

## Review Article

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# Germination ecology of three Asteraceae annuals *Arctotis hirsuta*, *Oncosiphon suffruticosum*, and *Cotula duckittiae* in the winter-rainfall region of South Africa: A review

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**Abstract:** Asteraceae annuals from South Africa's winter-rainfall region often exhibit poor germination, and it is a challenge to establish a garden display using fresh seeds from the wild. *Arctotis hirsuta* (Harv.) Beauvard is a popular ornamental, *Oncosiphon suffruticosum* (L. Bolus) K. Bremer & Humphries is important in traditional medicine, and *Cotula duckittiae* (L. Bolus) K. Bremer & Humphries has a vulnerable (VU) status on the red list of South African plants. *C. duckittiae* is teetering on the brink of extinction in a few localities on severely threatened ecosystems due to continued pressure on land for housing developments and invasive aliens. At present, there is no knowledge of *O. suffruticosum* being cultivated exclusively for its healing properties. The successful cultivation of this species may allow it to fulfil not only a more acute medicinal role in society but also in the economy to create precious job opportunities. The potential to develop or improve certain plant breeding lines of *A. hirsuta* commercially, besides just normal wild forms of these species at the Kirstenbosch National Botanical Garden, is huge. This, in addition to the ongoing pressure exerted on wild populations of *C. duckittiae*, warrants investigations into aspects of germination ecology of this VU species of the West Coast.

**Keywords:** African Asteraceae, extinction, red-listed plants, seed dispersal, sowing depth

## 1 Introduction

Annuals plants complete a full life cycle in 1 year. Germination in winter annuals occurs in the autumn, and growing is completed in the winter. The plant flowers during winter and shed seeds during spring [1,2]. This group of plants normally grows rather quickly, and after planting, they can bring colour into a part of the garden within about 8 months [3].

The ornamental spring-annuals at the Kirstenbosch National Botanical Garden (KNBG) have been displayed since the Garden's inception in 1913, as stated by Sisanda Velembo (Plant recorder, KNBG, 16 August 2018). This collection is one of the core display collections of the Garden but also one with its own set of challenges. *Arctotis hirsuta* (Harv.) Beauvard, *Cotula duckittiae* (L. Bolus) K. Bremer & Humphries, and *Oncosiphon suffruticosum* (L.) Källersjö are three South African winter-rainfall annuals of the Asteraceae. This family shows a remarkable variation in the growth form and general morphology because it occurs in so many different localities and habitats [4]. These variations allow humans to benefit from genetic diversity since seeds offer the potential to introduce an exciting range of plants with new floral or habit forms [5].

Despite the economic value they may offer, the full potential of South African Asteraceae species for gardening has not been fully utilised [4] since poor germination is limiting the cultivation of many Asteraceae species [6]. *A. hirsuta*, *C. duckittiae*, and *O. suffruticosum* are three annual species that horticulturists have been struggling to introduce as bedding plants propagated from fresh wild-collected seed.

Temperature is a critical element in seed germination [7–9]. The regulation of seasonal changes in the temperature

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often ensures some changes in the level of seed dormancy [10]. Further, seeds of wild plants display immense variability in their light requirements for germination [11]. This important aspect has proven to contribute to the breaking of seed dormancy since light requirements influence the timing of germination in the wild [10,12,13].

The pre-treatment of seeds can result in the breaking of dormancy of several other native herbaceous plants. Pre-treatments with scarification and chemical treatments with gibberellic acid all resulted in breaking seed dormancy of winter annuals [14]. Gibberellic acid has proven to be the most effective of all the gibberellins in breaking seed dormancy of many Asteraceae winter annuals [6,15,16].

The process of after-ripening has resulted in the breaking of seed dormancy of many arid zone species, including Asteraceae [17]. After-ripening under ambient conditions is a slow process that can be detrimental to seed stockists, researchers, or growers.

