to Van den Heever and Coertze (1996:1), amaranth species are known to be tolerant to relatively high temperatures and to generally thrive well within a temperature range of 22 °C to 30 °C. Cristaudu *et al.* (2007:327) stated that amaranth was adapted to a wide climatic range and grew optimally in the dry and hot summers of the Mediterranean environment, which could explain the germination percentage of 95 to 99% attained in the
28 °C to 40 °C observed in this study. The optimum temperature for maximum germination of *A. cruentus* observed in this study was 31 °C.

According to Drost (2005), *Beta vulgaris* var. *cicla* seed germinated best when the temperature ranged between 12 °C and 23 °C, with temperatures above 26 °C reducing germination. Similar results were obtained in this study. The highest germination percentage of more than 80% was attained at 12 °C to 24 °C. When temperature exceeded 24 °C, germination was reduced to below 80%. Time to 50% germination was, however, shorter when temperature ranged between 24 °C and 36 °C.

Generally, *Brassica* species, achieve high germination percentages at temperatures ranging between 15 °C and 35 °C, low germination percentage at 5 °C and very low germination percentage at 45 °C (Tokumasu, Kanada & Kato, 1985:368). Toxopeus and Baas (2004:148) stated that optimum temperature for germination for *B. rapa* subsp. *chinensis* was between 20 °C and 25 °C, but that *Brassica rapa* subsp. *chinensis* seed was known to germinate even at temperatures as low as 5 °C. In this study the highest germination percentages were attained at temperatures ranging between 20 °C and 36 °C, lower germination percentages at 8 °C to 16 °C and very low at 4 °C and 40 °C. Time to 50% germination was shortest at 24 °C to 36 °C and the optimum temperature was 29 °C.

At 28 °C and 32 °C, maximum germination attained by *Cleome gynandra* was significantly higher than at other temperatures. Germination percentage at 44 °C was still noticeable (13%), suggesting that *Cleome gynandra* is adapted to hot environments as indicated by Fletcher (1999:3); Mnzava and Chigumira Ngwerume (2004:193) and Silué (2009:1). Poor and delayed seed germination of *Cleome* is believed to be due to the hard seed coat,
immature embryos or induced secondary dormancy (Ochuodho & Modi, 2005:50; Ekpong, 2009:236). In this study the germination of *Cleome gynandra* was higher than reported by Böhringer, Lourens and Jansen van Vuuren (1999:24). This could be due to the seed lots used in the current study having been in storage for a longer period than those used by Böhringer, Lourens and Jansen van Vuuren (1999:24), which were only six months old. According to Chweya and Mnzava (1997:16), highest germination of *Cleome gynandra* seed occurs after 12 months of storage. However, this requires further investigation since it has been observed that seeds from dry capsules might germinate immediately after harvest. Long storage periods probably allow immature embryos to reach maturity (Ochuodho & Modi, 2005:52), since *Cleome gynandra* seeds have a rest period that extends to the fifth months after collection (Chweya & Mnzava, 1997:15; Fletcher, 1999:2).

According to Kurtar (2010:1344), minimum and maximum temperatures for Cucurbits were 15 °C and 45 °C, respectively, with large differences amongst cultivars, whilst the reported optimum germination temperatures ranged from 20 °C to 32 °C. The germination of the seed of both Cucurbits (*Citrillus lanatus* and *Cucurbita maxima*) used in this study was in line with the findings of Kurtar (2010:1344). The minimum temperature for germination was 20 °C for *Citrillus lanatus* and 16 °C for *Cucurbita maxima*, resulting in a germination percentage of approximately 3% and 42%, respectively. Time to 50% germination was shortest at 24 °C to 36 °C for *Citrillus lanatus* and 28 °C to 36 °C for *Cucurbita maxima*. Maximum temperature for germination was 40 °C for both species. From this study it was evident that both cucurbits were warm climate crops that were sensitive to cold, explaining why both required relatively high temperatures for germination. These findings support those of Schippers (2002:64) and Chingumira Ngwerume and Grubben (2004:265).
In this study, germination of *Corchorus olitorius* occurred over the wide range of 8 °C to 44 °C, with the highest germination percentage of 93% to 99% being obtained at 16 °C to 44 °C. Optimum temperature was 35 °C and maximum temperature 44 °C. At 12 °C, germination was reduced significantly. Time to 50% germination of *Corchorus olitorius* was shortest (less than 20 h) at temperatures ranging between 24 °C and 40 °C. These findings are in line with those reported by Nkomo and Kambizi (2009:1079) who stated that *Corchorus olitorius* grew well when day temperatures averaged 30 °C and above.

Final germination percentage of *Solanum retroflexum* seed was very low, with a final germination of 11% at 12 °C being the highest that was recorded. According to Abukutsa-Onyango (2007:9) nightshades have inherent dormancy problems, especially if seeds are not properly harvested and processed. It was difficult to extrapolate the cardinal temperatures for *S. retroflexum* germination due to low germination, which might be the result of inadequate removal of sugars and germination inhibitors present in the fruit during extraction of the seed (Abukutsa-Onyango, 2007:11; Jansen van Rensburg *et al.*, 2007:322). The dormancy problem of *S. retroflexum* is revisited in Chapter 5.

According to Vural *et al.* as quoted by Balkaya (2004:180), minimum and optimum temperatures for germination of *V. unguiculata* seeds were between 8 to 10 °C and 20 to 25 °C, respectively. In this study, minimum and optimum temperature for *V. unguiculata* germination were found to be 12 °C and 36 °C, respectively, with the maximum temperature being 40 °C. Time to 50% germination was shortest over the wide 20 °C to 40 °C range of temperatures. Cool temperatures (below 12 °C) and high temperatures (above 36 °C) significantly reduced germination of *V. unguiculata* seed. Balkaya (2004:180) reported that germination among vegetable legume species showed variability
in terms of temperature response with seeds of some legumes, including *V. unguiculata*, germinating poorly at low temperatures. The trend in the response of germination to temperature and the cardinal temperatures of *V. unguiculata* recorded in this study were similar to those reported by Craufurd *et al.* (1996:5-7), who stated that the optimum temperature for germination of *V. unguiculata* seed ranged from 30 °C to 36 °C.

### 3.5 CONCLUSION

The temperature during seed imbibition was found to affect germination rate and final germination percentage of all eight African leafy vegetables tested. Every species tested had a temperature range at which germination was possible and for each species temperature controlled the germination rate in a characteristic, unique pattern. The minimum, optimum and maximum temperature for seed germination varied among the species tested. A wide range of temperatures supported germination of *Amaranthus cruentus*, *Cleome gynandra*, *Citrullus lanatus*, *Cucurbita maxima*, *Corchorus olitorius*, *Vigna unguiculata*, *Brassica rapa* subsp. *chinensis*, and *Beta vulgaris* var. *cicla*, and depending on the species, germination was successful at temperatures of 8 °C to 44 °C. In general, however, low temperatures of 8 °C to 20 °C delayed germination and raising the temperature increased germination rate until a temperature of about 30 °C to 35 °C was reached. When increasing temperature above 35 °C, the rate of germination for all species decreased significantly and the extent of this reduction was species dependent. Very poor germination rates were observed for *Solanum retroflexum* over the whole spectrum of temperatures tested. *Cleome gynandra* also displayed a poor germination, and only reached 50% germination at temperatures between 28 °C and 36 °C.
The results of this study indicated that seed germination of the eight species was optimal in the temperature range of 29 °C to 36 °C. This result confirmed that these species were adapted to warm climates, and that they might grow optimally during summer when temperatures are warm. It is reported that most ‘weedy/wild’ species germinate better at high temperatures than exotic species. Therefore, simulation of germination at these high temperatures in this study probable was an important pre-adaptation for the weedy or wild habit of these species.

The minimum temperature range at which germination occurred was 8 °C to 20 °C. This might imply that below some critical temperature within this range, the African leafy vegetables may exhibit substantial reduction in rate of germination and subsequent growth, referred to as chilling injury. In addition, early sowing can be beneficial because it enables crops to have a long growing season and be ready for harvest prior to cool weather or rain at the end of the season. For the eight species tested, the maximum temperature range for seed germination ranged between 36 °C and 44 °C.

The ability to predict germination rate and the cardinal temperatures for seed germination is important for understanding seedling establishment in cropping ecosystems. Knowledge of seed germination response to temperature can help to optimise yield and monetary value of crops. For the majority of African leafy vegetables, the effect of temperature on seed germination has not been reported before. As was shown, the cardinal temperatures had a pronounced effect on rate and germination percentage of these crops. Considering that there has been marked interest among many workers in modelling plant growth and development, the results of this study could contribute to these efforts. Models such as those predicting days to germination and those predicting optimum temperatures could be
used to determine the optimum time for sowing of these crops in different regions and to utilize the growing season of these regions as productively as possible.

The cardinal temperatures derived for seed germination of the different African leafy vegetables could be used for the prediction of subsequent stages of growth. Germination is a function of environmental conditions and it can be expected that factors other than temperature might contribute to the field performance of these crop species. One implication of this study is that care should be taken to interpret germination responses to temperature for these species as adaptations to climatic factors. Future studies should aim to identify the selective forces acting on the ability to germinate under these temperature ranges, with a focus on post germination traits. It is also important to keep in mind that these experiments were conducted at constant temperatures, whereas under natural conditions temperature is subject to diurnal fluctuations. Consequently, the cardinal temperatures estimated in this study might differ from those that apply under natural conditions.
CHAPTER 4

4 EFFECT OF TEMPERATURE ON EMERGENCE OF SELECTED AFRICAN LEAFY VEGETABLES

4.1 INTRODUCTION

Seedling emergence is the first development stage after seed germination and is a pre-condition for successful crop establishment and survival (Huang et al., 2008:183). Awal and Ikeda (2002:101) stated that seedling emergence is the phase during which the young plantlet enters the productive phase and establishes itself. This growth phase may be the single most important in a plant’s life, affecting the success of the plant. Rapid, uniform and complete emergence of seedlings is needed to obtain high crop yields. Rapid emergence shortens the time from sowing to complete ground cover. Uniform and complete emergence of seedlings allows for the establishment of the optimum canopy structure, minimising both intra-specific competition and competition from weeds (Soltani et al., 2006:157).

Seedling emergence is affected by temperature, soil water availability, aeration and light (Craufurd et al., 1996:2; Forcella et al., 2000:128; Huang et al., 2008:183). Several other factors also affect seedling emergence, such as row spacing, distance between seeds in the rows, depth of planting and degree of seed-soil contact, which may interact with environmental factors, such as soil water availability and light (Hemmat, Khashoei &
Ranjbar, 2003:87). Temperature can be used as a predictor of seedling emergence (Forcella et al., 2000:129).

Knowledge of the cardinal temperatures for emergence of any plant species is useful in decisions on optimal sowing time (Soltani et al., 2006:157). The body of literature describing the effect of temperature on seed germination is extensive but studies of temperature effects on seedling emergence are less abundant. The present study was conducted to determine the cardinal temperatures for seedling emergence of the selected African leafy vegetables.

4.2 MATERIALS AND METHODS

4.2.1 Seed emergence

The same batches of seed as those described in Chapter 3 were used in this experiment and the seed pre-treatment method was also similar. Emergence experiments were conducted by sowing seeds on germination sand [Rolfes Silica, 0.4-0.85 grading; dry graded silica sand (SiO$_2$, 98% Fe$_2$O$_3$, 0.18%)] moistened with distilled water for small seeds (0.0675 l kg$^{-1}$ sand) and large seeds (0.4675 l kg$^{-1}$ sand), respectively. Once water was added, the water in the sand was allowed to be redistributed in the sand before the sand was transferred to the incubators.

Prior to sowing, sample containers (280 mm x 190 mm) containing the moist sand were incubated for 24 h at the designated treatment temperatures to allow the sand to attain the desired temperatures. Water was replenished as needed. Treatments were arranged using a
completely randomized design in controlled temperature incubators for all experiments. Spacer sticks were used to separate sample containers inside the incubators to allow sufficient circulation of air around the containers (Fig. 4.1).

