Cape Peninsula
University of Technology

A CULTIVATION STUDY OF THE GROWTH PARAMETERS AND FLOWERING INITIATION OF *STREPTOCARUS FORMOSUS* FOR THE FLOWERING POTLANT PRODUCTION INDUSTRY

by

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in the Faculty of Applied Sciences

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DECLARATION

I, Cherise Christina Viljoen, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

17 August 2021

Signed Date

ABSTRACT

The purpose for this study was to investigate whether *Streptocarpus formosus* was suitable for cultivation in hydroponics and to determine whether different solution temperatures in the root zone of the plants would have an effect on the vegetative growth, semi-dormancy and inflorescence formation of the plant. The experiment was conducted over a period of 8 weeks. Fifty plants were cultivated from one initial mother plant obtained from Kirstenbosch National Botanical Garden, Cape Town. All the plants were planted in Leca, a soilless inert growth medium, held suspended in a deep water hydroponic system with identical concentrations of nutrient solution. Five treatments were evaluated with 10 sample replicates. Treatments were made up of 5 different temperatures, namely: 18 degrees Celsius (TEMP1), 22 degrees Celsius (TEMP2)' 26 degrees Celsius (TEMP3) which was used as the control, 30 degrees Celsius (TEMP4), 34 degrees Celsius (TEMP5). Leaf and root lengths; number of leaves, abscission layers, flower buds and flowers; and wet weight were all measured pre-and post-harvest.

Chapter 2 reviewed the commercial potential of *Streptocarpus formosus* as a flowering potted plant. It was found that S. formosus has economic importance not only as a potted indoor house plant but also for use outdoors and possibly could be considered for the cut flower market. It can also make significant contributions to the breeding development of further Streptocarpus hybrids.

In chapter 3 it was seen that the various treatments had significant effects in terms of plant vegetative growth, leaf formation and root development. Treatment WT1 showed the highest individual mean value for vegetative growth, leaf formation and root development. The lowest individual mean value for vegetative growth, leaf formation and root development. was observed in treatment WT5. Overall treatments with a lower temperature regime had better vegetative growth, leaf formation and root development, that being WT1-WT2, while the higher temperature regimes WT3-WT4 showed sub-optimal root growth and the highest, WT5 resulted in negative values.

. In chapter 4 it was seen that the various treatments had significant effects in terms of semi-dormancy in the plant abscission layer formation and inflorescence development. Treatment WT1 showed the highest individual mean value for inflorescence development. The lowest individual mean value for inflorescence development was observed in treatment WT5. All the treatments showed an optimal result for overcoming the formation of abscission layers.

Chapter 5 investigated a detailed protocol for production and cultivation of *Streptocarpus formosus* as a commercial flowering pot plant for both indoors and outdoors where it could also be used as a bedding plant and even as a cut flower for the vase.

Overall this study has found that S. formosus is suitable for cultivation as a flowering pot plant and that while root zone heating will overcome the eco-dormancy period in cultivation it will have limited positive effects of the vegetative growth, and no positive effects on inflorescence formation during this eco-dormancy period. This research has shown that the lowest temperature treatment had the most advantageous result on the vegetative growth of the plant.

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CHAPTER ONE:

VEGETATIVE GROWTH AND FLOWER DEVELOPMENT OF *STREPTOCARPUS FORMOSUS* IN RESPONSE TO DIFFERENT ROOTZONE TEMPERATURE REGIMES IN HYDROPINICS

GENERAL INTRODUCTION, STRUCTURE OF THESIS, BACKGROUND OF THE STUDY, PROBLEM STATEMENT, AIMS, HYPOTHESES AND OBJECTIVES

1.1 GENERAL INTRODUCTION

Streptocarpus spp. are flowering herbaceous perennials indigenous to South Africa that have enormous untapped commercial potential which is currently limited by a five-month semi-dormancy period during the late autumn and winter months. This study was to investigate whether root zone heating would reduce the dormancy period and to further investigate if the heated hydroponic solution would extend the flowing period and to enhance the quality and quantity of flower production. The significance of the study could increase the commercial flowering potted plant production with the application of heat to the root zone in winter, the semi-dormant period of the species.

1.2 STRUCTURE OF THE THESIS

The thesis is drafted differently to the alternative of a traditional format for a thesis. The article-format thesis includes examples of published, co-published and/or "ready-for-publication" articles that was prepared during candidature and applies to the format prescribed by CPUT for 100% master's studies which complies to the following principles:

1.2.1 The overriding principle of the thesis is that it remains an original contribution to the discipline or field by the candidate.

1.2.2 Chapters containing the journal articles form a coherent and integrated body of work, which focused on a single project or set of related questions or propositions. All journal articles form part of the sustained thesis with a coherent theme.

1.2.3 The study does not include work published prior to commencement of the candidature.

1.2.4 The number of articles included depending on the content and length of each article and take full account of the university's requirements for the degree as well as the one article already published or "ready-for-publication" expected for a master's degree in this discipline.

1.2.5 The thesis should be examined in the normal way and according to the normal requirements as set out by the "Guidelines for Examiners of Dissertations and Theses" (using form HDC 1.7).

The thesis consists of the following chapters, which are concisely discussed as:

Chapter One: This chapter provides the significance of the research, its aim and the overall list of specific objectives, which guided the study.

Chapter Two: This chapter provides insight on the potential of *S. formosus* as a flowering potted plant.

Chapter Three: This chapter evaluated the vegetative growth responses of *S. formosus* in response to different root zone temperature regimes in hydroponics.

Chapter Four: This chapter evaluated the inflorescence development and semi-dormancy formation of abscission layers of *S. formosus* in response to different root zone temperature regimes in hydroponics.

Chapter Five: This chapter evaluated the production and cultivation protocol for of *S. formosus* as a flowering potted plant.

Chapter Six: General discussion, conclusions and recommendations.
This chapter deals with the general discussion, which connects the previous chapters and is followed by the conclusions of the study. Recommendations are made for further work; to introduce future research topics.

Chapter Seven: Compilation of all the references used for each chapter.

1.3 BACKGROUND OF THE STUDY

Considering the wealth of flora found in South Africa that has contributed significantly to the horticulture world (Rycroft, 1972; Brits, 2001), it is imperative that further research is conducted on these indigenous species. Research is necessary in contributing to the commercialization of many South African species by improving and documenting their propagation, cultivation and post-harvest protocols (Coetzee *et al.,* 1999; Marasas *et al.,* 1998). Baker & Rosenqvist (2004), stated that temperature optimization is a key factor to improve horticulture production. According to Jamnadass *et al.* (2011)*,* an improvement in the yield and quality of indigenous plants can contribute to improving livelihoods of communities. *Streptocarpus* is an ornamental plant group of economic horticultural importance due to the beauty of their flowers (Hentig, 1995). There is growing interest and demand for *Streptocarpus spp. internationally including* Africa where they occur naturally (Hilliard & Burtt , 1971). *Streptocarpus* hybrids are widely cultivated in Europe and America for their floral variety and beauty as popular indoor flowering pot plants (Dibley & Dibley, 1995). Hybrids are typically easy to grow by nature due to their genetic vigour versus the temperamental nature of true species which less tolerant of conditions that do not precisely mimic their natural environment (Birchler *et al.*, 2006).

The commercial potential for developing species of *Streptocarpus* as indoor and outdoor perennials including new hybrids is under explored, as explained by Cantor *et al.* (2004), where only a few true species were originally used as mother stock to develop current day cultivars. The great variation within the remaining true species, all of which easily cross pollinate and hybridize, has potential for further horticultural product development as they remain largely un-experimented with (Dibley & Dibley, 1995). The horticultural use of most *Streptocarpus* as flowering potted plants is limited by the fact that this genus has a dormancy period during winter (short days) during which their growth rate slows significantly from the end of summer onwards when abscission layers form (indicated by chlorosis at the leaf ends) and flower formation is reduced resulting in little to no commercial value for approximately five months of the year (Noel & Van Staden, 1975; Dibley, 2003; Keever, 2003). Greenhouse and soil-less culture systems (SCS's) have proven to be the most effective method for production by providing flexibility as well as control of plant growth responses (Salas *et al.,* 2012) and in their natural habitat, *Streptocarpus* spp. often grow within limited substrates (Van der Walt, 2001) both of which could indicate a positive potential for hydroponic culture productions. Very little recorded research has been done on the viability of using temperature to keep *Streptocarpus* spp. in active growth by reducing or inhibiting their semi-dormancy during winter thereby extending their commercial viability throughout the year. The data collected during the investigation will make it possible to recommend the optimal hydroponic growing temperature for cultivation of *S. formosus* and that root-zone heating could be effective in overcoming the semi-dormancy by keeping *Streptocarpus formosus,* a long-day plant, in an active vegetative growth stage during a short day period that occurs during winter.

1.4 PROBLEM STATEMENT

Investigating the effect of different root zone temperatures on the vegetative growth; prevention of semi-dormancy; biomass yield; and inflorescence production of *S. formosus* will contribute to developing optimal cultivation protocols for expanding the scope of cultivating this species commercially.

1.5 AIMS

This study aims at cultivating *S. formosus* in hydroponics using five different root zone temperature regimes in order to determine which treatment is optimal for commercial cultivation of the plant in terms of the vegetative growth, avoiding semi-dormancy and the inflorescence formation of the plant.

1.6 HYPOTHESIS

It is hypothesized that each hydroponic solution temperature will have different effects on the overall growth and flowering of *S. formosus.*

1.7 OBJECTIVES OF THE RESEARCH

The data collected during the investigation will make it possible to recommend the optimal hydroponic growing temperature for cultivation of *S. formosus* and that root-zone heating could be effective in overcoming the semi-dormancy by keeping *S. formosus,* a long-day flowering plant, in an active vegetative growth stage during a short day period that occurs during winter.

1.7.1 Main Objective

To investigate the vegetative growth, abscission layer formation and inflorescence formation of *S. formosus* when treated with different hydroponic root-zone temperature regimes.

1.7.2. Specific objectives

- To assess the effect of different root-zone temperature regimes on the vegetative leaf growth of *S. formosus* grown in hydroponics
- To assess the effect of different root-zone temperature regimes on the vegetative root growth of *S. formosus* grown in hydroponics
- To assess the effect of different root-zone temperature regimes on the overall wet biomass yield of *S. formosus* grown in hydroponics
- To assess the effect of different root-zone temperature regimes on the inflorescence production of *S. formosus* grown in hydroponics
- To assess the effect of different root-zone temperature regimes on the absence or presence of leaf abscission layers in the semi-dormancy period of *S. formosus* grown in hydroponics
- To assess the overall effect of different root-zone temperature regimes *on S. formosus* in determining an optimal hydroponic cultivation protocol in producing high quality flowering potted plants.

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CHAPTER TWO:

THE POTENTIAL OF *STREPTOCARPUS FORMOSUS* AS A FLOWERING POTTED PLANT: A REVIEW

THE POTENTIAL OF *STREPTOCARPUS FORMOSUS* AS A FLOWERING POTTED PLANT: A REVIEW

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2.1 ABSTRACT

Streptocarpus are floriferous herbaceous perennials indigenous to the subtropical region of the Eastern Cape province of South Africa, belonging to the Gesneriaceae family. The common name given to *Streptocarpus* is the Cape Primrose. *Streptocarpus* hybrids are well known in the northern hemisphere indoor plant markets for their truly beautiful flowers, their preference for well-lit shaded conditions, and their considerable ease of propagation. Introducing more species to the pot plant flowering trade would lead to the development and commercialization of additional new hybrids. *Streptocarpus* spp. are not as commercially viable as their hybrid counterparts as they have a semi-dormancy period in the winter months of their growth cycle during which they do not flower and can look unattractive, with yellowing leaves caused by abscission layers. By heating the root zone of plant grown hydroponically it could be possible to overcome this semi-dormancy and possibly encourage *Streptocarpus* to flower earlier and in greater quantity thereby extending the shelf life and increasing their commercial value as a flowering potted plants. This review assesses the commercial cultivation potential of the species *Streptocarpus formosus.*

Keywords: abscission, Cape Primrose, commercial cultivation, endemic, floriculture, flowering ornamental, indoor pot plant, Gesneriaceae, hydroponics, semi-dormancy, *Streptocarpus*

2.2 INTRODUCTION

Streptocarpus is a genus of herbaceous plants containing approximately 160 species which naturally occur mainly in Africa and Madagascar, limited to shaded and moist habitats such as forest and south facing rocky outcrops, making them perfectly suited as indoor potted plants (Hilliard & Burtt, 1971). The genus displays significant morphological variation, within the

subgenus Streptocarpella which has caulescent species and the subgenus Streptocarpus consisting of a variety of acaulescent growth forms unifoliates, plurifoliates and rosulates (De Villiers, 2008) all of which provide much potential for ornamental novelty (Dibley & Dibley, 1995). In view of the wealth of flora found in South Africa it is crucial that further research is conducted on endemic indigenous plants (Faber *et al.*, 2019, Brits, 2001)to contribute to the commercialization of South African plants by scientifically improving propagation, cultivation and post-harvest protocols (Coetzee *et al.*, 1999). *Streptocarpus* is an ornamental plant group of economic importance horticulturally due to the beauty of their flowers (Chaudhury *et al., 2010;* Hârţa *et al*., 2018; Nishii *et al.,* 2015) stated that due global horticultural importance of Cape Primroses (*Streptocarpus*) and African Violets (*Saintpaulia*), both belonging to the Gesneriaceae family, research is justified. Cultivation of plants for their beauty (Fig. 2.1) is worthy of attention when able to contribute to relieving people's poverty (Baudoin *et al*., 2007).

Figure 2.1. The beauty of indigenous endemic *S. formosus* flowers (Picture: C. Viljoen)

The ornamental use of most *Streptocarpus* spp. has untapped commercial potential which is currently limited by a five-month semi-dormancy period during the late autumn and winter months (Dibley & Dibley, 1995). Commercial *Streptocarpus* cultivation requires a technique that produces flowering plants all year round (Davies, 1974). Very little recorded research has been done on the viability of using root zone temperature to keep the plants in active growth by reducing or inhibiting their semi-dormancy during winter thereby extending their commercial viability throughout the year.

Research is essential to provide scientific information on crop characteristics, pest and disease resistance, flower initiation, water, temperature, light intensity, day length and nutrition

requirements, determining optimum flower yield and the manipulation of the flowering period, all of which is required to guide the process of crop development, from initiation to marketing stage (Hentig, 1995; Reinten & Coetzee, 2002; van Wyk & Viljoen, 2011). According to Wessels *et al*. (1998) research results and growth in the floricultural industry are interrelated. The need for more efficient, controlled cultivation methods and out-of-season production has increased dramatically (Nxawe *et al.,* 2010). Cultivation in greenhouses during the cold season can be achieved by increasing the temperature of the irrigation water to optimum levels (Kozai, 2006). Soilless culture systems (SCS) have been proved to be one of the most effective cultivation practices in the agriculture industry and SCS within a greenhouse environment can be more cost-effective than soil-based cultivation in producing higher quality products, higher yields, more frequent harvests, and uniform crops with controlled nutrition (Grillas *et al*., 2001; Kozai, 2006; Asao *et al*., 2014; Agung Putra & Yuliando, 2015). Soilless culture has major influence on the floriculture industries as a possible means of quality flower production throughout the year (Roh & Hong, 2007).

Therefore, it would be a useful method of investigation to establish the ideal cultivation practices of *S. formosus* in a hydroculture system. Hydroponic culture has potential to produce plant material year-round under controlled growth conditions (Phantong *et al.,* 2018). Crops can be produced in and out of season, while the solution can easily be monitored for its total nutrient status (Grillas *et al.*, 2001). Heating of hydroponic solution in greenhouse production has been successful in a variety of crops (Moorby & Graves, 1980). By heating hydroponic solutions to specific temperatures ornamental plants can be grown hydroponically in greenhouses during the short-day periods to optimise growth of flowering plants and the production of flowers during winter periods (Nxawe *et al*., 2011). In the cultivation of ornamental pot plants, the flower is the often the commercial commodity and so the control of the flowering time is a key aspect in the marketing and success (Davies, 1974) because it allows timing of flowering to coincide with specific periods of peak market demand (Halvey, 1990).

The aim of this review paper is to determine whether *S. formosus* has economic viability and how the commercial value of the plant could be affected by applying various root zone temperature treatments when cultivating the plant.

2.3 RELEVANCE OF COMMERCIALISATION OF INDIGENOUS PLANTS

Numerous researchers agree that South Africa (SA) is remarkably rich in biodiversity, with over 24 000 indigenous plant species, (Smith *et al*., 1996; Coetzee *et al*., 1999; Brits *et al.*, 2001; Germishuizen & Meyer, 2003; Klopper *et al*., 2010). Between different species, and even within a species, there are unique characteristics that could be utilised commercially, particularly as

interest is increasing internationally in an ever broadening range of the plant diversity available in SA with ornamental horticultural and floricultural potential (Brits *et al.*, 2001; Reinten & Coetzee, 2002; van Wyk & Viljoen, 2011). De (2017) stated that South Arica was a good source of ornamentals with a global trade on about 600 species which is approximately 12% of garden plants, but this seems an insignificant amount when compared with the total number of indigenous species. However, Brits *et al*. (2001) cautioned that with the country being so well scoured and exploited by plant collectors dating as far back to the 1600's (Victor, 2016) possibly only relatively few species with utilizable commercial potential could still be present.

Both in the domestic and export markets, the potential of flowers and ornamentals is notable (De, 2017). Marasas *et al.* (1998) stated that the value of the South African flower industry had increased from R100 million in 1985 to R332 million in 1995, and Baudoin *et al*. (2007) reported that the local floriculture market was valued at ±R240 million in 2007 and export revenue amounted to about ±R280 million at that time, extrapolating that increase to 2015, and even further to 2025, allows for the assumption that investing in the commercialization of indigenous plant products is economically viable. Wessels *et al. (*1998) reported a 15.5% growth trend in the export market from 1994-1995. Trade figures on the international markets reflect the importance of some species of southern African origin, and in 2011 Multiflora Johannesburg (Africa's largest flower market) reported an annual turnover of €18 million (Reinten *et al.,* 2011). According to Buta *et al.* (2010) and Nishii *et al.* (2015) well over $30 million has been earned in the international trade of *Gesneriaceae* species for horticultural and decorative purposes.

However, Brits *et al.* (2001) again cautioned that plant breeding entrepreneurs in SA hoping for a share of this market may face severe challenges due to the lack of market-oriented breeding improvement evident in the local green industry, and scarcity of the market itself within SA, the lack of access to and choice of legal and technical resources, and the lack of experience required to profitably launch new cultivars to the ornamental plant markets in internationally and lack of research funding (Reinten & Coetzee, 2002).

Regardless of enormous richness in plant species and economic opportunity, only a small proportion of these plants are economically utilized from within SA (Marasas *et al.*, 1998). The majority of the economic efforts in SA have focussed on food crops, cosmetics, traditionally used and medical plants (Wyk & Viljoen, 2011). Over the past few centuries European collectors sourced an immense amount of plant species from SA's floricultural wealth with ornamental potential and, particularly in the Northern hemisphere, developed a range of new horticultural products that are now available globally (Victor, 2016). Recently SA began to recognise her indigenous plant species as a valuable natural resource and acknowledged the responsibility of conserving her unique flora. Attempts are being made to utilize SA's plant

kingdom economically for the nation, including acknowledgement of the legal owners who are lawfully entitled to benefit sharing. New crop development and re-development of already well-known crops is essential to create opportunities to sustain livelihoods (Coetzee *et al.,* 1999; Reinten & Coetzee, 2002). Beyond the potential to earn foreign exchange and improve national income, the intensive labour needs of floriculture production can improve livelihoods by generating employment and income for the country's unemployed peoples, particularly the youth, as well as contributing to the conservation of its biodiversity (Baudoin *et al*., 2007; De, 2017).

Figure 2.2. *S. formosus* flowers cut for vase (Picture: C. Viljoen)

Within ornamental plant markets the aesthetic value of plants is their currency, and there are increasing market demands for new forms, sizes, colours, function versatility, flower profusion, repeat blooming, pest and disease resistance within the green trade, as well as the international out-of-season supply of cut flowers (De, 2017). In *Streptocarpus with the* rosette leaf formation each mature leaf can produce up to six inflorescences, each with 3 to 6 flowers and with new leaves constantly developing with the ability to produce flowers while still quite small, large floriferous pot plants can be produced during the summer season (Marston, 1964). *Streptocarpus sp* have a prolonged post-greenhouse life when released onto the market with sufficient numbers of juvenile buds already formed and much appeal as a spring-flowered pot plant (White, 1975). *Streptocarpus* flower stems (Fig 2.2) are long lasting and make beautiful

vase displays (Dibley & Dibley,1995). To compete internationally in the floriculture markets, plants need to be true to type, have an extended vase life, be available in large and consistent quantities preferably for more than just a single season to enjoy a profitable marketing period (Reinten *et al.,* 2011), Functionality opportunities include plants for small space gardens and apartments, indoor use, balconies and terraces, vertical walls, hydroculture; included are plants that have long flowering periods, tolerant of a wide temperature range, and those that can withstand being droughted (Hentig, 1995; Uhl, 2012). Product development focussed on flowering pot plants should also include hanging basket plants and floriferous outdoors plants for semi-shaded situations (Marston, 1964; Reinten *et al.*, 2011; Uhl, 2012). Research done by Middleton (2015) selection criteria for ornamental plants clearly defined compact neatness, lifestyle-complementing plants, long-lived with instant attraction particularly of flowers to be in the top 80-90 percent. Streptocarpus, and for the purposes of this study S. formosus in particular, have immense potential to meet these market demands and utilise all these economic opportunities (Fig 2.3a-c, Fig 2.8, Fig. 2.9). It is important to know whether it is possible to increase flowers and regulate the timing of flowering in pot plant production (Friis & Christense, 1989).

Figure 2.3a. *S. formosus* flowering in a pot

Figure 2.3b. *S. formosus* flowers and densely arranged leaf growth habit (Pictures: C. Viljoen)

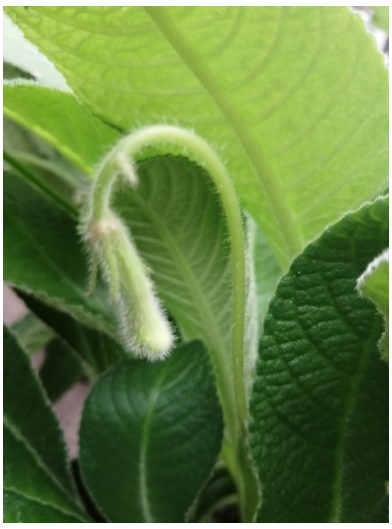

Figure 2.3c. *S. formosus* close-up of leaves and a flower bud forming

Houseplants such as Cape Primroses (*Streptocarpus* Lindl.) and African Violets (*Saintpaulia* H.Wendl.) have already proven themselves to hold significant economic importance (Buta *et al*., 2010). Interestingly, the indoor houseplant sub-market is affected significantly by the informal exchange of propagules in the form of seed and vegetative material and although the value might be small when measured in monetary terms, the ecological and genetic impact is

worth considering. Houseplants are unacknowledged as a means by which biological plant diversity circulate and are conserved. The difficulty of measuring the scale of these exchanges, have led to underestimating their possible economic significance (Ellen & Komáromi (2013). This is relevant as *Streptocarpus* is easily propagated from seed, or just a single leaf or stem cutting and by division of the rhizome (Van der Walt, 2002; Viljoen, 2011).

Streptocarpus hybrids are currently grown by a few specialist growers in SA and by many globally in Europe, South East Asia and America as beautiful indoor pot plants, popular for their range of array of forms, variety of striking flower colours, extended peduncle length and ease of cultivation (White, 1975; Dibley & Dibley, 1995; Chaudhury *et al.,* 2010; Hârţa *et al*., 2020). Some *Streptocarpus* spp. have become popular with plant enthusiasts and collector for their remarkable diversity in leaf structure, flower colours and shapes. Even within a species there can be variation in flower colour and throat markings (Hilliard & Burtt, 1971; Jong *et al*., 2011; Martens, 2016). Hybrids are typically easy to grow by nature of their genetic strength (Birchler *et al.*, 2006) as opposed to the temperamental nature of species that are not as tolerant of conditions that do not precisely mimic their natural environment. There is promising commercial potential in developing *Streptocarpus* spp. as indoor and outdoor perennials (Fig. 2.9) and also in utilising them to develop new hybrids as only a few species were originally used as breeding parent stock to develop current day cultivars (Marston, 1964; Afkhami-Sarvestani *et al*., 2012).

The first known species *Streptocarpus rexii* Lindl, discovered in the early 1800's, is the foundation of the majority of garden strains produced by hybridization with various other species (Marston, 1964; Hilliard & Burtt, 1971; White, 1975; Afkhami-Sarvestani *et al*., 2012). In its day it created much horticultural excitement, which was once again revived in 1940's by the creation of the amazing hybrid 'Constant Nymph' and by the mid 1950's *Streptocarpus* was the most widely cultivated plants in the genus (Moore, 1957) Genetic studies on *Streptocarpus* began in earnest in the 1950's and have continued to date (White, 1975). Irradiation led to extended colour forms of 'Constant Nymph' (Broertjes, 1969), that renewed interest in *Streptocarpus* as potted plants in the 1960-1970's as reviewed by White (1975). Present day commercial cultivars from both hybridization and mutagenesis characteristically exhibit an extensive range of multi-coloured flowers combined with a compact rosette growth and considerably smaller leaves 15 - 20 cm and these rosette forms of this genus have been much hybridized (Cantor *et al*., 2004; Chaudhury *et al.*, 2010; Martens, 2016). Unifoliates have been crossed with rosulates to broaden the gene pool of hybrids with many atypical *Streptocarpus* spp. that have not yet been introduced into cultivation (Gesneriad Society, 2007). In both subgenera of *Streptocarpus, Streptocarpella* and *Streptocarpus* numerous hybrids have been created and the genus is gaining more popularity in horticulture (Martens, 2016).

According to Cantor *et al.* (2004) the most important species to date that are included within the numerous bred cultivars are, S. *candidus, S. caulescens, S. fasciatus, S. floribundus, S. gardenii, S. formosus, S. rexii, S. roseoalbus, S. silvaticus, S. wendlandii.* As there are over 132 species this is not a significant number although two other species are worthy of mention is the red flowering, bird pollinated *S. dunni,* as well as *S. johannis* and *S. parviflorus.* The following species should be of particular interest for breeders as they have scented flowers from sweet to smoky aromas, *S. fanniniae*, *S. candidus, S. vandeleurii*. *S. wilmsii* (Martens, 2016). *S. kentaniensis* has an unusual short-day (winter) flowering period that will make it a sought-after parent to extend the flowering time of the garden hybrids (Van der Walt, 2002). As a contributor to hybridizing programs see Figure 2.1, *S. formosus* is noted for its elegant flower shape and corolla with an intense yellow throat colour and interesting markings (Martens, 2016). With great variation within the remaining under-utilised species which easily cross pollinate with other species, although many are naturally self-pollinated, the potential for further extensive horticultural development remains largely undiscovered (Dibley & Dibley, 1995; Viljoen, 2008; Martens, 2016; Boodhraj, 2018).