There is limited research on the temperature and light requirements, the pre-treatment of seeds, and the effects of after-ripening at different regimes on seed dormancy of the three species. This is a gap in the existing body of knowledge on the germination ecology of Asteraceae annuals of the winter-rainfall region in South Africa. Investigating the effect of temperature, light, different pre-treatments, and after-ripening under different regimes will contribute to the development of optimal propagation protocols of the three annual species.

## 1.1 The family Asteraceae

Asteraceae represents the largest plant family in the world [18,19]. The family consists of an estimated 1,200 genera and 21,400 species worldwide. In southern Africa, where it is also the largest family, it is represented by 2,481 species, and the large concentration of Asteraceae species can be found in the winter rainfall region [19,20]. The family is known to be used for various purposes, including medicines, foods, herbs, cut flowers, and ornamentals (bedding and potted plants) [19]. The family is further represented by only a handful of trees [21], various forms of shrubs, herbaceous perennials, biennials, annuals, and aquatics [4,20]. In the beautification of both the natural and artificial South African landscape, several species are crucial role players [22,23]. This is exemplified in some natural areas of South Africa, especially the West Coast and Namaqualand, where several annual species, including *A. hirsuta*, *O. suffruticosum*, and *C. duckittiae* are just some of the species responsible for the kaleidoscope of

colour during late winter to early spring [2,3,24]. In some areas, annuals also show immense potential for landscape rehabilitation [22].

## 1.2 The genus *Arctotis*

This exclusively African genus of 63 species consists mainly of annuals, perennials, and small shrubs and is found throughout southern Africa towards Angola. The highest concentration of species is confined to Namaqualand and the Western and Eastern Cape of South Africa. Some of the species are easy to grow and make superb garden plants [25,26].

## 1.3 The genus *Cotula*

This genus contains  $\pm 55$  species, mainly annuals and perennials, and it is predominantly confined to southern Africa. Several other species can also be found in Tristan da Cunha, Australia, and South to Central America [27–29].

## 1.4 The genus *Oncosiphon*

The genus *Oncosiphon* is endemic to southern Africa and consists of seven species, which are mainly found in Namibia and the Western and Northern Cape [2,30].

# 2 Methodology

Materials used for this review were obtained from the following sources:

- KNBG Plant-recording database;
- KNBG Annuals-collection propagation records;
- 150 articles were reviewed;
- 80 peer-reviewed articles;
- 112 articles have been cited;
- Searched text strings: Asteraceae, winter-annuals, *A. hirsuta*, *C. duckittiae*, *O. suffruticosum*, germination, germination ecology, light, temperature, pre-germination treatments, after-ripening, dry storage, dormancy, gibberellic acid;
- Data from Australian Grain Research Department (work on naturalised South African species in Australia);
- First author's unpublished Master's thesis.

### 3 Ecology and botanical description of three important annual Asteraceae species

#### 3.1 *Arctotis hirsuta*

*A. hirsuta* is a robust, spreading annual growing to 50 cm wide to 50 cm tall with orange, yellow, or cream-coloured solitary flower heads (Figure 1) from July to October. Plants start seeding from October to November. The habitat is sandy slopes and flats from Elandsbaai to the Agulhas Plain in the Western Cape [31,32]. This species has a least concern (LC) conservation status [33,34].

#### 3.2 *Cotula duckittiae*

*C. duckittiae* is a robust, soft hairy annual of 30 cm wide to 30 cm tall with brightly showy orange rays (Figure 2) from September to October. The light seeds are dispersed from October to early November. It occurs on sandy coastal slopes from Yzerfontein to Bokbaai along the West Coast of South Africa [24,32]. The conservation status of this species is vulnerable (VU) due to threats from crop farming, invasive alien plants, and urban encroachment [34,35]. According to the South African Red Data List, this VU species occurs sparsely in habitats such as Cape Flats Dune Strandveld, Saldanha Limestone Strandveld, Saldanha Flats Strandveld, Atlantis Sand Fynbos, and Hopefield Sand Fynbos.



