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EDIBILITY OF *Trachyandra ciliata* (L.f.) KUNTH- AN UNDERUTILIZED VEGETABLE FROM SOUTH AFRICAN WESTERN CAPE COAST: A REVIEW

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ABSTRACT

The aim of Sustainable Development Goal 2 (SDG2) is to end hunger, improve food security and nutrition and promote sustainable crop production by 2050. However, climate change, increasing soil salinization and the inadequate availability of fresh water have negatively affected crop production around the world including South Africa, making it difficult to meet the required target. This necessitates the use of wild edible plants that are adapted to adverse conditions such as drought and salinity in order to mitigate this problem. The genus *Trachyandra* (Asphodelaceae) consist of three edible species (*T. ciliata, T. divaricata and T. falcata*) which are native to the dry saline environments of the western Cape coastal sand dunes. The genus is less studied with no record of cultivated species, although the existing literature states that *T. ciliata,* (wild cabbage) was originally used as a food source by the indigenous Khoi-san people who lived on the South African Cape coast. Colonization and removal of indigenous people from cultural lands led to erosion and detachment from the knowledge of the land and its useful plants. The species is used in selected restaurants where the inflorescence is steamed and eaten as a vegetable or added into a stew. This review explores the importance of Asphodelaceae family, *T. ciliata* as a vegetable crop and its potential as a pharmaceutical candidate. Furthermore, this review examines potential technological advances such as hydroponics that could be used for sustainable crop production of *T. ciliata*. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was utilized in the selection of articles in this review. The existing literature provided useful information on the potential of *T. ciliata* as a vegetable crop and the importance of using halophytes to achieve food security. This appraisal is expected to serve as a template for researchers, food enthusiasts, potential farmers and policy makers who may be keen in exploring further nutritional composition and medicinal potential of this plant.

Key words: Asphodelaceae, food security, halophytes, hydroponics, *Trachyandra ciliata,* water scarcity

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INTRODUCTION

Agricultural production in southern Africa is greatly limited by inadequate availability of water as the region is the third to be confronted by devastating water scarcity after North Africa and the Middle East [1]. Amongst agricultural aspects affected is the inability of the country to increase agricultural production in order to keep up with the increasing population growth to sustain food security. This is partly due to water scarcity to supplement summer rains [2]. Demands for water have tripled since the 1950s while freshwater supplies have been declining consistently ever since it is predicted that South Africa will face physical water scarcity by 2025 because of the rapid population growth and decreasing fresh water supply [3]. In South Africa, the province that is extremely affected by water scarcity is the Western Cape and it is also predicted that in the near future, this province would be unable to cater for its agricultural needs [3]. This then calls for the cultivation of halophytic plants that are tolerant to high levels of drought and salinity to be used for food [4]. Condon *et al*. [5] reported that of the world's allocated water resource, about 80% is currently dedicated to irrigated agriculture and this level of consumption by agriculture is not sustainable in the future. They further suggested that projected population growth of about two billion people within two to three decades to come will require that more of the available water resource be used for domestic, municipal, industrial, and environmental needs. It is predicted that by 2050, crop production must increase by at least 50 to 100% in order to cater for the constantly growing global population, but in actual fact the current increase is around 1 to 1.5% and therefore it is a major challenge to guarantee sustainable agriculture [3].

Salinity presents limitations in plants and leads to a decline in general yield, leaf production, delayed flowering, and abortion of flower buds [6]. It is, therefore, a big challenge for researchers to determine sustainability with regards to water resource preservation and food availability for underprivileged populations in the future. The use of salt and drought tolerant crops to ensure increased agricultural production while preserving water resources should be extensively researched in preparation for the future. Coastal lands represent large areas that are currently underexploited for conventional agriculture but have the potential of being used for halophytic food crops. Halophytes are highly productive under saline conditions and that could be the solution to the issue of freshwater depletion and their use could ensure the productivity of saline soils [7].

Furthermore, the increasing population has led to the industrialization of lands that were used for agricultural purposes. An increase in soil salinization together with the growing scarcity of freshwater stimulates the need to develop more innovative techniques to enhance sustainable crop production [4]. Therefore, technological advances and improvements are key factors in determining sustainability and agricultural production in the future.