FIGURE 4.1: Rectangular containers separated by spacer sticks inside an incubator used for the seed emergence experiments

Seeds were sown in the moist germination sand. Seeds were considered to have emerged once the cotyledons visually appeared above the surface of the sand (Fig. 4.2a and 4.2b) (Bavec & Mlakar, 2002:96; Koger, Reddy & Poston, 2004:991; Kurt & Bozkurt, 2006:542; Maraghi, Gorai & Neffati, 2010:3).
FIGURE 4.2: Emerged seedlings of (a) *Corchorus olitorius* (small seed) and (b) *Cucurbita maxima* (large seed) sown inside rectangular plastic containers

4.2.2 Data analysis

The following parameters were determined:

- **Emergence percentage**

  The trend in emergence over time referred to the average number of seeds that emerged expressed as a percentage of the total number of seeds used per temperature treatment per incubation time, calculated by the following formula:

  \[
  \text{Emergence \%} = \frac{\text{Number of seeds emerged}}{\text{Number of seeds used}} \times 100
  \]

  The final emergence percentage was determined after 336 h and was represented as a percentage of the total number of seeds incubated.
• **Time to 50% emergence**

Time to 50% emergence was modelled using the model for 50% germination (Jami Al-Ahmadi & Kafi, 2007: 309) presented in Chapter 3. Time to 50% emergence refers to the time taken for 50% of the total number of seeds incubated to emerge.

• **Cardinal temperatures (minimum, optimum and maximum)**

The optimum temperature was determined by fitting two straight lines using a non-linear (NLIN) procedure with SAS between temperature and the inverse of time to 50% emergence for each specie separately. Regression lines were drawn separately for temperatures lower and higher than the optimum, as recommended by Rezazadeh and Koocheki (2006:13). The inverse of the time taken to achieve 50% emergence was used as the basis for determining optimum temperature, while the temperature extremes at which 50% emergence was recorded were used as the minimum and maximum temperatures.

### 4.2.3 Statistical analysis

Analysis of variance (ANOVA) was used to test for treatment effects. Treatment means were separated using Fishers' protected least significant difference test at the 1% level of significance instead than the 5% level (Snedecor & Cochran, 1980) because of heterogeneity of variances. The sigmoid function as described in TableCurve® 2D (2002) was fitted with SAS/NLIN (non-linear procedure) and the time to 50% germination was calculated and subjected to an appropriate analysis of variance (ANOVA) using SAS® statistical software version 9.2 (SAS, 1999).
4.3 RESULTS

4.3.1 Emergence percentage

The effect of temperature on cumulative percentage of emerged African leafy vegetable seed is shown in Figures 4.3 to 4.18, and the statistical analysis of the data is presented in Annexures J to R.

4.3.1.1 *Amaranthus cruentus* L.

The effect of temperature on the emergence of *A. cruentus* seed is shown in Figure 4.3 and the statistical analysis is presented in Annexure J.

**FIGURE 4.3:** Cumulative percentage of emerged *Amaranthus cruentus* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h
Commencement of emergence of the *A. cruentus* seed occurred after 48 h of incubation in the 28 °C treatment and after 72 h in the 24 °C, 32 °C, 36 °C and 40 °C temperature treatments. Emergence occurred after 96 h of incubation in the 20 °C treatment and after 144 h in the 16 °C treatment. Emergence was delayed to 240 h in the 12 °C treatment and no emergence of *A. cruentus* seed was observed at the low temperatures of 4 °C and 8 °C and the high temperature of 44 °C.

Cumulative emergence was highest in the 28 °C treatment (37.5%) until 48 h of incubation but after 72 h, the 77% emergence in the 32 °C treatment was significantly higher (*p*≤0.01) than the 58.5%, 61% and 9% attained in the 28 °C, 36 °C and 40 °C temperature treatments, respectively. After 144 h, emergence percentage was statistically (*p*≤0.01) not different among the 28 °C, 32 °C, 36 °C and 40 °C treatments but after 192 h it was lower (*p*≤0.01) in the 28 °C than in the 32 °C to 40 °C treatments. Although commencement of emergence was substantially delayed in the 16 °C treatment, the emergence percentage of 69% after 168 h was statistically not different (*p*≤0.01) from that attained in the 32 °C to 40 °C treatments.

Final emergence percentage was reached after 168 h in the 20 °C and 24 °C treatments, after 192 h in the 28 °C treatment, after 240 h in the 16 °C treatment, after 264 h in the 32 °C and 36 °C treatment, and after 288 h in the 40 °C temperature treatment. Final emergence percentage was highest in the 36 °C (88.5%) treatment, but statistically, the values recorded in the 16 °C (74.5%), 32 °C (82%), and 40 °C (80.5%) treatments did not differ significantly (*p*≤0.01) from that in the 36 °C treatment. In the 12 °C treatment, final emergence percentage was 66.5%, and that in the 20 °C and 24 °C treatments was 53.5% and 39%, respectively. The emergence percentage of 74% recorded in the 16 °C treatment
was higher than the emergence percentage of 53.5% in the 20 °C treatment and the 39% recorded in the 24 °C treatment, which was surprising.

4.3.1.2 *Beta vulgaris* L. var. *cicla*

The effect of temperature on the emergence of *Beta vulgaris* var. *cicla* seed is shown in Figure 4.4 and the statistical analysis is presented in Annexure K.

**FIGURE 4.4:** Cumulative percentage of emerged *Beta vulgaris* var. *cicla* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h

Emergence of *Beta vulgaris* var. *cicla* seed occurred after 72 h of incubation in the 28 °C and 32 °C treatments, after 96 h at 20 °C, 24 °C and 36 °C, after 144 h in the 16 °C treatment and after 240 h in the 12 °C treatment. No emergence was observed at the low temperatures of 4 °C and 8 °C, and in the high temperature treatments of 40 °C and 44 °C.
Emergence of *Beta vulgaris* var. *cicla* occurred after 72 h in both the 28 °C and 32 °C treatments. The emergence percentage of 29.5% in the 28 °C treatment was significantly higher (*p*≤0.01) than the 22% in the 32 °C treatment. From 120 h onwards, differences in emergence percentage were no longer statistically significant (*p*≤0.01) among the 24 °C, 28 °C and 32 °C temperature treatments, but at temperatures below 24 °C and above 32 °C emergence percentage was lower. After 264 h of incubation, emergence percentage in the 16 °C was statistically not different (*p*≤0.01) from that observed in the 24 °C to 32 °C treatments.

Time to final emergence percentage was reached after 264 h in the 28 °C treatment, after 288 h in the 36 °C treatment and after 312 h in the 20 °C and 24 °C treatments. Emergence percentage was increasing in the 12 °C and 16 °C treatments during that same period. Final emergence percentage was 75.5%, in the 24 °C treatment, 77.0% in the 28 °C treatment, and 81.5% in the 32 °C treatment. Final emergence percentage was 57% at 12 °C, 66% at 16 °C, 60.5% at 20 °C and 47.5% at 36 °C.

**4.3.1.3 Brassica rapa** L. subsp. *chinensis*

The effect of temperature on the emergence of *Brassica rapa* subsp. *chinensis* seed is shown in Figure 4.5 and the statistical analysis is presented in Annexure L.
FIGURE 4.5: Cumulative percentage of emerged *Brassica rapa* subsp. *chinensis* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h

Emergence commenced after 72 h of incubation in the 20 °C to 32 °C treatments, after 96 h in the 16 °C treatment and after 120 h in the 12 °C and 36 °C treatments. Commencement of emergence was substantially delayed in the 8 °C treatment, occurring after 216 h of incubation. No emergence was observed in the 4 °C treatment and the high temperature treatments of 40 °C and 44 °C.

After 72 h of incubation, emergence percentage was significantly higher (*p*≤0.01) in the 28 °C (60.5%) and 32 °C (53.5%) treatments than that at 20 °C (38%) and 24 °C (46.5%). After 120 h, emergence percentage was significantly higher (*p*≤0.01) in the 24 °C and 28 °C treatments than in the 32 °C treatment. After 168 h, the emergence percentages of *Brassica rapa* subsp. *chinensis* seed incubated in the 12 °C to 20 °C treatments were similar. Emergence in the 8 °C treatment commenced only after 216 h but increased to...
84%, and statistically it was not different \( (p \leq 0.01) \) from the emergence percentage recorded in the 24 °C and 28 °C treatments after 288 h.

Final emergence percentage was reached after 120 h of incubation in the 24 °C treatment, after 144 h in the 20 °C and 28 °C treatments, after 192 h in the 16 °C treatment, after 240 h at 12 °C, 32 °C and 36 °C, and after 321 h in the 8 °C treatment. Final emergence percentage was 84.5%, 81% and 88.5% in the 8 °C, 24 °C and 28 °C, respectively. Final emergence percentage was reduced to 65.5% at the temperature of 32 °C and to 17% at 36 °C and was 62%, 57.5% and 58.5% in the 12 °C, 16 °C and 20 °C treatments, respectively.

4.3.1.4 *Citrillus lanatus* L.

The effect of temperature on the emergence of *Citrillus lanatus* seed is shown in Figure 4.6 and the statistical analysis is presented in Annexure M.
FIGURE 4.6: Cumulative percentage of emerged *Citrillus lanatus* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h.

Emergence commenced after 96 h in the 28 °C to 36 °C treatments, after 120 h in the 24 °C treatment, and after 144 h in the 40 °C treatment. Commencement of emergence in the 20 °C treatments occurred after 192 h with that of seed incubated in the 16 °C treatment occurring only after 312 h of incubation. No emergence was observed below 16 °C and above 40 °C.

Within the period of 96 h to 168 h, emergence of more than 90% of *Citrillus lanatus* seed occurred and was highest in the 28 °C and 32 °C treatments, but after 216 h, the emergence percentages in the 20 °C to 36 °C treatments were similar, statistically. Above 36 °C and below 20 °C emergence percentage was reduced. Time to final emergence was reached after 168 h in the 28 °C treatment, after 192 h in the 36 °C treatment, after 216 h in the 24 °C and 32 °C treatments and after 240 h in the 20 °C treatment. Final emergence
percentage was significantly higher \((p \leq 0.01)\) in the 20 °C (94%), 24 °C (93.5%), 28 °C (92%), 32 °C (91%) and 36 °C (87%) treatments than the 50% and 10.5% attained in the high 40 °C treatment and low 16 °C treatment, respectively.

### 4.3.1.5 *Cleome gynandra* L.

The effect of temperature on the emergence of *Cleome gynandra* seed is shown in Figure 4.7 and the statistical analysis is presented in Annexure N.

**FIGURE 4.7:** Cumulative percentage of emerged *Cleome gynandra* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h

Emergence commenced after 72 h of incubation in the 28 °C to 40 °C treatments, after 96 h in the 24 °C treatment, after 120 h in the 20 °C and after 192 h in the 16 °C treatment. No emergence was observed below 16 °C and above 40 °C. Emergence percentage of *Cleome gynandra* remained below 40% irrespective of temperature treatment.
Emergence percentage after 72 h was significantly higher \((p \leq 0.01)\) at 32 °C (32.5%) than that at 28 °C (7%), 36 °C (23.5%) and 40 °C (8%). After 96 h, emergence percentage was statistically not different \((p \leq 0.01)\) among the 24 °C to 32 °C treatments. After 144 h of incubation, the emergence percentages in the 20 °C to 32 °C were similar. Relative to the emergence percentages recorded in this temperature range, emergence percentage was significantly reduced \((p \leq 0.01)\) above 32 °C and below 20 °C.

Final emergence percentage was reached after 144 h in the 40 °C treatment, after 168 h in the 36 °C treatment and after 216 h in the 32 °C treatment and was delayed in the 16 °C to 28 °C treatments. The final emergence percentages of 33.5% at 16 °C, 33% at 20 °C, 39.5% at 24 °C, 33% at 28 °C and 38.5% at 32 °C were significantly higher \((p \leq 0.01)\) than the 27.5% recorded at 36 °C and the 11.5% at 40 °C.

4.3.1.6 *Corchorus olitorius* L.

The effect of temperature on the emergence of *Corchorus olitorius* seed is shown in Figure 4.8 and the statistical analysis is presented in Annexure O.
Commencement of emergence of the seed of *Corchorus olitorius* occurred after 48 h of incubation at 28 °C to 36 °C and reached levels in excess of 95% over that same period. Emergence occurred after 72 h of incubation in the 24 °C and 40 °C treatments, after 96 h in the 20 °C and 44 °C treatment and after 168 h in the 16 °C treatment. No emergence was observed below 16 °C.