**Figure 1:** *Arctotis hirsuta* (source: Roger Oliver) 1/10/2013: Kleinmond 34.3392417S 19.0177145E.



**Figure 2:** *Cotula duckittiae* (Source: Roger Oliver). 30/9/2015: Kirstenbosch NBG 33.990574S 18.43199,390E.

#### 3.3 *Oncosiphon suffruticosum*

This is a robust erect aromatic annual herb with dense yellow corymb flower heads (Figure 3) from September to December. It grows from 30 cm wide 30 cm tall and is found on sandy flats and slopes from southern Namibia and Western Karoo to Gansbaai [32]. The seeds are produced from late October to late January and dispersed by wind [30,36]. The conservation status of *Oncosiphon suffruticosum* (L.) Källersjö is LC with no serious threats [34,37].

### 3.4 Winter annuals and their values as medicine, ornamental, and crops

#### 3.4.1 Medicinal values

##### 3.4.1.1 *Arctotis hirsuta*

Currently, there is no medicinal use for this species recorded [3].

##### 3.4.1.2 *Cotula duckittiae*

No form of medical usage, in modern medical science or traditional medicines, has been reported for this species [25,38].

##### 3.4.1.3 *Oncosiphon suffruticosum*

This species is extensively used for its medicinal value and was critical in several remedial applications used by



Figure 3: *Oncosiphon suffruticosum* (Source: Anthony Magee).

the Khoi indigenous tribe of South Africa [39]. A mixture of fresh plant material is crushed with *Carpobrotus edulis* and *Exomis microphylla*, or *Ruta graveolens* to relieve convulsions in infants [38]. A leaf-poultice is also applied topically and is used in relieving the pain associated with inflammation and scorpion stings [40]. Small quantities of juice from the leaves are often added to mother's milk and act as gripe-water for infants and cramps. An infusion of the entire plant can also often be orally consumed to treat various ailments associated with stomach pain, intestinal worms, several types of fevers, and respiratory illnesses [2].

### 3.4.2 Ornamental values

#### 3.4.2.1 *Arctotis hirsuta*

This species can be planted *en masse* in mixed plantings for the small or large garden. Flowering is from winter to early spring [3,18].

#### 3.4.2.2 *Cotula duckittiae*

This species is suited to mix plantings; works wonders as a seasonal border plant or mass plantings. In high rainfall areas, *C. duckittiae* is preferably displayed in well-

drained areas such as rockeries or along slopes. Plant in full sun [35].

#### 3.4.2.3 *Oncosiphon suffruticosum*

This widespread species grows well in disturbed areas where it covers large areas. It thrives in coastal areas and due to its scraggly habit is suited to mass planting with other species. Optimum flowering is achieved in full sun [2].

### 3.4.3 Agricultural values

#### 3.4.3.1 *Arctotis hirsuta*

There is no information available on such a role, although there are seed stockists making seed available to the public [41]. Plant breeding could contribute to the development of superior forms [42].

#### 3.4.3.2 *Cotula duckittiae*

No records exist of where *C. duckittiae* is being used as a crop plant [25]. According to [43], *C. sericea* Del., a popular African annual, is being extensively utilised in traditional African medicine.

#### 3.4.3.3 *Oncosiphon suffruticosum*

There is no record of this species being actively utilised as an agricultural crop. Its myriad of functions as a medicinal plant make it an excellent prospect as a seasonal crop in disturbed areas of South Africa's winter-rainfall region. Research from Australia, where this species is considered a weed, indicate that it may lower the production yield of cereal crops, displaces pasture plants, is unpalatable to stock, and contributes to the tainting of milk and meat products [44].