Hydroponic propagation is turning to be a favourite method of cultivating plants at present in South Africa because it allows the production of plants and flowers throughout the year. South Africa has many areas of dry land ranging from semi-desert

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to desert as well as places with inadequate groundwater. In response to this, farmers in most cases have no other options but to use high-density crops that use less amount of water [7]. Production of crops in controlled environments gives chances of improved growth, quality, purity, and consistency. It is imperative that techniques that have the potential to increase agricultural production and ensure food security be studied extensively so that the risk of unavailability of food in the future is mitigated.

MATERIALS AND METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was utilized in the selection of articles in this review, following the method defined by Hutton *et al.* [8]. Various scientific reports, online databases and theses/dissertations were explored using the library of the Cape Peninsula University of Technology. Search engines such as Scopus, Web of Science (WOS) and AgriFor were primarily used to conduct thorough search, while other quick checks were conducted in *google scholar*, *science direct* and *web of science*. For this review, the search was limited to Southern Africa with special attention given to South Africa and the literature search period was from 1984 to 2020.

Figure 1: *Trachyandra ciliata* plant growing on the sand dunes of the Agulhas Plain (Picture: Charles Laubscher, 2018) – co-author

Food security

Herrero *et al*. [9] reported that the present world food production derived from 1.5 billion hectares of land, and that is about 12% of the global land area. It has been reported that in the last 50 years, cultivated land has been reduced by 13% due to urbanisation and that global agricultural productivity growth is projected to decrease by 1.5% every year until 2030, and then further decline by 0.9% to 2050 [10,11]. Continuous declines in agricultural progress will one way or the other affect world food production. In future, food supply will depend on the proper management of agricultural resources and investments in machinery as well as strict policies to try and achieve reasonable increases in food production [9].

Food security is regarded as a broad term but the basic definition is that it is the availability of food to all people at all times for an active healthy life [12]. Du Toit *et al*. [12] further stated that food security is also regarded as being closely related to poverty in a country. South Africa is one of the countries that have high proportions of income variation in the world and it has high levels of poverty compared to other middle-income countries. In response to this problem, continuous efforts are being made by the government to obtain high productivity in order to increase profitability and to meet the constantly increasing demand for food [12].

At the national level, food security means a situation in which the country has the ability to produce, import, sustain, and retain food that is needed to support its people with minimum per capita dietary standards [12]. At a community level, it means a situation in which the people in a particular community are able to access food that is safe and nutritionally satisfactory through a viable system that ensures sustainability within the community. At a household level, food security refers to a situation in which people can access food in their homes such that people in a specific home are not threatened by hunger or undernourishment [12].

Food insecurity and the aspects of it are most experienced at household and individual levels [13]. Du Toit *et al*. [12] reported that South Africa is regarded as a food secure country at a national level because of its capacity to produce enough staple food and having the ability to import from other countries in order to cover the demand for food. However, this was rebutted by the report that 20% of South African homes have insufficient access to food [14].

According to Hanjra and Qureshi [11], "The key drivers which have recently impacted and will impact on food production and supply include: (a) water (and to some extent land) crisis; (b) climate change crisis; (c) energy prices and (d) credit crisis." They further report that competition among different segments, regions, countries, and human activities associated with water is already occurring. This is supported by a previous report that about 40% of the global population live in areas where they directly compete for water resources and that China and Africa are already experiencing water shortages [15].

The food security problems propagate the need for the introduction of drought and salt-tolerant plants to substitute and add capacity to sustain agricultural production to counter the projected shortage of food in the future [7]. Asphodelaceae is a family of succulent plants that have been extensively studied throughout the years because of the high medicinal properties they contain and they are a big part of the world pharmaceutical industry. Also, *Trachyandra* species could be having numerous applications such as a novel vegetable and a source of secondary metabolites with numerous uses in the pharmaceutical industry [16].