Emergence of *Corchorus olitorius* was significantly higher (*p*≤0.01) in the 16 °C to 40 °C than at 44 °C. Final emergence percentage was reached after 72 h of incubation at 32 °C and 36 °C, after 96 h in the 24 °C treatment, after 120 h in the 40 °C, after 144 h at 20 °C, after 168 h in the 44 °C treatment and after 216 h at 16 °C. Final emergence percentages ranging between 96% to 100% were achieved in the 16 °C to 40 °C and these were significantly higher (*p*≤0.01) than the 19% attained in the 44 °C treatment.

**FIGURE 4.8:** Cumulative percentage of emerged *Corchorus olitorius* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h
4.3.1.7 *Cucurbita maxima* Duchesne

The effect of temperature on the emergence of *Cucurbita maxima* seed is shown in Figure 4.9 and the statistical analysis is presented in Annexure P.

**FIGURE 4.9:** Cumulative percentage of emerged *Cucurbita maxima* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h

Emergence commenced after 72 h of incubation in the 28 °C and 32 °C treatments, after 96 h in the 24 °C and 36 °C treatments and after 144 h in the 20 °C treatment. Commencement of emergence was substantially delayed in the 16 °C treatment and only occurred after 240 h of incubation. No emergence of *Cucurbita maxima* seed was observed below 16 °C and above 36 °C.

After 72 h, the emergence percentage of 94.5% in the 32 °C was significantly higher ($p \leq 0.01$) than the 86.5% in the 28 °C treatment. After 120 h of incubation, differences
among the 24 °C to 32 °C treatments were no longer statistically significant and the same applied for differences in the 20 °C to 36 °C treatments from 240 h of incubation onwards.

Time to final emergence percentage was reached after 96 h of incubation in the 28 °C and 32 °C treatments, after 120 h in the 24 °C treatment and after 192 h in the 20 °C and 36 °C treatments. When seed of *Cucurbita maxima* was incubated at 16 °C, the final emergence percentage of 72.5% was only reached after 336 h. Final emergence percentages of 98% to 100% were reached in the 20 °C to 36 °C treatments and these were significantly higher \((p\leq0.01)\) than the 72.5% in the 16 °C treatment.

### 4.3.1.8 Solanum retroflexum Dun.

The effect of temperature on the emergence of *S. retroflexum* seed is shown in Figure 4.10 and the statistical analysis is presented in Annexure Q.
Emergence of *S. retroflexum* only occurred in the 20 °C to 32 °C temperature treatments and was very low throughout the entire incubation period. Compared to the 28 °C treatment, where emergence commenced after 144 h, incubation at 24 °C delayed the onset of germination to 168 h, and to 240 h and 264 h at 20 °C and 32 °C, respectively.

After 168 h of incubation, the emergence percentage of 13.5% at 28 °C was significantly higher ($p \leq 0.01$) than the 2.5% recorded in the 24 °C treatment. After 240 h, emergence percentage at 20 °C was significantly higher ($p \leq 0.01$) than in all other treatments. Final emergence percentage was attained after 288 h in the 28 °C treatment and after 312 h in the 20 °C treatment. Emergence percentage of seed incubated in the 32 °C treatment remained constant (0.5%) after the start of emergence. The final emergence percentage of 43% in the
20 °C treatment was significantly higher ($p \leq 0.01$) than the 5.5% recorded in the 24 °C treatment, the 17% at 28 °C and the 0.5% in the 32 °C treatment.

**4.3.1.9 Vigna unguiculata (L.) Walp.**

The effect of temperature on the emergence of *V. unguiculata* seed is shown Figure 4.11 and the statistical analysis is presented in Annexure R.

**FIGURE 4.11:** Cumulative percentage of emerged *Vigna unguiculata* seed at different constant temperatures covering the range of 4 °C to 44 °C over 336 h

Commencement of emergence occurred after 72 h of incubation in the 24 °C to 40 °C treatments, after 96 h in the 20 °C treatment and after 192 h in the 16 °C treatment. No emergence was observed below 12 °C and above 40 °C.
After 72 h, emergence of *V. unguiculata* seed was highest in the 28 °C to 36 °C treatments. After 168 h of incubation, emergence percentage in the 24 °C to 36 °C treatments was significantly higher \((p\leq0.01)\) than in the other temperature treatments. After 264 h, emergence percentage in the 16 °C treatment did not differ significantly \((p\leq0.01)\) from that in the 40 °C treatment, but after 288 h, emergence percentage was significantly higher \((p\leq0.01)\) in the 16 °C treatment than in the 40 °C treatment.

Final emergence percentage was reached after 144 h in the 28 °C and 40 °C treatments, after 192 h in the 36 °C treatment and after 240 h in the 20 °C, 24 °C and 32 °C treatments. Final emergence percentage was highest at 24 °C to 36 °C, being 82.5% in the 24 °C treatment, 87.5% in the 28 °C treatment, 85.0% in the 32 °C treatment and 89.0% in the 36 °C treatment. In the 16 °C and 40 °C temperature treatments, final emergence percentage was reduced to 68.0% and 25.5%, respectively.

**4.3.2: Time to 50% emergence**

**4.3.2.1 Amaranthus cruentus** L.

The effect of temperature on time to 50% emergence of *A. cruentus* seed is shown in Figure 4.12.
FIGURE 4.12: Effect of temperature on time taken to achieve 50% emergence of *Amaranthus cruentus* seed (values with the same letter are not significantly different \( p \leq 0.01 \))

The minimum incubation time required to reach 50% emergence was 64 h in the 28 °C and 32 °C treatments. Below 28 °C and above 32 °C, time to 50% emergence was increased to 98 h (20 °C), 101 h (36 °C) and 120 h (40 °C). Time to 50% emergence was 157 h at 16 °C and 281 h at 12 °C.

4.3.2.2 *Beta vulgaris* L. var. *cicla*

The effect of temperature on time to 50% emergence of *Beta vulgaris* var. *cicla* is shown in Figure 4.13.
FIGURE 4.13: Effect of temperature on time taken to achieve 50% emergence of Beta vulgaris var. cicla seed (values with the same letter are not significantly different \( p \leq 0.01 \))

Time to 50% emergence of Beta vulgaris var. cicla seed was shortest at 28 °C, being 87 h. However, statistically, this was not different \( (p \leq 0.01) \) from the time to 50% emergence in the 32 °C (97 h), 24 °C (122 h) and 36 °C (131 h) treatments. Time to 50% emergence was significantly increased \( (p \leq 0.01) \) to 201 h and 290 h when temperature was reduced 16 °C and 12 °C, respectively.

4.3.2.3 Brassica rapa L. subsp. chinensis

The effect of temperature on the emergence of Brassica rapa subsp. chinensis seed is shown in Figure 4.14.
Incubation time required to reach 50% emergence was 70 h, 71 h and 74 h in the 24 °C, 28 °C and 32 °C treatments, respectively. Time to 50% emergence in the 24 °C treatment was statistically not different \((p ≤ 0.01)\) from the 83 h in the 20 °C treatment but significantly different from the 71 h in the 28 °C and the 74 h in the 32 °C treatments. Time to 50% emergence was increased to 119 h in the 16 °C treatment, 149 h in the 12 °C treatment and 258 h in the 8 °C treatment.

**4.3.2.4 Citrillus lanatus** L.

The effect of temperature on time to 50% emergence of *Citrillus lanatus* seed is shown in Figure 4.15.
The shortest time to 50% emergence of *Citrullus lanatus* seed was 92 h, which was recorded in the 28 °C treatment, followed by 95 h in the 32 °C treatment. Time to 50% emergence was 131 h in the 24 °C treatment, 193 h in the 20 °C treatment, 115 h in the 36 °C and 221 h in the 40 °C treatment.

4.3.2.5 *Corchorus olitorius* L.

The effect of temperature on time to 50% emergence of *Corchorus olitorius* seed is shown in Figure 4.16.

**FIGURE 4.15:** Effect of temperature on time taken to achieve 50% emergence of *Citrillus lanatus* seed (values with the same letter are not significantly different \(p \leq 0.01\))
FIGURE 4.16: Effect of temperature on time taken to achieve 50% emergence of *Corchorus olitorius* seed (values with the same letter are not significantly different \((p \leq 0.01)\))

Time to 50% emergence was shortest in the 28 °C to 36 °C treatments. Time to 50% emergence was 31 h in the 28 °C treatment, and 37 h in the 32 °C and 36 °C treatments. Above and below this temperature range, time to 50% emergence was significantly increased \((p \leq 0.01)\). Time to 50% emergence was 61 h in the 24 °C treatment, 66 h in the 40 °C treatment, 85 h in the 20 °C treatment and 168 h in the 16 °C treatment.

**4.3.2.6 Cucurbita maxima** Duchesne

The effect of temperature on time to 50% emergence of *Cucurbita maxima* seed is shown in Figure 4.17.
FIGURE 4.17: Effect of temperature on time taken to achieve 50% emergence of *Cucurbita maxima* seed (values with the same letter are not significantly different \[ p \leq 0.01 \])

Time to 50% emergence of *Cucurbita maxima* seed was shortest (59 h) in the 32 °C and the 28 °C (66 h) treatments. Below 28 °C and above 32 °C, time to 50% emergence was significantly increased \( p \leq 0.01 \).

**4.3.2.7 Vigna unguiculata** (L.) Walp.

The effect of temperature on time to 50% emergence of *V. unguiculata* seed is shown in Figure 4.18.
FIGURE 4.18: Effect of temperature on time taken to achieve 50% emergence of *Vigna unguiculata* seed (values with the same letter are not significantly different \( p \leq 0.01 \))

Statistically, there were no significant differences \( (p \leq 0.01) \) in time to 50% emergence of *V. unguiculata* seed among the 24 °C to 36 °C temperature treatments. Time to 50% emergence was 65 h in the 32 °C treatment, 67 h in the 28 °C treatment, 68 h in the 36 °C treatment and 73 h in the 24 °C treatment. Time to 50% emergence was increased to 118 h at 20 °C and to 212 h at 16 °C.

### 4.3.3 Cardinal temperatures

The cardinal temperatures for 50% emergence of the African leafy vegetables are summarised in Table 4.1.
TABLE 4.1: Cardinal temperatures for 50% emergence of selected African leafy vegetables

<table>
<thead>
<tr>
<th>African Leafy Vegetables</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>A. cruentus L.</td>
<td>12</td>
</tr>
<tr>
<td>B. vulgaris var. cicla</td>
<td>12</td>
</tr>
<tr>
<td>B. rapa subsp. chinensis</td>
<td>8</td>
</tr>
<tr>
<td>C. lanatus L.</td>
<td>20</td>
</tr>
<tr>
<td>C. olitorius L.</td>
<td>16</td>
</tr>
<tr>
<td>C. maxima Duchesne</td>
<td>16</td>
</tr>
<tr>
<td>V. unguiculata (L.) Walp.</td>
<td>16</td>
</tr>
<tr>
<td>Cleome gynandra L.</td>
<td>Did not reach 50% emergence</td>
</tr>
<tr>
<td>Solanum retroflexum Dun.</td>
<td>Did not reach 50% emergence</td>
</tr>
</tbody>
</table>

4.4 DISCUSSION

The results indicate that for the African leafy vegetables studied, the lower limit of the temperature range for emergence was between 12 °C and 20 °C and the upper limit between 36 °C and 40 °C. The temperature at which the highest emergence percentage of most African leafy vegetables was obtained in the shortest time (optimum) ranged between 24 °C and 36 °C. Emergence was either greatly reduced or inhibited by temperatures ranging between 4 °C and 8 °C and between 40 °C and 44 °C. Only Brassica rapa subsp. chinensis seed emerged at temperatures lower than 12 °C, confirming its status of cool season crop (Jansen van Rensburg et al., 2007:321).
The observed reduction in emergence at the low and high end of the temperature range could be due to poor germination combined with improper development of seedlings. At high temperatures, increase in the rate of respiration and failure of metabolic activity of seed could also cause reduced emergence. At low temperatures, sub-optimal metabolic activity could result in prolongation of the germination period and decreased vigour of seedlings, which could, therefore, result in lower emergence (Singh & Dhaliwal, 1972:443). As duration from sowing to emergence is increased by low temperatures, the likelihood of low emergence percentages also increases due to seed and seedling diseases, which cause rotting of the cotyledons (Ndunguru & Summerfield, 1975:63; Soltani et al., 2006:160). Although the cardinal temperatures for some of these African leafy vegetables species appeared to be fairly specific and constant, which supports modelling of emergence, it is believed that most cardinal temperatures for non-crop species are not stable due to genetic variability within the population (Wang, 2005:45).