Streptocarpus spp. are a breeder's delight as the seeds are numerous and germinate in several days or weeks, most of the species obligingly flower in 6 to 12 months from seed, they also have exhibited great success within laboratory culture and micro propagation (North & Ndakidemi, 2012). Micro-propagation through tissue culture techniques is one of the most important approaches for large-scale ornamental plant propagation (Hârta *et al*., 2018, Rout & Jain, 2020). In the case of *Streptocarpus,* micro-propagation would allow plants to be supplied out of season from country of origin/production to countries currently experiencing the favourable growth season. According to De (2017) advanced breeding techniques, such as *in vitro* mutagenesis, somaclonal variation, haploid culture, protoplast fusion, embryo recovery, genetic transformation and DNA finger printing can provide immense scope for improving floricultural crops and *Streptocarpus* has also proven itself to be very responsive to these types of biotechnological tools (Hughes *et al*., 2007; Afkhami-Sarvestani *et al*., 2012; Nishii *et al.*, 2015; Hârţa *et al*., 2020).

As confirmed by Hârţa, *et al*. (2020) hybridization followed by phenotypic selection was the most commonly used breeding selection method for *Streptocarpus* varieties, as well for many horticultural and ornamental species. Their research revealed that both sequence-related amplified polymorphism (SRAP) molecular markers and Fourier-transform infrared (FT-IR) spectroscopy techniques applied in combination with morphological descriptions can be used as a new breeding strategy for *Streptocarpus* to obtain new valuable varieties. Employing phenotypic and genotypic methods to analyse and evaluate inter-specific hybridisation among cultivars is now possible due to advances in DNA sequencing methods and technology, this

combination of conventional selection with marker-assisted selection (MAS) can enable the identification and characterization of the hybrids more precisely and effectively in ornamental species (Röper *et al*., 2015). In research done by Reinten *et al.* (2011) the potential of *Streptocarpus* as a potted flower is listed as high and it is noted that potted flowers have become an important part of the florist trade and therefore interesting new cultivars are being developed for this expanding market. Today new hybrids are continued to be introduced to the huge and growing global pot-plant market (Marasas *et al*., 1998).

2.4 GESNERIACEAE RICH. & JUSS. EX DC

Streptocarpus belongs in Gesneriaceae, a large diverse family of mostly tropical and subtropical herbs, with a few temperate species in Europe, China, and Japan consisting of ± 130 genera, and ± 2900 species world-wide. There are 8 genera in Africa, with the one large genus *Streptocarpus* native to southern Africa (Smith *et al.,* 1997; Pooley, 1998; Leistner, 2000; Tarr, 2008). The family is named after Conrad Gesner (1516 – 1565), a Swiss naturalist who made noteworthy contributions towards describing many floral and faunal species (Van der Walt, 2001).

The Gesneriaceae family is characterized by flowers that are zygomorphic (Fig. 2.1; Fig. 2.6a), i.e. they are symmetrical in only one plane and by species with a vast range of morphological variation (Jong and Burtt, 1975; Woodson *et al*., 1978; Môller and Cronk, 2001). Both the Streptocarpus subgenus display the phenomenon of anisocotyly (Môller & Cronk, 1997; Nishi *et al.,* 2004). Most members of the gesneriad family are perennial herbs but also some annuals, shrubs, vines and small trees. Many of these are epiphytic or lithophytic or alternatively occur in soil on rocky outcrops, in forests and along streams or within spray reach of waterfalls (Madison, 1977, Woodson *et al*., 1978; Smith *et al.,* 1997).

This family has received a large amount of attention in the past century as a great number of the species are favoured ornamentally as showy flowering pot plants have an impressive variety of colours and growth forms, grown in indoors and in glasshouses across the world, particularly in the UK, Asia, Europe and Untied States (Van der Walt, 2001; Gesneriad Society, 2007). Noteworthy members of this family are *Saintpaulia* (African violets) and *Sinningia* (Gloxinias). A variety of studies and research on Gesneriaceae is being done in many parts of the world since the turn of the 21st century, with the main focus on floristic and revision studies, and descriptions of new genera and species discovered (Skog, 2005). Intensive taxonomic research has led to the proposition of a new formal classification by Burtt and Wiehler in the 1990's and more recently by utilising molecular studies in plant systematics (Môller and Clark, 2013) which has aligned the classification largely along phylogenetic boundaries leading to the

most notable result of *Saintpaulia* Wendl. now being nested within *Streptocarpus* instead (Smith *et al*., 1997; Smith *et al*., 1998; Môller & Cronk, 2001). This work on Gesneriaceae likely demonstrates an interest in the family that is increasing rather than diminishing (Môller & Santhosh, 2020).

2.5 THE GENUS *STREPTOCARPUS* LINDL.

The name of the genus *Streptocarpus* is derived from Greek origins, with *'streptos*' meaning twisted and '*carpus*' meaning fruit referring to the twisted seed pods of this genus (Pooley, 1998; Boodhraj, 2018). *Streptocarpus* is the only genus within the Gesneriaceae family that has a twisted construction of the fruit. The fruit capsules twist open in a spiral when dry (Fig. 2.7), releasing lots of small, lightweight, dark brown seeds (Gesneriad Society, 2007; Viljoen, 2011).

The genus *Streptocarpus* comprised of 132 species (Hilliard & Burtt, 1971), 87 of these originate from South Africa, 41 species from Madagascar and the Comoro Islands and 4 species are found in Asia, which are not closely related to the African and Madagascar species (Van der Walt, 2001; Afkhami-Sarvestani *et al*., 2006; Boodhraj, 2018).

Streptocarpus has two subgenera, the caulescent subgenus *Streptocarpella* Fritsch. comprising of 44 species and the acaulescent subgenus *Streptocarpus* Lindl. comprising of 88 species (Afkhami-Sarvestani *et al.,* 2006). These two subgenera have completely different growth habits. Streptocarpella are upright shrubby plants, with a clearly defined stem, axil and leaf structure. Subgenus *Streptocarpus* consists of plants that are stem-less and demonstrate immense variation in their vegetative construction from plants that consist only of one leaf to those with a rosette of leaves that look like primrose leaves, explaining the common name, Cape Primrose (Fig. 2.3a). *Streptocarpus* spp. are striking for their non-classical morphology (Jong, 1973, 1978; Jong & Burtt, 1975).

In *Streptocarpus* subgenus *Streptocarpus* the two main forms are referred to as the unifoliates and the plurifoliates. In the former, typical shoot apical meristem does not form so the whole vegetative plant structure can consist of only a single huge cotyledon, which can grow up to 0.75 m in length or the latter, where multiple leaves develop from the original germination structure (Joshi, 1938; Hilliard & Burtt, 1971; Môller & Cronk, 2001).

Most unifoliates, having one single leaf, are also monocarpic; meaning they flower only once form seed, then perish. *Streptocarpus* with more than one leaf are called plurifoliates, they are usually perennial and there are two main types: the multiple layered leaf form, which displays

repetitive production of phyllomorphs, similar to the monocarpic plant with inflorescences that bear many flowers and the rosulate form, made up of a basal rosette of leaves where the inflorescences bear fewer, larger flowers (Fig. 2.3b*). S. formosus* forms part of this last group (Jong, 1973; Hilliard & Burtt, 1971). The distribution pattern of all the growth forms of the genus Streptocarpus is shown in Fig 2.4.

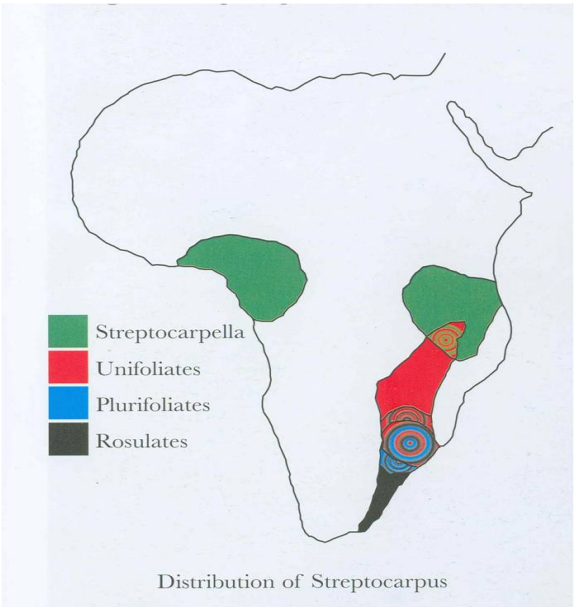

Figure 2.4: *Streptocarpus* distribution in Africa.
(Picture: D. Bellstedt)

Streptocarpus subgenus *Streptocarpus*, including the *S. x hybridus*, challenges the traditional morphological division of leaf, stem and axillary bud, as no stems are present, instead each leaf is actually an individual plant (Fig. 2.5a, 2.5b), with its own roots and flowering stems (Jong & Burtt 1975; Môller & Cronk, 2001). The vegetative plant body consists of recurring components, called phyllomorphs. Jong and Burtt (1975) introduced the 'phyllomorph' concept, a leaf construct composed of a lamina and petiolode which is a structure with a dual function of petiole and stem. A phyllomorph's petiolode (stalk) displays a mixture of petiole-stem and leaf-axil features, and its leaf blade has the notable ability to grow continuously from the base (Jong 1973, 1978; Jong & Burtt 1975; Burtt, 1978; Môller & Cronk, 2001; Edwards *et al*., 2008). The phyllomorph is first formed by the enlarging of only one of the cotyledons, unequal growth of the cotyledons after germination is called anisocotyly (Burtt, 1978; Nishi *et al*., 2004). Phyllomorph growth is controlled by three meristem tissue types located at the intersection point of the petiolode and lamina (Jong & Burtt 1975; Nishi & Nagata, 2005). Basal meristem generates new growth at the lamina base; petiolode meristem is responsible for the growth of the midrib as the lamina enlarges and to the elongation of the petiolode; and groove meristem

instigates growth of additional phyllomorphs and the inflorescences (Jong & Burtt, 1975; Jong, 1978; Imaichi *et al.,* 2000; Mantegazza *et al.,* 2007; Nishii & Nagata, 2007).

Figure 2.5a. Stages in phyllomorph development of *S. formosus* (Picture: C. Viljoen)

Figure 2.5b. Flowering phyllomorph of *S. formosus* (Picture: C. Viljoen)

Within *Streptocarpus* spp. there is also a diversity of floral morphology from colour, and flower markings to scent to size and shape, with small, 5-7.5 mm long, pouch-shaped flowers, to short flat-faced key-hole flowers, to the long funnel-shaped open tube flowers up to 55 mm long found in the type species, *S. rexii* Lindl. (Hilliard & Burtt, 1971; Harrison *et al.*, 1999). The flowers arise from the upper part of the midrib of the leaf (Appelgren & Heide, 1972) and are grouped in a cyme inflorescence with two to six zygomorphic tubular flowers on an upright peduncle (Hilliard & Burtt, 1971). Every leaf has 3 to 5 flowering stems developing in succession (Figures 2.5a, 2.5b) in various stages of development (Gesneriad Society, 2007).

A phyllomorph usually does not produce any flowers in its first season of growth, it must first last though an unfavourable dry season at least once. Survival is achieved by the loss of a large part of the lamina, a line or arc of abscission forms right across it and the part distal to this line withers and eventually fall away (Noel & van Staden, 1975). New laminal tissue is produced by the basal meristem when favourable conditions return but abscission strategies are not utilised if the plants are growing in moist sheltered conditions (Hilliard & Burtt, 1971; Jong & Burtt, 1975; Jong, 1978).

2.6 THE SPECIES *STREPTOCARPUS FORMOSUS* (HILLIARD & B.L.BURTT) T.J.EDWARDS

S. formosus forms part of the rosulate group of herbaceous stem-less plants within the Gesneriaceae family as it does not have a single dominant phyllomorph, even though the arrangement of the phyllomorphs are slightly irregular (Hilliard & Burtt, 1971; Nishii & Nagata, 2007). Numerous rough, hairy leaves between 250–500 mm long and 45–100 mm wide with prominent abaxial veins grow on a stout horizontal rhizomatous rootstock. The leaves are narrow broadening near the apex, curving slightly downwards, with shallow notched margins. The five calyx sepals are hairy with reddish brown tips. Large, single or paired glandular thinly hairy flowers each with 5 broad, uneven petals are borne on long slender peduncles in summer, long day plants. The zygomorphic flower (Fig. 2.6a), 70-105 mm long, is a tubular trumpet shape with the corolla mouth roundly open and with corolla tube widening from the base outwards, typically has two lips, the upper is 2-lobed and the lower 3-lobed. Five corolla lobes and tube are whitish in colour, with the floor of the corolla tube longitudinally divided by a distinctive bright yellow zone flecked with purplish-brown that widens in the throat and extends slightly onto the lower lip; this is a diagnostic feature (Fig. 2.6b). The five main veins on the lobes of the lower lip and the rest of the corolla tube are all minutely spotted violet-purple (Hilliard & Burtt, 1971; Pooley, 1998; Van der Walt, 2001; Hughes, *et al*., 2007; Manning, 2009).

Figure 2.6a. Flower: side view, of zygomorphic *S. formosus* (Picture: C. Viljoen)

Figure 2.6b. Flower: front view, of *S. formosus* (Picture: C. Viljoen)

The stigma is 2-lipped; the two stamens are attached to the corolla tube with anthers usually cohering face to face (Fig. 2.6b). Ovary is superior and upon fertilisation forms a slender, cylindrical fruit capsule, 111-179 mm long, dehiscing when dry by the untwisting (Fig. 2.7), of the four spiral slits releasing numerous small seeds (Hilliard & Burtt, 1971; Pooley, 1998; Van der Walt, 2001; Hughes, *et al*., 2007; Manning, 2009).

Figure 2.7. Cylindrical fruit capsule twisting while dehiscing numerous small seeds (Picture: C. Viljoen)

The geographical distribution of the species is of morphological interest as *Streptocarpus* habitats and growth habits are closely correlated (Marson, 1964). *In its natural wild habitat S. formosus* grows around Port St Johns in northern Pondoland in the Eastern Cape, hence its common name Pondo Strep, and along the sandstone gorges in the sub-tropical forests of Umtamvuna and Oribi in southern Kwazulu-Natal. The plants are selective, always occurring away from direct sunlight or in dappled shade, growing in shady rock crevices and ledges or on soil slopes that face south or southwest, often growing in association with lichens and moss. (Van der Walt, 2001) Similar species *S. primulifolius*, as *S formosus* was previously classified under synonym *S. primulifolius subsp. formosus* (Weigend & Edwards, 1994). 'Formosus' means beautiful (Fig. 2.8) in Latin (Pooley, 1998).

Figure 2.8. Flower and bud of S. formosus (Picture: C. Viljoen)

S. formosus has a conservation status under threatened species as Rare (R). Habitat degradation and a restricted, specialized habitat have been cited as a threat to this South

African endemic (Scott-Shaw *et al*., 2008). The use of this plant in commercial opportunities would ensure the species continued existence.

2.7 COMMERCIAL VIABILITY OF *STREPTOCARPUS* IN HYDROPONICS

Hydroponics, a SCS, is a method of growing plants in nutrient solution (Shrouf, 2017; Savvas & Gruda, 2018). Hydroponic systems have been recommended as an alternative method for cultivating plants (Phantong *et al*., 2018). South Africa is obligated to treat its water as a valuable natural resource and accordingly all plant-related industries are expected to demonstrate efficient water use due it being a limited resource constantly under pressure of insufficiency (Oliver & Singels, 2015). The modern cultivation systems of hydroponics could offer a solution, using approximately 5 percent of the water and a much smaller proportion of the land required to produce an equivalent amount of plant produce (AlShrouf, 2017). The applications of SCS are increasing globally and are expected to demonstrate a world growth of 18.8 % from 2017 to 2023, corresponding to a global hydroponic market of $490.50 million by 2023 (Aires, 2018)

With ever-increasing industrialization and urbanization cultivable land is ever-decreasing and conventional agricultural practices are causing a range of negative impacts on the environment (Sarmah *et al*., 2020) and there is much potential in using containerized plants (Fig 2.9) in the urban environment which can rather be grown in inert growth media within hydroponics systems requiring no soil and minimizing the use of natural resources (Schnitzler *et al.,* 2003; Sharma *et al.*, 2019). The future possibilities of the application hydroponics are still being discovered as technological advances are being made and combined with SCS to allow for successful plant production in locations, climates or seasons that are unfavourable. Ornamental and food crop production is now possible by using SCS where arable soil is scarce with limited resources, such a rocky islands, arid and polar areas, hard surface areas in urban environments, (both indoors and outdoors) with the ability to be stacked vertically within these landscapes as green facades, furniture and infrastructure while providing a green environment (Montero *et al.,* 2010; Lakkireddy *et al.,* 2012; Salas *et al.,* 2015; Aires, 2018; McCartney & Lefsrud, 2018; Dhanraj, 2020). Some of the most successful plants used in vertical greening systems are epiphytic or lithophytic, and from topical or subtropical areas (Pérez-Urrestarazu *et al*., 2015), all of which are characteristics of many *Streptocarpus* spp.

The current global expansion of hydroponics and SCS could be due to their ability to be independent of all the soil related problems like the decline of soil structure and fertility, high salinity or nutrient saturation (Raviv & Lieth, 2008; Sarmah *et al*., 2020). Greenhouse industry systems have moved from open to closed hydroponics (Papadopoulos *et al*., 2008) as closed

systems allow for the collection and recycling of the nutrient solution (Ferrante *et al*., 2000). Closed hydroponic systems are not in direct contact with the soil in the local environment, therefore leaching of pollution of the soil due to waste nutrients is significantly diminished (Gontier *et al*., 2002; Ikeda *et al*., 2002). Soilless cultivation has become more commercially viable due to scientific research and technological advances in plastics manufacturing, automation, soluble fertilizers, and availability of a variety suitable of substrates (Sharma *et al.,* 2019). The application of these new advancements in technology and research can greatly assist the precision in plant production by increasing yield and efficiency for optimal cultivation of high quality plant crops (Domingues *et al.,* 2012) while curtailing waste and utilizing renewable resources (Barrett *et al.,* 2016). Hydroponics could repurpose or utilise recycled hard materials as growing containers and potentially also assist with cleaning wastewater and utilisation of saline water while producing profitable crops (Sonneveld *et al.,* 1999; Vaillant-Gaveau *et al.,* 2014) with other potential environmental, ecological and aesthetic benefits still being explored (Salas *et al*., 2012; Pérez-Urrestarazu, 2015).

Commercial growers have proven hydroponics to be successful in the production of fast-growing horticultural crops (Asao *et al.,* 2014) and research has proven hydroponics encourage faster growth as there is no mechanical hindrance to the roots combined with the entire spectrum of all the required nutrients being consistently and readily available to the plants (Sharma *et al.,* 2019). The achievement of high growth, flower and fruit yields and good quality uniform greenhouse crops are accomplished with hydroponics due to the precise control of nutrition and growing conditions (Adams, 1992; Schnitzler, 2004). Nutrients, EC, pH, growth substrates, temperature, aeration and irrigation systems can all easily be designed to specifically suit the crops cultivation requirements with proven positive results (Gontier *et al.,* 2002; Samartzidis *et al*., 2005; Sgherri *et al.,* 2010; Nxawe *et al.,* 2011) and when managed correctly labour, diseases, pesticides, space, water use and costs are reduced significantly when compared to soil cultivation systems (Kozai, 2006; Sgherri *et al.,* 2010). Combined with optimisation of factors in aerial environment such as the temperature, light and humidity maximum growth potential can be achieved (Adams, 1992). Jovicich *et al.* (2003) and Ikeda *et al*. (2002) point out that commercial hydroponic systems which are automated eliminate several traditional agricultural practices, such as weeding, spraying, pest and disease treatment, manual watering and tilling. A number of different systems are available to the growers for the design of hydroponic installations to meet a particular plant's needs and to suit any budget (Schnitzler *et al.,* 2004; Sarmah *et al*., 2020)

SCS cultivation has many advantages but its limitations are of significance, such as considerably higher initial installation costs and the requirement of the necessary technical and cultivation knowledge (Resh, 2013). Light and energy supply may be required. Hot weather

and limited oxygenation can limit production and can result in loss of plant crops. The long-term application of available technologies and energy efficiency is vital to consider (McCartney & Lefsrud, 2018). Maintenance of pH, EC and proper concentration of the nutrient solution is essential (Ikeda *et al.*, 2002; Sharma *et al.,* 2019). Certain crops require good quality clean water (Schnitzler, 2004; Os, 2008). Research has shown that recycling the nutrient solution causes several problems such as nutrient imbalance, continual increase in electrical conductivity (EC), and accumulation of some elements which may cause toxicity in a predisposed crop (Ferrante *et al*., 2000; Aires, 2018) and in a hydroponics system with plants sharing the exact same solution water borne diseases can be transferred from one to another (Ikeda, 2002; Schnitzler, 2004)

Hydroponics have been used in the floriculture industry for cultivating ornamental crops such as African Violets (Gesneriaceae), Asters, Carnations, Chrysanthemums, Geraniums, *Gerberas*, *Gypsophila*, Lilies, Marigolds, Poinsettias and Roses, resulting in significant increases in their growth and yields (Leonhardt & McCall, 1982; Baas *et al.*, 1995; Sonneveld *et al.,* 1999; Hyun *et al*., 2005; Samartzidis *et al*., 2005:, Karras *et al.,* 2007; Wahome *et al.,* 2011; Hassan, 2015; Phantong *et al*., 2018; Sarmah *et al*., 2020). Research has been done on many herbaceous ornamental crops indicating their potential to be grown commercially within hydroponic systems, *Begonia*, Lemon balm, *Nasturtium*, Foxgloves, *Fuchsia*, *Pelargonium*, Sage and Snapdragon (Hood & Mills, 1994; Ferrante *et al*., 2000; Manukyan *et al*., 2004; Papadopoulos *et al.,* 2008; Melo & Santos, 2011; Valliant *et al.,* 2014; Phantong *et al*., 2018; Sarmah *et al*., 2020). Herbaceous foliage ornamental plants such as Asparagus fern, *Ceropegia*, *Hosta*, Maidenhair fern, *Pepperomia, Philodendron*, *Pteris, Rhoiscissus*, *Sinningia* (Gesneriaceae)*, Syngonium*, and Wandering Jew have all been commercially grown and displayed within hydroponic systems (Phonpho & Saetiew, 2017; Dhanraj, 2020). The successful results proven with these and other herbaceous ornamental and food crops indicate a potentially positive outcome for *Streptocarpus* hydroponic cultivation.

2.8 DISCUSSION AND CONCLUSION

This paper highlights the significant commercial potential in the further development of *Streptocarpus* as flowering pot plants. Many atypical species within both subgenera have not yet been utilised in breeding programs or even introduced into cultivation, this allows for substantial scope for the development of new and unusual hybrids. As a species that has not yet had much attention, *S. formosus* would make a good candidate for new breeding programs for a number of reasons. The corolla's splash of yellow, combined with purple lines and speckling could create some beautiful colour combinations. Its natural resilience when

compared to other peers would allow for its use for both indoor and outdoor pot culture. A study including hydroponic cultivation for *S. formosus* may expand its future commercial production potential by increasing growth and flowers yields while aiding in reducing nutrient wastage, run-off into soils and conserving water in dry climate countries, such as in SA where *S. formosus* occurs naturally where the species would potentially be produced commercially as a new flowering potplant (Fig. 2.9).

Figure 2.9. *S. formosus* as a flowering pot plant (Photo: C. Viljoen)

2.9 References

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CHAPTER THREE:

VEGETATIVE GROWTH OF *STREPTOCARPUS FORMOSUS* IN RESPONSE TO DIFFERENT ROOT ZONE TEMPERATURE REGIMES IN HYDROPONICS

VEGETATIVE GROWTH OF *STREPTOCARPUS FORMOSUS* IN RESPONSE TO DIFFERENT ROOT ZONE TEMPERATURE REGIMES IN HYDROPONICS

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3.1 ABSTRACT

Streptocarpus formosus (Hilliard & B.L.Burtt) T.J.Edwards is a flowering herbaceous perennial indigenous to South Africa and is part of the rosulate group of herbaceous stem-less plants within the Gesneriaceae family. The cultivation of most *Streptocarpus* spp. commercially as flowering pot plants is limited during the winter months (short days), as they slow their growth rate significantly for an annual rest period. This study was done to investigate the effectiveness of applying root zone heating (RZH) to plants grown in deep water culture (DWC) hydroponics to assess the effect on the plant growth activity during this eco-dormancy period. The experiment was conducted over an eight-week period during short days in the greenhouse at Kirstenbosch National Botanical garden, using water tanks each maintained at the experimental temperatures of (18, 22, 26= control, 30 and 34 °C) applied to 10 sample replicates. At pre-planting and post-harvest number of leaves were counted, lengths of leaves and roots were measured (mm) and wet weights (g) were calculated. These results showed a heated solution of 18 °C had a significant effect on the growth and development of *S. formosus* grown in hydroponics, with the highest average increases in fresh weight (1078 g), root length (211 cm), overall leaf length (362 cm) and number of new leaves formed (177 = n), all noted as statistically significant, with all other temperature treatments giving negative results. Further studies into lower root zone temperature regimes on the growth of this plant would be advantageous.

Keywords: Cape Primrose, commercial cultivation, eco-dormancy, flowering pot plant, hydroponics (DWC), Gesneriaceae, root zone heating, phyllomorph, *Streptocarpus*, vegetative growth

3.2 INTRODUCTION

3.2.1 *Streptocarpus formosus* (Hilliard & B.L.Burtt) T.J.Edwards

Within the *Gesneriaceae* family *Streptocarpus* forms part of an economically important ornamental plant group with other significant members such as African Violets (*Saintpaulia)* and *Gloxinia* spp. (Hilliard & Burtt , 1971) all of which are herbaceous perennials known for the beauty of their flowers (Van der Walt, 2001; Gesneriad Society, 2007) (see Fig 3.1).

The commercial potential and ornamental use of *S. formosus* and other *Streptocarpus* spp. is currently restricted by a semi-dormancy period during cold season months (Dibley & Dibley, 1995). Ideally commercial production of *Streptocarpus* spp. requires a method of cultivation that would produces flowering plants all year round. Much research has been done on the viability of using root zone temperature (RZT) to keep crops and ornamental plants in active growth for out-of-season production thereby extending their commercial viability throughout the year (Moorby & Graves, 1980; Stoltzfus *et al.*, 1998; Grillas *et al.*, 2001; Agung Putra & Yuliando, 2015; Phantong *et al.,* 2018). Research on *Streptocarpus* x hybridus 'Constant Nymph' done by Appelgren and Heide (1972) over a temperature range of 12 °C to 30 °C resulted in the highest formation of roots and buds at both the relatively low temperatures of 12 °C and 18 °C. Cultivation in greenhouses during the cold season can be achieved by increasing the temperature of the irrigation water to optimum levels (Kozai, 2006).