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Genus *Trachyandra* and species *T. ciliata*

The genus *Trachyandra* also known as wild cabbage, is a genus that consists of more than 50 species, belonging to Asphodelaceae family [17,18]. The name *Trachyandra* is derived from Greek words, trachy, which means rough, and andro, which means male, and refers to the hairy filaments. *Trachyandra* species are perennial plants that are woody or herbaceous with granular pubescence in some species. They are deciduous plants because they lose their leaves during cold seasons. The root systems are fibrous or spindle-shaped and sometimes swollen near the tips to form thin tubers. The stems are upright and woody or herbaceous mostly naked but sometimes covered with old leaf bases, or mostly developed as a vertical or rarely horizontal rhizome.

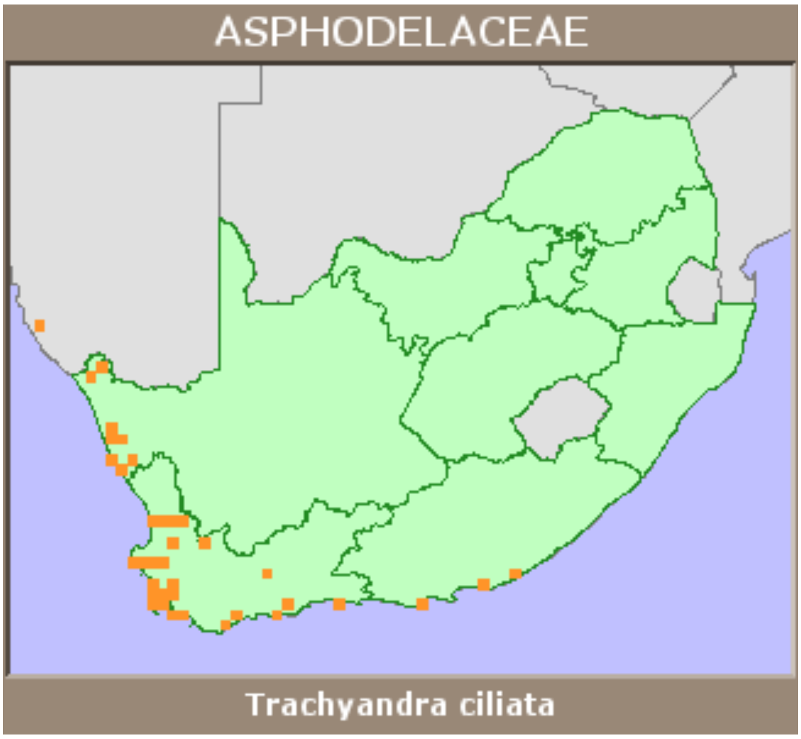

Figure 2: Distribution of *T. ciliata* in South Africa
(Picture: http://redlist.sanbi.org/species.php?species=2203-18)

Trachyandra is largely a South African genus with the majority of species found in the south Western Cape (Figure 2). Species of *Trachyandra* are occurring throughout Southern Africa with few of them occurring in southern Zimbabwe, Angola, Kenya, and one extending as far as Ethiopia, while the majority of them are restricted and endemic to the winter rainfall area of the South Western Cape. As this plant grows on the Cape coast dunes it is also a good addition to coastal gardens; it can be thought that it is highly tolerant to salinity because most plants that grow in this environment are halophytes.

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Figure 3: *T. ciliata* growing on coastal sand dunes in the habitat (Picture: Charles Laubscher, 2018) – co-author

Trachyandra as a genus is less studied with little to no literature available and there are no *Trachyandra* species that are currently cultivated [16,18]. However, it has been documented that *T. ciliata*, *T. divaricata* and *T. falcata* are edible and were used as food by Khoi-san people that lived on the South African cape coast [16]. Colonization and removal of indigenous people from cultural lands led to erosion and detachment from the knowledge of the land and its useful plants [19]. Current information indicates that the inflorescence can be steamed and eaten as a vegetable or added into a stew [16]. (Figure 4). However, the nutrient contents of these plants are yet to be scientifically proven, hence further studies are needed to support the current information.