In *A. cruentus*, emergence was fastest at 28 °C and 32 °C and final emergence percentage was highest at 32 °C to 40 °C. Brenner *et al.* (2000:232) reported that across Africa vegetable types of amaranth were adapted to areas with hot climates. The findings of this study support this statement.

Emergence of *Beta vulgaris var. cicla* occurred in the 12 °C to 36 °C treatments. Although time to 50% emergence was shortest in the 24 °C to 36 °C treatments, final emergence percentage was highest in the 24 °C to 32 °C treatments, with the optimum being 30 °C. In this study, highest emergence percentage was obtained in the 24 °C to 32 °C temperature range. The minimum temperature for *Beta vulgaris var. cicla* seed to emerge was 12 °C.
These results confirm that this crop grows best in comparatively cool climates where the temperature does not exceed 25 °C (Swiss chard, S.a; The Owlcroft Company, 2010).

Time to 50% emergence of *Brassica rapa* subsp. *chinensis* was shortest at 24 °C to 32 °C and final emergence percentage was highest in the 24 °C to 28 °C treatments. However, statistically, final emergence recorded in the 8 °C treatment was not different from that at 24 °C to 28 °C. Jansen van Rensburg *et al.* (2007:321), reported that *Brassica rapa* subsp. *chinensis* prefered cool conditions for development. In this study, emergence of *Brassica rapa* subsp. *chinensis* seed occurred in the 8 °C to 36 °C treatments, but emergence percentage was highest in the 8 °C, and the 24 °C to 28 °C treatments.

*Cleome gynandra* did not reach 50% emergence, but was highest at 16 °C to 36 °C, with a maximum temperature between 40 °C and 44 °C. This observed temperature range for emergence indicate that *Cleome gynandra* is able to withstand high day-time temperatures as reported by Silué (2009:1). No emergence of *Cleome gynandra* occurred below 16 °C, which supports accounts that growth of this specie is inhibited at temperatures lower than 15 °C (Jansen van Rensburg *et al.*, 2007:320). According to Fletcher (1999:3), temperatures of 18 °C to 25 °C are favourable for *Cleome gynandra*, but in this study, emergence was optimal at 16 °C to 36 °C with 40 °C to 44 °C as the maximum temperature. This high maximum temperature is in line with the distribution of this specie, which is primarily in tropical and subtropical regions (Mnzava & Chigumira Ngwerume, 2004:191; Silué, 2009:1).

*Citrillus lanatus* and *Cucurbita maxima* belong to the Cucurbitaceae, and their seed requires high temperatures for successful seedling emergence (Singh *et al.*, 2001:59). In
this study, time to 50% emergence of the seed of both *Citrullus lanatus* and *Cucurbita maxima* was shortest in the 28 °C to 32 °C treatments, and final emergence percentage was highest in the 20 °C to 36 °C temperature range for both species. The minimum temperature for emergence of *Citrullus lanatus* was 20 °C. Singh *et al.* (2001:61) reported that *Citrullus* spp. seed could be germinated up to a temperature as low as 14 °C, whilst Maynard (2007) reported emergence at 12 °C. Maynard (2007), found that time to emergence of *Citrullus* was reduced from 12 to just 3 days when temperature was increased from 20 °C to 35 °C, which is supported by the findings of the current study. Maynard (2007) stated that optimum mean daily temperature for *Cucurbita maxima* growth ranged from 18 °C to 23 °C. The current study showed that optimum temperature for emergence was 32 °C. This could indicate that the requirements for emergence and growth of *Cucurbita maxima* are different.

According to Fondio and Grubben (2004:219), optimum temperature for growth of *Corchorus olitorius* ranges between 25 °C and 32 °C. This is similar to the results obtained in this study where emergence was fastest in the 28 °C to 36 °C temperature range, with 33 °C being the optimum. The high temperatures at which emergence of *Corchorus olitorius* was recorded suggest that this plant species prefers a warm climate. No emergence below 16 °C was obtained, and this supports the findings of Fondio and Grubben, (2004:219) and Plants For A Future, (2008:2) who stated that growth of *Corchorus olitorius* was inhibited below 16 °C.

The optimum temperature for emergence of *S. retroflexum* in this study was 20 °C. Edmonds and Chweya (1997:82) reported the optimum temperature for the growth of *S. nigrum* species ranged between 20 °C and 30 °C, but indicated that most of these species
grew within the 15 °C to 30 °C range. Final emergence percentage of *S. retroflexum* in this study was low (43%). This could be due to inadequate removal of sugars and germination inhibitors present in the fruit during extraction of the seed that was used (Jansen van Ransburg *et al.*, 2007:322).

The minimum (16 °C), optimum (25 °C) and maximum (36 °C) temperature for seedling emergence of *V. unguiculata* recorded in this study suggests that *V. unguiculata* is adapted to warm areas (Coertze & Venter, 1996:1). Ndunguru and Summerfield (1975:63) reported that hypocotyl elongation of *V. unguiculata* was inhibited at temperatures above 40 °C. This is supported by the results obtained in this study in which no emergence was recorded above 40 °C. Time to 50% emergence was shortest in the 28 °C to 36 °C treatment range, and final emergence percentage was highest in the 24 °C to 36 °C temperature range.

### 4.5 CONCLUSION

Temperature was found to have an effect on the emergence of all African leafy vegetables that were investigated. The minimum, optimum and maximum temperature for seedling emergence varied for all species tested. Generally, emergence of the seed of these African leafy vegetables occurred over a broad range of temperatures, typically from 8 °C to 44 °C. The minimum temperature at which emergence was recorded ranged from 8 °C to 20 °C and the maximum from 32 °C to 40 °C. Most of the African leafy vegetables studied emerged optimally at temperatures ranging between 25 °C to 32 °C.

Temperature often had a dramatic effect on emergence percentage at the low temperatures of 4 °C to 12 °C and the high temperatures of 40 °C to 44 °C. A significantly reduced
percentage or no emergence at all was obtained when seed of *A. cruentus, Citrillus lanatus, Cleome gynandra, Corchorus olitorius, Cucurbita maxima, S. retroflexum* and *V. unguiculata* were incubated at low temperatures of 4 °C to 12 °C. Only emergence of *Brassica rapa* subsp. *chinensis* seed was discernible at the temperature of 8 °C. Increasing temperature in excess of 40 °C reduced emergence significantly in all species, but the extent of the reduction was specie dependant. Only seed of *Corchorus olitorius* emerged at the high temperature of 44 °C, although percentage emergence was low (19%). Very low emergence percentage (<30%) at this temperature were observed in both *Cleome gynandra* and *S. retroflexum*.

To maximise seedling emergence percentage, a temperature range of 29 °C to 32 °C is recommended for *A. cruentus, C. lanatus, C. olitorius* and *C. maxima*, which appear to be well adapted to warm climates. Seed of *B. rapa* subsp. *chinensis, S. retroflexum* and *V. unguiculata*, on the other hand, emerged best when the temperature ranged between 20 °C and 25 °C.

The emergence at low temperatures for most of the crop species indicate that seed could be planted when the temperatures are low, with the assumption that as temperatures rise towards the optimum, the process of emergence will accelerate over time. The optimum and maximum temperature ranges at which emergence was recorded, indicated that most of the African leafy vegetables studied were adapted to warm climates. From Chapter 3, seed of these African leafy vegetables germinated at much lower and higher temperatures than they emerged, suggesting that temperatures at which germination occurs may be inhibitory for seedling emergence.
Finally, it needs pointing out that the cardinal temperatures for seedling emergence were determined under controlled environmental conditions of constant temperatures. Under natural conditions where temperatures fluctuate, cardinal temperatures for seedling emergence could be different. Future studies should focus on the interactive effects of these factors to refine the results obtained in this study. Emergence has not been studied in sufficient detail to permit reliable predictions for many annual crops, especially the African leafy vegetables.
CHAPTER 5

5 EFFECT OF DORMANCY ON GERMINATION OF SELECTED AFRICAN LEAFY VEGETABLES

5.1 INTRODUCTION

In the majority of plant species, seed germination and development are separated by a period of low metabolic activity known as dormancy (Ochuodho & Modi, 2005:49). Bradford and Nonogaki (2007:55) defined seed dormancy as the failure of seeds to germinate under environmental conditions favouring germination. It is an important survival mechanism of many plants achieved by delaying germination, which allows time for dispersal and prevents germination of all the seeds at one time when conditions appear favourable (Bewley, 1997:1055; Fenner & Thompson 2005:99). According to Bewley (1997:1055), extensive domestication and breeding of crop species have seemingly removed dormancy mechanisms present in wild seeds. However, under adverse conditions, dormancy in crops can re-appear.

Dormancy may be caused by an impermeability of the seed coat to water and gaseous exchange. Hard seed coats act as barriers to germination by preventing embryo expansion or radicle growth (Materechera & Materechera, 2001:1142). Immature embryos, light and temperature requirements, or the presence of germination inhibitors are other factors causing dormancy (Stidham et al., 1980:115). Physiological dormancy in seeds may be related to the proportion between inhibitors, especially abscisic acid, and growth regulators such as gibberellins (Fenner & Thompson, 2005:97).
Several methods have been suggested to break seed dormancy. Amongst others these include stratification, scarification and leaching and soaking of seeds. According to Çetinbaş and Koyuncu (2006:120), stratification also known as cold treatment, or pre-chilling, stimulates structural gibberellic acid synthesis. Stratification is believed to limit the effects of inhibitors, such as abscisic acid, and promote the effects of growth stimulators, such as gibberellic acid (Stidham et al., 1980:115). Scarification is a treatment procedure that damages the seed coat of seeds to improve permeability to water and gaseous exchange (Stidham et al., 1980:115). This treatment procedure can include rubbing seed against an abrasive surface, nicking of seeds and warm water treatment. Soaking seed in chemicals, such as gibberellins and potassium nitrate, has been shown to stimulate germination (Stidham et al., 1980:115; Hilton, 1984:31). Gibberellins may be used to eliminate the chilling requirement of peach and apple seeds and increase their germination (Çetinbaş & Koyuncu, 2006:119).

Dormancy normally leads to poor and delayed germination and is an undesirable characteristic in agricultural crops, where rapid seed germination and growth are required (Bewley, 1997:1055). Furthermore, dormancy may cause irregular emergence, which can cause poor establishment of crops. One of the main problems that could prevent sustainable use of indigenous plants native to arid lands is that they readily germinate within their native environment, but fail to show good germination under laboratory conditions or when cultivation is attempted (Nadjafi et al., 2006:543).

Therefore, the objective of this study was to determine whether the selected African leafy vegetables had any form of seed dormancy and if so, whether pre-sowing treatments could break seed dormancy.
5.2 MATERIALS AND METHODS

5.2.1 Seed germination

The methods used for seed treatment and diagnosis of germination were similar to those described in Chapter 3. Pre-sowing tests for seed dormancy included four treatments:

- **Scarification**: seeds were scarified by rubbing them between two sheets of cabinet abrasive paper (P100 GRIT)
  - Small seeds were gently rubbed 5 times between two abrasive papers (P100 GRIT) without extensively damaging the seed (Abu-Zanat & Samarah, 2005:142; Travlos, Economou & Karamanos, 2007:502).
  - Large seed were rubbed at the seed tip (attachment of the funiculus) with abrasive paper (Materechera & Materechera, 2001:143; Abu-Zanat & Samarah, 2005:142).

- **Chemical soaking**: 0.2% potassium nitrate (KNO₃) was used instead of distilled water to moisten the germination substratum on which seeds were sown (Stidham et al., 1980:116; Abu-Zanat & Samarah, 2005:142; Ochuodho & Modi, 2005:50; ISTA, 2008:14).

- **Stratification (pre-chilling)**: imbibed seeds were incubated for 7 days at 5 °C under continuous darkness in a controlled Labcon™ low-temperature incubator (Ochuodho & Modi, 2005:50; Nadjafi et al., 2006:544).

- **Control**: seeds were left untreated.

After the pre-sowing treatments were completed, seeds were germinated at a constant temperature of 25 °C under alternating light (8 h light and 16 dark) for 336 h (14 days).
Germination experiments were conducted by sowing small seeds on top of four layers of pre-cut (115 mm x 125 mm) brown anchor germination paper (top paper) and moistened with 10 mL distilled water. Large seeds were sown on four layers of rolled germination paper (260 mm x 380 mm) moistened with 50 mL distilled water (ISTA, 2008:13).