## 4 Germination ecology of annuals

### 4.1 *Arctotis hirsuta*

#### 4.1.1 Seed anatomy

The fruit is a tiny achene (to 2.75 mm long) with two ovate-linear abaxial cavities and uniseriate trichomes,

no coma is present, and very small pappus scales are present [30,45]. The median abaxial wing exceeds that of the lateral abaxial wings. The cavities have a rounded to obtuse appearance at the apex and base. The lower section of the three abaxial wings is fused above the carpodium section. The base of the cypsela is constricted and short. The abaxial wings are transversely rugose. These wings can bear short, obtuse teeth when not entire. There is dense presence of clavate trichomes on the smooth adaxial surface. Very few clavate trichomes are present in the abaxial area. The achenes has a uniseriate pappus containing eight to nine rounded scales (0.15 mm in length). Trichomes present on the adaxial surface are often longer than those present in the abaxial area [45].

4.1.2 Seed colour

The wild-collected achenes are black. In seed harvested from cultivation plants, achenes with a yellowish-brown and darker brown colour can be distinguished according to Roger Oliver (Curator, Annuals Living Plant Collection, Kirstenbosch NBG, 13 March 2020).

4.1.3 Seed mass

The impact of achene (seed) mass is of considerable importance for Asteraceae in unpredictable environments [46,47], and this will impact seedling characteristics such as emergence, the timing of germination, and seedling size [48,49]. When research was carried out on some annuals with a mass less than 0.5 mg indicated that such seeds have a light requirement for germination, while high-mass seeds do not have the same requirement [17]. Mass is pivotal to the dispersal method, and some achenes have low mass and a pappus [50] (Table 1).

4.1.4 Seed coat thickness

Achenes of the genus *Arctotis* and other members of the Asteraceae clade Arctotidinae often possess a lignified well-

developed pericarp that surrounds the embryo. This centrally developed pericarp is several cell layers thick. The pericarp is also marked by the presence of oblong sclerified cells found within one or two subepidermal layers [51].

4.2 *Cotula duckittiae*

4.2.1 Seed anatomy

Achenes in the genus *Cotula* generally appear oblong, obovoid to terete with variable (either 2–3 or 3–19) ribs. When three to four angled achenes contain two lateral, wing-like ribs and often appear dorsoventrally compressed. Myxogenic cells and/or ribs containing resin canals are features of several species. Achenes are either papillose or hairy. In *Cotula* embryo, sac development is monosporic [52].

4.2.2 Seed colour

Achenes with two colours are produced: light brown and yellowish-brown. Light brown achenes are more abundant than yellow-brown ones. Achenes from wild populations are black, while those from cultivated plants are yellowish-brown or dark brown in colour and are slightly winged according to Roger Oliver (Curator, Annuals Living Plant Collection, Kirstenbosch NBG, 13 March 2020).

4.2.3 Seed coat thickness

4.2.3.1 *Cotula duckittiae* and *Oncosiphon suffruticosum*

Both species form part of the clade Anthemideae and share several similarities at the genus level. The species have a centripetally well-developed pericarp that is a few layers thick. The pericarp also contains are oblong sclerified cells in one or two subepidermal layers. There is also a persistent testa epidermis present with varied reinforcement patterns [52].

4.3 *Oncosiphon suffruticosum*

4.3.1 Seed anatomy

The obovoid-shaped achenes are between 1 and 2 mm long, cut-off at the top to have a three-angled appearance.

**Table 1:** The determined mass of achenes for the three winter-rainfall annuals at KNBG

| Species                         | Mass (mg) |
|---------------------------------|-----------|
| <i>Arctotis hirsuta</i>         | 0.2       |
| <i>Cotula duckittiae</i>        | 0.1       |
| <i>Oncosiphon suffruticosum</i> | 0.07      |

Small glands can be found between the hairy ribs [44,53]. When three- to four-angled achenes contain two lateral, wing-like ribs and often appear dorsoventrally compressed. The fruits are non-myxogenic (no mucus formed when wet) [2,51].

#### 4.3.2 Seed colour

This species only produces yellowish-brown achenes [2].

### 4.4 Seed dispersal

#### 4.4.1 *Arctotis hirsuta*

In Arctotidinae, the annual species in the *Arctotis* clade all have tiny achenes in which the pappus can be either lost or highly reduced [45]. The lack of a pappus greatly reduces the chance of *A. hirsuta* being dispersed by wind, and achenes may mostly end up close to the mother plant [54]. The achene has a uniseriate pappus of eight or nine rounded scales to 0.15 mm long [45].