According to Jaarsveld [18], different names were assigned to *T. ciliata* which include; *Anthericum ciliatum* Linné fil. (1781), *Anthericum longifolium* Jacquin (1786), *Bulbine ciliata* (Linné fil.) Link (1821), *Phalangium canaliculatum* (Aiton) Poiret (1804), *Trachyandra canaliculata* (Aiton) Kunth (1843), *Phalangium longifolium* (Jacquin) Poiret (1804), *Trachyandra longifolia* (Jacquin) Kunth (1843), *Anthericum canaliculatum* Aiton (1789), *Bulbine canaliculata* (Aiton) Sprengel (1825), *Phalangium vespertinum* (Jacquin) Poiret (1804), *Trachyandra vespertina* (Jacquin) Kunth (1843), *Anthericum recurvatum* Dinter (1931) among others. The plant is a fast-growing geophyte, acaulescent with ciliated leaf margins. The flowers are white, translucent and born on a racemose inflorescence [18].

Throughout the years, the Asphodelaceae family has been intensively studied based on medicinal properties and is widely used in the pharmaceutical and beverage industry [20]. This could be the case for these undocumented *Trachyandra* species and they might have numerous applications such as a novel vegetable and a source of secondary metabolites with uses in the pharmaceutical industry. Ventura and Sagi [4] suggest that the cultivation of indigenous salt and drought tolerant halophytic plants for food could

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be one of the approaches to sustain food security. *T. ciliata* has no literature rating to its nutritional properties and potential medicinal properties. Therefore, studying its closely related species in the Asphodelaceae family may also lead to scientific justification of its edibility and potential as a pharmaceutical candidate.

Figure 4: Edible inflorescence of *T. ciliata* showing the asparagus type inflorescence
(Picture: http://www.fynboshub.co.za/catablog-items/trachyandra-ciliata/)

Asphodelaceae Family

Asphodelaceae is a family of angiosperms in the order Asparagales. The family is made up of 12 genera and approximately 1060 species native to Africa, Arabian Peninsula, Central Asia, the Mediterranean basin, west and central Europe, Madagascar, New Zealand, and Australia. Klopper *et al.* and Chase *et al.* [21,22] reported that the name Asphodelaceae was first scientifically published in Jussieu's *Genera Plantarum* in 1789 and this date is regarded as the starting date for the nomenclature of this family. Within the family, there are two sub-families namely Asphodeloideae and Alooideae [22].

Members of Asphodelaceae family are very broad with a few characteristics common to all members. They range from small to medium-sized plants that are often succulent, herbs or large trees with leaf arrangements of terminal rosettes on fibrous and woody stems rather than succulent. According to Smith and Van Wyk [15], "Leaves are dorsiventral, lanceolate-acuminate, linear or subulate, terete, often succulent and thickly conical, spirally arranged or distichous as in some species of Aloideae, amplexicaul, margins toothed, serrate or entire, sharply pointed, parallel veins often obscure".

The importance of Asphodelaceae species in the food industry

Although plants in the Asphodelaceae family are popular with high medicinal properties, recent studies, investigating the potential of South African indigenous species as food crops have shown that some species could be valuable products for the food and beverage industries [20]. Cock [23] described the use of the inner, non-bitter gel of *Aloe* plants as a food supplement and as new development in research. There is little documented evidence of this species being used as a traditional food except for the use as preservatives by Cape farmers in the production of jam. Cock [23] also reported the presence of flavonoids in Aloe plants and what this finding adds to the popular use of the genus. As reported earlier *Trachyandra* can be eaten as a vegetable and was used by Khoi-san people traditionally [16]. The species grows naturally in highly saline soils of the south-western Cape coast which makes this one of the candidates as salt-tolerant food crop to be introduced into the food market, especially while drought and salinity of agricultural lands are constantly increasing. Hence studies to evaluate salt tolerance and nutrition, research studies on this plant should be conducted to introduce *T. ciliata* as a salt-tolerant food crop.

Nutrient content of Asphodelaceae plants

Researchers have determined the health benefits of food and beverage products that are comprising of the leaf parenchyma of Aloe species [23]. The Food and Drug Administration has certified and granted permission for the use of *A. faro* as a direct food additive for human consumption [24]. Cock [23] reported the presence flavonols and of some essential vitamins (vitamin C, vitamin B1, vitamin B2, vitamin B6, vitamin B12, and vitamin E) for the efficiency of the human body to be contained in unspecified Aloe leaf gels. He further reported that leaf gel of aloe plants contains essential minerals including zinc, iron, manganese, phosphorous, molybdenum, sodium, potassium, magnesium, calcium, and copper. As it is documented that *Trachyandra* is an edible vegetable, more focus and more studies should be carried out to evaluate the nutrient content of plants in this genus. Equally so, the issue of the water crisis that is threatening agricultural production needs to be addressed and explored in order to develop techniques that will increase production without exerting more pressure on the demand for freshwater.