5.2.2 Statistical analysis

Analysis of variance (ANOVA) was used to test for treatment effects. Treatment means were separated using Fishers' protected least significant difference test (LSD) at the 5% level of significance (Snedecor & Cochran, 1980). Data were analysed using the statistical program GenStat® (Payne et al., 2007).

5.3 RESULTS

5.3.1 Amaranthus cruentus L.

Effects of the dormancy pre-sowing treatments on the germination of A. cruentus are shown in Figure 5.1 and the statistical analysis is presented in Annexure S.
FIGURE 5.1: Cumulative germination percentage of *Amaranthus cruentus* subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C

Commencement of germination of the seed of *A. cruentus* occurred after 24 h of incubation in all the dormancy treatments, including the control. Scarifying and pre-chilling *Amaranthus* seed significantly (*p*≤0.05) improved the onset of germination after 24 h from 18.5% in the control to 92.5% for scarifying and 55.0% for pre-chilling. Furthermore, these two treatments also significantly (*p*≤0.05) increased final germination percentage, which was reached after 48 h and 96 h, respectively. Soaking seeds in potassium nitrate (KNO₃) did not significantly (*p*≤0.05) improve germination of *Amaranthus* relative to the control. However, the germination percentage of seeds imbibed with KNO₃ tended to be higher than in the control treatment over the full incubation period. Final germination of 97.5%, 95.5%, 84.5% and 72.5% attained for seed that were pre-chilled, scarified, soaked in KNO₃ and the control, respectively, was reached after 120 h, 48 h, 84.5 h and 72 h, respectively.
5.3.2 Beta vulgaris L. var. cicla

Effects of the dormancy pre-sowing treatments on the germination of Beta vulgaris var. cicla seed are shown in Figure 5.2 and the statistical analysis is presented in Annexure T.

![Cumulative germination percentage of Beta vulgaris var. cicla subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C](image)

**FIGURE 5.2:** Cumulative germination percentage of Beta vulgaris var. cicla subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C

The onset of germination started after 48 h in all treatments. After 72 h, germination percentage of scarified Beta vulgaris var. cicla seed was significantly lower ($p \leq 0.05$) (67.5%) than in the control (77.5%). After 96 h, there were no significant differences ($p \leq 0.05$) among treatments. Seeds imbibed with KNO3 tended to have a higher final germination percentage (87.0%), than seeds in the other treatments but final germination percentage in the KNO3 treatment occurred later (after 264 h) than in the other treatments. Final germination percentages were 77.0% for pre-chilled seed, 73.5% for scarified seed
and 79.0% in the control. Final germination was achieved after 216 h (scarified), 240 h (pre-chilled) and 264 h (KNO$_3$), compared to 120 h in the control.

5.3.3 Brassica rapa L. subsp. chinensis

The effects of the dormancy pre-sowing treatments on the germination of Brassica rapa subsp. chinensis are shown Figure 5.3 and the statistical analysis is presented in Annexure U.

![Cumulative germination percentage of Brassica rapa subsp. chinensis subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C](image)

**FIGURE 5.3:** Cumulative germination percentage of Brassica rapa subsp. chinensis subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C

Germination of Brassica rapa subsp. chinensis seed started after 24 h in the scarification, KNO$_3$ and control treatments. Commencement of germination in the pre-chill treatment was observed after 48 h. Germination percentage after 24 h was significantly higher ($p<0.05$) when seed was scarified (21%) compared to the control (6%). After 48 h, the
scarification and KNO$_3$ treatments significantly increased ($p \leq 0.05$) germination percentage of Brassica rapa subsp. chinensis from 63.5% in the control to 86.5% and 86.0%, respectively. Subjecting Brassica rapa subsp. chinensis seed to pre-chilling conditions significantly reduced ($p \leq 0.05$) germination percentage throughout the entire incubation period. The highest germination percentages of 90% and 95% were reached after 72 h and 120 h when seed was scarified and imbibed with KNO$_3$, respectively. Final germination percentages in these two treatments were significantly higher ($p \leq 0.05$) than those in the control (74%) and pre-chill (60%) treatments, which attained final germination percentage after 120 h and 312 h, respectively.

5.3.4 Citrillus lanatus L.

Effects of the dormancy pre-sowing treatments on the germination of Citrillus lanatus are shown in Figure 5.4 and the statistical analysis is presented in Annexure V.
Germination commenced after 48 h in the scarification, KNO$_3$ and control treatments and after 72 h in the pre-chill treatment. Onset of germination of seed of *Citrillus lanatus* was delayed when seed of this specie was pre-chilled (0%) or imbibed with KNO$_3$ (6%), compared to when seed was scarified (16.5%). After 72 h, the germination percentage (78.0%) of pre-chilled seed, although statistically not different from that in the control (85.0%), was significantly lower ($p \leq 0.05$) than scarified seed (92%) or KNO$_3$ treated seed (93%). However, after 96 h, differences in germination percentage among treatments were no longer statistically significant ($p \leq 0.05$) and this persisted until the end. Final germination percentage in all dormancy pre-treatments tended to be higher than in the control, but statistically differences were not significant ($p \leq 0.05$). Final germination percentage of 96.5% (KNO$_3$), 95.5% (scarified), 94.5% (pre-chilled) and 91.5% (control) was reached after 144 h, 120 h, 96 h and 144 h, respectively.
5.3.5 *Cleome gynandra* L.

Effects of the dormancy pre-sowing treatments on the germination of *Cleome gynandra* seed are shown in Figure 5.5 and the statistical analysis is presented in Annexure W.

**FIGURE 5.5:** Cumulative germination percentage of *Cleome gynandra* subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C

Germination of *Cleome gynandra* seed commenced after 24 h in the scarification and control treatments and after 48 h in the pre-chill and KNO₃ treatments. After 48 h, scarification improved the onset of germination of seed of *Cleome gynandra* significantly \((p \leq 0.05)\) compared to the other treatments and pre-chilling seed significantly reduced \((p \leq 0.05)\) onset of germination from 31.5\% (control) to 14.5\%. After 72 h, germination percentage of scarified seed (45\%) did not differ significantly \((p \leq 0.05)\) from that in the control (36.5\%). After 96 h, germination of pre-chilled seeds remained significantly lower
than seeds that were scarified, but did not differ statistically \((p \leq 0.05)\) from the other treatments.

After 120 h, differences among treatments were no longer different statistically \((p \leq 0.05)\) and this persisted until final germination percentage of 47.5\%, 42.5\%, 40.5\% and 32.5\% was attained for scarification, control, KNO\(_3\) (after 144 h) and pre-chill (after 168 h), respectively.

**5.3.6 Corchorus olitorius L.**

In Figure 5.6, the effects of dormancy pre-sowing treatments on the germination of *Corchorus olitorius* seed are shown and the statistical analysis is presented in Annexure X.

![Cumulative germination percentage of *Corchorus olitorius* subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C](image)

**FIGURE 5.6:** Cumulative germination percentage of *Corchorus olitorius* subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C.
Commencement of germination of the seed of *Corchorus olitorius* occurred after 24 h of incubation. When seed of *Corchorus olitorius* was pre-chilled, the germination percentage after 24 h (77.5%) was significantly lower (*p*≤0.05) than the 89.5% in the control. From 48 h onwards, differences among all treatments were not significant (*p*≤0.05). Final germination was attained after 48 h in the scarification, KNO₃ and control treatments, and after 72 h in the pre-chill treatment. Final germination percentage was 97.5% (scarified), 97.0% (KNO₃), 96.5% (pre-chilled) and 95.5% (control).

5.3.7 *Cucurbita maxima* Duchesne

Effects of dormancy pre-sowing treatments on the germination of *Cucurbita maxima* seed are shown in Figure 5.7 and the statistical analysis is presented in Annexure Y.

**FIGURE 5.7:** Cumulative germination percentage of *Cucurbita maxima* subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C
Commencement of germination in the seed of *Cucurbita maxima* occurred after 48 h of incubation in all treatments. After 48 h, germination of *Cucurbita maxima* seed was significantly lower (*p*≤0.05) in the pre-chilling treatment (82.5%) than the 99.5% in the control. From 72 h onwards, treatment effects were no longer significant. Final germination was 100% for scarified seed and was reached after 48 h. Final germination was reached after 72 h for KNO₃, pre-chill and control. Final germination percentage was 100% in the KNO₃ and control treatments, and 99.0% for pre-chilled seed.

### 5.3.8 *Solanum retroflexum* Dun.

Effects of the dormancy pre-sowing treatments on germination of *S. retroflexum* are shown in Figure 5.8 and the statistical analysis is presented in Annexure Z.

**FIGURE 5.8:** Cumulative germination percentage of *Solanum retroflexum* subjected to different dormancy pre-treatments for 14 days (336 h) at 25°C
Germination of *S. retroflexum* seed commenced after 48 h of incubation in the scarification treatment and after 72 h of incubation in all other dormancy pre-sowing treatments. Germination percentage after 48 h was significantly improved ($p \leq 0.05$) from zero to 1.5%, when seed of *S. retroflexum* was scarified. After 72 h, germination percentage of seed imbibed with KNO$_3$ (20.5%) was significantly higher ($p \leq 0.05$) than in the control (7%) and thereafter, KNO$_3$ treatment significantly improved ($p \leq 0.05$) germination percentage until final germination percentage was attained after 336 h of incubation. From 120-192 h there was no significant difference ($p \leq 0.05$) between scarification and the control. However, after 216 h, germination percentage in the scarification treatment was significantly ($p \leq 0.05$) lower than in the control.

Relative to the control, pre-chilling seed of *S. retroflexum* significantly reduced ($p \leq 0.05$) germination percentage throughout the incubation period. Germination percentage after 216 h of scarified (34.5%) and pre-chilled (16.0%) seed was significantly reduced ($p \leq 0.05$) than the 46% in the control. Final germination percentage was reached after 264 h in all treatments and was 95.0% (KNO$_3$), 52.5% (control), 35.5% (scarification) and 18.0% (pre-chill).

5.3.9 *Vigna unguiculata* (L.) Walp.

Effects of the dormancy pre-sowing treatments on the germination of *V. unguiculata* seed are shown in Figure 5.9 and the statistical analysis presented in Annexure Z$_1$. 
Germination of *V. unguiculata* seed commenced after 24 h in all treatments. After 24 h, germination of pre-chilled seed (24%) was significantly lower (*p*≤0.05) than that of seed in the control treatment (64%). However, after 48 h, there were no more significant differences (*p*≤0.05) among treatments and final germination percentages of 97.5% (KNO₃), 95.5% (scarification), 95.0% (pre-chill) and 94.5% (control) were reached after 120 h, 48 h, 120 h and 72 h of incubation, respectively.

5.4 DISCUSSION

Results from this study showed that scarification positively improved onset and final germination of *A. cruentus* and *Brasica rapa* subsp. *chinensis* seed, but negatively affected that of *S. retroflexum*. Pre-chilling had a positive effect on onset and final germination of  

![Cumulative germination percentage of *Vigna unguiculata* subjected to different dormancy pre-treatments for 14 days (336 h) at 25 °C](image.png)
A. cruentus but negatively affected germination of Brassica rapa subsp. chinensis, C. gynandra and S. retroflexum. KNO$_3$ positively affected both onset and final germination of Brassica rapa subsp. chinensis and S. retroflexum. Dormancy treatments did not have a significant effect on the final germination percentage of Beta vulgaris var. cicla, Citrillus lanatus, Corchorus olitorius, Cucurbita maxima and V. unguiculata.

The significant improvement in germination when seed of A. cruentus and Brassica rapa subsp. chinensis was scarified suggested that the cause of dormancy in these plant species might be attributed to hard seed coats acting as physical barriers to water absorption. According to Materechera and Materechera (2001:145), during the early stage of germination, the rate of oxygen uptake by a seed is proportional to the moisture content of the cotyledons, which is responsible for germination rate. Scarifying the seed probably ruptured the seed coat thus permitting the water imbibition rate to increase. Therefore, success with using the abrasion technique is probably dependent on the thoroughness of abrasion. In this study, seeds of A. cruentus and Brassica rapa subsp. chinensis were abraded on the surface of sandpaper, which appears to have been sufficient to produce adequate scarification, explaining the improved germination. It could be concluded that scarification increased the water imbibitions rate of the seeds and hence improved their final germination percentage. Although this study has attempted to document this process in detail, it was still impossible to determine the level of abrasion required to achieve optimum results. Therefore, future studies need to establish the degree of abrading required to break seed dormancy most effectively.