Figure 3.1a. Growth habit of a flowering *S. formosus* (Picture: C. Viljoen)

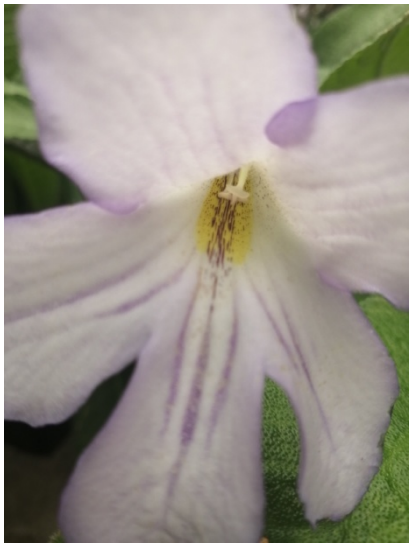


Figure 3.1b. Flower, close-up front view, of *S. formosus* (Picture: C. Viljoen)

3.2.2 Hydroponic root zone temperature effects on vegetative growth

Soilless culture systems (SCS), also referred to as hydroponics, is used to describe methods of growing plants without soil where artificial or soilless substrate can be used to provide structural support for the plants within systems that provide nutrients in water depending on the grower, the plant and method used (Al-Shrouf, 2017; Savvas & Gruda, 2018). With a notable global increase in scarcity of resources and climate change, SCS's offer workable solutions utilizing renewable resources and minimising waste all while improving the efficiency and yield of crop production (Barrett *et al.*, 2016; Savvas & Gruda, 2018; Dhanraj, 2020). Hydroponics achieve high growth yields and good quality uniform greenhouse crops due to the precise control of nutrition and growing conditions (Grillas *et al*., 2001; Kozai, 2006; Agung Putra & Yuliando, 2015). Yields in hydroponics average at 20 - 25 % higher than in conventional soil cultivation and have demonstrated the significantly more growth and development in root systems, which also improves nutrient uptake ability of the plants which in turn leads to better shoot and leaf growth (Asao *et al.,* 2014).

Heat is required to increase growth in order to expand plant production during the cold season with the use of greenhouses (Sethi & Sharma, 2007), while hydroponic growing has become common practice to improve winter yields and to obtain optimum production under periods of suboptimal climatic conditions (Moorby & Graves, 1980; Grillas *et al*., 2001; Kozai, 2006). Morgan *et al.* (1980) report that *Chrysanthemum* responded positively to heated solution when grown in a SCS with notably increased vegetative growth and that the use of a heated solution in combination with a low night air temperature produced the most favourable response. Similar findings were presented by Larigauderie *et al.* (1991) with root zone and air temperature heating of *Ceanothus greggii* seedlings. RZT has shown significant results in a variety of herbaceous leafy crops, increasing growth of both roots and shoots due to ideal nutrient availability, while encouraging earlier readiness of a crop (Moorby & Graves, 1980; Hood & Mills, 1994; Nxawe *et al.,* 2009; Sharma *et al.,* 2019). There is a positive correlation between root-to-shoot ratio and the between 10 °C and 35 °C (Curtis & Clarke, 1960). Research findings on exposure of red leaf lettuce roots to low temperature indicated significantly reduced leaf area, stem diameter, and fresh weight of tops and roots suggesting that low temperature treatment of roots triggers stress responses in the whole plant, resulting in the reduction of leaf and root growth (Sakamoto & Suzuki, 2015).

Additional benefits of heating the nutrient solution are providing the energy requirements for plant development and active metabolism (Reid, 1991; Calatavud *et al.,* 2008) and reduction

in pathogenic activity (Van Os, 2017). The optimum temperature of the growth medium can contribute beneficially to plant physiological processes such as accumulation of phenolic compounds (metabolites), chlorophyll pigment formation, and an increase in the photosynthesis (Nxawe *et al.,* 2010). When RZH is applied in a DWC system the volume of water buffers temperature, making the system practical in regions where nutrient solution temperature fluctuations can be a problem (Van Os *et al.,* 2008). RZH contributes to energy savings compared with expense of heating entire greenhouse structures (Papadopoulos *et al., 2008;* Nxawe *et al.,* 2009).

Limitations are that a reliable source of energy is required while Electrical conductivity (EC) and the toxicity from salt concentrations due to evapotranspiration and evaporation must be closely monitored. Adequate and regular nutrient solution replenishment is necessary. In some hydroponic systems additional oxygenation will be required (Morimoto *et al.,* 1989). Some crops prefer a cooler RZT for optimum growth (Sattelmache *et al.,* 1990; Al-Rawahy *et al.,* 2018; Xu & Huang, 2000).

Investigating the effect that different RZT regimes would have on vegetative growth *of S. formosus* will contribute to developing optimal growing protocols for increasing production. The aim of this study was to determine an optimal temperature for the vegetative growth of *S. formosus* in the cold season to order to produce consistently higher yields for cultivating quality pot plants in hydroponics for commercial production.

3.3 MATERIALS AND METHODS

3.3.1 Greenhouse experiment

The experiment was conducted in the plant production nursery greenhouse facility at the Kirstenbosch National Botanical Garden (KNBG), Cape Town, South Africa; GPS co-ordinates - 33° 98ˈ 56.12S, 18° 43ˈ 60.25E, for 8 weeks from mid-June 2019 to mid-August 2019, in the winter season. Plants were grown under natural daylight conditions which provided a short-day photoperiod, 9:59:26 hr (15th June) to 10:54:49 hr (15th August) day lengths required to conduct the experiment. *S. formosus* is then in a semi-dormancy period of its annual vegetative growth (Hilliard & Burtt , 1971). An overhead Aluminet shade net screen provided 40 % shading to reduce excessive temperature fluctuations while maximum day temperatures ranged between 13°C - 18 °C and night temperatures between 3 °C - 7.8 °C, with an average relative humidity between 77 - 81 %.

3.3.2 Plant preparation

Fifty genetically identical plantlets were propagated vegetatively (Fig. 3.2a) from one *S. formosus* mother plant which was sourced from KNBG in Cape Town. After the rooting period of four months (Fig. 3.2b), the plantlets were thoroughly rinsed to remove rooting media and all foreign matter form their leaves and roots. They were then potted into lattice-net plastic pots filled with 4 - 10 mm lightweight expanded clay aggregate (LECA) and placed in the hydroponic system with only their roots submerged in water. LECA was the preferred SCS growth medium for this study as it is lightweight with added porosity, will not degrade in water, while its pH remains neutral with the additional advantage of protecting the roots with its thermal insulation properties (Tosi & Tesi, 1987; Boudaghpour & Hasemi, 2008).

Figure 3.2a. Leaf cuttings of *S. formosus, freshly made* (Picture: C. Viljoen)

Figure 3.2b. Leaf cuttings of *S. formosus*, matured, with plantlets (Picture: C. Viljoen)

3.3.3 Hydroponic cultivation

Hydroponics is a SCS, where plants are grown in nutrient solution (Savvas & Gruda, 2018). Based on the recommendations, discussions and methodologies of Bracnher and Both (1996), Ferrante *et al*. (2000), Kratky (2004, 2010a), Al-Shrouf (2017) and Clayton (2017) a SCS of a closed deep-water hydroponic system with an air stone and a circulating pump were used. DWC hydroponics allows for methods of heating the nutrient solution to the required temperature supplied directly to the plant roots (Morgan *et al.,* 1980; Larigauderie *et al.,* 1991; Stoltzfus *et al.,* 1998; Nxawe *et al.,* 2009). Closed hydroponics systems allow for the reuse of nutrient solution reducing the negative environmental impacts such as leaching of fertilizers, soil and ground water pollution, water wastage, while saving on labour (Adams, 1992; Ferrante *et al.*, 2000; Kozai, 2006). The DWC system was used to maintain a consistent nutrient supply and temperature over the entire root surface area of the replicates (Agung Putra & Yuliando, 2015; Savvas & Gruda, 2018). LECA provided support for the plants needing to be suspended in the nutrient solution while providing excellent aeration qualities (Boudaghpour & Hasemi, 2008).

Five identical DWC hydroponic systems were constructed and placed onto wire mesh tables. Each system consisted of one 70 litre capacity low-density polyethylene (LDPE) reservoir filled with 60 litres of aqueous nutrient solution. Each reservoir was covered with a LDPE sheet into which holes were cut to hold the 10 lattice-net plastic pots (7.5 cm) suspended (Fig. 3.3). The pot size and depth ensured that the root zones of the plants were submerged in the nutrient solution without wetting the plant's leaf crowns.

To prevent oxygen deficiency and the limitations this would place on the plant growth (Drew, 1983; Zeroni *et al*., 1983; Morard *et al.,* 2004) root aeration is essential in SCS, especially in DWC where there is limited air-water exchange capacity (Savvas *et al*., 2013) and particularly when heating solution as there is a direct correlation between the temperature of water and the amount of oxygen it contains (Sharma *et al*., 2019; Roblero, 2020). As water temperature increases less oxygen becomes available to the roots (Adams, 1992). To increase aeration all the solutions were aerated using one electromagnetic air compressor (BOYU ACQ-003) linked to each system's single air stone (50 mm) which bubbled the air up through the nutrient solution, supplying oxygen to the roots of the plants. To assist with the even distribution of both the additional air (O^2) and the heated water (Jones, 2014), each individual system's solutions were circulated using an 800 L/h hour HT submersible pump (HJ-941) (see Fig. 3.3).

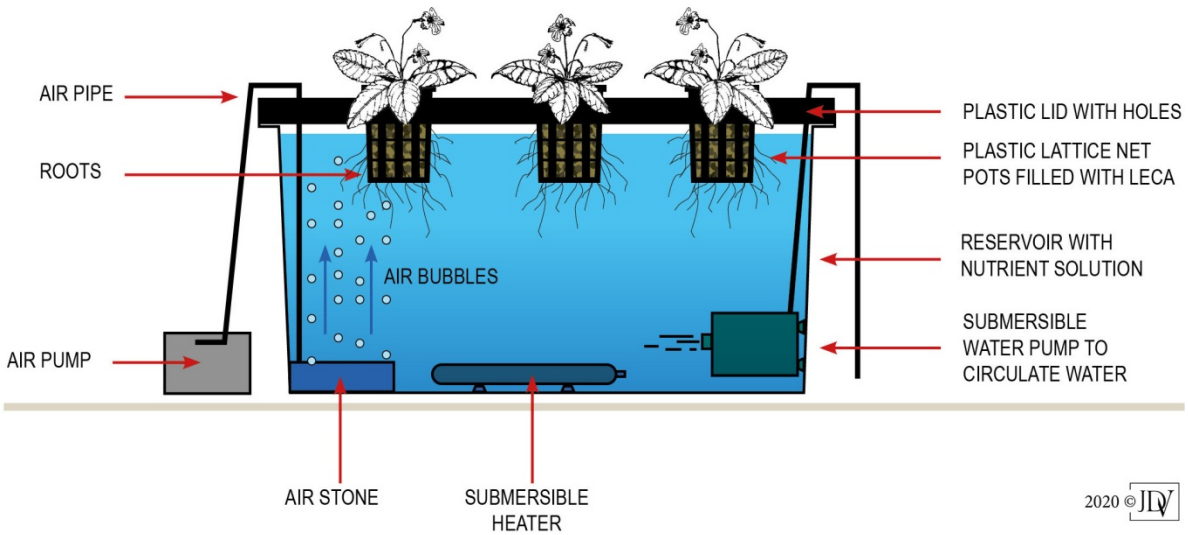


Figure 3.3. Deep water culture hydroponics, with air stone and circulating pump, and plants in lattice-net pots filled with LECA aggregate held suspended in nutrient solution

(Diagram: J.D. Viljoen)

The solution comprised of ozone treated borehole water containing Nutrifeed (Fig. 3.4) (Manufactured by Starke Ayres Pty. Ltd. Hartebeefontein Farm, Bredell Rd, Kaalfontein,

Kempton Park, Gauteng, 1619). This nutrient product supplied all the essential macro and micronutrients required for healthy plant growth as hydro-soluble fertilizer salts (Harris, 1992; Savvas *et al*., 2013). As the experiment would fall within a two-month growth period it was decided that replacing the nutrient solution to overcome the build up phototoxic substances in the nutrient solution (Yu *et al.,* 1993; Ferrante *et al*., 2000; Kratky *et al.*, 2002, 2005) would not be required and to prevent potential disturbance damage to the roots (Kratky, 2010).

- Nitrogen [N] - 6.5 %
- Phosphorous [P] - 2.7 %
- Potassium [K] - 13.0 %
- Calcium [Ca] - 7.0 %
- Magnesium [Mg] - 2.2 %
- Sulphur [S] - 7.5 %
- Plus: Iron, Manganese, Boron, Zinc, Copper and Molybdenum.

Figure 3.4. Hydroponic solution nutrients provided by Nutrifeed™ (Picture: C. Viljoen)

As it is essential in DWC to monitor the oxygen supply, nutrient concentrations, salinity, pH (Domingues *et al.,* 2012) and for the purposes of this experiment, the temperature was included, all were examined bi-weekly and if necessary adjusted as required. The pH levels of all the nutrient solutions were monitored using a using a calibrated hand held digital pH meter (HM Digital PS PH-200). Although Trejo-Tellez and Gomez (2012) demonstrate that the optimal pH in the root zone of most crop species grown hydroponically ranges from 5.5 - 6.5 and Sharma *et al.* (2019) recommended a range of 6.0 - 6.8 for African Violet (*Gesneriaceae*) the pH was kept within a range of 6.4 - 7.0 as recommended by the Gesneriad Society (2007) for *Streptocarpus* and by Agung and Yuliando (2015). The pH was adjusted accordingly using either sodium hydroxide (NaOH) to raise the pH, or hydrochloric acid (HCL) to lower the pH. The various temperatures of the five test solutions were also measured for monitoring.

Electrical conductivity (EC) that is too high will prevent nutrient absorption due to osmotic pressure and an unfavourably low EC will negatively influence yield and plant health as stated by Sharma *et al.* (2019), who also stated that the ideal EC range for most hydroponics crops is between 1.5 dSm^{-1} and 2.5 dSm^{-1}, with a specific recommendation of an EC of 1.2 - 1.5

dSm^{-1} for African Violet (*Gesneriaceae*). Uhl (2012) suggested an EC range of between 0.8 - 1.0 dSm^{-1} for *Streptocarpus,* so an EC range of 0.9 - 1.1 dSm^{-1} was adhered to in this experiment. The EC levels and temperatures of all the nutrient solutions were monitored using a calibrated hand held digital EC & Temp meter (HM Digital PS COM-100). For decreasing the EC of aqueous nutrient solutions ozone treated borehole water was added into reservoirs, while adding Nutrifeed™ increased EC levels.

3.3.4 Water temperature treatments and Experimental design

The experiment consisted of five different hydroponic solution temperatures which were applied to 50 plants of *S. formosus* using a completely randomised bock design (Fig. 3.5). Each temperature treatment consisted of 5 treatments with 10 replicates (n = 10), one per pot suspended in DWC system. Pots were individually numbered and arranged randomly. The five test solutions were heated using submersible EHEIM thermo-control heaters as standard aquarium equipment.

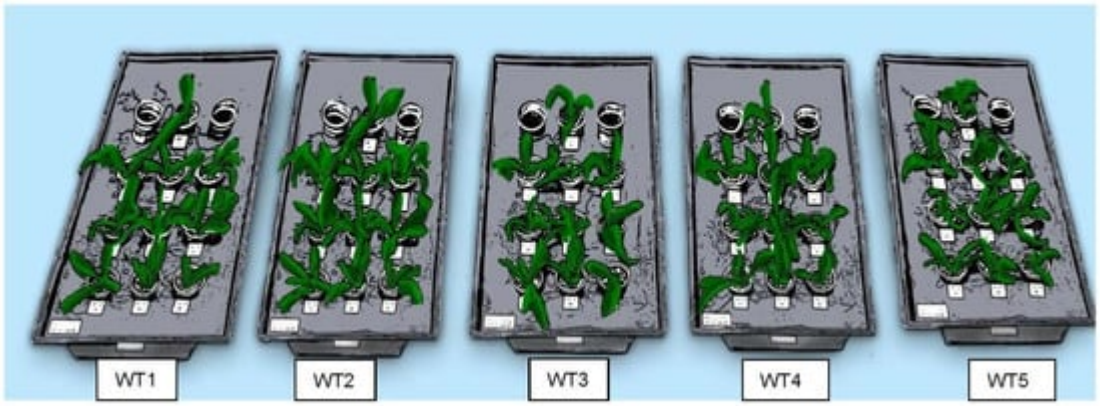


Figure 3.5. Completely randomised block design for experiment (Picture: J.D. Viljoen)

1) WT1 = water temperature heated to 18 °C
2) WT2 = water temperature heated to 22 °C
3) WT3 = water temperature heated to 26 °C
4) WT4 = water temperature heated to 30 °C
5) WT5 = water temperature heated to 34 °C

The water temperature selection was based on the ideal temperature recommendations for growing Gesneriads from the Gesneriad Society (2007) and on the research done by Curtis and Clarke (1960), Morgan *et al.* (1980), Stoltzfus *et al.* (1998), Nxawe *et al.* (2009, 2010), and

Al-Rawahy *et al*. (2018) demonstrating an increase in vegetative growth on various perennial crops within this range. As reported by Merryweather (2008) the mean annual temperature at Port St Johns which is *S. formosus* natural habitat, is 19.9 °C as recorded between 1961-1990 with a mean summer min-max of 17.1 °C - 27.6 °C when the plants are in full growth and flowering, as opposed to the mean winter min-max of 7.4 °C - 20.5 °C when the plants are semi-dormant. This experiment focussed on the summer temperatures to test whether the plants could be stimulated into active growth and flowering in the colder winter months and, WT3 at 26 °C was selected for the control as the literature reviewed indicated this to be both the ideal ambient air temperature for *Streptocarpus* under non experimental circumstances, and a RZH median for root to shoot ratios under experimental conditions for a selection of perennial crops (Davidson, 1969; Larigauderie,1991; Hood & Mills, 1994; Chung *et al.*, 2002; Nxawe *et al.,* 2009; Odhiambo *et al.*, 2018; Nguyen *et al.*, 2020).

3.3.5 Vegetative growth and Data collection

Various measurements were taken to determine plant growth response to different nutrient solution temperatures. Data capturing took place pre-planting and at the time of planting the plants into the quantitative research experiment system, and again post-harvest after a two-month growth period.

Before planting, each plantlet was weighed, and the lengths of both the smallest and longest leaves as well as root length for each were recorded. Immediately after being transplanted in to the leca filled pots and placed in the DWC hydroponic test solutions the number of leaves, were then counted and recorded. Post-harvest these same measurements were taken, and the data recorded.

3.3.5.1 Leaf formation

Leaf lengths

The length of each plant's shortest and longest leaves was measured using a ruler at pre-planting and post-harvest. The measurement was recorded from the growth media level to the apex point of each leaf. All present and emerging leaves were measured, but not if less than 2 mm in length.

Leaf quantity

The number of leaves per plant was recorded at time of planting and post-harvest. All present and emerging leaves were counted, but not if less than 2 mm in length.

3.3.5.2 Root development

The length of each plant's roots was measured using a ruler at pre-planting and post-harvest from the points at which roots emerge from the stem to the tip of the root mass.

3.3.5.3 Wet weight

The plants as a whole (roots and shoots together) were weighed pre-planting and post-harvest using an electronic laboratory scale (Sartorius Analytical Balance Scale Model type 1518) with 0.001 g readability.

3.3.6 Statistical analysis

All data collected was statistically analysed using one-way analysis of variance (ANOVA and computed software program TIBC STATISTICA Version 13.6.0. Occurrence of statistical difference was determined by using the Fisher Protected Least Significance Difference (L.S.D.) at values of $P < 0.05$; $P < 0.01$ and $P < 0.001$ levels of significance (Steel & Torrie, 1980).

3.4 RESULTS

3.4.1 Total leaf growth

Leaf number

Leaf number was highly significant at P ≤0.001 in the WT1 (18 ºC) treatment compared to the control at week 8 of the experiment. The rate of leaf growth increased at the lowest temperature treatment (WT1) with a Means of 36.22 when compared to the control (WT3). Leaf numbers also displayed notably poorer results in WT2 (Mean 13.3), WT3 (Mean 6.7) and WT4 (Mean 3.3). WT5 resulted in almost complete leaf fatality (Table 3.1). The effect of the various temperatures on *S. formosus* was clearly visible through observation throughout the experimental period with reduction of leaf numbers at higher temperatures (Fig. 3.6).

Total leaf length

Leaf length became highly significant at P ≤0.001 in the WT1 (18 ºC) treatment compared to the control at week 8 of the experiment. The length showed a Mean of 36.22 in the highest reading (WT1) when compared to the control WT3 (Mean 6.68). There was thus a significant reduction of the rate of leaf length at both WT2 (Mean 15.85) and WT3 (Mean 6.68), with a further reduction in leaf length in WT4 (Mean -2.18) (Table 3.1). This sharp decline can be

observed in the leaf quality and length with an increase in temperature towards treatment WT5 (34 ºC) compared to the control (Table 3.1 and Fig. 3.6).

Table 3.1. The effect of various roots zone temperatures on total leaf and root growth and fresh weight of *S. formosus* grown in a DWC hydroponic system.

Treatment	Temperature (ºC)	Total Leaf Growth				Total Root Growth		Total Biomass	
		Leaf Number		Total Leaf Length		Mean	Std Err + Mean Group	Mean	Std Err + Mean Group
		Mean	Std Err + Mean Group	Mean	Std Err + Mean Group				
WT 1	18	17.7	±1.91a	36.22	±3.75a	21.05	±2.28a	107.90	±21.07a
WT 2	22	13.3	±1.30b	15.85	±2.24b	0.45	±0.88c	18.67	±1.96b
WT 3	26	6.7	±0.91d	6.68	±1.68c	-0.54	±1.02c	7.32	±1.71b
WT 4	30	3.3	±1.56d	-2.18	±2.78d	-2.33	±0.79bc	-0.80	±2.16b
WT 5	34	-2.8	±0.99c	-11.76	±2.18e	-4.82	±0.41b	-3.70	±1.74b
One-way ANOVA F-Statistic		34.2670***		49.0178***		69.6300***		23.7484***	

Statistical analysis using One-way ANOVA. Values presented are means ±SE. The mean values followed by different letters are significantly different at P ≤0.001 (***) as calculated by Fisher's least significant difference.

WT1 = heated to 18 °C	WT2 = heated to 22 °C	WT3 = heated to 26 °C contol	WT4 = heated to 30 °C	WT5 = heated to 34 °C
				

Figure 3.6. Effect of increasing water temperature on the leaves of *S. formosus* plants in a DWC hydroponic system.

3.4.2 Total root growth

The root growth was significantly different (P ≤ 0.01) between WT1 treatment and the control WT3 treatment (Table 3.1). Root elongation was significantly influenced which improved top growth. The relationship between temperature and the relative rates of increases and decreases in root length were obtained as temperature affected the root growth negatively (Fig. 3.7).

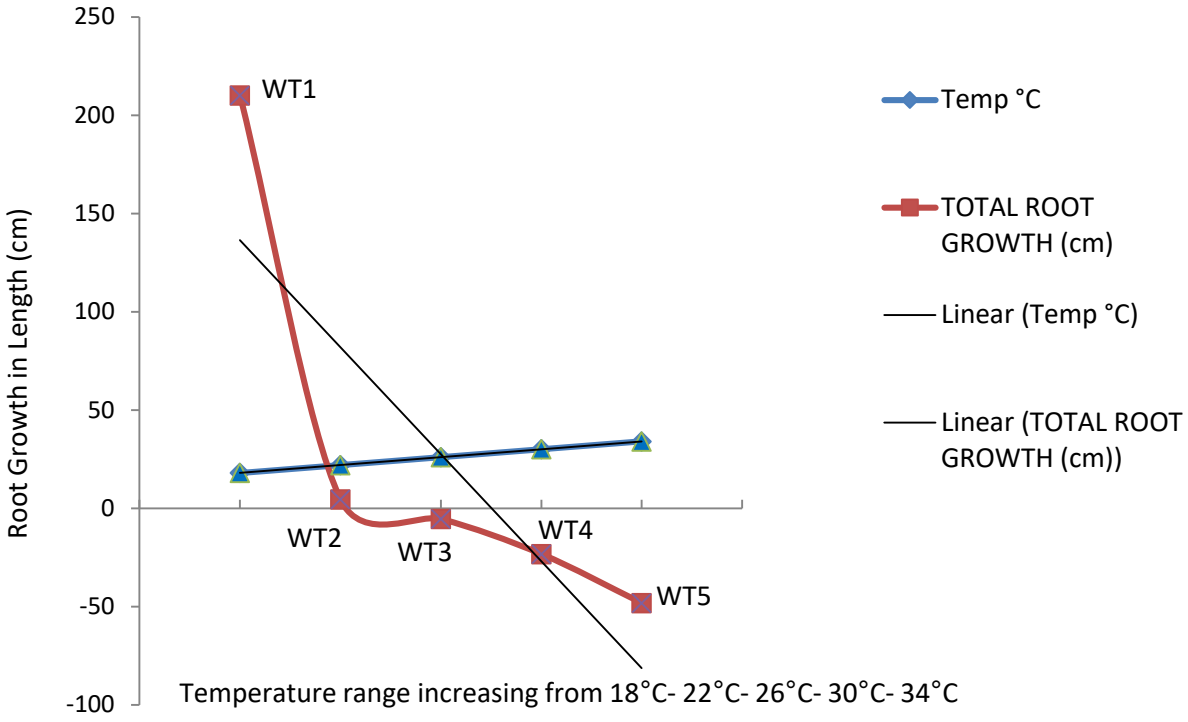


Figure 3.7. Effect of increasing temperature on the roots of *S. formosus* plants

At the WT1 (18 °C) treatment there was a 210 cm overall increase in root length, with only 4.5 cm at WT2 (22 °C), comparing this with the overall negative growths of -5.4 cm at the control WT3 (26 °C) and -23.3 cm at WT4 (30 °C) treatment, with complete death of the roots at WT5 (34 °C) treatment. The RZH above a critical temperature pointed results to poor growth and development of *S. formosus* plant's root system (Fig. 3.8).