#### 4.4.2 *Cotula duckittiae*

Ref. [28] suggested that the presence of an apically inflated peduncle of some species in *Cotula* where the embryo sac development may be significant in seed dispersal through a shaking process and thereby dispersing seed in the wind. During fruiting, this inflation is at its largest. This phenomenon is present in some *Cotula* species.

#### 4.4.3 *Oncosiphon suffruticosum*

At the end of the flowering season, the flowering stem is broken off, and the seeds are spread via wind movement of the plant. Some seeds also remain within the flower head. A small crown of white scales (1 mm in length) represents the pappus [2,36].

### 4.5 Seedling emergence

#### 4.5.1 *Arctotis hirsuta*

Seed harvested from cultivated plants in the Annuals collection at KNBG took 7 days to germinate when sown

at the beginning of March. Seeds were sown in open conditions (outside) without any temperature or light control according to Roger Oliver (Curator, Annuals Living Plant Collection, Kirstenbosch NBG, 13 March 2020).

#### 4.5.2 *Cotula duckittiae*

Seed harvested from cultivated plants in the Annuals collection at KNBG took 8 days to germinate when sown at the beginning of March. Seeds were sown in open conditions (outside) without any temperature or light control according to Roger Oliver (Curator, Annuals Living Plant Collection, Kirstenbosch NBG, 13 March 2020).

#### 4.5.3 *Oncosiphon suffruticosum*

No records could be found for plants grown from seeds harvested from cultivated or wild plants [55].

### 4.6 Conditions affecting seed germination

#### 4.6.1 Sowing depth

The depth at which seeds are buried in the soil can influence the germination percentage and rate [56–58]. When the seeds *A. hirsuta* and *C. duckittiae* were covered with a soil layer exceeding 5 mm, seedling emergence occurred after 6 and 8 days, respectively, according to Roger Oliver (Curator, Annuals Living Plant Collection, Kirstenbosch NBG, 13 March 2020). No records are available for *O. suffruticosum*, but research from [55] indicated that seeds of a naturalised species of *Oncosiphon* in Australia had optimum germination while buried between 2 and 10 cm deep.

#### 4.6.2 Temperature

Temperature is integral to the success or failure of plant establishment and impacts germination and the dormancy status of the seed [59–62]. The seeds of annual species are conditioned to germinate at a specific period of the year. The change in temperature ensures that dormancy break occurs during the time of the year that is not favourable for seedling survival, i.e., summer in the case of winter annuals. Thus, seeds are non-dormant at the beginning of the favourable season, which for winter annuals would be the cool moist autumn-winter [10].

The ability to germinate over a wide spectrum of temperatures is a common characteristic of many species of Asteraceae [63,64]. Seeds of winter annuals are normally in a state of conditional dormancy following dispersal and germination is restricted to a limited range of low temperatures [65]. The majority of seeds, including some winter annuals, from the Namaqualand region of South Africa, germinated best at temperatures between 12 and 22°C [66,67]. The optimum germination temperature for *Arctotis fastuosa* varied from that for other species of this region and was at 32°C [66]. The annual *Senecio coinnyi* germinated to 90% between 15 and 30°C. Germination decreased to less than 20% at a temperature below 10°C [68]. There is a need to investigate the role of temperature on dormancy break and germination of these three species if the species are to be successfully grown.

#### 4.6.3 Light

Among cultivated plants, there is very little evidence for light as a factor influencing germination and seed usually germinate equally well in the dark and in the light [10]. In contrast, among wild plants, there is variability in the response of seeds to light [12,69].