When seed of Cleome gynandra was abraded with sandpaper, the rate of germination was accelerated. However, final germination percentage attained was not significantly different
from seed that was pre-chilled, imbibed with KNO$_3$ or left untreated. These findings partly support the conclusions of Ochoudho and Modi (2005:53) and Ochuodho et al. as cited by Ekpong (2009:236), that scarification improves germination of *Cleome* seed. However, since final germination percentage was not significantly improved, the cause of dormancy might not be due to the seed coat acting as a physical barrier to water absorption for effecting final germination. Furthermore, since pre-chilling did not improve final germination percentage of *Cleome* seed, embryo dormancy can also be ruled out (Ekpong, 2009:238).

Scarification could have improved the onset of germination of *S. retroflexum* by increasing the rate of imbibition leading to rupturing of the seed coat, thus permitting germination to commence (Bewley, 1997:1062; Materechera & Materechera, 2001:145; Mwamburi, Kimondo & Kyalo, 2005:24). However, final germination percentage of scarified seed was significantly lower than in the other seed dormancy treatments and the control, suggesting that abrasion could have caused damage to the seed (possibly the embryo) resulting in less seeds germinating. Slow germination rate of seeds with physical dormancy could be of benefit during dry periods, acting as a delaying mechanism responsible for inhibiting simultaneous germination, thus enabling survival of the species under harsh conditions. On the other hand, seed without any physical dormancy could be responsible for maintenance of high population levels during favourable periods (Bewley, 1997:1055).

Pre-chilling was able to break dormancy and increase germination of *A. cruentus* only. Pre-chilling seed of this specie could have assisted in releasing embryo dormancy inhibitors, thus triggering germination. This could include increasing the level and responsiveness of endogenous gibberellins, and possibly decreasing the abscisic level (Stidham et al.,
Contrary to the findings of this study, Aufhammer et al. (1998:128) reported that dormancy of *A. cruentus* could not be broken by pre-chilling. Pre-chilling is believed to simulate cold winter conditions for seeds with internal dormancy. In untreated seed, oxygen does not diffuse through the seed coat, which leads to germination failure of the embryo. However, at cold temperatures, more oxygen diffuses in soluble water thus better satisfying the oxygen requirements of the embryo (Seed dormancy and treatments, S.a).

Although pre-chilling seed is known to break dormancy of viable seed and enhance germination, it is also known to cause lethal effects on viable seed (Ekpong, 2009:238; Nkomo & Kambizi, 2009:1079). Seed of *Brassica rapa* subsp. *chinensis*, *Cleome gynandra* and *S. retroflexum* showed significantly lower germination when pre-chilled. Ochoudho & Modi (2005:53) also reported low germination when seeds of *Cleome gynandra* were pre-chilled. Ekpong (2009:238) stated that the decrease in germination of pre-chilled seeds might be due to water trapped in tissues between the embryo and seed coat, creating an oxygen barrier. Seed of *Citrullus lanatus*, *Corchorus olitorius*, *Cucurbita maxima* and *V. unguiculata* appeared not to possess any dormancy mechanism that inhibited germination. When compared with the other treatments (scarification and KNO₃), pre-chilling *Citrullus lanatus*, *Corchorus olitorius*, *Cucurbita maxima* and *V. unguiculata* seed delayed onset of germination, but this effect was temporary.

The results obtained for seed of *Corchorus olitorius* contradicted the work of Nkomo and Kambizi (2009:1080), who stated that final germination of *Corchorus olitorius* seed was highest after 84 h of pre-chilling. They also stated that experiments involving pre-chilling of seeds, for plant species that mostly grow in summer, record the highest germination
percentages when seeds are pre-chilled for approximately seven days. In this study, there were no significant differences in germination percentage between pre-chilled seed and untreated seed after 72 h (3 days).

Both the onset and final germination percentage of *Brassica rapa* subsp. *chinensis* and *S. retroflexum* were significantly improved when seed of these species was imbibed with KNO$_3$. According to Fenner and Thompson (2005:125), nitrate (NO$_3^-$) is known to stimulate germination, especially in weedy species. The use of KNO$_3$ has been an important seed treatment in laboratories for many years without a clear explanation of the specific action in the seed (Çetinbaş & Koyuncu, 2006:119). It is believed that physiological dormancy in seeds is closely related to the proportion between inhibitors and growth regulators (Çetinbaş & Koyuncu, 2006:121). Imbibing seed with KNO$_3$ and a combination of gibberellic acid could stimulate germination by increasing the level and responsiveness of endogenous gibberellins, while substantially decreasing abscisic levels (Stidham *et al*., 1980:117; Ekpong, 2009:238). This could explain why germination of *Brassica rapa* subsp. *chinensis* and *S. retroflexum* seed improved by imbibing them in KNO$_3$. The response to KNO$_3$ by these two species could be interpreted as a dormancy-breaking mechanism, thus promoting germinability of the seeds. Fenner and Thompson (2005:126) however, stated that the germination response to nitrate is highly dependent on other environmental factors, such as light. This is in agreement with results published by Hilton (1984:33); Ochuodho and Modi (2007:591) and Mollard and Insausti (2009:60), who reported that the effect of KNO$_3$ on seed germination is dependent on both light and its quality. During this study, when the effect of light on both *Brassica rapa* subsp. *chinensis* and *S. retroflexum* was investigated, it was found that a significantly higher germination percentage was obtained in both species under alternating light than in
darkness (Chapter 6). It appears therefore, that seed germination of *Brassica rapa* subsp. *chinensis* and *S. retroflexum* could be optimised by imbibing seed with KNO$_3$ and germinating the seed under alternating light conditions.

Ekpong (2009:238) reported that when seed of *Cleome gynandra* was germinated with KNO$_3$ and gibberellins at various concentrations, the germination percentage was significantly increased relative to the control. This is contrary to findings of this study, where the KNO$_3$ treatment had no significant effect. Ochoudho and Modi (2005:53) also reported that imbibing with KNO$_3$ did not significantly improve germination percentage of *C. gynandra* seed. Final germination percentages attained were below 50% in all treatments and were similar to those attained by Ekpong (2009:238).

5.5 CONCLUSION

The findings of this study indicated that *A. cruentus, Brassica rapa* subsp. *chinensis, Cleome gynandra* and *S. retroflexum* exhibited some form of dormancy within their seed. Seed of these vegetables demonstrated:

- Physical dormancy whereby the seed coat acted as a physical barrier for water uptake and gaseous exchange.
- Embryo dormancy in which the seed when shed probably was immature thus a period of growth or differentiation was required.
- Physiological dormancy whereby germination was stimulated once a chemical change took place in the seed.
The results also suggested that *Amaranthus cruentus* and *Brassica rapa* subsp. *chinensis* had some form of physical dormancy that could inhibit successful germination. Scarification positively improved the onset and final germination of these two species. Although germination onset of *Cleome gynandra* and *S. retroflexum* seed was improved by scarification, the treatment significantly reduced final germination of *S. retroflexum*, but not of *Cleome gynandra*.

The findings suggest possible embryo dormancy in seed of *A. cruentus*, because the pre-chilling treatment positively affected the germination of this species. No embryo dormancy is expected in *Brassica rapa* subsp. *chinensis*, *Cleome gynandra* and *S. retroflexum* seed, because pre-chilling significantly reduced germination percentage, while for *Citrillus lanatus*, *Corchorus olitorius*, *Cucurbita maxima* and *V. unguiculata*, only germination onset was significantly reduced, not final germination percentage. The pre-chill requirement suggests that *Amaranthus cruentus* seed probably needs a form of overwintering before being used for planting. The pre-chilling treatment conditions may actually be simulating the events that occur during winter before the onset of summer.

The germination percentage of *Brassica rapa* subsp. *chinensis* and *S. retroflexum* seed was significantly improved when imbibed with KNO₃, whilst the onset of germination of *C. lanatus* seed was significantly reduced when seed was imbibed with KNO₃. Soaking seed with potassium nitrate (KNO₃) prior to planting to eliminate dormancy that could be associated with chemical inhibitors within the seed, thus improving germination by enhancing growth regulators within the seed, could be useful for *Solanum retroflexum* Dun. and *Brassica rapa* subsp. *chinensis*. Abrasion of seed with sandpaper before planting could be used to improve germination and consequently, stand establishment of
Amaranthus cruentus L., Brassica rapa subsp. chinensis and Cleome gynandra, but should be avoided for Solanum retroflexum Dun. seed.
CHAPTER 6

6 EFFECT OF LIGHT ON THE GERMINATION OF SELECTED AFRICAN LEAFY VEGETABLES

6.1 INTRODUCTION

Germination, which is the resumption of embryo growth sufficient to extend beyond the coverings surrounding the embryo, will not proceed unless favourable environmental conditions such as light, temperature, water and oxygen prevail (Manoto, Ferreira & Agenbag, 2004:214). Exposing seeds to light helps to break dormancy of some seeds, thus inducing germination (Bewley & Black, 1994:237; Khan & Gulzar, 2003:134; Ochuodho & Modi, 2005:49). Light requirements for seed germination differ among species (Mpati, 2006:39). Fenner and Thompson (2005:116) stated that the requirement of seeds to be exposed to light in order to germinate, prevents the occurrence of germination in places and times not favourable for seedling establishment. This enables the seed to have some control over where and when germination takes place, and prevents stored seed reserves from weakening before penetrating the soil surface.

In nature, the germination of light-requiring seeds is triggered by disturbance when soil is turned over (cultivation), gaps in the plant canopy and decline in water depths (Kettenring, Gardner & Galatowitsch, 2006:869). These mostly occur in forest settings where seeds will often not germinate until an opening in the canopy allows them to receive sufficient light for the growing seedling. Many weeds are light sensitive germinators. This is the reason why cultivating lands, which brings up seeds from deeper layers, causes weeds to
germinate. According to Fenner and Thompson (2005:116), the presence of light, or its absence, can trigger the germination process, inhibit germination in some seeds that are buried too deeply or in others not buried at all. Light can penetrate into the dormant embryo in seeds that have thin seed coats. In many plant species, germination is stimulated once their hydrated seeds are exposed to light, which is perceived through photoreceptors, especially those belonging to the phytochrome family (Bradford & Nonogaki, 2007:81). The objective of this study was to determine the effect of light on germination of selected African leafy vegetables.

6.2 MATERIALS AND METHODS

6.2.1 Seed germination

Methods used for seed treatment and diagnosis of germination were identical to those described in Chapter 3. Two experiments were executed to investigate the effect of light on germination of the selected African leafy vegetables:

- Alternating light/dark and continuous darkness, with evaluation every 24 h; and
- Alternating light/dark and continuous darkness, with evaluation only after 240 h.

The rationale for incubating the seeds for 240 h was that during the first experiment maximum germination was reached after 240 h. The experiments were designed in such a way that seeds exposed to alternating light conditions received light for 8 h and dark for 16 h daily. In experiment one, the dark treatment only received normal light during evaluations every 24 h for approximately 10 to 15 minutes. In experiment two, no daily
evaluations were done. Seeds were kept in the respective incubators for 10 days (240 h) without evaluation and germination count was done only after 240 h.

Seeds were considered to have germinated once the radicle had protruded from the testa by at least 2 mm. A Nikon™ dissecting microscope (model, C-LEDS, 100-240v, 0.2A, 50/60 Hz) was used to determine the length of the radical when not clearly visible to the naked eye. Seed germination was expressed as a percentage of the total number of tested seeds.

6.2.2 Data analysis

The final germination percentage was determined after 336 h and was represented as a percentage of the total number of seeds incubated.

\[
\text{Germination\%} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds incubated}} \times 100
\]

6.2.3 Statistical analysis

Analysis of variance (ANOVA) was used to test for treatment effects of the nine species and the interaction between treatment and species. The data were acceptably normal with heterogeneous treatment variances in experiment one not in experiment two. Therefore treatment means were separated using Fishers' protected t-test least significant difference (LSD) at the 1% level of significance for the 24 h evaluation experiment and at 5% level of significance for the 240 h experiment (Snedecor & Cochran, 1980). Data were analysed using the statistical program GenStat® (Payne et al., 2007).
6.3 RESULTS

6.3.1 Experiment one – evaluation every 24 h

6.3.1.1 Amaranthus cruentus L.

The effect of light on the germination of A. cruentus seed is shown in Figure 6.1 and the statistical analysis is presented in Tables 6.1 and 6.2.