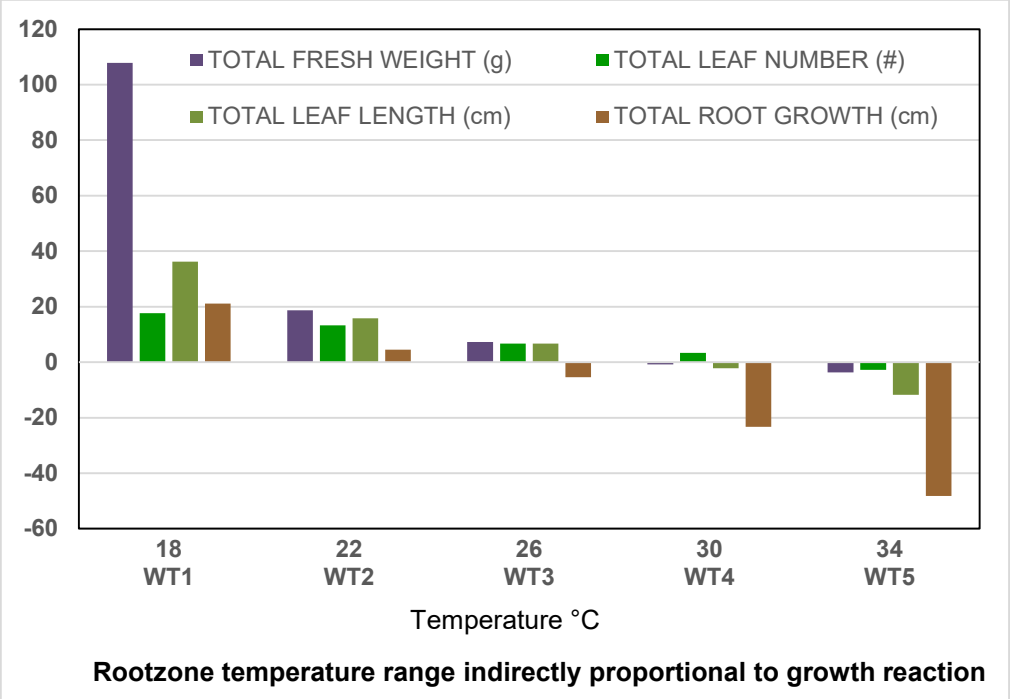
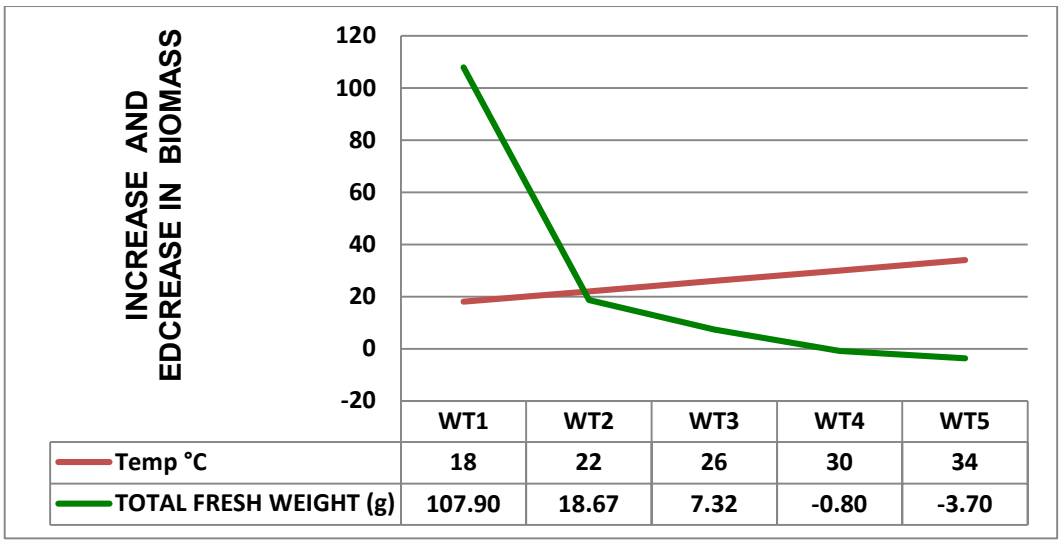


Figure 3.8. Effect of variation in temperature on the total vegetative growth (g), leaf and roots lengths (cm) and number of leaves of *S. formosus* per treatment.

3.4.3 Total fresh weight

Combined root and leaf wet weights in Table 3.1 were significantly ($P \leq 0.01$) affected by the treatments. Results in Figure 3.9 shows that an increase in water temperature from 18 °C - 34 °C decreased fresh weight, to the point of notable fatality at the highest temperatures of 30 °C and 34 °C. The WT1 (18 °C) treatment offering the highest significant ($P \leq 0.01$) increase in overall weight when compared to the control and all other treatments. Generally, in this study increasing temperature did not promote the growth and development of *S. formosus.*



	WT1	WT2	WT3	WT4	WT5
Temp °C	18	22	26	30	34
TOTAL FRESH WEIGHT (g)	107.90	18.67	7.32	-0.80	-3.70

Figure 3.9. Effect of increasing temperature on the fresh weight of *S. formosus* after eight weeks growth.

3.5. DISCUSSION & CONCLUSION

S. formosus responded in various ways to different temperature regimes with a clear trend that results in death of the leaves and roots at higher temperatures with more optimal growth at lower temperatures. It is also clear roots were more sensitive than shoots. Treatments applied in this investigation had a significant effect on the vegetative root and leaf growth as well as the overall fresh weight of *S. formosus.* The results obtained from this research disagrees with various previous studies which yielded positive results in other leafy perennials and crops at higher temperature ranges (TR) such as 24 °C - 28 °C for spinach (Nxawe *et al.,* 2009); 25 °C - 30 °C for tomatoes and lettuce (Moorby & Graves, 1980); 25 °C - 45 °C for muskmelon plants (Stoltzfus *et al.,* 1998) and 15 °C - 30 °C, for *Chrysanthemum* with an optimum of 24 °C (Morgan *et al.,1980)*.

Some other studies done on soft shrubs, such as roses where shoot growth was reduced at root temperatures at lower than 18 °C (Moss & Dalgleish, 1984) and, at this specific temperature or above, heat in the root zone was beneficial (Zeroni & Gale, 1982). For Poinsettia cuttings the optimum TR for rooting was 25 °C - 28 °C (Gislerød, 1983). Results for conifer seedlings, such as pine TR 8 °C - 20 °C, had significantly new root growth at 20 °C (Anderson *et al.,* 1986). TR 5 °C - 25 °C for *Ceanothus greggi* showed best root length increases at higher temperatures (Larigauderie *et al.,* 1991) agreeing with a study done by Davidson (1969) with TR 5-35 °C on twelve different grasses which averaged the most foliage growth between 20 - 27 °C, which in turn agrees with a study done on rape and barley which showed best root growth results at 25 °C (Macduff *et al., 1986).* Pienaar and Combrink (2007) showed that lowering the temperature from 21.4 °C to 16.8 °C for *Disa* spp. had a negative effect on root growth and fresh weight.

The vegetative growth responses of *S. formosus* in this study contradicts the results of research done on cooler RZT ranges indicating that lower range temperatures can restrict photosynthetic, respiration, metabolic and osmotic activities (Moorby & Graves, 1980; Vapaavuori *et al*., 1992; Nxawe *et al.,* 2009; Chung *et al*. 2002; Yan *et al*., 2012) and concurs more with research done on *Streptocarpus* hybrid leaf cuttings in the laboratory which produced the most roots and buds at 12 °C and 18 °C (Appelgren & Heide,1972) as well as with research done on cucumbers where the lowest temperature within the range 22 °C - 33 °C yielded the best results (Al-Rawahy *et al*., 2018).

It should be noted that DWC hydroponic growing, was selected to meet the measurement parameters of the experiment and as Jones (2014) pointed out it has limited commercial application for potted flowering plants and suggests rather that for commercial applications, the flood-and-drain method, the gravity flow bed system or the dripper system would be more viable for large scale production and supply. Depending on the plant and the growers desired outcome with regards to quality, quantity, and rate of growth, the amount of water applied should also be carefully considered as *Streptocarpus* prefer a moist medium above a wet medium with require quick drainage with substantial aeration (Van der Walt, 2001).

As *S. formosus* holds value in the domestic environment as a floriferous perennial in the landscape and indoor plant trade, and *S. x* hybrids have global value as ornamental pot plants within floriculture this study contributes to furthering research on *Streptocarpus* spp. and guides commercial production growers in cultivation of *S. formosus* in particular.

It is concluded that high root-zone temperatures decreased the vegetative growth of *S. formosus.* The results showed that the cooler root-zone temperature 18 ºC improved growth (leaf number, leaf and root lengths and fresh weight). Further studies would be required to determine optimal growing protocols for vegetative growth and development and flowering experimental work for commercial cultivation.

3.6 ACKNOWLEDGEMENTS

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CHAPTER FOUR:

INFLORESENCE DEVELOPMENT AND SEMI-DORMANCY FORMATION OF ABSCISSION LAYERS OF *STREPTOCARPUS FORMOSUS* IN RESPONSE TO DIFFERENT ROOT ZONE TEMPERATURE REGIMES IN HYDROPONICS

CHAPTER FOUR: INFLORESENCE DEVELOPMENT AND SEMI-DORMANCY FORMATION OF ABSCISSION LAYERS OF *STREPTOCARPUS FORMOSUS* IN RESPONSE TO DIFFERENT ROOT ZONE TEMPERATURE REGIMES IN HYDROPONICS

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4.1 ABSTRACT

Streptocarpus formosus (Hilliard & B.L.Burtt) T.J.Edwards belongs to the *Gesneriaceae* family, an ornamental plant group of economic importance horticulturally due to the beauty of their flowers. The commercial cultivation of most *Streptocarpus* spp. as flowering pot plants is limited by an eco-dormancy rest phase in the short-day photoperiod coinciding with the colder months of the year in which they slow their metabolism, do not produce any flowers and form unattractive abscission layers on the distal end of many of their leaves. This study was done to investigate the effectiveness of applying root zone heating (RZH) to plants grown in deep water culture (DWC) hydroponics in preventing abscission layer formation and in encouraging flowering during cold short-days. The experiment was conducted over an eight week period during the winter season in the greenhouse at Kirstenbosch Botanical garden, using water reservoirs each maintained at 5 different experimental temperatures treatments (18, 22, 26-control, 30 and 34 °C) applied to 10 sample replicates. At pre-planting and post-harvest the number of leaves with abscission layers were counted, and the presence of flower stalks, buds and flowers were noted. These results showed that all heated solutions had a significant effect on preventing the formation of abscission layers of *S. formosus* but a less significant effect on inflorescence formation. Findings from this study also revealed that the lowest root zone temperature of 18 °C had the most significant effect on the flower development of *S. formosus* grown in hydroponics, and that all the heated solutions were effective in eradicating any abscission layers already present and preventing any from originating during the winter period in which the experiment took place.

Keywords: abscission layers, Cape Primrose, commercial cultivation, eco-dormancy, flowering pot plant, hydroponics (DWC), Gesneriaceae, inflorescence, root zone heating, phyllomorph, *Streptocarpus*

4.2 INTRODUCTION

4.2.1 *Streptocarpus formosus* (Hilliard & B.L.Burtt) T.J.Edwards

Within the *Gesneriaceae* family *Streptocarpus* forms part of an economically important ornamental plant group with other significant members such as *Achimenes* spp.*, Saintpaulia* spp. (African Violets*), Cyrtandra* spp.*, Gloxinia* spp*. and Sinningia* spp*.* (Hilliard & Burtt., 1971) all of which are herbaceous perennials known for the beauty of their flowers (Van der Walt, 2001; Gesneriad Society, 2007) as seen in Fig 4.1.

a. **b.** **c.** **d.**

Figure 4.1. *S. formosus*: a) flower bud forming b) flower bud before opening c) flower frontal view d) flower side view (Pictures: C. Viljoen)

In its natural habitat in the Eastern Cape province of South Africa and in cultivation, *S. formosus,* and a significant majority of *Streptocarpus* spp*.* found elsewhere in the country*,* flower only in long-day, warm, summer months of the year (Hilliard & Burtt, 1971; Pooley, 1998). As *Streptocarpus* spp*.* grow naturally in summer rainfall localities they get very little irrigation through precipitation during the cold seasons (Van der Walt, 2001; Van Jaarsveld,

2013; Boodhraj, 2018). This abiotic combination of reduced water and low temperatures often triggers a survival tactic where the nutrients and carbohydrate reserves in the leaves are transported and remobilized to actively growing parts of the plant (Doorn & Woltering, 2004; Matos *et al.,* 2020) before the plants enter a state of eco-dormancy (Lang *et al.,* 1987). A study done by Matos *et al*. (2017) suggests that low air temperature exerts the primary activation effect on leaf senescence, while a lack of water exerts a secondary effect. In *Streptocarpus* spp., with no predetermined abscission zone, leaves are either shed entirely or a 2-3 mm wide demarcation line (Noel & van Staden, 1975) forms on the leaves and a visible difference between the basal and distal sections of the lamina is distinguishable (Fig 4.2) with a dark green base and a bright yellow upper section (Marston, 1964). Leaf yellowing is the result of deliberate chlorophyll depletion in senescing leaves (Munné-Bosch & Alegre, 2004). This partial senescence in *Streptocarpus* is perennation mechanism which ensures protection of the basal meristem (Noel & van Staden, 1975; Rohde & Bhalerao, 2007). When the distal leaf section is completely brown and dry this part breaks away cleanly along the abscission layer (Gawadi & Avery, 1950) and the leaf can continue to lengthen with new growth from the base (Van der Walt, 2002).

Figure 4.2. Abscission layers on *S. formosus* leaves (Photo: C. Viljoen)

This annual process of only long-day flowering, slowed growth processes of eco-dormancy and shedding leaf mass through unsightly abscission layers limits the ornamental commercial use of *Streptocarpus* spp. and so cultivation methods that would keep plants looking attractive in active growth and extend the flowering season are required (White, 1975; Dibley & Dibley, 1995). Manipulation of flowering is an important aspect in the cultivation of many horticultural crops (Halevy, 1990). There is a high demand for flowering pot plants during all seasons, even in winter when temperatures are below optimum for flower production (Nxawe *et al*., 2010) and annual plant senescence due to low temperatures causes yield reduction that results in

significant economic losses to growers (Mills *et al.,* 1990; Sade *et al*., 2017). Root temperature is one of the key environmental factors that control plant growth and physiology activities in cold seasons (Yan *et al*., 2013). Manipulating root zone temperature (RZT) to keep plant crops and ornamentals actively growing for commercial out of season production to meet market demands has been comprehensively researched (Moorby & Graves, 1980; Stoltzfus *et al.*, 1998; Grillas *et al.*, 2001; Agung Putra & Yuliando, 2015; Phantong *et al.,* 2018).

In *Streptocarpus*, flowering occurs mostly under 15 hr long days as compared to 8 hr short days (White, 1975) while at night, air temperatures between 16-18 °C is required for optimal flowering and growth, and during the day, temperature must remain below 27 °C or flowering is impeded (Cantor *et al.,* 2004; Gesneriad Society, 2007). Furthermore, growth cessation, abscission formation and dormancy development are considerably affected by temperature (Estiarte & Penulas, 2015). Leaf loss is a physiological strategy for the avoidance of water stress in plant species adapted to drought because it reduces the transpiring surface of the foliage and therefore lessens the water demand (Estiarte & Penulas 2015; Kooyers, N.J. 2015). However, leaf senescence is mainly caused by cold and less commonly by high temperature (Addicott, 1968; Matos, *et al.* 2020). Also, chlorophyll content is an important criterion when evaluating the ornamental value of a pot plant, and it is strongly influenced by nutrition (Anoop, 1998; Dhanraj & Jasmine, 2019). Various research studies have shown the positive effect of heated water on the retention of chlorophyll and the increased amount present within leaves (Tian *et al.,* 1996; Chung *et al.,* 2002; Nxawe *et al.,* 2011; Wang *et al.,* 2016; Al-Rawahy *et al.,* 2018; Odhiambo *et al.,* 2018). Degradation of chlorophyll is the cause of leaf yellowing during senescence (Ougham *et al.,* 2009; Avila-Ospina *et al.,* 2014). Lopez-Ayerra *et al.* (1998) showed that low temperature (8 °C) significantly reduced the amount of chlorophyll in spinach leaves (*Spinacea oleraceae* L.). Similarly, Adebooye *et al.* (2009) proved that sub-optimal RZT adversely affected the chlorophyll content and photosynthesis by retarding the uptake of nutrients in African snake tomato (*T. cucumerina*).

However, according to Christopher and Nicholas (2015) *Streptocarpus* do not require an environmental stimulus such as day length (photoperiod) or cool temperatures (vernalization) for flower induction and development. Although manipulating light, ambient air temperature and photoperiod could induce flowering in *S. formosus* in the cold season short days this study focussed on whether manipulating RZT would yield satisfactory results. This study was therefore designed to investigate the possibility of achieving optimum growth during the winter season by determining how application of root zone heat could viably increase the annual production period of *S. formosus* by evaluating the effect different RZT regimes had on semi-dormancy activated abscission layers and the earlier formation of flowers *S. formosus*. The aim of this study was to assist in determining an optimal temperature for the active growth and

inflorescence formation of *S. formosus* in order to produce consistent high yields of growth and flowers for cultivating superior quality pot plants in hydroponics for commercial production to benefit the ornamental and floriculture plant industries.

4.3 MATERIALS AND METHODS

4.3.1 Greenhouse experiment

The experiment was conducted in the plant production nursery greenhouse facility at the Kirstenbosch National Botanical Garden (KNBG), Cape Town, South Africa; GPS co-ordinates - 33° 98′ 56.12S, 18° 43′ 60.25E, for 8 weeks from mid-June 2019 to mid-August 2019, in the winter season. Plants were grown under natural daylight conditions which provided a short-day photoperiod, 9:59:26 hr (15th June) to 10:54:49 hr (15th August) day lengths required to conduct the experiment. *S. formosus* is then in a semi-dormancy period of its annual vegetative growth (Hilliard & Burtt , 1971). An overhead Aluminet shade net screen provided 40 % shading to reduce excessive temperature fluctuations while maximum day temperatures ranged between 13 °C - 18 °C and night temperatures between 3 °C - 7.8 °C, with an average relative humidity between 77 - 81 %.

4.3.2 Plant preparation

Fifty genetically identical plantlets were propagated vegetatively (Fig 4.3a) from one *S. formosus* mother plant which was sourced from KNBG, Cape Town. After the rooting period of four months (Fig 4.3b), the plantlets were thoroughly rinsed to remove rooting media and all foreign matter form their leaves and roots. They were then potted into lattice-net plastic pots filled with 4 - 10 mm lightweight expanded clay aggregate (LECA), and placed in the hydroponic system with only their roots submerged in water. LECA was the preferred SCS growth medium for this study as it is lightweight with added porosity, will not degrade in water, while its pH remains neutral with the additional advantage of protecting the roots with its thermal insulation properties (Tosi & Tesi, 1987; Boudaghpour & Hasemi, 2008).

Figure 4.3a. Leaf cuttings of *S. formosus, freshly made* (Picture: C. Viljoen)

Figure 4.3b. Leaf cuttings of *S. formosus*, matured, with plantlets (Picture: C. Viljoen)

4.3.3 Hydroponic cultivation

Hydroponics, is a SCS, where plants are grown in nutrient solution (Savvas & Gruda, 2018). Based on the recommendations, discussions and methodologies of Bracnher and Both (1996), Ferrante *et al*. (2000), Kratky (2004, 2010a), Al-Shrouf (2017) & Clayton (2017) a SCS of a closed deep-water hydroponic system with an air stone and a circulating pump were used. DWC hydroponics allows for methods of heating the nutrient solution to the required temperature supplied directly to the plant roots (Morgan *et al.,* 1980; Larigauderie *et al.,* 1991; Stoltzfus *et al.,* 1998; Nxawe *et al.,* 2009). Closed hydroponics systems allow for the reuse of nutrient solution reducing the negative environmental impacts such as leaching of fertilizers, soil and ground water pollution, water wastage, while saving on labour (Adams, 1991; Ferrante *et al*., 2000; Kozai, 2006). The DWC system was used to maintain a consistent nutrient supply and temperature over the entire root surface area of the replicates (Agung Putra & Yuliando, 2015; Savvas & Gruda, 2018). LECA provided support for the plants needing to be suspended in the nutrient solution while providing excellent aeration qualities (Boudaghpour & Hasemi, 2008).

Five identical DWC hydroponic systems were constructed and placed onto wire mesh tables. Each system consisted of one 70 litre capacity low-density polyethylene (LDPE) reservoir filled with 60 litres of aqueous nutrient solution. Each reservoir was covered with a LDPE sheet into which holes were cut to hold the 10 lattice-net plastic pots (7.5 cm) suspended (Fig. 4.4). The pot size and depth ensured that the root zones of the plants were submerged in the nutrient solution without wetting the plant's leaf crowns.

To prevent oxygen deficiency and the limitations this would place on the plant growth (Drew, 1983; Zeroni *et al*., 1983; Morard *et al.,* 2004) root aeration is essential in SCS, especially in DWC where there is limited air-water exchange capacity (Savvas *et al*., 2013) and particularly when heating solution as there is a direct correlation between the temperature of water and the amount of oxygen it contains (Sharma *et al*., 2019; Roblero, 2020). As water temperature increases less oxygen becomes available to the roots (Adams, 1992). To increase aeration all the solutions were aerated using one electromagnetic air compressor (BOYU ACQ-003) linked to each system's single air stone (50 mm) which bubbled the air up through the nutrient solution, supplying oxygen to the roots of the plants. To assist with the even distribution of both the additional air (O^2) and the heated water (Jones, 2014), each individual system's solutions were circulated using an 800 L/h hour HT submersible pump (HJ-941) (see Fig. 4.4).

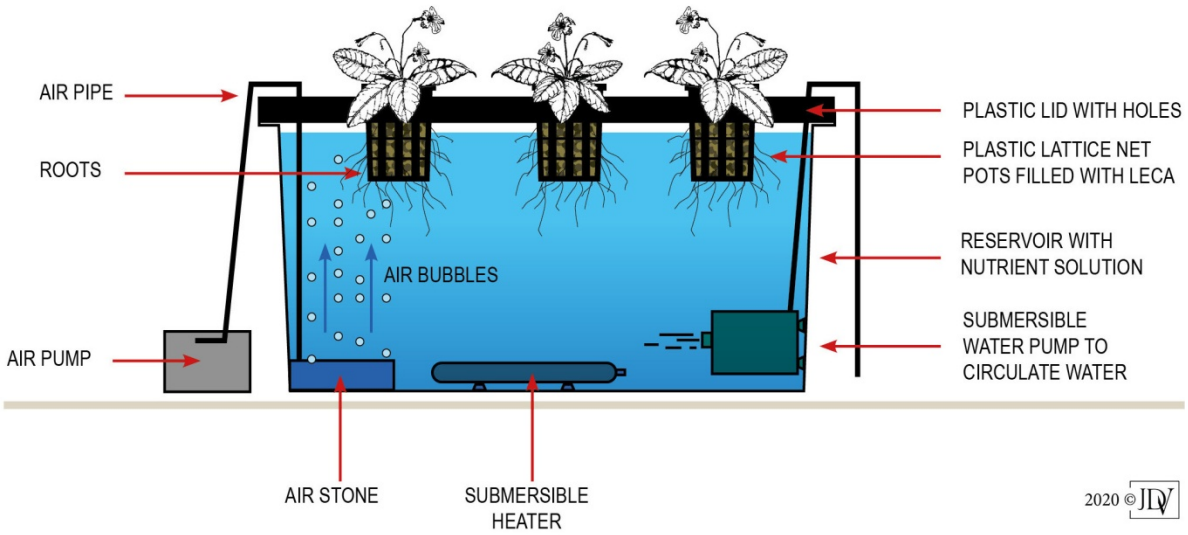

Figure 4.4. Deep water culture hydroponics, with air stone and circulating pump, and plants in lattice-net pots filled with LECA aggregate held suspended nutrient solution. (Diagram: J.D. Viljoen)

The solution comprised of ozone treated borehole water containing NUTRIFEED (Fig. 4.5). (Manufactured by STARKE AYRES Pty.Ltd. Hartebeefontein Farm, Bredell Rd, Kaalfontein, Kempton Park, Gauteng, 1619). This nutrient product supplied all the essential macro and micronutrients required for healthy plant growth as hydro-soluble fertilizer salts (Harris, 1992; Savvas *et al*., 2013). As the experiment would fall within a two-month growth period it was decided that replacing the nutrient solution to overcome the build up phototoxic substances in the nutrient solution (Yu *et al.,* 1993; Ferrante *et al*., 2000; Kratky *et al*., 2002, 2005) would not be required and to prevent potential disturbance damage to the roots (Kratky, 2010).

- Nitrogen [N] - 6.5 %
- Phosphorous [P] - 2.7 %
- Potassium [K] - 13.0 %
- Calcium [Ca] - 7.0 %
- Magnesium [Mg] - 2.2 %
- Sulphur [S] - 7.5 %
- Plus: Iron, Manganese, Boron, Zinc, Copper and Molybdenum.

Figure 4.5. Hydroponic solution nutrients provided by Nutrifeed™ (Picture: C. Viljoen)

As it is essential in DWC to monitor the oxygen supply, nutrient concentrations, salinity, pH (Domingues *et al.,* 2012) and for the purposes of this experiment, the temperature was included, all were examined bi-weekly and if necessary adjusted as required. The pH levels of all the nutrient solutions were monitored using a using a calibrated hand held digital pH meter (HM Digital PS PH-200). Although Trejo-Tellez and Gomez (2012) demonstrate that the optimal pH in the root zone of most crop species grown hydroponically ranges from 5.5 - 6.5 and Sharma *et al.* (2019) recommended a range of 6.0 - 6.8 for African Violet (*Gesneriaceae*) the pH was kept within a range of 6.4 - 7.0 as recommended by the Gesneriad Society (2007) for *Streptocarpus* and by Agung and Yuliando (2015). The pH was adjusted accordingly using either sodium hydroxide (NaOH) to raise the pH, or hydrochloric acid (HCL) to lower the pH. The various temperatures of the five test solutions were also measured for monitoring. Electrical conductivity (EC) that is too high will prevent nutrient absorption due to osmotic pressure and an unfavourably low EC will negatively influence yield and plant health as stated by Sharma *et al.* (2019), who also stated that the ideal EC range for most hydroponics crops is between 1.5 dSm^{-1} and 2.5 dSm^{-1}, with a specific recommendation of an EC of 1.2 - 1.5 dSm^{-1} for African Violet (*Gesneriaceae*). Uhl (2012) suggested an EC range of between 0.8 - 1.0 dSm^{-1} for *Streptocarpus*, so an EC range of 0.9 - 1.1 dSm^{-1} was adhered to in this experiment. The EC levels and temperatures of all the nutrient solutions were monitored using a calibrated hand held digital EC & Temp meter (HM Digital PS COM-100). For decreasing the EC of aqueous nutrient solutions ozone treated borehole water was added into reservoirs, while adding Nutrifeed™ increased EC levels.

4.3.4 Water temperature treatments and Experimental design

The experiment consisted of five different hydroponic solution temperatures which were applied to 50 plants of *S. formosus* using a completely randomised bock design (Fig. 4.6). Each temperature treatment consisted of 5 treatments with 10 replicates (n = 10), one per pot suspended in DWC system. Pots were individually numbered and arranged randomly. The five test solutions were heated using submersible EHEIM thermo-control heaters as standard aquarium equipment.