Exposure to light, fluctuations in temperature [70], or combinations of these factors may be needed to promote germination [63,71]. The seed of some species may require light at one temperature, but no light at another. *Lactuca sativa* is an example of a species in which light is not a requirement for germination at low temperatures. However, light is required for germination at higher temperatures [12]. Research indicates that optimum germination for South African winter annuals *Felicia australis*, *Ursinia anthemoides*, *Dimorphotheca sinuata*, and *Arctotis fastuosa* occurs in light, whereas *Dimorphotheca polyptera* germinates best in the dark [17,66,67]. There are many species of Asteraceae whose seeds germinate equally well in light and dark. Determining the light requirements for germinations of seeds of the three Asteraceae species at the end of the summer dormancy-breaking period will be a crucial step towards the successful propagation of these annuals.

#### 4.6.4 Scarification of seeds

Seed coats can also exert a physical restraint on the mature embryo. However, should the amount of thrust developed through inhibition and growth be inadequate, the embryo will not puncture the seed coat resulting in no

germination. This dormancy type can be broken by some form of abrasion or decay of the hard seed coat [72]. Research indicates that scarification through puncturing the pericarp and testa is a successful technique that results in the breaking of seed dormancy of several Asteraceae species [6,67]. This could prove to be a very efficient method to break the dormancy of the three annuals and result in the successful germination and mass production of the species.

#### 4.6.5 Application of a growth hormone such as Gibberellic acid

The process of germination often involves plant hormones, and the presence of gibberellins, specifically gibberellic acid (GA<sub>3</sub>), in developing seeds is instrumental in facilitating germination and the breaking of dormancy in many species [13–15]. In the Asteraceae genus, *Lactuca* some species encounter challenges with germination since micropylar endosperm and testa tissue prevent the protrusion of the radicle. The removal of the micropylar and testa tissue enables protrusion of the radicle and results in improved germination. However, in some species, pre-treating with GA<sub>3</sub> can result in enervating the micropylar endosperm through limiting the restrictiveness of the seed coverings and therefore break dormancy [73,74]. Several other workers have indicated experimental successes in germinating Asteraceae species with GA<sub>3</sub> [75–77]. Pre-treatment with a combination of scarification followed by a soaking in GA<sub>3</sub> achieves optimum germination in the two Australian annuals species [6]. Various concentrations of GA<sub>3</sub> can be applied, and this varies according to species. Germination has improved in several species by soaking in a concentration of 500 ppm [6,78]. In some species, a concentration of 300 ppm can result in improved germination [79,80]. There is clear evidence of the proven ability of GA<sub>3</sub> to optimise germination through a reduction of the dormancy levels of various Asteraceae species. This warrant an investigation into the soaking of seeds in GA<sub>3</sub> using different strengths over different periods to determine whether it can improve germination of the three annual species.

#### 4.6.6 After-ripening treatment

Winter annuals may cover various open spaces that experience unfavourable conditions from late spring to early autumn. A survival mechanism for many winter annual species is that seed dormancy is broken by high

temperatures during summer, thereby allowing seeds to germinate as habitat temperatures decrease in autumn and the soil is moist [65,81]. Research indicates that the breaking of physiological dormancy during dry storage plays a vital role in the breaking of seed dormancy of many arid zone species [17,67,82], including Asteraceae [83,84]. Winter annuals may require after-ripening that involves a high temperature during summer [65]. The literature suggests further that conditions of high temperature and low humidity during after-ripening are required to break seed dormancy [85,86]. Species from Mediterranean climates after-ripen better at high temperatures than at low temperatures [82,85,87]. However, research has shown that after-ripening of some species of Asteraceae can be achieved at high and low temperatures [88]. The after-ripening period is species dependent [89]. In two everlasting annuals from Western Australia, *Schoenia filifolia* subsp. *filifolia* and *Rhodanthe cholorocephala* germinated to more than 85% after 3 months of after-ripening. This germination was obtained for seeds stored at 25, 30, and 40°C. *R. cholorocephala* germinated to more than 90% after storing for 3 months at temperatures of 15, 25, 30, 40, and 55°C. Research on winter annuals from Mediterranean areas or semi-arid areas indicate that the exposure of seed to after-ripening may reduce dormancy in some species. This form of pre-treatment may provide important information on how the species respond to after-ripening and whether it should be considered the most effective pre-treatment method to overcome dormancy in some of the species.