FIGURE 6.1: Percentage germination of Amaranthus cruentus under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 ºC

The onset of germination for A. cruentus was accelerated by exposing the seed to alternating light. Differences in germination percentage between the dark and the alternating light treatment were statistically significant (p≤0.01) after 24 h, 48 h and 72 h. At 24 h, 48 h and 72 h, mean germination percentage was 7.5%, 10.5% and 41% in
darkness compared to 24 %, 79.5% and 80.5% in alternating light, respectively, but subsequently germination in darkness increased rapidly. After 96 h the germination percentage in darkness had reached 86% compared to 80.5% in alternating light. Statistically, the difference between the final germination percentage of 99.5% in darkness and 81.5% in alternating light was not significant ($p \leq 0.01$).

6.3.1.2 Beta vulgaris L. var. cicla

The effect of light on the germination of Beta vulgaris var. cicla seed is shown in Figure 6.2 and the statistical analysis is presented in Tables 6.1 and 6.2.

**FIGURE 6.2:** Percentage germination of Beta vulgaris var. cicla under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 ºC

Commencement of germination of the seed of Beta vulgaris var. cicla occurred after 24 h of incubation when exposed to darkness and after 48 h when exposed to alternating light.
After 48 h, the effect of light on germination of *Beta vulgaris* var. *cicla* was very minor, with 68.5% of seed germinated in alternating light compared to 75% in darkness. The difference in the final germination percentage of 83% in darkness and 80.5% in alternating light was statistically not significant (*p*≤0.01).

**6.3.1.3 Brassica rapa* L. subsp. chinensis**

The effect of light on the germination of *Brassica rapa* subsp. *chinensis* seed is shown in Figure 6.3 and the statistical analysis is presented in Tables 6.1 and 6.2.

**FIGURE 6.3:** Percentage germination of *Brassica rapa* subsp. *chinensis* under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 °C

Germination percentage of *Brassica rapa* subsp. *chinensis* seeds after 24 h was significantly (*p*≤0.01) improved by exposure to alternating light. Only 5% germination occurred in darkness after 24 h, compared to 38.5% under alternating light conditions.
Treatment differences continued to be significant until final germination was attained. The final germination percentage obtained under alternating light conditions was 93\% compared to 53.5\% under darkness.

6.3.1.4 *Citrillus lanatus* L.

The effect of light on the germination of *Citrillus lanatus* seed is shown in Figure 6.4 and the statistical analysis is presented in Tables 6.1 and 6.2.

**FIGURE 6.4:** Percentage germination of *Citrillus lanatus* under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 °C

From 48 h to 72 h, germination was significantly ($p \leq 0.01$) improved when seed was germinated in continuous darkness as compared to alternating light. After 48 h, 86\% of the seed in complete darkness had germinated, whereas only 10\% of seed exposed to
alternating light had germinated. After 72 h, treatment means converged. The same final mean germination percentage of 97% was reached in both treatments after 168 h.

### 6.3.1.5 Cleome gynandra L.

Germination of *Cleome gynandra* seed as affected by light is shown in Figure 6.5 and the statistical analysis is presented in Tables 6.1 and 6.2.

![Percentage germination of Cleome gynandra](image)

**FIGURE 6.5**: Percentage germination of *Cleome gynandra* under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 °C

Commencement of germination of the seed of *Cleome gynandra* occurred after 24 h of incubation when seed was exposed to darkness and after 48 h in the alternating light treatment. The rate at which germination occurred in both treatments was not significantly different \((p \leq 0.01)\) throughout the entire 336 h but tended to be higher in darkness than in alternating light conditions with 37% seeds germinated after 48 h in the dark, and only with 28.5% seeds germinated in alternating light. After 72 h, germination remained slightly
higher in darkness (41.5%) than in alternating light (37%) but the effect of light on germination disappeared completely after 336 h when the same final germination percentage of 43.5% was reached in both treatments.

6.3.1.6 Corchorus olitorius L.

The effect of light on the germination of *Corchorus olitorius* seed is shown in Figure 6.6 and the statistical analysis is presented in Tables 6.1 and 6.2.

![Figure 6.6: Percentage germination of *Corchorus olitorius* under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 °C](image)

Alternating light positively affected the onset of germination of *Corchorus olitorius* seed. After 24 h, the rate at which germination occurred was significantly higher \((p \leq 0.01)\) under alternating light conditions than under complete darkness. The mean germination percentage was 95.5% in alternating light and only 82% in complete darkness. However,
significance of the treatment differences completely disappeared from 48 h onwards when the final germination percentages of 96.5% and 96% were reached under alternating light and darkness, respectively.

6.3.1.7 Cucurbita maxima Duchesne

The effect of light on the germination of Cucurbita maxima seed is shown in Figure 6.7 and the statistical analysis is presented in Tables 6.1 and 6.2.

**FIGURE 6.7:** Percentage germination of Cucurbita maxima under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 °C

Germination of Cucurbita maxima commenced after 24 h of incubation in the darkness treatment and after 48 h in the alternating light treatment. After 24 h, 10% of the seed had germinated in darkness and none (0%) in alternating light. But, statistically this initial effect of light on germination was not significant ($p \leq 0.01$). Treatment effects weakened
even more, and the final germination percentage attained in both treatments was not significantly different, even though it tended to be slightly higher in alternating light than in darkness.

6.3.1.8 *Solanum retroflexum* Dun.

The effect of light on the germination of *S. retroflexum* seed is shown in Figure 6.8 and the statistical analysis is presented in Tables 6.1 and 6.2.

**FIGURE 6.8:** Percentage germination of *Solanum retroflexum* under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 °C

In both the alternating light and the continuous darkness treatments, the germination of *S. retroflexum* seeds only occurred after 72 h and was below 10% at that stage. The germination percentage over the entire 336 h period remained low in both treatments but tended to be higher in alternating light than in darkness. The difference between the two treatments tended to increase over time but statistically the final mean germination
percentage of 49.5% under alternating light was not significantly different ($p \leq 0.01$) from the 34% obtained in the dark treatment.

6.3.1.9 *Vigna unguiculata* (L.) Walp.

The effect of light on the germination of *V. unguiculata* seed is shown in Figure 6.9 and the statistical analysis is presented in Tables 6.1 and 6.2.

**FIGURE 6.9:** Percentage germination of *Vigna unguiculata* under constant darkness and alternating light (8 h light/16 h dark) for 14 days (336 h) at 25 ºC

After 24 h, germination percentage was significantly higher ($p \leq 0.01$) in the continuous darkness (84%) treatment than in the alternating light (69.5%) treatment. Thereafter, treatment effect disappeared. The final mean germination of 95% in darkness tended to be higher than the 94% attained in the alternating light treatment, but statistically this difference was not significant ($p \leq 0.01$).
6.3.2 Experiment two - evaluation after 240 h

The effect of light on the germination of the selected African leafy vegetables evaluated after 240 h of incubation is shown in Figure 6.10. In terms of the effect of light on final germination percentage, seeds could be divided into two groups, namely,

- Those which were indifferent to the presence or absence of light.
- Those which were significantly improved by exposure to light.

![Graph showing germination percentage of selected African leafy vegetables under different light conditions.]

**FIGURE 6.10:** Percentage germination of selected African leafy vegetables under constant darkness and alternating light (8 h light/16 h dark) over a period of 10 days (240 h) at 25 ºC.
The first group contained the seeds of species that were indifferent to the presence or absence of light for final germination percentage. Included in this group were *Amaranthus cruentus*, *Beta vulgaris* var. *cicla*, *Cleome gynandra*, *Cochrurus olitorius*, *Cucurbita maxima* and *Vigna unguiculata*. The second group contained the seeds of species of which final germination percentage was significantly improved by exposure to light. This group included *Brassica rapa* subsp. *chinensis*, *Citrillus lanatus* and *Solanum retroflexum*. In the continuous darkness treatment, the germination percentage of *Brassica rapa* subsp. *chinensis* seed was significantly lower (55%) than in alternating light (87.5%). In the case of *Citrillus lanatus*, the final germination percentage of 89% in alternating light was significantly higher (*p* ≤ 0.05) than the 79% recorded in continuous darkness. Final germination percentage of 0.5% for *S. retroflexum* seed when exposed to continuous darkness was significantly lower (*p* ≤ 0.05) than the 57.5% in alternating light. Generally, final germination percentage of the seed of all species when germinated in the alternating light treatment tended to be higher than when germinated in the continuous darkness treatment. The seed of *V. unguiculata* was the only exception.

The results obtained in both experiments (24 h and 240 h evaluation) are summarised in Table 6.1. Table 6.1 shows the effect of light on the onset of germination and final germination percentage measured every 24 h over 336 h (experiment 1) and the effect of light on final germination percentage measured after 240 h of incubation of selected African leafy vegetables under alternating light (8 h light/ 16 h dark) and constant darkness (experiment 2) at constant temperature of 25 °C.
TABLE 6.1: Effect of light on the onset and final germination percentage of nine leafy vegetable species

<table>
<thead>
<tr>
<th>Leafy vegetable species</th>
<th>Onset of germination (experiment 1)</th>
<th>Final germination (experiment 1)</th>
<th>Final germination (experiment 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Amaranthus cruentus</em></td>
<td>Positive</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><em>Beta vulgaris</em> var. <em>cicla</em></td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><em>Brassica rapa</em> subsp. <em>chinensis</em></td>
<td>Positive</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td><em>Citrillus lanatus</em></td>
<td>Negative</td>
<td>None</td>
<td>Positive</td>
</tr>
<tr>
<td><em>Cleome gynandra</em></td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><em>Cucurbita maxima</em></td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><em>Corchorus olitorius</em></td>
<td>Positive</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><em>Solanum retroflexum</em></td>
<td>None</td>
<td>None</td>
<td>Positive</td>
</tr>
<tr>
<td><em>Vigna unguiculata</em></td>
<td>Negative</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

In the first experiment, light significantly affected the onset of the germination of the seed of five of the nine species, namely, *Amaranthus cruentus, Brassica rapa* subsp. *chinensis, Citrillus lanatus, Corchorus olitorius* and *Vigna unguiculata*. Treatment significantly affected final germination percentage of *Brassica rapa* subsp. *chinensis* seed, with seed incubated in alternating light treatment attaining a higher percentage (93%) than that incubated in darkness (53.5%). In experiment two, alternating light had a statistically significant effect on final germination percentage of the seed of three species, namely, *Brassica rapa* subsp. *chinensis, Citrillus lanatus* and *Solanum retroflexum*. 
The mean cumulative germination percentage of the selected African leafy vegetables under alternating light (8 h light/16 h dark) and constant darkness at a constant temperature of 25 °C measured every 24 h over a period of 24 h-336 h (Experiment 1) is shown in Table 6.2.
CV% is the percentage coefficient of variation.

### TABLE 6.2: Cumulative germination percentage of selected African leafy vegetables under alternating light (16 h dark/ 8 h light) and constant darkness from 24 to 336 h

<table>
<thead>
<tr>
<th>Species</th>
<th>Light</th>
<th>24h</th>
<th>48h</th>
<th>72h</th>
<th>96h</th>
<th>120h</th>
<th>168h</th>
<th>216h</th>
<th>252h</th>
<th>288h</th>
<th>336h</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. retroflexum</td>
<td>25°C</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>C. maxima</td>
<td>25°C</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>C. olitorius</td>
<td>25°C</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Note:** The table continues with similar entries for other species and conditions, indicating germination percentages at various time intervals. The data includes statistical significance levels (e.g., <0.001, 0.001, <0.005) near the entries, suggesting comparisons within the data. The means per column followed by a different letter were significantly different at the 5% level.
The statistical significance of treatment effects on cumulative germination percentage of the selected African leafy vegetables incubated under alternating light (8 h light/16 h dark) and constant darkness conditions in the second experiment (240 h) is shown in Table 6.3.