1. WT1 = water temperature heated to 18 °C
2. WT2 = water temperature heated to 22 °C
3. WT3 = water temperature heated to 26 °C
4. WT4 = water temperature heated to 30 °C
5. WT5 = water temperature heated to 34 °C

Figure 4.6. Completely randomised block design (Picture: J.D. Viljoen)

This water temperature selection was based on the ideal temperature recommendations for growing Gesneriads from the Gesneriad Society (2007) and on the research done by Curtis and Clarke (1960), Morgan *et al.* (1980), Stoltzfus *et al.* (1988), Nxawe *et al.* (2009, 2010), and Al-Rawahy *et al*. (2018) demonstrating an increase in vegetative growth on various perennial crops within this range. As reported by Merryweather (2008) the mean annual temperature at Port St Johns, which is *S. formosus* natural habitat, is 19.9 °C as recorded between 1961-1990 with a mean summer min-max of 17.1 °C - 27.6 °C when the plants are in full growth and flowering, as opposed to the Mean winter min-max of 7.4 °C - 20.5 °C when the plants are semi-dormant. This experiment focussed on the summer temperatures to test whether the plants could be stimulated into active growth and flowering in the colder winter months and, WT3 at 26 °C was selected for the control as the literature reviewed indicated this to be both the ideal ambient air temperature for *Streptocarpus* under non experimental circumstances and a RZT median for root to shoot ratios under experimental conditions for a selection of perennial crops (Davidson, 1969; Larigauderie,1991; Hood & Mills, 1994; Chung *et al.*, 2002; Nxawe *et al.,* 2009; Odhiambo *et al.*, 2018; Nguyen *et al.*, 2020).

4.3.5 Semi-dormancy and Flowering and Data collection

Various measurements were taken to determine plant growth response to different nutrient solution temperatures. Data capturing took place pre-planting and at the time of planting the plants into the quantitative research experiment system, and again post-harvest after a two-month growth period. Immediately after being transplanted in to the leca filled pots and placed in the DWC hydroponic test solutions the number of pedicels, buds, flowers and abscission layers were then counted and recorded. Post-harvest these same measurements were taken, and the data recorded.

4.3.5.1 Inflorescence development

Pedicel development

The number of inflorescence stalks per plant was recorded at time of planting and post-harvest. All present and emerging pedicels were counted, but not if less than 2 mm lengths.

Flowers and flower bud quantity

The number of flower buds and flowers per plant was recorded pre-planting and post-harvest.

4.3.5.2 Abscission layer formation

The presence or absence of abscission layers in the leaves per plant was recorded at time of planting and post-harvest.

4.3.6 Statistical analysis

All data collected was statistically analysed using one-way analysis of variance (ANOVA and computed software program TIBC STATISTICA Version 13.6.0. Occurrence of statistical difference was determined by using the Fisher Protected Least Significance Difference (L.S.D.) at values of $P < 0.05$; $P < 0.01$ and $P < 0.001$ levels of significance (Steel & Torrie, 1980).

4.4 RESULTS

4.4.1 Flowering in response to five different temperature regimes in hydroponics

The effects of root zone heating on the inflorescence development of *S. formosus* was found to be statistically significant in both the flower and bud formation ($p \leq 0.01$), and the pedicel development ($P \leq 0.001$). The highest individual mean value was evident (see Table 4.1) in treatment WT1; both for numbers of flowers and buds (2.5), and for number of pedicels (5).

The aim of this study was to determine whether flowering in *S. formosus* would increase with higher RZT. The results however showed that higher root zone temperatures decreased flowering. Conversely, the cooler temperature of 18 °C significantly increased flowering of *S. formosus* compared to the control treatment at 26 °C (Fig. 4.7) and that the increasing water temperature range from 22 °C - 34 °C decreased flower development and led to total fatality of the plants at the highest temperatures of 34 °C (Fig. 4.7). As temperature increased above the control 26 °C flowering decreased while the colder RZT treatment WT1 18 °C treatment offered the highest increase in overall inflorescence development when compared to the control and all other treatments (Fig. 4.8 and 4.9).

Flowers also developed during colder short-day periods which indicate a strong possibility that manipulating the growing temperatures could induce *S. formosus* to flower earlier in the season and thereby extending the flowering period for all round year commercial marketing period. These findings do not agree with Morgan *et al.* (1980) and Vogelezang (1988) who reported that RZT heating increased blooms and extended the flowering period into the cold season months or encouraged earlier flowering. Likewise, *S. formosus* responded in various ways to different root zone temperatures see Figures 4.4 and 4.5. Treatments applied in this investigation had a significant effect on the flowering formation of *S. formosus.* Plants responded better to the lower root zone temperatures of 18 °C and 22 °C compared to the higher temperature intervals and flowers were formed during the colder short day periods which indicates a strong possibility that manipulating the growing temperatures could induce *S. formosus* to flower earlier in the season and thereby increasing its annual commercial marketing period.

Table 4.1 The effect of various root zone temperatures on the total flower development of *S. formosus.*

Treatment	Temperature (ºC)	Total inflorescence development			
		Total number of buds and flowers		Total number of pedicels	
		Mean	Std Err + Mean Group	Mean	Std Err + Mean Group
WT 1	18	2.5	±0.81a	5.00	±1.11a
WT 2	22	1.8	±0.68ab	0.90	±0.23b
WT 3	26	0.9	±0.35cd	0.40	±0.22b
WT 4	30	0.1	±0.10d	0.20	±0.13b
WT 5	34	0.0	±0.00d	0.00	±0.00b
One-way ANOVA F-Statistic		4.71716**		16.33995***	

Statistical analysis using One-way ANOVA. Values presented here are means ±SE. The mean values followed by different letters are significantly different at P ≤0.01 (**) and at P ≤0.001 (***) as calculated by Fisher's least significant difference

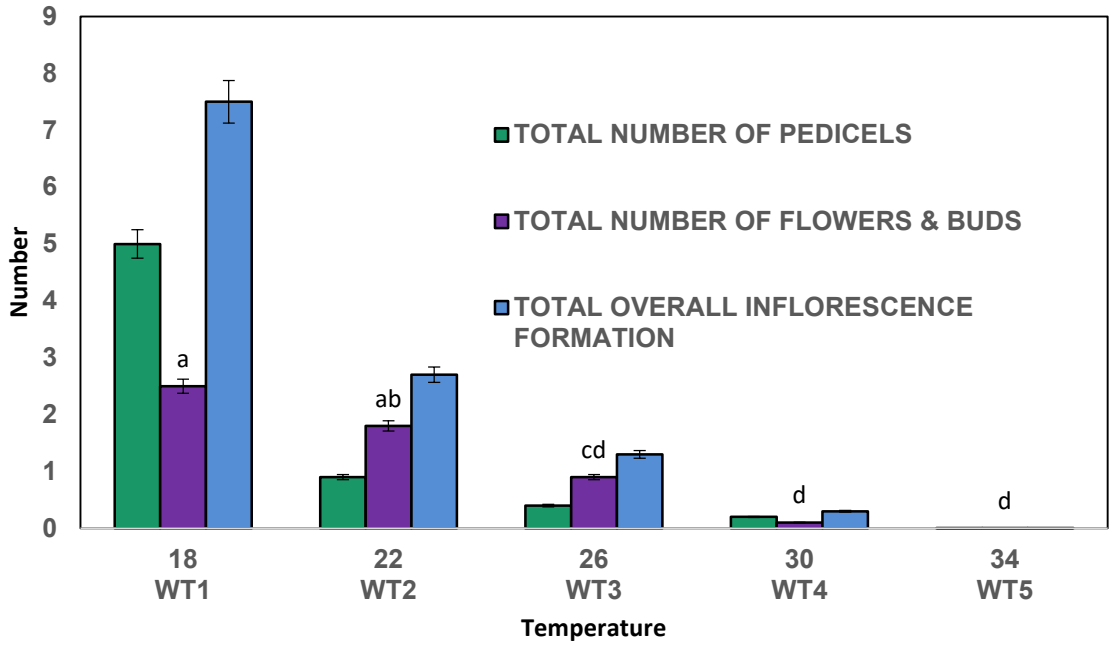

Figure 4.7. Effect of increasing root zone hydroponic solution temperature on the flower development of *S. formosus* plants

4.4.2 Reduction in abscission layers in response to five different temperature regimes in hydroponics

As shown in Table 4.2 the effects of RZT on the reduction of abscission layers already present on the *S. formosus* replicates leaves are not statistically significant (ns) at a value greater than $p \leq 0.05$. However what is significant is that the few abscission layers that were present at the time of the experiment's inception all disappeared (Fig 4.7) and even more significant is that no abscission layers formed on any plants in the heated treatments during the winter period as would usually occur (Fig. 4.8 and 4.9).Treatments applied in this investigation also had a significant effect on the abscission layer formation of *S. formosus* and indicate that RZH is a viable method for preventing the formation of abscission The results of this investigation agrees with other research papers which indicated a significant increase in the chlorophyll content of the leaves from 25 °C - 30 °C (Chung *et al.,* 2002; Nxawe *et al.,* 2011; Odhiambo *et al.,* 2018). As seen in Table 4.2, the effects of various root zone temperatures on the reduction of abscission layers already present of *S. formosus* are not statistically significant (ns) at a value greater than $p \leq 0.05$. None of the treatments significantly differed from one another. However, what is significant is that the few abscission layers that were present at the time of the experiment's inception all disappeared (Fig 4.7) and even more significant is that no abscission layers formed on any plants in the heated treatments during the winter period as would usually occur (Fig. 4.8 and 4.9).

Table 4.2: Effects of various root zone temperatures on the total reduction of abscission layers of *S. formosus*

Treatment	Temperature (ºC)	Total reduction in abscission layers	
		Mean	Std Err + Mean Group
WT 1	18	0.3	±0.153a
WT 2	22	0.4	±0.221a
WT 3	26	0.3	±0.153a
WT 4	30	0.4	±0.153a
WT 5	34	0.3	±0.483a
One-way ANOVA F-Statistic		0.10305ns	

Statistical analysis using One-way ANOVA. Values presented here are means ±SE. The mean values followed by the same letters not significantly different (ns) at greater than P ≤0.05 as calculated by Fisher's least significant difference

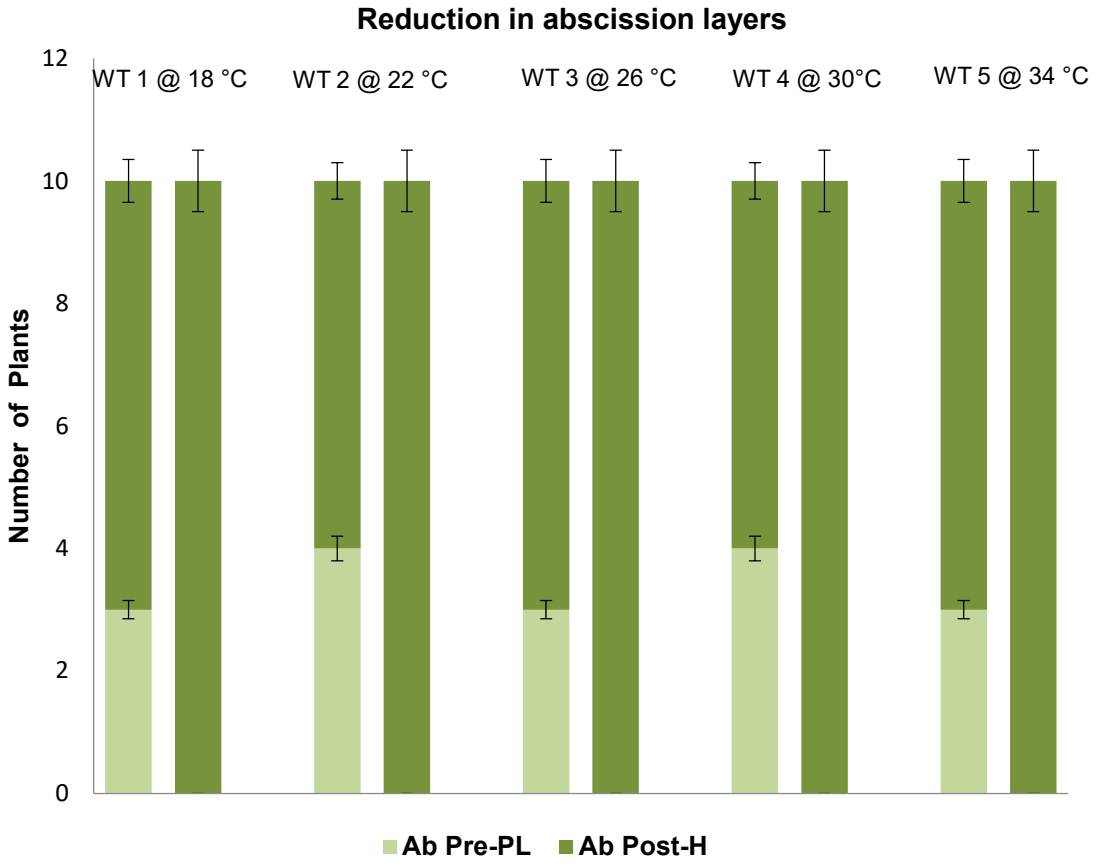

Figure 4.8. Effect of increasing root zone temperature on the abscission layers present and abscission layer development of *S. formosus* plants during the winter period

Figure 4.9a: Effect of increasing root zone temperature on the flower development and abscission layer formation *S. formosus* plants during the winter period, on (n) = A. (Photo: C. Viljoen)

Figure 4.9b. Effect of increasing root zone temperature on the flower development and abscission layer formation of *S. formosus* plants during the winter period, on (n) = G. (Photo: C. Viljoen)

4.5. DISCUSSION

Streptocarpus sp. naturally only produce flowers during the long-day summer months (Marston, 1964). This study however showed that *S. formosus* was able to produce flower buds during the winter short day period at lower temperatures. The importance to increase flowers and regulate the timing of flowering in pot plant production can support production of the species (Friis & Christense, 1989). As confirmed in Table 4.1 earlier, the effects of various root zone temperatures on the total flower development of *S. formosus* was statistically significant at the value of $p \leq 0.05$.

It is possible that there is a correlation between RZT and air temperatures for *Streptocarpus* where 16-18 °C at night for optimal flowering and growth while day time temperatures should remain below 27 °C degrees or flowering will be impeded (Cantor *et al.,* 2004; Gesneriad Society, 2007). Wigge (2013) reported that in *Arabidopsis* higher ambient temperatures can accelerate flowering under short day conditions as effectively as exposure to long days. Similarly in ornamental pot plants where photoperiod has no effect *Primula vulgaris and Centradenia inaequilateralis* 'Cascade' flowering was affected mainly by air temperature where just a 3 °C increase initiated flower formation (Selander & Welander, 1984; Friis & Christensen, 1989). However, variation in temperatures and short- and long-day controls were not tested during this current study. *S. formosus* was able to initiate flower buds during the colder winter period and with short days. Flowering in *Streptocarpus* occurs mostly under 15 hr long days as compared to 8 hr short days (White, 1975). It was found that is possible to induce short day plant *S. nobilis* to flower by manipulating the photoperiod length, anything less than 12.30 hours induced inflorescence formation (Handro, 1976). In sufficient light *S x hybridus* will bloom throughout the year and most *Streptocarpus* respond to supplemental winter lighting in the northern latitudes (Cantor *et al.,* 2004). However, according to Christopher and Nicholas (2015) *Streptocarpus* do not require an environmental stimulus such as day length (photoperiod) or cool temperatures (vernalization) for flower induction and development. Although manipulating light, ambient air temperature and photoperiod could induce flowering in *S. formosus* in the cold season short days this study focussed on whether manipulating RZT would yield satisfactory results.

High flower and fruit yields on quality greenhouse crops are possible with hydroponics due to the precise control of growing conditions and required nutrients (Adams, 1992; Schnitzler, 2004; Wahome, 2011). Nutrient solution temperature is easily controllable in SCS and may be manipulated to control plant growth and maximise the production of plants and flowering during winter periods (Nxawe *et al.,* 2011). Two cultivars of Saintpaulia

(Gesneriaceae) subjected to a RZT range of 17 - 25 °C exhibited a 10 - 15% reduced cultivation time and a significant increase in the rate of flower formation (Vogelezang, 1988). RZH has shown significant results in herbaceous leafy crops, increasing flower numbers by increasing nutrient uptake (Moorby & Graves, 1980). Chrysanthemum responded positively when grown in a SCS with a heated solution and produced flowers earlier with optimum results at 24 °C (Morgan *et al.,* 1980). In woodier crops, such as apple, a RZT of 15 °C proved to be optimal for flowering with a distinct reduction at 30 °C (Tromp, 1976; Greer *et al*., 2006) and roses grown in a heated SCS showed an increase in the number of blooms produced over the production season (Moss & Dalgleish, 1984).

In *S. formosus* the tips of the leaves often slowly die back to an abscission layer when stressed by drought, low temperature or when overwintered (Van der Walt, 2001). Growth cessation, abscission formation and dormancy development are considerably affected by temperature (Estiarte & Penulas, 2015). Leaf loss is a strategy for the avoidance of water stress in plant species adapted to drought because it reduces the transpiring surface of the foliage and therefore lessens the water demand (Estiarte & Penulas 2015; Kooyers, N.J. 2015). Leaf senescence in winter deciduous species is an indication of the change from an active to a dormant growth stage *(*Van Staden, 1973; Estiarte & Penulas, 2015). Leaf senescence is mainly caused by cold and less commonly by high temperature (Addicott, 1968; Matos, *et al.* 2020). When climatic conditions become unfavourable and the plants experience a state of stress, phytohormones react and leaf abscission that can lead to complete senescence is often the result (Jackson & Osborne, 1972; Van Staden, 1973; Horvath *et al.*, 2003; Estiarte & Penulas, 2015; Gillespie & Volaire, 2017; Han *et al.*, 2017). Some significant abiotic factors affecting leaf abscission are nutrient availability, temperature and water supply (Addicott, 1968; Munné-Bosch & Alegre, 2004; Matos, *et al.* 2020) all of which can be managed within hydroponic cultivation systems (Agung & Yuliando, 2015; Asaduzzaman *et al.,* 2015, Sakamoto & Suzuki, 2015). Uhl (2012) recommends that during colder months' sub irrigation should be used with minimal overhead irrigation as water that is considerably colder than the average leaf temperature causes unsightly leaf damage with yellow spots or blotches on *Streptocarpus* leaves.

Hilliard and Burtt (1971) reported that abscission occurred due to short photoperiods in some *Streptocarpus* spp. Maurya and Bhalerao (2017) also stated that photoperiod and temperature are the main cues controlling leaf senescence in winter deciduous species, with water stress imposing an additional influence (Estiarte & Penulas, 2015). Although manipulating light and photoperiod could prevent semi-dormancy in *S. formosus* in the cold season short days this study, however proved that manipulating RZT significantly affected the total flower development.

Chlorophyll is vital for the process of photosynthesis to occur. Chlorophyll content is an important criterion when evaluating the ornamental value of a pot plant, and it is strongly influenced by nutrition (Anoop, 1998; Dhanraj & Jasmine, 2019). Various research studies done have shown the positive effect of heated water on the retention of chlorophyll and the increased amount present within leaves (Tian *et al.,* 1996; Chung *et al.,* 2002; Nxawe *et al.,* 2011; Wang *et al.,* 2016; Al-Rawahy *et al.,* 2018; Odhiambo *et al.,* 2018). Degradation of chlorophyll is the cause of leaf yellowing during senescence (Ougham *et al.,* 2009; Avila-Ospina *et al.,* 2014). Lopez-Ayerra *et al.* (1998) showed that low temperature (8 °C) significantly reduced the amount of chlorophyll in spinach leaves (*Spinacea oleraceae* L.). Similarly, Adebooye *et al.* (2009) proved that sub-optimal RZT adversely affected the chlorophyll content and photosynthesis by retarding the uptake of nutrients in African snake tomato (*T. cucumerina*).

Plant growth can be controlled by the direct correlation between nutrient solution temperatures around the root zone and uptake of nutrients, with increased plant growth at elevated root temperature correlated with higher nutrient absorption (Adams, 1992; Livonen *et al.,* 1999 Adebooye *et al.,* 2009; Yan *et al*., 2012; 2013). Cumbus and Nye (1982) found that low RZT applied to rape (*Brassica napus* cv. Emerald) reduced the amount of N present in the plant. Research done on *Arabidopsis* showed plant growth inhibition and a reduction in photosynthesis when plants were subjected to low root temperature (Lee *et al.,* 2012). Nitrogen (N) is essential for plant growth and a vital component of amino- and nucleic-acids and its presence in foliage is visibly indicated by a dark green colour in leaves, conversely N-deficiency is commonly revealed by chlorosis (Anoop *et al.,* 1998; Djukic, 2008; Olfati, 2015). N also plays a critical role in the structure of chloroplasts and the photosynthetic capacity of leaves is directly related to their N concentration (Evans, 1989).

Lack of water or nutrients results in leaf yellowing in many plant species and which in some species can be reversed upon removing the stress (Van Doorn & Woltering, 2004). In *Streptocarpus* even if the leaves are clearly displaying a distal depletion of chloroplasts, it is still possible for the reversal of the formation of the abscission layer and the senescence processes (Hilliard & Burtt, 1971) if the plants are maintained under conditions of high temperature and humidity (Noel & van Staden, 1975). Leaf senescence can be delayed by warming despite photoperiodic triggers and growth proficiency could increase because of a slower speed or prevention of leaf senescence (Norby *et al.*, 2003; Estiarte & Penulas, 2015).

S. formosus responded in various ways to different root zone temperatures (Figures 4.4 and 4.5). Treatments applied in this investigation had a significant effect on the flowering

formation of *S. formosus.* Plants responded better to the lower RZT's 18 °C and 22 °C compared to the higher temperature intervals and flowers were formed during the colder short day periods which indicates a strong possibility that manipulating the growing temperatures could induce S. *formosus* to flower earlier in the season and thereby increasing its annual commercial marketing period. These findings agree with Morgan *et al.* (1980) and Vogelezang (1988) in which RZH increased blooms and extended the flowering period into the cold season months or encouraged earlier flowering. Moreover, treatments applied in this investigation also had a significant effect on the abscission layer formation of *S. formosus* and indicate that RZH is a viable method for preventing the formation of abscission The results of this investigation agrees with other research papers which indicated a significant increase in the chlorophyll content of the leaves from 25 °C - 30 °C (Chung *et al.,* 2002; Nxawe *et al.,* 2011; Odhiambo *et al.,* 2018).

4.6. CONCLUSION

This study established that increasing RZT did not promote the flowering of *S. formosus,* however plants responded positively to flowering at decreased temperatures from 22 °C - 18 °C. *S. formosus* has commercial potential as an indoor flowering pot plant, a flowering landscape perennial and shows potential within the cut-flower trade. Therefore, these results from investigating the effect that different temperatures can have on overall growth processes and inflorescence production of *S. formosus* will contribute to further research on developing optimal cultivation protocols for cultivating *Streptocarpus* spp. and its hybrids commercially.

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CHAPTER FIVE:

PRODUCTION AND CULTIVATION PROTOCOL FOR *STREPTOCARPUS FORMOSUS* AS A COMMERCIAL FLOWERING POT PLANT

CHAPTER FIVE: PRODUCTION AND CULTIVATION PROTOCOL FOR *STREPTOCARPUS FORMOSUS* AS A COMMERCIAL FLOWERING POT PLANT

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5.1 ABSTRACT

Streptocarpus formosus (Hilliard & B.L.Burtt) T.J.Edwards is a beautiful flowering perennial indigenous to South Africa and is part of the rosulate group of herbaceous stem-less plants within the Gesneriaceae family. The ornamental use of *S. formosus* has untapped commercial potential as a flowering indoor pot plant, an outdoor bedding plant for shade and as a cut flower for the vase, all of which is limited by a five-month eco-dormancy period during the late autumn and all through the cold season in the short-day winter months. Viable commercial production will require cultivation techniques that produce flowering plants all year round. This study aimed to collect data form published records and cultivation trials to produce a complete cultivation protocol on the seed and vegetative propagation for *S. formosus* contributing to furthering research on the species which is currently very limited. The study took place over several years between 2015 and 2020 where data was collected and record keeping of experimental trials. *S. formosus* holds value as a floriferous perennial in the landscape and indoor plant trade and the development of *S. formosus* within commercial opportunities would also contribute to the conservation of this highly endemic species that is listed as rare(R) in the wild.

Keywords: Cape Primrose, cultivation protocol, commercial, eco-dormancy, cut flower, endemic, flowering pot plant, Gesneriaceae, ornamental, propagation, *Streptocarpus*

5.2 INTRODUCTION

Streptocarpus is an ornamental plant group of economic importance horticulturally due to the beauty of their flowers (Chaudhury *et al.,* 2010; Hârţa *et al*., 2018) (Fig 5.1). The name *Streptocarpus* is derived from the Greek words *streptos* meaning twisted and *carpus* meaning fruit, which is a perfect description of the plants' twisted seedpods. Cape primroses do not tolerate excessive heat or bright sun, so are most often grown as houseplants (Pers. Obs.).

There is much interest and a growing demand for *Streptocarpus not only internationally, but also* in South Africa where the plants occur naturally (Hilliard & Burtt, 1971). Nishii *et al.* (2015) stated that due global horticultural importance of Cape Primroses (*Streptocarpus*) and African Violets (*Saintpaulia*), both belonging to the Gesneriaceae family, research is justified.

Figure 5.1. The beauty *S. formosus* flowers
(Picture: C. Viljoen)

Research is essential to provide scientific information on optimal growing protocols for vegetative growth and development (Davies, 1974). According to Wessels *et al*. (1998) research results and growth in the floricultural industry are interrelated. Therefore, it would be a useful to establish the ideal cultivation practices of *S. formosus*.

5.3 *STREPTOCARPUS FORMOSUS* (Hilliard & B.L.Burtt) T.J.Edwards AS A FLOWERING POT PLANT

Gesneriaceae

Streptocarpus belongs in Gesneriaceae, a large diverse family of mostly tropical and subtropical herbs, with a few temperate species in Europe, China, and Japan consisting of ±130 genera, and ±2900 species world-wide. There are 8 genera in Africa, with the one large genus *Streptocarpus* native to southern Africa (Smith *et al.,* 1997; Leistner, 2000; Tarr, 2008). *Streptocarpus* is the only genus within the Gesneriaceae family that has a twisted construction

of the fruit (Fig 5.6). *S. formosus* is an endemic flowering herbaceous perennial occurring in summer rainfall area of South Africa (Pooley, 1998). This family contains many well-known ornamental flowering houseplants such as African Violets (*Saintpaulia*) *and Gloxinia* spp. (Hilliard & Burtt, 1971) which along with Cape Primroses have already proven themselves to hold significant economic importance (Buta *et al*., 2010). According to Nishii *et al.* (2015) approximately $30 million has been earned through the international trade of *Streptocarpus* spp. for horticultural and decorative purposes.