#### 4.6.7 Seed dormancy

Seed dispersal in winter annuals during unfavourable dry conditions of summer may result in the postponement of germination until the more favourable conditions of autumn. This process of suspending germination is termed dormancy and may affect the seed embryo, seed coat, or seed covering [17,90].

Dormancy is a common phenomenon in the daisy family, particularly in areas experiencing a Mediterranean and arid or semi-arid climate [87]. Dormancy limits the introduction of various species into horticulture [91]. Thus far, the only kind of dormancy found in seeds of Asteraceae is non-deep physiological dormancy [90]. This form of dormancy [84] affects germination brought on by the low growth potential of the embryo and an inability of the embryo to push through the pericarp [92]. Experiments have shown that high summer temperatures can break dormancy in seeds of winter annuals [82] as it enable the

growth potential of the embryo to increase and break through the pericarp [92].

However, it is also possible to induce germination of dormant seeds using single or multiple actions such as fluctuations in temperature and light conditions [10] and individual or combinational applications of scarification and GA<sub>3</sub> [6].

#### 4.6.8 The importance of annual displays in botanical gardens and the need to introduce measures to improve germination

Annual displays can fulfil various functions in a botanical garden. They can be the centre stage and have garden beds just exclusively dedicated to it to enable visitors to marvel at the combinations of colour, leaf textures, or shape of the flowers. Annuals can also play an auxiliary function where they can be used to fill in gaps where perennials, shrubs, or mesembs are slow growing [3]. This group of plants can also be exhibited as part of the medicinal or food crops [2,93].

Studies into the propagation of indigenous species and the transplanting of some species contributed significantly to the successful introduction to the wild. Results from such studies are of critical importance as they enabled horticulturists from botanical gardens to propagate, cultivate, and restore some plant species successfully [94]. The inability of the three species to germinate from fresh, wild-collected seeds will not enable it to be showcased in the ornamental display of annuals. Like several other species, the inability to grow plants successfully will compromise the ability to promote the use of indigenous species in gardening. This will also impact the variety or the diversity of species that can be utilised in an annuals display. From a conservation perspective, not being able to grow some of the species successfully may also place additional pressure on red-listed species due to a lack of understanding of the germination ecology of the species. Knowledge of not only how to successfully propagate but also the implementation of measures to sustain the species going forward will be critical for this species to form part of the annuals display and to be grown for economic or conservation initiatives. After-ripening at 15°C and 15% relative humidity for 28–32 months resulted in improved germination of *C. duckittiae* under various temperatures and light conditions. After-ripening the seeds of *A. hirsuta* and pre-treating with GA<sub>3</sub> only resulted in a minimal increase of germination. Additional after-ripening periods of exposing seeds to 30 and 45°C over 4 weeks and 8 weeks did not improve germination of *A. hirsuta* or *O. suffruticosum* [95].

## 5 Conclusion

The lack of studies into proper germination research for the three highlighted species points to a definite need for more studies on fresh seeds (from the wild) in this specific field. Low to no germination for seeds of the three species will limit the ability of *O. suffruticosum* and *A. hirsuta* to be showcased in a bedding display of annuals. Additional pressure will also be placed on red-listed species since the lack of a proper understanding of the germination-ecology of *C. duckittiae* can minimise successful efforts to restore this species to its native habitat. Knowledge of how to successfully propagate the species and the implementation of measures to sustain the cultivation management of the three species going forward will therefore be critical for the use of this species either as bedding plants or in conservation initiatives. It is therefore important that the limited research on the temperature or light requirements, the pre-treatment of seeds, and the effects of after-ripening at different regimes on seed dormancy of the three species be significantly expanded. Future research such as different methods of seed-pre-treatment, the form or period of after-ripening or the storage conditions can contribute to the development of an optimal propagation protocol.

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