**TABLE 6.3:** Cumulative germination of selected leafy vegetables under alternating light (L) (8 h light/16 h dark) and constant darkness (D) for 240 h

<table>
<thead>
<tr>
<th>Specie x TMT</th>
<th>240 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>L X <em>A. cruentus</em></td>
<td>91.50bcd</td>
</tr>
<tr>
<td>D X <em>A. cruentus</em></td>
<td>89.00cd</td>
</tr>
<tr>
<td>L X <em>B. vulgaris var. cicla</em></td>
<td>74.50ef</td>
</tr>
<tr>
<td>D X <em>B. vulgaris var. cicla</em></td>
<td>69.00f</td>
</tr>
<tr>
<td>L X <em>B. rapa</em></td>
<td>87.50d</td>
</tr>
<tr>
<td>D X <em>B. rapa</em></td>
<td>55.00g</td>
</tr>
<tr>
<td>L X <em>C. lanatus</em></td>
<td>89.00cd</td>
</tr>
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<td>79.00e</td>
</tr>
<tr>
<td>L X <em>C. gynandra</em></td>
<td>40.50h</td>
</tr>
<tr>
<td>D X <em>C. gynandra</em></td>
<td>37.50h</td>
</tr>
<tr>
<td>L X <em>C. olitorius</em></td>
<td>97.50ab</td>
</tr>
<tr>
<td>D X <em>C. olitorius</em></td>
<td>96.50abc</td>
</tr>
<tr>
<td>L X <em>C. maxima</em></td>
<td>100.00a</td>
</tr>
<tr>
<td>D X <em>C. maxima</em></td>
<td>100.00a</td>
</tr>
<tr>
<td>L X <em>S. retroflexum</em></td>
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</tr>
<tr>
<td>D X <em>S. retroflexum</em></td>
<td>0.5i</td>
</tr>
<tr>
<td>L X <em>V. unguiculata</em></td>
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</tr>
<tr>
<td>D X <em>V. unguiculata</em></td>
<td>92.50abcd</td>
</tr>
</tbody>
</table>

SEM 1.474
Probability <0.001
LSD (1%) 4.180
CV% 7.9
6.4 DISCUSSION

This study provided evidence of positive photosensitivity of final germination percentage in three of the nine species that were investigated, namely, *Brassica rapa* subsp. *chinensis*, *Citrillus lanatus* and *S. retroflexum*. All three species attained higher final germination percentage under alternating light than under complete darkness. The rate at which onset of seed germination of *Amaranthus cruentus*, *Brassica rapa* subsp. *chinensis* and *Corchorus olitorius* occurred was significantly increased when exposed to alternating light conditions. Therefore, the onset of germination for these species is positively photosensitive. This results suggests that disturbance by turning soil over and exposing seeds to light (Kettenring, Gardner & Galatowitsch, 2006:869), or other ways of bringing about a brief illumination (Mpati, 2006:16) might stimulate germination of these species, an attribute commonly observed among weeds (Taylorson & Borthwick, 1969:48).

Exposure to alternating light had a significant effect on final germination percentage of *Brassica rapa* subsp. *chinensis*, *Citrillus lanatus* and *S. retroflexum* in the 240 h incubation treatment, although only final germination percentage of seed of *Brassica rapa* subsp. *chinensis* was significantly improved by exposure to the alternating light treatment during the experiment involving 24 h evaluations. The apparent positive effect of light on final germination percentage of these three species suggests that germination of their seed is a photochrome-mediated response. Environmentally induced photosensitivity is usually interpreted as an adaptation that ensures that seed germinates in places where there is a high probability of seedling establishment (Mpati, 2006:17). Therefore, it would appear that the seeds of *Brassica rapa* subsp. *chinensis*, *Citrillus lanatus* and *S. retroflexum* have a preference of germination at or near the soil surface (Bayo & King, 1994:24). In the case of
*Brassica rapa* subsp. *chinensis*, the preference of its seed to germinate near the soil surface is supported by indigenous knowledge in the Venda region, where the crop is grown widely. According to Tshikalange (2006:3), people in Venda refer to the land race of *Brassica rapa* subsp. *chinensis* used in the study as ‘dabadaba’, because it germinates like a weed, following soil disturbance.

The germination of the seeds of the remaining six species, *Brassica vulgaris* var. *cicla* included, was essentially indifferent to light, even though there was some evidence of a minor negative effect on the onset of germination in the case of *Citrillus lanatus* and *V. unguiculata*. In the case of *Citrillus lanatus* and *V. unguiculata*, the onset of seed germination was somewhat delayed when seed was exposed to light. Negative photosensitivity has been attributed to light inhibiting cell elongation by suppressing the expression of selected proteins that enhance germination (Ochoudho, Modi & Beukes, 2008:1468). Mpati (2006:117) pointed out that even in species of which seed germination is known to be indifferent to light, there were usually a few individual seeds that were light-sensitive. This could explain the observed minor effect of light on the onset of germination in *Citrillus lanatus* and *V. unguiculata*.

Final germination percentage of *Cleome gynandra* and *S. retroflexum* seed was very low (below 50%) in both experiments. The low final germination percentage of *S. retroflexum* seeds could possibly be attributed to inadequate removal of sugars and germination inhibitors present in the fruit during extraction of the seed, therefore, necessitating pre-sowing treatments to release seed from dormancy (Jansen van Rensburg *et al.*, 2007:322). Other researchers have reported similar low germination in *Cleome gynandra* (Böhringer, Lourens & Jansen van Vuuren, 1999:24; Jansen van Rensburg, 2009, personal communication).
Cleome gynandra seed reaches physiological maturity after a period of about 12 months in storage, at which full germination potential is achieved (Böhringer, Lourens & Jansen van Vuuren, 1999:24; Ochuodho & Modi, 2005:51). Therefore, it could be possible that the low germination percentage in Cleome gynandra observed in the current study was caused by incomplete physiological maturity status of the seed.

6.5 CONCLUSION

This study showed that African leafy vegetables varied in their response to light during germination. Exposure to alternating light had a significant effect on the onset of germination of several species, either by increasing or reducing the rate at which germination occurred. Based on the onset of germination, the seeds of African leafy vegetables could be divided into three categories:

- Those that were improved by light (positively photosensitive).
- Those that were not inhibited by light (negatively photosensitive).
- Those that were indifferent to the presence or absence of light.

The first group contained the species that were positively photosensitive for onset of germination. Included in this group were Amaranthus cruentus, Brassica rapa subsp. chinensis and Corchorus olitorius. The second group contained the species that were negatively photosensitive for the onset of germination. This group contained Citrillus lanatus and Vigna unguiculata. The last group contained species indifferent to light, and included Beta vulgaris, Cleome gynandra and Cucurbita maxima. Effect of light on final germination percentage was only significant for the seed of Brassica rapa subsp. chinensis, Citrillus lanatus and Solanum retroflexum. The positive response to light of the seed of these
vegetable species could have important implications for the germination of their seeds and establishment of their seedlings. In Citrullus lanatus and Vigna unguiculata, the initial negative effect of light on germination was cancelled out by an improvement in the final germination percentage.

From a practical perspective the germination of Brassica rapa subsp. chinensis, Citrullus lanatus and Solanum retroflexum is expected to be improved by sowing seed at or close to the soil surface. The seed of these three species could germinate faster when sown very shallow or even when broadcasted on the surface of the soil. Further investigation of the effect of light on germination of these three indigenous vegetables is expected to yield more definitive results.
CHAPTER 7

7 GENERAL CONCLUSION

Using laboratory incubation, the response of seed germination and seedling emergence to variability in temperature, pre-sowing dormancy treatments and light was examined for eight African leafy vegetables, namely, spider flower (Cleome gynandra L.), amaranth (Amaranthus cruentus L.), non-heading Chinese cabbage (Brassica rapa L. subsp. chinensis), nightshade (Solanum retroflexum Dun.), pumpkin (Cucurbita maxima Duchesne), tsamma melon (Citrillus lanatus L.), Jew’s mallow (Corchorus olitorius L.) and cowpea (Vigna unguiculata (L.) Walp.).

Amaranthus cruentus seed germinated optimally at 31 °C, with 16 °C as the minimum temperature and 40 °C as the maximum temperature. A. cruentus seedling emergence was optimal at 29 °C with 12 °C as the minimum temperature and 40 °C as the maximum temperature. Improved onset and final germination percentage was observed when the seed of A. cruentus was scarified and pre-chilled. Exposure of the seed to light improved onset of germination of A. cruentus, but final germination percentage was indifferent to light.

Brassica rapa subsp. chinensis seed germinated optimally at 29 °C, with 12 °C being the minimum temperature and 40 °C the maximum temperature. Emergence of Brassica rapa subsp. chinensis was optimal at 25 °C, with 8 °C being the minimum temperature and 32 °C, being the maximum temperature. Onset and final germination percentage of Brassica rapa subsp. chinensis was improved by scarification and imbibing with potassium nitrate (KNO₃).
However, pre-chilling negatively affected germination percentage of this specie. Exposure to light improved onset and final germination percentage of *Brassica rapa* subsp. *chinensis*.

*Cleome gynandra* seed germinated optimally at 31 °C, with 12 °C being the minimum temperature and 36 °C, being the maximum temperature. Cardinal temperatures for seedling emergence of *Cleome gynandra* could not be extrapolated due to the very poor emergence percentage. Onset of germination percentage of *Cleome gynandra* was improved by scarification but final germination percentage was indifferent to the other treatments (pre-chilling and KNO₃) and the control. Germination of *Cleome gynandra* seed was indifferent to light.

*Citrillus lanatus* seed germinated and emerged optimally at 30 °C, with 20 °C being the minimum temperature and 40 °C, being the maximum temperature. Seed of *Citrillus lanatus* was indifferent to any of the dormancy pre-treatments. Exposure to light tended to negatively affect onset of germination, but improved final germination percentage.

*Corchorus olitorius* seed germinated optimally at 35 °C, with 12 °C being the minimum temperature and 44 °C, being the maximum temperature. Seed of *Corchorus olitorius* emerged optimally at 33 °C, with 16 °C being the minimum temperature and 40 °C, being the maximum temperature. Germination of *Corchorus olitorius* seed was indifferent to any of the dormancy pre-treatments. Exposure to light improved onset of germination, but final germination percentage was indifferent to light exposure.

*Cucurbita maxima* seed germinated and emerged optimally at 32 °C, with 16 °C being the minimum temperature and 40 °C, being the maximum temperature. Seed of *Cucurbita maxima* was indifferent to the different dormancy pre-treatments and to light exposure.
*Vigna unguiculata* seed germinated optimally at 36 °C, with 12 °C being the minimum temperature and 40 °C the maximum temperature. Seed of *V. unguiculata* emerged optimally at 25 °C, with 16 °C being the minimum temperature and 36 °C, the maximum temperature. Seed of this specie was indifferent to the dormancy pre-treatments. Exposure to light negatively affected onset of germination, but final germination percentage was indifferent to light.

*Solanum retroflexum* seed germination percentage and seedling emergence percentage was very poor. Therefore, extrapolation of the cardinal temperatures was not possible. Germination percentage never reached 50% and emergence percentage was below 15%. Potassium nitrate (KNO₃) treatment improved germination of *S. retroflexum* seed, while scarification and pre-chilling reduced germination percentage. Improved onset and final germination percentage was observed when the seed of *S. retroflexum* was exposed to light. Previous studies of *Cleome gynandra* and *Solanum retroflexum* reported similar difficulty with the germination of these species.

Based on the study results, seeds of *Amaranthus cruentus*, *Citrullus lanatus*, *Cleome gynandra*, *Corchorus olitorius*, *Cucurbita maxima* and *Vigna unguiculata* germinate and establish better when planted when the temperature is warm. *Vigna unguiculata*, however, shows a preference for cooler conditions during seedling emergence than for seed germination. *Brassica rapa* subsp. *chinensis* seed could be planted when the temperature is still cool.
Some form of seed abrasion to remove seed coat resistance of *Amaranthus cruentus* and *Brassica rapa* subsp. *chinensis* seed could enhance the onset of germination and improve final germination percentage if germination problems are encountered. Overwintering of *Amaranthus cruentus* seed could also improve germination. Germination of *Brassica rapa* subsp. *chinensis* and *Solanum retroflexum* could be improved by imbibing its seed with potassium nitrate.

Seeds of *Brassica rapa* subsp. *chinensis*, *Citrillus lanatus* and *Solanum retroflexum* could remain in the soil without germinating when covered by plant canopy, litter or soil, until exposed to adequate light. Therefore, seed of these three species could be planted close to the soil surface in order to improve their germination. For the other species, exposure to light is not a critical factor, and standard procedures for planting seeds can be followed.

A combination of light and potassium nitrate could form part of a strategy aimed at optimum germination for *Brassica rapa* subsp. *chinensis* and *Solanum retroflexum* seed, since both this species germinated well when subjected to these treatments.

This study contributed information on the agronomy of African leafy vegetables. By encouraging production and use of these food species, by promoting further work, and by awareness of the use of the nutritional benefits of these crops, some of the food and nutrition problems in Southern Africa and Africa as a whole could be addressed.
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