Growth habit of *Streptocarpus formosus*

S. formosus is a herbaceous perennial plant forming (Fig 5.2a & 5.2d) a dense clump of numerous long, strappy leaves between 250–500 mm long and 45–100 mm wide, with prominent abaxial veins, and rounded symmetrical notched margins. Numerous of these rough, hairy leaves grow in a rosulate formation on a horizontal rhizomatous rootstock, each long leaf originates at ground level, narrow at the base and broader at the apex, extending outwards, curving gently (Van der Walt, 2001). An unusual feature of this soft perennial is that no stems are present, each leaf is actually an individual plant with its own roots and flowering stems (Jong, 1973; Jong & Burtt 1975; Môller & Cronk, 2001). The vegetative plant body consists of these individual recurring components, called phyllomorphs (Burtt & Hilliard, 1971; Nishii & Nagata, 2007). Jong and Burtt (1975) introduced the ‘phyllomorph’ concept, where the leaf is composed of a compressed, combined lamina and petiolode with the dual function of petiole and stem. A phyllomorph's petiolode (stalk), displays a mixture of petiole-stem and leaf-axil features, and its leaf blade has the notable ability to grow continuously from the base while the distal ends of the leaves can be discarded whenever required (Jong 1973, 1978; Jong & Burtt 1975; Burtt, 1978; Môller & Cronk, 2001; Nishii & Nagata, 2007; Edwards *et al*., 2008). New leaves and flowers form from the older leaves, which continue to grow even after fully extended (Cantor *et al*., 2004) with the flowering stems (peduncles) forming in a single line, in acropetal succession, along the base of the petiolode (Marston, 1964; Dibley & Dibley, 1995).

***S. formosus* flowers**

The lovely large, 70-105 mm long, trumpet-shaped flowers of *S. formosus* (Fig. 5.2b & 5.2c) borne on cyme inflorescences, are distinguished by a pale violet corolla (Potgieter & Edwards, 2005) with a dark-stippled throat where the five main veins on the lobes of the lower lip (Fig 5.2c) and the rest of the corolla tube are all minutely spotted with violet-purple speckles, and by the distinctive bright-yellow colour zone on the base of the corolla tube, also flecked with purplish-brown (Fig. 5.3), that widens in the throat and extends slightly onto the lower lip (Hilliard & Burtt, 1971; Weigend & Edwards, 1994). In Latin 'formosus' means beautiful (Pooley,

1998). The zygomorphic flower, whitish in colour lightly tinged with lilac, typically has five hairy calyx sepals with reddish brown tips and five broad, uneven corolla petals with two lips, the upper is 2-lobed and the lower 3-lobed with the corolla mouth roundly open (Fig. 5.2b & 5.2c) and with corolla tube widening from the base outwards (Hilliard & Burtt, 1971). The long cylindrical fruit capsules 111-179 mm long, are a deep brown and velvety to the touch when forming and once dry they dehisce by twisting open in a four-split spiral (Fig. 5.6) releasing masses of very small, brown, dust-like, lightweight seeds (Hilliard & Burtt, 1971; Pooley, 1998; Hughes, *et al.,* 2007; Viljoen, 2008; Manning, 2000). From early spring to early autumn, each leaf will produce 6-10 bloom stalks from the upper portion of the leaf midrib bearing large, single or paired, glandular flowers on long upright slender stalks, in succession throughout the long day summer period (Appelgren & Heide, 1972; Yelanich, 2020). A well-developed plant with numerous healthy leaves can produce plenty of blooms over the season (Robinson, 1998).

Figure 5.2a. *S. formosus* as a medium flowering pot plant

(Picture: C. Viljoen)

Figure 5.2b. *S. formosus* in cultivation as an ornamental pot plant, darker flower form, with slightly wavy petals
(Picture: C. Viljoen)

Figure 5.2c. *S. formosus* in cultivation as a ornamental pot plant, paler flower form

(Picture: C. Viljoen)

Figure 5.2d. *S. formosus* in cultivation as a large flowering pot plant

(Picture: C. Viljoen)

Breeding with *S. formosus*

There is much commercial potential in utilising previously ignored or unknown *Streptocarpus* spp. as to develop new hybrids (Marston, 1964; Boodhraj, 2018; Afkhami-Sarvestani *et al*., 2012). *Streptocarpus* cross pollinate easily as there are no breeding barriers within the genus (Weigend & Edwards, 1994) and also naturally self-pollinate so the potential for horticultural cultivar development is considerable to improve the species (Dibley & Dibley, 1995; Martens, 2016). Currently *Streptocarpus* hybrids are grown by only a small number of specialist growers in SA, and by numerous growers globally as beautiful floriferous indoor potted house plants, popular for their widely different range of forms, the variety of striking flower colours, an extended peduncle length and ease of both propagation and cultivation (White, 1975; Dibley & Dibley, 1995, Chaudhury *et al.,* 2010; Hârţa *et al*., 2020). Some *Streptocarpus* spp. have also become popular with plant enthusiasts and collectors for their remarkable diversity in leaf structure, flower colours and forms as even within a species there can be notable variation in flower colour, shape and throat markings (Burtt & Hilliard, 1971; Jong *et al*., 2011, Martens, 2016).

Figure 5.3. The possible characteristics the breeding of *S. formosus* could contribute: dark-stippled throat, five main veins all minutely spotted with violet-purple speckles, and the distinctive bright-yellow colour zone (Picture: C. Viljoen)

As a potential contributor to hybridizing programs *S. formosus* is noted for (Fig. 5.3) its elegant flower shape and corolla with an intense yellow throat colour and interesting purple speckled flower markings (Martens, 2016). Hybrids are typically easy to grow by nature of their genetic strength (Birchler *et al.*, 2006) as opposed to the temperamental nature of species that are not as tolerant of conditions that do not precisely mimic their natural environment, unlike *S. formosus* which has a wider range of tolerance for varying environmental conditions and the ability to thrive outdoors (Fig. 5.4) making this species an ideal breeding parent in developing new *Streptocarpus* cultivars as outdoor perennials and bedding plants (Van der Walt, 2001, Yelanich, 2002, Maharaj, 2012). Similar species, S. *floribundus* and *S. primulifolius*, with *S. formosus* previously being classified under synonym *S. primulifolius subsp. formosus* (Weigend & Edwards, 1994) could cross-hybridize easily and as they exhibit a similar resilience to outdoor conditions this could lead to them sharing their hardiness, colours and flower characteristics with their hybrid progeny (Pers. Obs.).

Figure 5.4 a-d. *S. formosus* in various outdoor localities as a flowering perennial (Picture: C. Viljoen)

Potted flowers have become an important part of the florist trade and *Streptocarpus* as a potted flower is listed as high because of the attractive flowers (Fig. 5.2a-d, Fig. 5.3), foliage and long flowering period (Van der Walt, 2001; Reinten *et al.,* 2011). Flowering stems will also last very well when cut (Fig. 5.5) for the vase (Dibley & Dibley,1995).

Figure 5.5. Cut flower stems of *S. formosus* (Picture: C. Viljoen)

Conservation status of *S. formosus*

The use of *S. formosus* in commercial opportunities would ensure this highly endemic species continued existence as it has a conservation status under threatened species as Rare (R). Habitat degradation and a restricted, specialized habitat have been cited as a threat to this South African endemic (Scott-Shaw *et al*., 2020).

Production of *S. formosus*

Streptocarpus spp. in general are easily propagated from seeds, leaves, division and in vitro (Plant Grower, 1991; Van der Walt, 2001; Cantor, *et al.,* 2004; Viljoen, 2011 & 2008) however requirements for individual species are different. Micropropagation with in-vitro tissue culture techniques is the solution to plant propagation on a large-scale (Cantor *et al*., 2004) and *Streptocarpus* have been extensively researched with positive results with laboratory culture and micro propagation (Menhenett, 1970; Beaufort-Murphy, 1984; Peck & Cumming, 1984; Mantegazza *et al*., 2007; Chaudhury *et al*., 2010; North & Ndakidemi, 2012; Afkhami-Sarvestani *et al*., 2012; Hârta *et al*., 2018). This study aimed to collect data form published records and cultivation trials to produce a complete cultivation protocol on the seed and vegetative propagation for *S. formosus* (Table 5.1).

5.4 MATERIALS AND METHODS

The propagation and cultivation of *Streptocarpus* were done at the greenhouse facility at the Kirstenbosch National Botanical Garden (KNBG), Cape Town, South Africa; GPS co-ordinates - 33° 98ˈ 56.12S, 18° 43ˈ 60.25E. The study took place over several years between 2015 and 2020 where data was collected through Pers. Obs. and record keeping of experimental trials. In winter, the maximum day temperatures ranged between 15 °C - 17 °C and night temperatures between 9 °C - 12 °C, with an average of 71 - 76 % relative humidity. In summer maximum day temperatures ranged between 23 °C - 26 °C night temperatures between 14 °C - 17 °C, with an average of 62 - 68 % relative humidity Aluminet shade net overhead provides 40 % shading. Seeds were sown and cuttings were made annually throughout the seasons of each year where recordings of data were done to provide a seasonal cultivation protocol. Data was assessed and adjustments were made from year to year to improve the methodology to assist in the completion of a cultivation protocol.

5.5 RESULTS AND DISCUSSION

5.5.1 Seed propagation

Streptocarpus spp. make sexual propagation very easy as the seeds are numerous and germinate within 10 to 24 days, most of the species then flower in 6 to 12 months after germination (Van der Walt, 2001; Dibley, 2005; Tarr, 2008; Yelanich, 2020). Seed counts range from 32000 to 640000 per gram (Plant Grower, 1991; Yelanich, 2020). *S. formosus* sets seed easily and can readily be grown from the numerous miniscule brown seeds produced in the fruit capsules (Van der Walt, 2002). *S. formosus* will come true to type (Dibley & Dibley,1995), although if grown in close proximity to other species particlularly *S. floribundus, S. rexii* and *S. primulifolius* cross-pollination can occur (Pers. Obs.). *Streptocarpus* commonly self-pollinate, to assure true-to-type seed hand pollination can be done (Dibley & Dibley, 1995). The ideal sowing time is in spring (Table 5.1) once temperatures are above 16°, using matured seed collected the year before and the plantlets should flower from six months after sowing (Dibley & Dibley, 1995). Satisfactory results have also been achieved from sowing seed fresh during the late summer as the fruit capsules (Fig. 5.6) have ripened and dried during the growing season (Pers. Obs.), however this strategy is not ideal for efficient production as it allows less time for the seedlings to establish themselves before the semi-dormancy period and they have to survive an overwintering first before being potted up (Dibley & Dibley,1995; Boodhraj, 2018).

Figure 5.6. Twisted seed capsule of *S. formosus* (Picture: C. Viljoen)

Seed can be stored up to two years and maintain viability if kept cool and dry (Probert *et al.,* 2009). When sowing seeds, mix a pinch of the dust-like seeds with a small amount of fine sand to assist with spreading them evenly, and to prevent sowing too densely, using the broadcast method of sowing (Wilson & Colt, 1991). Do seed sowing in a still-air environment (Pers. Obs.). Use a sterile, spongy yet well-drained, sowing medium with a fine texture that will hold the minute seeds securely on the surface, ensure it is moist before sowing **(**Dibley & Dibley,1995). The medium must also retain moisture without remaining saturated otherwise algae will develop and smother the tiny seedlings (Baley, 2018). Depending on the levels of humidity either cover seeds directly with a very thin covering of sand (60-70% humidity), or leave uncovered (70-80% humidity), keep warm if possible by using bottom heating (Wilson & Colt, 1991; Dibley & Dibley,1995). Water regularly with a fine spray with the aim of never allowing the seedlings to dry out and seedling trays can be covered with plastic film or a glass cover **(**Dibley & Dibley,1995; Boodhraj, 2018). The seeds are light sensitive and require light for germination and seedling development but must be kept from direct sunlight (Wilson & Colt, 1991; Van der Walt, 2001; Nishii *et al*., 2012). Germination will take place between 16 - 24°C with faster results at the higher temperature (Plant Grower, 1991; Boodhraj 2018). The germinated seedlings appear as just a smattering of fine green colour on the growth medium, and growth is slow at first (Pers. Obs.), only one true leaf will develop (Robinson, 1998; Nishii & Nagata, 2007) due to *Streptocarpus* displaying the phenomenon of anisocotyly (Nishii *et al*. 2004; Mantegazza *et al.,* 2007). If the seedlings have been covered, once germination has occurred, three to four weeks thereafter gradually start to slide off the covering a section at a time, so within a week's interval they are completely uncovered **(**Dibley & Dibley,1995). When seedlings are 30 days old, begin fertilization with 100 ppm Nitrogen (Cantor *et al*., 2004). Plantlets will be ready to be planted out from 8 to 12 weeks onward if sown in late spring but should remain in the sowing medium overwinter if sown in mid to late summer, or until large

enough to comfortably handled (5-6 mm) or until they have grown to become crowded, as they are sensitive to both root disturbances and repotting when very small **(**Dibley & Dibley,1995)

5.5.2 Vegetative propagation

Cuttings

S. formosus plants can most easily and quickly be increased by way of leaf cuttings and the best results are when propagation is done in late spring and early summer (Table 5.1) during the active growth period with enough time for the young plantlets to establish themselves before the winter eco-dormancy period beings in Autumn (Van der Walt, 2001). A variety of propagation mediums for the rooting can be used as long as they meet the requirements of being well drained and able to firmly hold the cut sections of leaf, sand, bark, palm fibre and polystyrene or vermiculite in different ratios are all suitable. Water the medium well and treat with a suitable fungicide before use (Gesneriad Society, 2007). *S. formosus* can be propagated from a single leaf. Simply cut off a young, healthy leaf at its base using a sharp scissors or blade and insert the cut petiolode into a rooting hormone and then directly into a well-drained rooting growth medium (Dibley & Dibley, 1995; Van der Walt, 2001). The most active growing region (meristem) is present at phylomorph's base resulting in a decreasing age gradient from apex to base a lamina with distal end of a *Streptocarpus* leaf being older so better rooting success will be achieved closer to stronger meristematic activity (Marston, 1964; Yelanich, 2020). If many new plants are required leaves can be sliced into 3 cm segments by cutting across the midrib (Fig. 5.7a), trim away the outer edges to size more evenly or if the leaf is very large (Cantor *et al.,* 2004). Take careful note of the orientation of leaf cutting before dipping the base cut into rooting hormone (Pers. Obs.) and placing firmly in the medium (Fig 5.7b) by making a furrowed slit into which the leaf section can easily be placed, but not too deep as this will encourage rot, pressing gently to secure the cuttings in an upright position (Dibley & Dibley, 1995; Cantor *et al.,* 2004). Alternatively, cut along either side of the midrib remove the centre vein and treat the two resulting sections in the same manner but this method does yield the same success rate as cutting across the leaf midrib (Dibley & Dibley, 1995).

Figure 5.7a: Preferred method of leaf cutting for *S. formosus* (Picture: C. Viljoen)

Figure 5.7b: Leaf cuttings of *S. formosus* newly placed in medium to root (Picture: C. Viljoen)

Keep the cuttings in warm protected shade; bottom heat is not essential but decreases the time before roots appear (Marston, 1964). Within a month or two small plantlets and adventitious roots will have formed along the edge placed in the rooting medium at each of the intersecting lateral veins (Cantor *et al.,* 2004). A single length of leaf can produce 2-10 plantlets (Fig. 5.8b) with more heavily veined leaves producing more plantlets (Marston, 1964; Cantor *et al.,* 2004). The original leaf sections turn brown and dead as the young leaves start to grow (Pers. Obs.). Each small single leaf that appears from a rooted strep cutting is an entire plant (phyllomorph), pairs of leaves will not form (Pers. Obs.). When the plantlets are well established (3-5 cm), the old leaf can be teased from the medium and the plantlets gently pulled off and separated before potting into individual pots or cell packs (Robinson, 1998; Cantor *et al.,* 2004).

Figure 5.8a. *S. formosus* Mother leaf with fully developed plantlet (Picture: C. Viljoen)

Figure 5.8b. *S. formosus* plantlet ready to be potted on as an individual (Picture: C. Viljoen)

Division

S. formosus plants growing for more than a year in the same pot will become root-bound or simply too large with very dense foliage and division can then be done in early spring (Table 5.1) as the active growth season begins (Van der Walt, 2001; Viljoen, 2011). Each leaf is a separate plant, a phyllomorph, so the rosettes can easily be divided by cutting carefully through the shared rootstock, and pulling the sections gently apart ensuring that each piece has its own root-ball, re-pot these individually into fresh growth medium taking care not to over-pot (Cantor *et al*., 2004; Pers. Obs.). The original potted plant can be separated into two to four plantlets in this manner (Robinson, 1998; Pers. Obs.).

5.5.3 Hardening off and Growing on

Rooted leaf cuttings or seedlings of *S. formosus* take 2 - 4 months to be large and strong enough to be potted up, preferably done from spring through summer (Table 5.1) when the plants are in active growth (Robinson, 1998; Cantor *et al*., 2004). Use a free-draining lightweight medium such as a specialist indoor multi-purpose plant compost and ensure that both the new soil and the plantlet's soil are moist, not dry or sodden, create a "molded indent" in the larger pot's soil by using the smaller pot as a 'place holder', having done this the plantlet readily slides into the exact sized molded hole, complete the process by firming the soil around the plantlet and watering lightly (Robinson, 1998; Cantor *et al*., 2004). For 2-3 weeks after any potting up activity water sparingly as the recently repotted plant's new roots need to first penetrate into the additional soil (Robinson, 1998). Pot on as often as the plants require as they enlarge in size over the growing season (Table 5.1) going only one pot size larger each time to avoid over-potting or potting below the soil-line as either can lead to wet-rot death (Cantor *et al*., 2004; Gesneriad Society, 2007). One plant per pot is sufficient unless filling large hanging baskets or display pots (Yelanich, 2020).

Ensure sufficient ventilation in the growing environment and space the plants to reduce contact between their leaves to reduce the occurrence of fungal problems and pest infestations (Robinson, 1998; Yelanich, 2020). Regularly remove all dead, unhealthy, yellowing, brown or dying leaves by pinching of the leaf base as close to the rootstock as possible (Pers. Obs.). Discoloured leaf tips or margins can be caused by many types of environmental stresses and incorrect cultivation practices, or simply because the leaf is old or the plant is root-bound and requires repotting (Robinson, 1998; Van der Walt, 2001). Remove all spent flowers to keep the plant looking neat and attractive (Pers. Obs.). Remove flower peduncles entirely by cutting off at the base as close to the petiolode as possible, doing so before they go to seed will extend the flowering period by stimulating a second flush of flowers as the phyllomorph responds by

producing new successive inflorescences, (Dibley & Dibley,1995; Van der Walt, 2001; Maharaj, R. 2012).

5.6 CULTIVATION REQUIREMENTS

S. formosus will thrive in cultivation under in conditions the most closely mimic its natural habitat (Boodhraj, 2018) in the Port St Johns area, in the Eastern Cape province of South Africa, which has rain in summer and a microclimate of warm temperatures modified by cooler coastal breezes (Merryweather, 2008). *S. formosus* actively grows during the humid, long-day photoperiod (Mean of 14.2 hrs) in summer and slows its growth processes to survive during the cold dry short-day photoperiod (Mean of 10.1h) winter season with very little rain irrigation (Van der Walt, 2001; Boodhraj, 2018; Pers. Obs.). In cultivation all *Streptocarpus* require good ventilation and a minimum of 60% humidity, particularly at higher temperatures (Dibley & Dibley,1995; Gesneriad Society, 2007). As reported by Merryweather (2008) the Mean annual temperature at Port St Johns is 19.9 °C as recorded between 1961-1990 with a Mean summer min-max of 17.1 °C – 27 6 °C and Mean winter min-max of 7.4 °C - 20.5 °C. The abiotic combination of reduced water and low temperatures in short days triggers a state of eco-dormancy (Lang *et al.,* 1987) and the plants metabolism slows right down (Pers. Obs.). In order to reduce leaf mass in preparation for this annual rest period nutrients and carbohydrate reserves in the leaves are relocated to actively growing parts of the plant (Doorn & Woltering, 2004; Matos *et al.,* 2020; Pers. Obs.) and a clearly defined abscission layer line (Fig. 5.9) develops on some or all of the leaves (Dibley & Dibley,1995). The ends of the leaves turn yellow, but leaf base stays green, and is able to continue with new growth as soon as the conditions are more favourable (Marston, 1964; Cantor *et al*., 2004). The tips of the leaves can also turn brown and die off with age and any environmental or cultivation stresses but it is caused particularly by drought or low temperature, this dead dried leaf end breaks away cleanly away with no damage to the rest of the leaf (Dibley & Dibley,1995; Van der Walt, 2001). This annual response to environmental stimulus can be avoided by keeping the plants sufficiently hydrated and warming the greenhouse or root zone to no more than 20 °C during the colder months to keep the plants in an active growth phase (Pers. Obs.).

Figure 5.9. Abscission layers on *S. formosus* leaves (Picture: C. Viljoen)

5.6.1 Temperature, Light intensity and Photoperiod

Temperature

Streptocarpus do not require the environmental stimulus of cool temperatures (vernalization) for flower induction and development (Christopher & Nicholas, 2015) but air temperatures for *S. formosus* should be below 27 °C during the day for optimal growth and flowering and go no lower than 16 °C - 18 °C at night (Plant Grower, 1991; Cantor *et al*., 2004). During summer the growing area needs to be kept cool for *S. formosus,* in the range of 17 °C – 25 °C, which is best done with good air circulation and increasing the humidity (Gesneriad Society, 2007; Pers. Obs.) as the plants can withstand cooler temperatures, even as low as 5 °C as long as the growth medium is relatively dry, but extremely high temperatures cause wilt, even death (Robinson, 1998; Dibley & Dibley,1995; Pers. Obs.). If wanting to keep the plants in active growth in winter, heat the growing area (Reid, 1991; Sethi & Sharma, 2007) to remain between 14 °C – 24 °C (Gesneriad Society, 2007) which will prevent the plants from forming unsightly abscission layers (Van der Walt, 2001; Uhl, 2012).

Light intensity

S. formosus plants are extremely selective about light in their natural habitat, at all times occurring away from direct sunlight, in light or dappled shade, growing in the cooler shaded rock crevices, on ledges and soil slopes that face south or southwest, often growing in association with lichens and moss (Hilliard & Burtt, 1971; Gesneriad Society, 2007; Pers. Obs.). In cultivation if the light is too bright and the temperature high the leaves and flowers will burn and wither, if the light is too low the plants respond by expanding their leaves and failing to flower **(**Dibley & Dibley,1995; Gesneriad Society, 2007; Baley, 2018). Robinson

(1998) stated that *Streptocarpus* do equally well under natural and artificial light requiring a range of 11 - 32 Klux to flower well, confirmed by Plant Grower (1991) that optimal growth requires high light intensity in the range of 5 - 45 Klux, which is recommended to be further narrowed by Uhl (2012) to 11 - 16 Klux and more specifically to exactly 12 Klux by Dibley and Dibley (1995). Leaves are readily burned by direct sun and insufficient shading the symptoms of which are hardened leaf margins and bleached yellow-white leaves, however as the plants do not flower well in deep shade, a light shade cover of 40 - 60% is recommended for growing healthy plants with plenty of flowers (Van der Walt, 2001; Gesneriad Society, 2007; Uhl, 2012).

Photoperiod

S. formosus flowers only in long-day summer months of the year (Table 5.1) and as the days become shorter the number of flowers decreases with no flowering in the winter (Burtt & Hilliard, 1971; Pooley, 1998). Plants can be grown under natural daylight or under fluorescent light (Gesneriad Society, 2007) however they will produce more blooms with 15 hrs than with 9 hrs of light (White, 1975; Plant Grower, 1991; Robinson, 1998). *Streptocarpus* can be encouraged to grow and flower year-round given light of suffient duration and intesity in the correct colour spectrum, and respond well to supplemental winter lighting in the northern latitudes (Dibley & Dibley, 1995). Increasing the photoperiod to 12 or 16 hours in the winter increases the growth and flowering of the plant (Cantor *et al.,* 2004). According to Christopher and Nicholas (2015) *Streptocarpus* do not require an environmental stimulus such as day length (photoperiod) for flower induction and development, however there are also studies disproving this (Yelanich, 2020) as it is possible to induce short day plant *S. nobilis* to flower by manipulating the photoperiod length to anything under 12 hrs (Handro, 1976) so it is possible the reverse could be true in long day species.

5.6.2 Growth media, pH and EC

Growth media

Soil should be light and porous, rather than heavy, providing good soil aeration for sufficient water drainage to leave the medium evenly moist but never continuously saturated, both of which are essential to the plant health (Robinson, 1998; Cantor *et al.,* 2004; Gesneriad Society, 2007) root aeration for *Streptocarpus* is essential prevent oxygen deficiency and the limitations this would place on the plant growth (Drew, 1983). The growth medium proportions may vary depending on growing and watering practices being implemented but should contain some organic material to maintain suitable amounts of moisture and nutrients (Cantor *et al.,* 2004; Gesneriad Society, 2007). Potting mixes with fibre and peat composts allow for best root development (Dibley & Dibley, 1995) so mediums which give the best results are 1:1:1 combination of these typical growing mediums perlite, peat moss, coco fibre, sand, compost

or vermiculite with some dolomitic lime added to adjust the pH (Cantor *et al.,* 2004; Gesneriad Society, 2007).

pH

The recommended pH range varies; Uhl (2012) suggests keeping the pH at a wide range of 5.5 to 7.0 with 6.0 being optimal. Whipker (2014) strongly recommends avoiding pH levels below 5.4. A range of 6.4 to 7.0 as recommended by the Gesneriad Society (2007) for *Streptocarpus* and by Agung and Yuliando (2015) and concurred with personal observation made. *Streptocarpus* will display a purplish-black discoloration (Fig. 5.10) on both the top and bottom of the leaf to indicate that the substrate pH is too low (Whipker, 2014)

Figure 5.10. Discoloration on *S. formosus* leaves indicative of unsuitably low pH (Picture: C. Viljoen)

EC

Electrical conductivity (EC) that is too high will prevent nutrient absorption due to osmotic pressure and an unfavourably low EC will negatively influence yield and plant health as stated by Sharma *et al.* (2019) with a specific recommendation of an EC of 1.2 to 1.5 dSm^{-1} for African Violet (*Gesneriaceae*) whereas Uhl (2012) suggested an EC range of between 0.8 to 1.0 dSm^{1} for *Streptocarpus*. With very little to be found in the literature regarding specifics for *Streptocarpus*, more research is required to investigate the ideal range for optimum growth.

5.6.3 Watering, Nutrition, Pest and Disease management

Watering

S. formosus prefers a moist to slightly dry medium above a wet or constantly sodden medium and requires quick drainage after a thorough saturation, combined with substantial aeration throughout the growth medium (Gesneriad Society, 2007). During the warm summers, when *S. formosus* are actively growing, they regularly require a substantial amount of water, and the complete opposite is required during their cold winter dormancy when they infrequently require only a little water, so the amount of irrigation water must be drastically adjusted per season (Dibley & Dibley; 1995). The critical time period for altering the watering regime is in autumn (Table 5.1) when *S. formosus* responds to environmental triggers and slows its metabolism quite suddenly from active growth into a rest period, any overwatering during this critical time leads to the roots not actively absorbing water from the drenched medium which then remains wet causing severe rotting and plant losses (Pers. Obs.). Over-watering is generally far more damaging than under-watering (Pers. Obs.) as *Streptocarpus* have quite shallow root systems-in nature, mostly thriving in very little soil (Dibley & Dibley; 1995; Gesneriad Society, 2007). *S. formosus* recovers turgidity quickly even when more than slightly wilted but plants will also look wilted when over-watered, check the growth medium before watering (Marston, 1964; Dibley & Dibley; 1995; Van der Walt, 2001). Severe droughting during flowering time can cause the inflorescences to abort and flowers to drop (Marston, 1964).

Avoid getting water on the foliage *Streptocarpus* prefer being watered from below than from above but do not like standing in water (Dibley & Dibley; 1995) so wick watering and the use of a capillary matting or stand pots on a bed of grit/Leca with water to just below the surface, all provide the plants with bottom 'irrigation' these options will also assist with increasing humidity (Gesneriad Society, 2007). *Streptocarpus* adapt to growing in self-watering pots (Robinson, 1998). Avoiding water on the foliage reduces overall occurrence of fungal infections and leaf damage (Gesneriad Society, 2007). During colder months, irrigation water temperature should be monitored and overhead irrigation minimized, as water that is significantly colder than the average leaf temperature can create unsightly yellowing or blotches (Robinson, 1998; Uhl, 2012). Cultivation in greenhouses during the cold season can be achieved by increasing the temperature of the irrigation water to optimum levels (Kozai, 2006) which in the case of *Streptocarpus* would be within the range of 16 - 20 °C, visually observed and recorded showed best results at 18 °C obtained from root zone heating of *S. formosus*. Uhl (2012) recommends the use of sub irrigation is as the best way to avoid any type of leaf splotches or unsightly residues however Van der Walt (2001) observed no damage to *S. formosus* leaves when wetted during irrigation in the summer months. (Table 5.1).

Nutrition

Streptocarpus are very vigorous growers and need to be fed regularly (Table 5.1) and adequately to obtain substantial vegetative development and to encourage the formation flowers (Robinson, 1998; Cantor, *et al.,* 2004). The Gesneriad Society (2007) recommends what is known as continuous feeding, which entails fertilizing every time water is applied, but with a 50% reduced concentration of a balanced fertilizer, this is supported by Uhl (2012). Feeding continuously as full strength will lead to overly lush leaf growth, reduced flowering and a build-up of salts in the growing medium (Plant Grower, 1991; Gesneriad Society 2007; Uhl, 2012). *S. formosus* responds well to both organic and inorganic feeding in both liquid and granular or powder formulations being applied throughout their actively growth phase in summer, it is usually not necessary to feed in winter (Dibley & Dibley, 1995; Van der Walt, 2001).

Pest and Disease management

Correct cultivation practices, close to ideal growing conditions, combined with effective preventative sanitation and hygiene practices will greatly reduce the potential for insect and disease problems (Dibley & Dibley, 1995; Uhl, 2012) however despite these actions *S. formosus* leaves are not always sufficiently protected from pests by their rough hairiness. Most issues can be resolved by solving a cultivation problem, invariably the plant that has been stressed is the one that gets attacked by pests or infected by a pathogen (Pers. Obs.). Regular inspections for infestations of wide a range of possible pests must be done regularly, looking out for aphids, caterpillars, leaf minor, mealy bug, mites, thrip and whitefly all of which might be problematic (Dibley & Dibley, 1995; Robinson, 1998; Van der Walt, 2001; Cantor *et al.,* 2004; Gesneriad Society, 2007). These pests cause unsightly damage not only hindering the growth of the plant, but also damaging the flowers (Naicker, 2019). Fungal infections such as crown rot, botrytis, powdery mildew, phytophtera are also a cause for concern (Dibley & Dibley, 1995; Cantor *et al.,* 2004; Gesneriad Society, 2007). If fungus is found on any part of the plant, remove the affected parts and treat with a suitable fungicide. Incorrect watering practices and inadequate ventilation are the main cause of fungal problems occurring (Maharaj, 2012).

Table 5.1: A propagation and growing protocol depicting a seasonal schedule for the annual production of S. *formosus* (C. Viljoen).

SEASON in SA for Months of the Year	SPRING			SUMMER			WINTER			AUTUMN		
CULTIVATION PRACTICE	September	October	November	December	January	February	March	April	May	June	July	August
Propagation Seeds												
Propagation Leaves												
Division												
Re-Potting												
Watering Daily ▪ Weekly ▪											X	
Fertilisation												
Kelpak application Weekly ▪ Monthly ▪										X	X	
GROWTH PHASE	Se	Oct	No	De	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Au
Active Growth										Semi-Dormant	Semi-Dormant	
Flowering & Seeding	F	F	F/S	F/S	F/S	F/S	F/S	F/S	S	-	-	-

5.7 CONCLUSION

S. formosus holds value as a floriferous perennial in the landscape and indoor plant trade. While *Streptocarpus x* hybrids have global value as ornamental pot plants within floriculture this study contributes to furthering research on the cultivation of the species, in this case *S. formosus,* which is limited. The cultivation protocol developed guides commercial production

for growers in future cultivation of *S. formosus,* particularly to support the important cause of promoting species in line with commercial hybrids. Future studies could advance micro propagation techniques of *Streptocarpus* spp. for large scale commercial production purposes which could draw data from this cultivation protocol. As this study largely focused on seed and vegetative cultivation as simulated in nature it also contributes to supporting the conservation by cultivation of the endemic and threatened *S. formosus* currently declining in its natural habitat.

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CHAPTER SIX:

GENERAL DISCUSSION AND CONCLUSION AND RECOMMENDATIONS

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6.1 General discussion, conclusion and recommendations

Chapter 2 reviewed the commercial potential of *Streptocarpus formosus* as a flowering potted plant. It was found that *S. formosus* has economic importance not only as a potted indoor house plant but also for use outdoors and possibly could be considered for the cut flower market. It can also make significant contributions to the breeding development of further Streptocarpus hybrids due to its own unique characteristics. Furthermore, hydroponic cultivation for *S. formosus* may expand its future commercial production potential by increasing growth and flowers yields while aiding in reducing nutrient wastage, run-off into soils and conserving water in dry climate countries.

In chapter 3 the various treatments had significant effects in terms of *S. formosus* vegetative growth, leaf formation and root development. Treatment WT1 (18 °C), the coldest root zone temperature, showed the highest individual mean value for vegetative growth, leaf formation and root development with the lowest individual mean value being observed in treatment WT5 (34°C) the highest root zone temperature. Overall treatments with a lower temperature regime of 18 °C - 22 °C had better vegetative growth, leaf formation and root development, that being WT1 - WT2, while the higher temperature regimes WT3 - WT4, 26 °C - 30 °C, showed sub-optimal root growth and the highest, 16 °C, WT5 resulted in negative values and plant death. It was evident that roots were more sensitive than shoots as at higher temperatures roots were virtually destroyed while more leaf mass remained. It should be noted that DWC hydroponic growing is not ideal for achieving optimum growth for *S. formosus* as well as having limited commercial application for potted flowering plants. Flood-and-drain method, Nutrient Film technique, gravity flow bed system or the dripper system would be more viable for large scale production and supply of *S. formosus* commercially and be better suited to the plants cultivation requirements of a moist medium but not wet medium with quick drainage and substantial aeration. It is concluded that high root-zone temperatures decreased the vegetative growth of *S. formosus.* The results showed that the cooler root-zone temperature 18 ºC improved growth (leaf number, leaf and root lengths and fresh weight). Further studies would be required to determine optimal growing protocols for vegetative growth and development and flowering experimental work for commercial cultivation.

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In chapter 4 the various treatments had significant effects on the semi-dormancy of *S. formosus* in terms of in the plant abscission layer formation and inflorescence development. Treatment WT1 (18 °C) showed the highest individual mean value for inflorescence development with the lowest individual mean value observed in treatment WT5 (30 °C). Plants

responded better to the lower root zone temperatures of 18 °C and 22 °C compared to the higher temperature intervals and flowers were formed during the colder short day periods which indicates a strong possibility that manipulating the growing temperatures could induce S. *formosus* to flower earlier in the season and thereby increasing its annual commercial marketing period. WT5 (34 °C) resulted in plant growth deterioration to the pint of death. The results of nil abscission layers forming during the annual eco-dormancy period *S. formosus*, when they should normally be prevalent, combined with the evidence that the abscission layers that were already present dissipated, indicates that root zone heating is a viable method for preventing the formation of abscission layers. Treatments across the temperature range of 18 °C - 30 °C showed optimal results for overcoming the formation of abscission layers by increasing in the chlorophyll content of the leaves and keeping the plants in active growth during the cold, short-day season , so these results from investigating the effect that different temperatures can have on overall growth processes and inflorescence production of *Streptocarpus formosus* will contribute to further research on developing optimal cultivation protocols for cultivating both it and other *Streptocarpus* species and cultivars.

Chapter 5 collected data form published records and cultivation trials to produce a complete cultivation protocol on the seed and vegetative propagation for *S. formosus* contributing to furthering research on the species which is currently very limited and demonstrating that *S. formosus* has commercial potential and value as a indoor flowering pot plant, a flowering landscape perennial and also has potential within the cut-flower trade. This information will contribute to further research on developing optimal cultivation protocols for cultivating *Streptocarpus* species and cultivars commercially.

Overall this study has found that *S. formosus* is suitable for cultivation as a flowering pot plant and that while root zone heating will overcome the eco-dormancy period in cultivation it will have limited positive effects of the vegetative growth, and no positive effects on inflorescence formation during this eco-dormancy period. This research has shown that the lowest temperature treatment had the most advantageous result on the vegetative growth of the plant.

CHAPTER SEVEN:

REFERENCES

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Studies of Vegetative Growth, Inflorescence Development and Eco-Dormancy Formation of Abscission Layers in *Streptocarpus formosus* (Gesneriaceae)

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Abstract: *Streptocarpus formosus* (Hilliard & B.L. Burtt) T.J. Edwards is a flowering herbaceous perennial indigenous to South Africa and is part of the rosulate group of herbaceous acaulescent plants within the Gesneriaceae family. According to the National Assessment database for the Red List of South African Plants version 2020.1., the plant is listed as rare. The ornamental use of *S. formosus* has untapped commercial potential as a flowering indoor pot plant, an outdoor bedding plant for shade and as a cut flower for the vase, all of which are limited by a five-month eco-dormancy period during the late autumn and all through the cold season in the short-day winter months. Viable commercial production will require cultivation techniques that produce flowering plants all year round. This study investigated the effectiveness of applying root zone heating to *S. formosus* plants grown in deep water culture hydroponics during the eco-dormancy period in preventing abscission layer formation and in encouraging flowering and assessed the growth activity response of the plants. The experiment was conducted over eight weeks during the winter season in the greenhouse at Kirstenbosch Botanical garden in water reservoirs, each maintained at five different experimental temperature treatments (18, 22, 26—control, 30 and 34 °C) applied to 10 sample replicates. The results showed that the lowest hydroponic root zone temperature of 18 °C had the greatest effect on the vegetative growth of *S. formosus*, with the highest average increases in fresh weight (1078 g), root length (211 cm), overall leaf length (362 cm) and the number of newly leaves formed (177 = n), all noted as statistically significant when compared with the other water temperature treatments, which yielded negative results from reduced vegetative growth. Findings from the study also revealed that while all heated solutions significantly prevented the formation of abscission layers of *S. formosus*, they had a less significant effect on inflorescence formation, with only 18 °C having the greatest positive effect on flower development.

Keywords: abscission; cape primrose; eco-dormancy; flowering pot plant; hydroponics; Gesneriaceae; root zone heating; phyllomorphy; *Streptocarpus formosus*

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1. Introduction

Within the Gesneriaceae, Streptocarpus form part of an economically important ornamental plant group with other significant members such as *Saintpaulia* spp. (African Violets), *Gloxinia* spp. and *Sinningia* spp. [1], all of which are herbaceous perennials known for the beauty of their flowers [2,3]. In its wild habitat in the Eastern Cape province of South Africa, *Streptocarpus formosus* flowers only in long-day, warm, summer months of the year [1,4]. *S. formosus* grows naturally in a summer rainfall locality with very little irrigation through precipitation during the cold season [4]. This abiotic combination of reduced water and low temperatures triggers a survival tactic where the nutrients and carbohydrate reserves in the leaves are transported and remobilized to actively growing

parts of the plant causing yellowing of the part, or all, of the leaves [5,6] before the plants enter a survival state of eco-dormancy [7].

This annual process in *Streptocarpus* with flowering occurring mostly under 15 h long days as compared to 8 h short days [8] and combined with the slowed short-day growth processes of eco-dormancy and the shedding of leaf mass through unsightly abscission layers severely limits the ornamental commercial use of *Streptocarpus formosus.* Therefore, cultivation methods to keep plants looking attractive in active growth and to extend the flowering season are required [8,9]. The manipulation of flowering is an important aspect of the cultivation of many horticultural crops [10]. There is a high demand for flowering pot plants during all seasons, even in winter when temperatures are below optimum for flower production [11] and annual plant senescence due to low temperature causes yield reduction that results in significant economic losses to growers [12–14]. Root temperature is one of the key environmental factors that control plant growth and physiological activities in cold seasons [15,16]. Manipulating root zone temperature to keep plant crops and ornamentals actively growing for commercial out-of-season production has been comprehensively researched purposely to meet market demands [17–20].

Growth cessation, abscission formation and dormancy development, all of which are exhibited by *S. formosus*, are considerably affected by temperature [21]. Leaf loss is a physiological strategy for the avoidance of water stress in plant species adapted to drought, reducing the transpiring surface of the foliage and thereby lessening water demand [21,22]. However, leaf senescence is mainly caused by cold and less commonly by high temperature [5,23]. In *Streptocarpus formosus* with no predetermined abscission zone, leaves are either shed entirely or a 2–3 mm wide demarcation line [24] forms on the leaves and a visible difference between the basal and distal sections of the lamina is distinguishable with a dark green base and a bright yellow upper section [25]. This partial senescence in *Streptocarpus* is a perennation mechanism that ensures the protection of the basal meristem [24,26]. When the distal leaf section is completely brown and dry, this part breaks away cleanly along the abscission layer [27,28] and the leaf can continue to lengthen with new growth from the base [3,27].

The chlorophyll content is an important criterion when evaluating the ornamental value of a pot plant [29]. The degradation of chlorophyll is the cause of leaf yellowing during senescence [28,30,31]. Various studies have shown the positive effect of heated water on the retention of chlorophyll and the increased amount present within leaves [11,16,32]. The optimum temperature of the growth medium can contribute beneficially to plant physiological processes such as chlorophyll pigment formation, the accumulation of phenolic compounds and an increase in photosynthetic capacity [11].

Heat is required to increase growth to expand plant production during the cold season and can be provided with the use of greenhouses [30], and it can be combined with hydroponic growing which has become common practice to improve winter yields and to obtain optimum production under periods of suboptimal climatic conditions [11,31]. Additional benefits of heating the nutrient solution are the provision of the energy requirements for plant development, activating metabolism [32] and a reduction in pathogenic activity [33]. The application of root zone heating in a closed hydroponic system enables the volume of water to buffer temperature and contributes to energy savings compared with the expense of heating entire greenhouse structures [11,33]. With a notable global increase in the scarcity of resources and climate change, hydroponics offers workable solutions by achieving optimal growth yield and good quality crops due to the precise control of nutrition and growing conditions [17,34,35]. Yields in hydroponics average at 20–25% higher than in conventional soil cultivation and have demonstrated significantly more growth and development in root systems, which also improves the nutrient uptake ability of the plants which, in turn, leads to better shoot and leaf growth [34].

This study was designed to investigate the possibility of achieving optimum growth during the winter season by determining how the application of root zone heat could viably facilitate the ornamental production of *S. formosus*, and to evaluate the effects of

different regimes of root zone temperature on abscission layers activated by eco-dormancy and the earlier formation of *S. formosus* flowers. It was also envisaged that this study would assist in determining an optimal temperature for the active growth and inflorescence formation of *S. formosus* to produce consistently high vegetative growth and flowers for cultivating superior quality pot plants in hydroponics to benefit the ornamental and floriculture industries.

2. Materials and Methods

2.1. Greenhouse Experiment

The experiment was conducted over 8 weeks during winter in the greenhouse facility at the Kirstenbosch National Botanical Garden (KNBG), Cape Town, South Africa (33°98′ 56.12″ S, 18°43′ 60.25″ E) from mid-June 2019 to mid-August 2019. Plants were grown under natural daylight conditions which provided the short-day photoperiod, 9:59:26 hr day length (15th June) to 10:54:49 hr day length (15th August), required for the experiment as *S. formosus* is then in the eco-dormancy period of its annual vegetative growth [1]. An overhead Aluminet shade net screen provided 40% shading and minimized temperature fluctuations. Maximum day temperatures ranged between 13 °C and 18 °C and night temperatures between 3 °C and 7.8 °C, with an average relative humidity between 77 and 81%.

2.2. Plant Preparation

Fifty genetically identical *S. formosus* plantlets were propagated vegetatively (Figure 1a) from one *S. formosus* mother plant. After the rooting period of four months (Figure 1b), the plantlets were thoroughly rinsed to remove the rooting media and all foreign matter from their leaves and roots. They were then potted into lattice-net plastic pots filled with 4–10 mm lightweight expanded clay aggregate (LECA) and placed in the hydroponic system with only their roots submerged in water. LECA was the preferred soilless growth medium for this study because its lightweight properties, with added porosity, would not degrade in the water while its pH remained neutral with the additional advantage of protecting the roots with its thermal insulation properties [36].

(**a**) Leaf cuttings freshly done (**b**) Leaf cuttings matured with plantlets

Figure 1. Leaf cuttings of *S. formosus* provided n = 50 plants cultivated from one initial mother plant obtained from Kirstenbosch National Botanical Garden, Cape Town (Photos: C. Viljoen).

2.3. Hydroponic Cultivation

A closed deep water hydroponic system with an air stone and a circulating pump was used based on the recommendations, discussions and methodologies of [11,37,38]. Deepwater hydroponics allows for methods of heating the nutrient solution to the required temperature and maintains a consistent nutrient supply and temperature over the entire root surface area of the replicates. Closed hydroponics systems allow for the reuse of nutrient solution, reducing the negative environmental impacts such as leaching of fertilizers,

soil and groundwater pollution, and water wastage while saving on labor. LECA provided support for the plants needing to be suspended in the nutrient solution while providing excellent aeration qualities [11,36].

Five identical deep water hydroponic systems were constructed and placed onto wire mesh tables. Each system consisted of one 70 L capacity low-density polyethylene (LDPE) reservoir filled with 60 L of aqueous nutrient solution. Each reservoir was covered with an LDPE sheet into which holes were cut to hold the 10 lattice-net (7.5 cm) plastic pots suspended (Figure 2). The pot size and depth ensured that the root zones of the plants were submerged in the nutrient solution without wetting the plant's leaf crowns, avoiding possible crown rot. To prevent oxygen deficiency and the limitations this would place on the plant growth, root aeration is essential in a hydroponic system, especially in deep water culture where there is limited air-water exchange capacity and particularly when heating the solution as there is a direct correlation between the temperature of water and the amount of oxygen it contains [35,39]. As water temperature increases, less oxygen becomes available to the roots [40], so to increase aeration all the solutions were aerated using one electromagnetic air compressor (BOYU ACQ-003) linked to each system's single air stone (50 mm), which bubbled the air up through the nutrient solution at a rate of 50 L per minute, supplying oxygen to the roots of the plants. To assist with the even distribution of both the additional air (O^2) and the heated water [37], each system's solutions were circulated using an 800 L/h hour HT submersible pump (HJ-941).

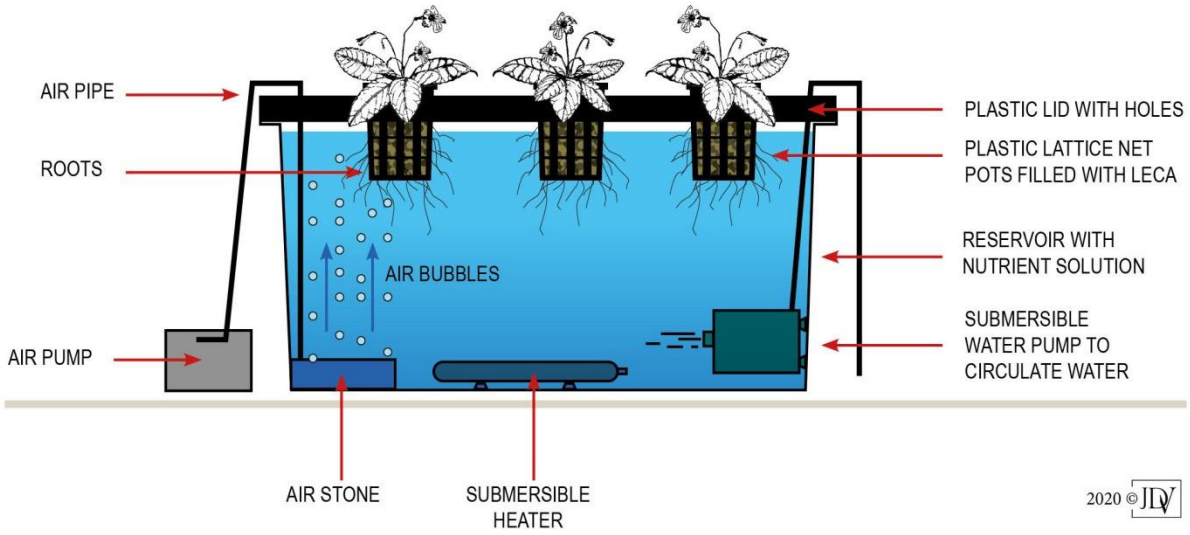

Figure 2. The closed hydroponic deep water culture system used for this study with air stone and circulating pump, and plants in lattice-net pots filled with LECA aggregate held suspended in nutrient solution (Diagram by J.D. Viljoen).

The solution comprised of ozone-treated borehole water containing Nutrifeed at a dilution rate of 1:500 (120 g in 60 L), as specified by the manufacturer Starke Ayres Pty. Ltd. Hartebeefontein Farm, Bredell Rd, Kaalfontein, Kempton Park, Gauteng, 1619, South Africa. This nutrient product supplied all the essential macro and micronutrients (6.5% Nitrogen, (N), 2.7% Phosphorous (P), 13.0% Potassium (K), 7.0% Calcium (Ca), 2.2% Magnesium (Mg), 7.5% Sulphur (S), plus Iron, Manganese, Boron, Zinc, Copper and Molybdenum) required for healthy plant growth as hydro-soluble fertilizer salts [38]. As the experiment would fall within a two-month growth period, it was decided that replacing the nutrient solution to overcome the build-up of phototoxic substances in the nutrient solution would not be required, to prevent potential disturbance damage to the roots [41,42].

The pH levels of all the nutrient solutions were monitored biweekly using a calibrated hand-held digital pH meter (HM Digital PS PH-200) and kept within a range of 6.4–7.0, a slightly acidic level recommended by [43]. The pH was adjusted accordingly using either sodium hydroxide (NaOH) to raise the pH, or hydrochloric acid (HCL) to lower

the pH [42]. The various temperatures of the five test solutions were also measured for monitoring consistency. The electrical conductivity (EC) level of each system was kept within a 0.9–1.1 dSm^{-1} range as suggested for *Streptocarpus* by [44] and was used as a measure of the nutrient concentration of the solution. The EC levels and temperatures of all the nutrient solutions were monitored biweekly using a calibrated handheld (PS COM-100) EC and temperature meter produced by HM Digital Inc., Culver City, CA, USA 90230. For decreasing the EC of aqueous nutrient solutions, ozone-treated borehole water was added into reservoirs, while adding 1:500 diluted Nutrifeed™ solution increased EC levels.

2.4. Water Temperature Treatments and Experimental Design

The experiment consisted of five different hydroponic solution temperatures which were applied to 50 plants of *S. formosus* using a completely randomized block design (Figure 3; Table 1). Each temperature treatment consisted of 5 treatments with 10 replicates (n = 10), one per pot suspended in a closed deep water culture system. Pots were individually numbered and arranged randomly. The five test solutions were heated using submersible EHEIM (Plochinger Str. 54 73779 Deizisau, Germany) thermo control manually adjustable heaters as standard aquarium equipment.

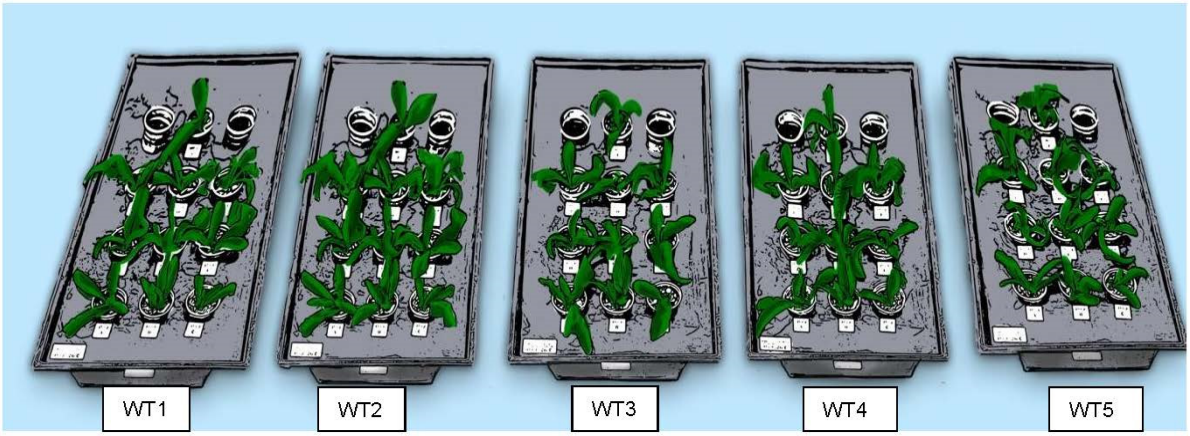

Figure 3. A completely randomized experimental block design used for the investigation (Diagram: J.D. Viljoen).

Table 1. Water temperature treatments and temperature ranges.

S/N	Treatment Code	Treatment Description
1	WT1	water temperature heated to 18 °C
2	WT2	water temperature heated to 22 °C
3	WT3	water temperature heated to 26 °C
4	WT4	water temperature heated to 30 °C
5	WT5	water temperature heated to 34 °C

The water temperature range applied was based on the ideal temperature recommendations for growing *Streptocarpus* [45], Gesneriad *Sinningia cardinalis*, [46] and other perennials [11,16], which were proven beneficial to both vegetative and inflorescence development in each case. The mean annual temperature at Port St Johns, which is *S. formosus*' natural habitat, is 19.9 °C as recorded between 1961 and 1990, with a mean summer min-max of 17.1 °C–27.6 °C when the plants are in full growth and flowering, as opposed to the mean winter min-max of 7.4 °C–20.5 °C when the plants are eco-dormant [47]. This experiment focused on applying a similar summer temperature range to the root zone to test whether the plants could thus be stimulated into active growth and flowering during the colder winter months, and WT3 at 26 °C was selected for the control as the literature reviewed indicated this to be both the ideal ambient air temperature for *Streptocarpus* under non-experimental circumstances, and a common root zone median tem-

perature for root to shoot ratios under experimental conditions for a selection of perennial crops [11,16,32,48,49].

2.5. Vegetative Growth and Data Collection

Various measurements were taken to determine plant growth response to different nutrient solution temperatures on leaf quantity, leaf lengths, root lengths and fresh weights. Data capturing took place pre-planting and at the time of planting the plants into the quantitative research experiment system, and again post-harvest after a two-month growth period.

Before planting, each entire plantlet (roots and shoots together) was weighed for a fresh wet measurement, using an electronic laboratory scale (Sartorius Analytical Balance Scale Model type 1518) with 0.001 g readability. Additionally, at this time the lengths of both the shortest and longest leaves, as well as root length for each plantlet, were measured using a ruler [50] and recorded. The measurement of leaves was taken from the growth media level to the apex point of each leaf. All present and emerging leaves were measured, but not if less than 2 mm in length. The root length of each plant was measured by the points at which roots emerged from the stem to the tip of the root mass. Immediately after being transplanted into the LECA filled pots and placed in the deep water culture solutions, the total number of present and emerging leaves on each plantlet was then counted, but not if less than 2 mm in length, and recorded. At post-harvest, these same measurements were repeated, and the data recorded.

2.6. Inflorescence Data Collection

Immediately after being transplanted into the LECA filled pots and placed in the hydroponic test solutions, measurement of various floral parts was performed. The numbers of inflorescence stalks per plant were counted and recorded, including all present and emerging pedicels, but not if less than 2 mm in length, and the numbers of flower buds and flowers per plant were counted and recorded. After a two-month growth period, at post-harvest, these same counts were repeated and the data recorded and analyzed to determine inflorescence development in response to different nutrient solution temperatures.

2.7. Eco-Dormancy Data Collection

Immediately after being transplanted into the LECA filled pots and placed in the hydroponic test solutions, the number of abscission layers present in the leaves per plant was counted and recorded. At post-harvest, the presence or absence of abscission layers was recounted and the data recorded.

2.8. Statistical Analysis

All data collected were statistically analyzed using one-way analysis of variance (ANOVA) and computed by the software program TIBC STATISTICA Version 13.6.0. The ANOVA test was used to determine if there was a statistically significant difference between each group of water temperature's mean value. A within-between ANOVA mixed model was applied to examine for potential differences in a continuous level variable between the treatment and the control group, and over time with pre and post-tests. The occurrence of statistical difference was determined by using the Fisher Protected Least Significance Difference (L.S.D.), a pair-wise comparison technique for the comparison of two means, at values of $p < 0.05$; $p < 0.01$ and $p < 0.001$ levels of significance [51].

3. Results

3.1. Total Leaf Number

There was an interaction between hydroponic root zone temperature and the final numbers of leaves produced by the plants. The increase in the number of leaves was highly significant ($F_{1,4} = 34.27$, $p \leq 0.0001$), and the WT1 (18 °C) treatment showed a greater increase in leaves compared to the control WT3 (26 °C) treatment by week 8 of

the experiment (Table 2). The greatest increase in leaf numbers occurred at the lowest temperature treatment 18 °C, with a mean of 17.7 when compared to the 26 °C control with a mean of 6.7. Leaf numbers also displayed notably poorer results in WT2 (22 °C), mean 13.3, and WT4 (30 °C), mean 3.3. WT5 (34 °C) resulted in almost complete leaf fatality.

Table 2. The interaction of various root zone water temperatures on the overall vegetative growth of *S. formosus.*

Treatments	Temp. (°C)	ΔLeaf Number	ΔLeaf Length (cm)	ΔRoot Growth (cm)	ΔTotal Biomass (g)
WT1	18	17.7 ± 1.91 a	36.22 ± 3.75 a	21.05 ±2.28 a	107.90 ± 21.07 a
WT2	22	13.3 ± 1.30 b	15.85 ± 2.24 b	0.45 ± 0.88 c	18.67 ± 1.96 b
WT3	26	6.7 ± 0.91 d	6.68 ± 1.68 c	−5.4 ± 1.02 c	7.32 ± 1.71 b
WT4	30	3.3 ± 1.56 d	−2.18 ± 2.78 d	−23.3 ± 0.79 bc	−0.80 ± 2.16 b
WT5	34	−2.8 ± 0.99 c	−11.76 ± 2.18 e	−48.2 ± 0.41 b	−3.70 ± 1.74 b
One-way ANOVA *F*-statistic		34.2670 ***	49.0178 ***	69.6300 ***	23.7484 ***

Note: Values presented are means ± SE. The mean values followed by different letters are significantly different at $p \leq 0.001$ (***) as calculated by Fisher's least significant difference and those followed by the same letter are not significantly different.

3.2. Total Leaf Length

There was an interaction between root zone water temperature and final leaf length produced by the plants with a highly significant *F*-statistic ($F_{1,4}$ = 49.02, $p \leq 0.0001$). The 18 °C (WT1) treatment with a mean of 36.22 cm had the highest reading compared to the control 26 °C (WT3) treatment, mean 6.68 cm, or any of the other treatments by the final 8th week of the experiment (Table 2). There was thus a significant reduction in the rate of leaf length development at both WT2 22 °C (15.85 cm) and WT3 (6.68 cm), with a further reductive loss in leaf length in WT4 30 °C (−2.18 cm). This sharp decline was visually observed in the leaf health, quality and length, as temperature increases to 34 °C (WT5) compared to the control WT1 of 18 °C (Figure 4) yielded the largest increase in leaf length.

Figure 4. The visible effect of the escalating hydroponic root zone temperatures on the vegetative aerial parts of *S. formosus* evident through simple observation over the experimental period with a directly proportional reduction in leaf numbers and lengths at increasingly higher temperatures (Photos: C. Viljoen).

3.3. Total Root Growth

The statistical analysis in Table 2 indicates the greater significant values ($F_{1,4}$ = 69.63, $p \leq 0.0001$) with root growth than with the aerial parts of the plant, and indicates that WT1 (18 °C) demonstrated a notable 210.5 cm overall increase in root length, compared with only 4.5 cm at WT2 (22 °C), versus the overall negative growths of −5.4 cm for the control WT3 (26 °C) and −23.3 cm at WT4 (30 °C) treatment, with the complete death of the roots at WT5 (34 °C) treatment. Figure 5 presents the treatment interaction effect on the total root growth of the *S. formosus* plants and it indicates that heat in the root zone is a severely limiting factor when heating above a critical temperature range. Root zone temperatures at 22 °C resulted in poor root development and all the temperatures above resulted in no development and sharply declining growth or death of the *S. formosus* plant's root system.

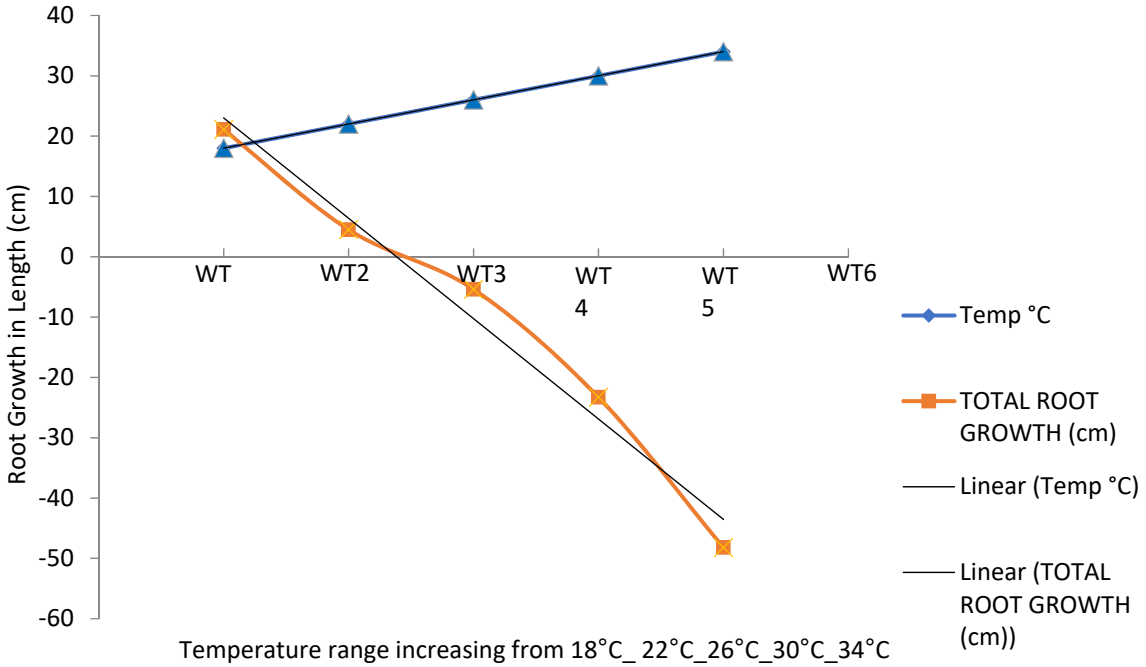

Figure 5. The relationship between root zone water temperature treatments and the relative rates of increase and decrease in root length.

3.4. Total Fresh Weight

Combined root and leaf fresh weights, as shown statistically in Table 2, were significantly affected by the root zone temperature ($F_{1,4}$ = 23.75, $p \leq 0.0001$), and the results show that incremental increases in water temperature treatments from 18 °C to 34 °C decreased fresh weight, to the point of notable fatality at the highest temperatures of 30 °C and 34 °C, clearly visible in Figure 4. The WT1 (18 °C) treatment offered the highest significant increase in overall fresh weight and vegetative growth when compared to the control WT3 (26 °C) and all the other treatments: WT2 (22 °C), WT4 (30 °C) and WT5 (34 °C). Findings from this study established that increasing hydroponic root zone solution temperature beyond the 18 °C–20 °C range did not promote the overall growth and development of *S. formosus* when compared with the significant increase in biomass growth in WT1, 18 °C, yielding a total of 107.90 g, which is equivalent to a 400% increase over 8 weeks.

3.5. Flowering in Response to Five Different Temperature Regimes in Hydroponics

The interaction between root zone heating and the inflorescence development of *S. formosus* was found to be statistically significant (Table 3), in the flower and bud formation ($F_{1,4}$ = 4.72, $p \leq 0.01$) as well as the pedicel development ($F_{1,4}$ = 4.72, $p \leq 0.001$). The highest individual mean value was evident in treatment WT1 18 °C (Figure 6); both for numbers of flowers and buds (mean 2.5) and the number of pedicels (mean 5), indicating

that higher root zone temperatures WT2 (22 °C), WT3 (26 °C), WT4 (30 °C) and WT5 (34 °C) incrementally decreased inflorescence formation.

Table 3. The effect of various root zone water temperatures on the total flower development of *S. formosus.*

Treatments	Temp. (°C)	Total Number of Buds and Flowers	Total Number of Pedicels
WT1	18	2.5 ± 0.81 a	5.00 ± 1.11 a
WT2	22	1.8 ± 0.68 ab	0.90 ± 0.23 b
WT3	26	0.9 ± 0.35 cd	0.40 ± 0.22 b
WT4	30	0.1 ± 0.10 d	0.20 ± 0.13 b
WT5	34	0.0 ± 0.00 d	0.00 ± 0.00 b
One-way ANOVA *F*-statistic		4.71716 **	16.33995 ***

Values presented are means ±SE. The mean values followed by different letters are significantly different at $p \leq 0.01$ (**) and at $p \leq 0.001$ (***) as calculated by Fisher's least significant difference and those followed by the same letter are not significantly different.

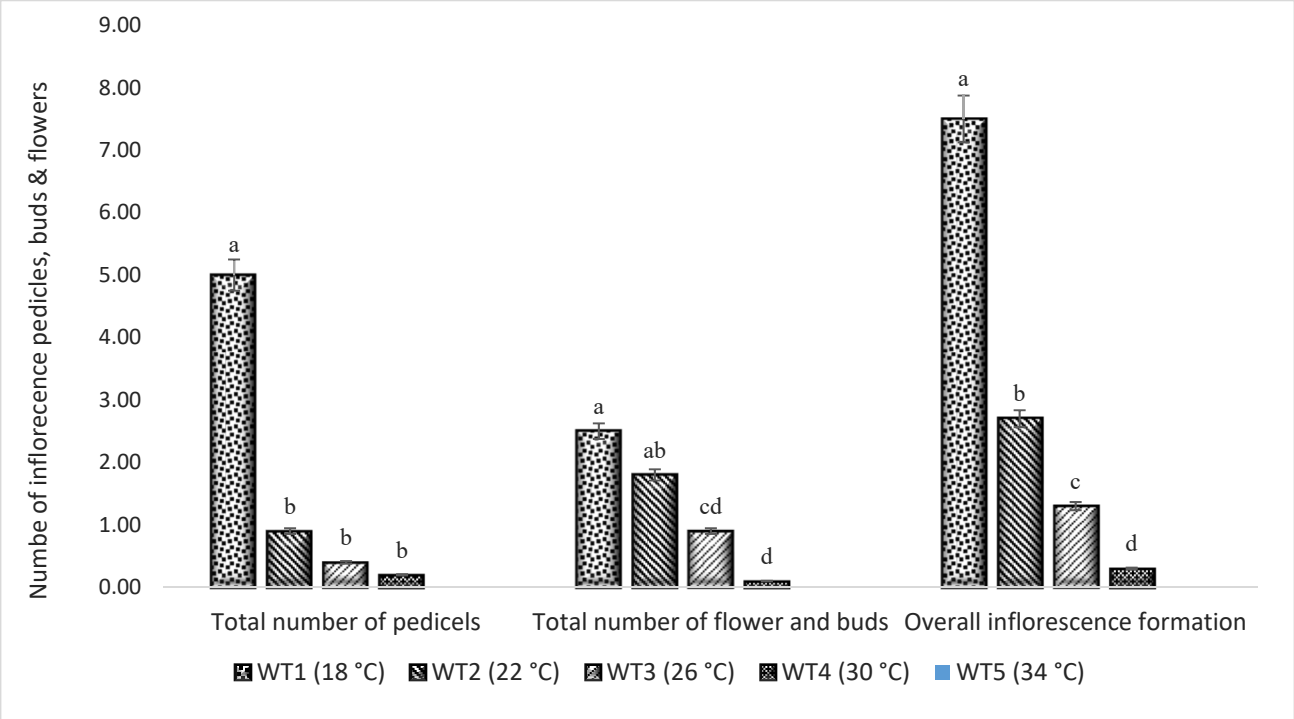

Figure 6. The relationship between root zone water temperatures and inflorescence formation. Note: The bars presented here are means ± SE. Bars with different letters are significantly different at $p \leq 0.01$ (**) (total number of flower and buds; overall inflorescence formation) and $p \leq 0.001$ (***) for the total number of pedicels as calculated by Fisher's least significant difference.

Conversely, the lowest temperature of 18 °C (WT1) significantly increased the inflorescence formation of *S. formosus.* Flowers were evident at lower root zone temperatures of 18 °C and 22 °C compared to the control treatment at 26 °C (WT3) or the higher temperatures. Increasing water temperature in the range from 26 °C to 34 °C not only decreased inflorescence formation but led to total fatality of the plants at the highest temperature of 34 °C (WT5), as seen in Figure 6. A positive finding is that at 18 °C (WT1) flowers did develop during colder short-day periods, which indicates a strong possibility that manipulating the growing temperatures could induce *S. formosus* to flower earlier in the season, thereby extending the flowering period for an all-round year commercial marketing period.

3.6. Reduction in Abscission Layers in Response to Five Different Temperature Regimes in Hydroponics

As shown in Figure 7, the effects of root zone water temperature on the reduction in abscission layers already present on the *S. formosus* replicates' leaves were statistically significant at a value ($F_{1,4}$ = 19.85, $p < 0.0005$). The few abscission layers that were present at the time of the experiment's inception all disappeared (Figure 8); however, more significantly, no abscission layers formed on any plants in the heated treatments during the winter period as would usually naturally occur (Figure 9a,b). Treatments applied in this study indicate that root zone heating is a viable method for overcoming and preventing the formation of abscission layers.

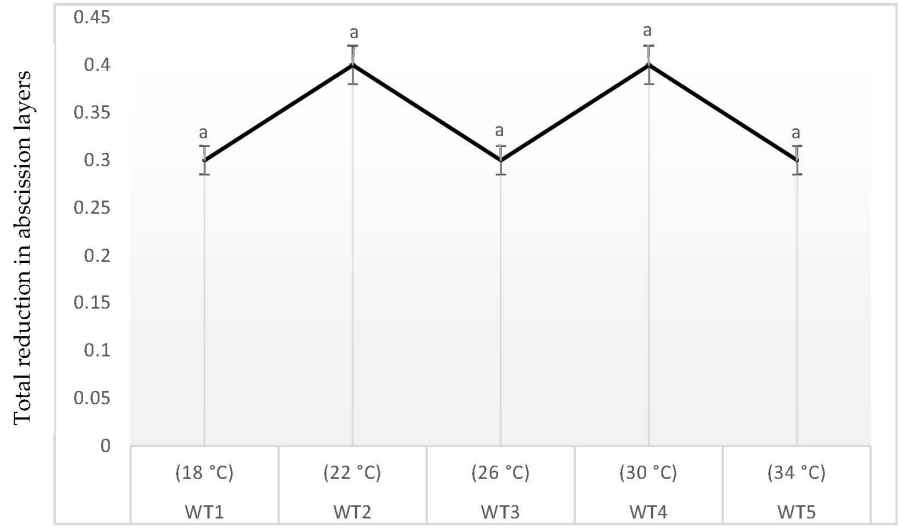

Figure 7. Root zone heating has the effect of minimizing abscission layers on *S. formosus.* Note: The line graph presented here depicts means of reduction in abscission layers ± SE. The mean values followed by the same letters are not significantly different (ns) at $p \leq 0.05$ as calculated by Fisher's least significant difference.

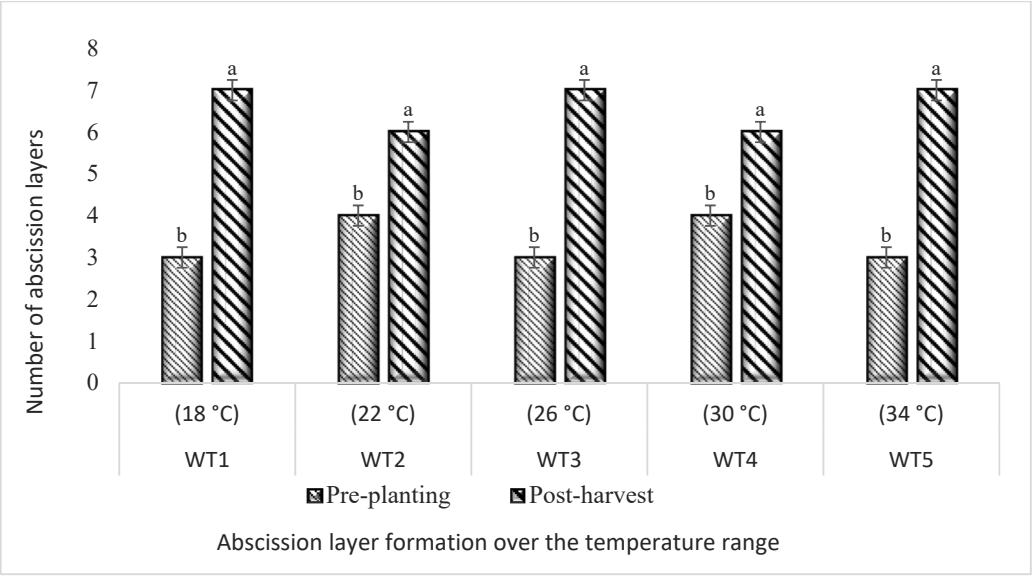

Figure 8. The correlation between all root zone water temperature treatments and the decrease in abscission layers that were present at the start, as compared to the complete absence of abscission layers at the end of the study. Note: Bar graphs presented here are means of the number of abscission layers ±SE. The mean values followed by the same letters are not significantly different (ns) at $p \leq 0.05$ as calculated by Fisher's least significant difference.

(**a**) Applied to (n) = A.

(**b**) Applied to (n) = G.

Figure 9. Postharvest photos display the effect of increasing root zone temperature across the temperature range 18 °C to 34 °C on flower and abscission layer formation on both n = A and n = G (Photos: C. Viljoen).

4. Discussion

High vegetative, flower and fruit yields in quality greenhouse crops are possible with hydroponics due to the precise control of growing conditions and required nutrients [42,52]. Nutrient solution temperature is easily controllable in hydroponics and may be manipulated to control plant growth and maximize the production of plants and flowering during winter periods [11]. Two cultivars of *Saintpaulia* (Gesneriaceae) subjected to a root zone

heating range of 17 °C–25 °C exhibited a 10–15% reduced cultivation time and a significant increase in the rate of flower formation [53]. Root zone heating has shown significant results in herbaceous leafy crops, increasing flower numbers by increasing nutrient uptake [20,48]. *Chrysanthemum* responded positively when grown in a soilless culture system with a heated solution and produced flowers earlier with optimum results at 24 °C [49]. In woodier crops, such as apple, a root zone temperature of 15 °C proved to be optimal for flowering with a distinct reduction at 30 °C [54], and roses grown in a heated soilless culture system showed an increase in the number of blooms produced over the production season [55].

Streptocarpus formosus responded in various ways to different temperature regimes with a clear trend that resulted in the death of the leaves and roots at higher temperatures (26 °C to 34 °C), with the most optimal growth at the lower temperature of 18 °C. It is also clear that the roots were more sensitive than the shoots. Treatments applied in this investigation had a significant effect on the vegetative root and leaf growth as well as the overall fresh weight of *S. formosus.* The results obtained from this research disagree with various previous studies which yielded positive results in other leafy perennials and crops at higher temperature ranges such as 24 °C–28 °C for spinach [56]; 25 °C–30 °C for tomatoes and lettuce [20]; 25 °C–45 °C for muskmelon plants [57]; and 15 °C–30 °C, for *Chrysanthemum* with an optimum temperature of 24 °C [49].

Several other studies performed on soft shrubs, such as roses, indicated that shoot growth was reduced at root temperatures lower than 18 °C [55] and, at this specific temperature or above, heat in the root zone was beneficial [58]. For *Euphorbia pulcherrima* cuttings, the optimum temperature range for rooting was 25 °C–28 °C [59]. Results for conifer seedlings, such as pine (temperature range 8 °C–20 °C), had significantly new root growth at 20 °C [60]. In [19], the authors showed that lowering the temperature from 21.4 °C to 16.8 °C for *Disa* spp. had a negative effect on root growth and fresh weight, which agrees with this study where optimum vegetative growth was recorded at root temperatures lower than 18 °C.

The vegetative growth responses of *S. formosus* in this study contradict the results of research performed on cooler root zone temperature ranges, indicating that lower temperature ranges can restrict photosynthetic, respiration, metabolic and osmotic activities [20,61,62]. However, findings from this study concur with research performed on *Streptocarpus* hybrid leaf cuttings in the laboratory, which produced the most roots and buds at 12 °C and 18 °C [63], as well as with research performed on cucumbers, where the lowest temperature within the range 22 °C–33 °C yielded the best results [16].

Streptocarpus species only naturally produce flowers during the long-day summer months [3,25]. This study, however, showed that *S. formosus* was able to produce flower buds during the winter short-day period at lower temperatures. The importance of increasing flowers and regulating the timing of flowering in pot plant production can support the production of the species [61]. As confirmed in Table 3 earlier, the effect of various root zone temperatures on the total flower development of *S. formosus* was statistically significant at $p \leq 0.05$.

In *S. formosus*, the tips of the leaves often slowly die back to an abscission layer when stressed by drought, low temperature or when overwintered [3]. Growth cessation, abscission formation and dormancy development are considerably affected by temperature [21]. Leaf loss is a strategy for the avoidance of water stress in plant species adapted to drought because it reduces the transpiring surface of the foliage and therefore lessens the water demand [21,22]. Leaf senescence is mainly caused by cold and less commonly by high temperature [5,23]. In winter deciduous species, leaf senescence is an indication of the change from an active to a dormant growth stage [21,64]. When climatic conditions become unfavorable and the plants experience a state of stress, phytohormones react and leaf abscission that can lead to complete senescence is often the result [21]. Some significant abiotic factors affecting leaf abscission are nutrient availability, temperature and water supply [5,21,23], all of which can be managed within hydroponic cultivation systems [17,38]. Ref. [44] recommends that during colder months sub-irrigation should be used with minimal overhead

irrigation as water that is considerably colder than the average leaf temperature causes unsightly leaf damage with yellow spots or blotches on *Streptocarpus* leaves.

In [65], the authors reported that abscission occurred due to short photoperiods in some *Streptocarpus* spp. In [66], the authors also stated that photoperiod and temperature are the main cues controlling leaf senescence in winter deciduous species, with water stress imposing an additional influence [21]. Although manipulating light and photoperiod could prevent eco-dormancy in *S. formosus* in the cold season short days, this study, however, proved that manipulating root zone temperature significantly affected the vegetative growth and flower development. A lack of water or nutrients results in leaf yellowing in many plant species, which can be reversed in some species upon removing the stress [6]. In *Streptocarpus*, it is still possible for the reversal of the formation of the abscission layer and the senescence processes even if the leaves are displaying a distal depletion of chloroplasts [65] if the plants are maintained under conditions of high temperature, nutrient levels and humidity [24]. Leaf senescence can be delayed by warming as photoperiodic triggers and growth proficiency could increase because of a slower speed or prevention of leaf senescence [21,62]. Plant growth can be controlled by the direct correlation between nutrient solution temperatures around the root zone and the uptake of nutrients, with increased plant growth at elevated root temperature correlated with higher nutrient absorption [15,67].

In this study, *S. formosus* responded in various ways to different root zone temperatures but showed the most significant vegetative mass increases in both shoots and roots at the lower temperature of 18 °C indicating that a low-temperature heating range can be used to keep *S. formosus* in active growth during the cold season. Treatments applied in this investigation had a significant effect on the flowering formation of *S. formosus.* Plants responded better to the lower root zone temperatures of 18 °C and 22 °C compared to the higher temperature intervals, and flowers were formed during the colder short-day periods, which indicates a strong possibility that manipulating the growing temperatures could induce *S. formosus* to flower earlier in the season, thereby increasing its annual commercial marketing period. These findings agree with [49] and [53], in which root zone heating increased blooms and extended the flowering period into the cold season months or encouraged earlier flowering. Moreover, treatments applied in this research also had a significant effect on the abscission layer formation of *S. formosus*. This indicates that root zone heating is a viable method for preventing the formation of abscission layers.

5. Conclusions

It is concluded that high root-zone temperatures decreased the vegetative growth of *S. formosus.* The results showed that the cooler root-zone temperature of 18 °C improved growth (leaf number, leaf and root lengths and fresh weight). This study further established that increasing root-zone temperatures did not promote the flowering of *S. formosus*; however, plants responded positively to flowering at decreased temperatures from 22 °C–18 °C. *S. formosus* has commercial potential as an indoor flowering pot plant and a flowering landscape perennial, and shows potential within the cut-flower trade. Therefore, these results will contribute to developing optimal cultivation protocols for cultivating *Streptocarpus* spp. and its hybrids and guide commercial growers in the cultivation of *S. formosus* in particular.

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