The water crisis in south-western cape Mediterranean climate regions

Arguments about world water scarcity and food security have intensified lately and the exact future demand for water and food supplies are unclear [11]. Globally, 1.1 billion hectares out of 1.5 billion hectares of cultivated land is depending on rain water without any irrigation systems which makes up to about 80% of the world's cultivated land that produces 60% of global staple foods [10]. Thenkabail *et al*. [25] reported that irrigated agricultural land covers 19% of the cultivated land which contributes about 40% to the global agricultural productivity. Astonishingly, irrigated agricultural land is also responsible for 70% of water withdrawals from the world's rivers despite contributing so little to global food production [26].

Water scarcity and food insecurity are inter-linked because water is very important for future global food security and water scarcity reduces agricultural productivity and thus contribute to the increasing trend of food security problems [11]. The demands of irrigation water for other industries such as environmental developments and urbanization exerts huge pressure on the agricultural industry and global food security [11,26]. It is predicted that South Africa will face physical water scarcity by 2025 because of the rapid population growth and decreasing freshwater supplies [3]. In South Africa, the province that is extremely affected by water scarcity is the Western Cape and it is also predicted that in the near future, this province would be unable to cater for its agricultural needs [3]. Salinity is also a growing threat to agricultural production as many agricultural lands have turned highly saline and cannot be used to produce plants any further. This then calls for the cultivation of plants that are tolerant to high levels of drought and salinity to be used for food [4]. Condon *et al*. [5] found that of the world's allocated water resource, about 80% is currently dedicated to irrigated agriculture and this level of usage by agriculture is not viable in the future. They further suggest that a predictable population growth of about two billion people within two to three decades to come will necessitate that more of the available water resources be used for municipal, industrial, domestic, and environmental needs.

Falkenmark and Molden [15] suggested that enhanced water management and new investments in irrigation infrastructure should be put in place in trying to minimize the influence of water shortage and partially meet the demand for food production. Currently, hydroponic cultivation is a popular technique to ensure maximum agricultural production while reducing the demand for fresh water in irrigation [27]. It is therefore paramount to extensively study and explore the potential of hydroponic techniques to grow salt-tolerant vegetable crops.

The importance of growing halophytic plans hydroponically

Gericke W.F. who conducted several experiments on planting crops in deep water culture was the person who gave the term "hydroponics" in 1936 [28]. Hydroponics is an alternative to conventional crop production and is defined as the growing of plants in a soilless medium or in an aquatic-based environment. In this case, an artificial medium is used to provide structural support to the plants and not to provide essential nutrients to the plant. Furthermore, all the essential nutrients needed by the plant are blended with water and are made available to the plant [29]. It has been reported that hydroponics allow for the attainment of high yields without compromising the quality of crops [30].

Hydroponic production of plants is becoming popular in the modern world with ecological imbalances such as extreme temperatures, drought, chemical toxicity, and oxidative stress threatening conventional agricultural practices [31]. Hydroponics can be applied in places where there is limited availability of space, where there is a shortage of water, where the soil is chemically imbalanced, and where there are high levels of pathogen infestation. In South Africa, challenges like population growth, water scarcity, and increasing demand for food have raised a necessity for sustainable and efficient cultivation methods [3,11,26]. It was also reported that hydroponically grown plants use 10 times less water than soil-grown plants because in soil-grown plants water quickly leaches to the soil while in hydroponics, water is collected and circulated again [31,32]. It is further reported that hydroponic cultivation limits the loss of water and nutrients. It has been found that hydroponically grown plants grow faster and healthier because they get nutrients in exact amounts according to the grower [29].

Considering water scarcity that is currently hitting South Africa, especially the western Cape, hydroponic cultivation of vegetable crops can be the solution because it has been proven that it is the most sustainable, efficient, and effective cultivation method in the agriculture industry of today [31]. Furthermore, hydroponic cultivation of halophytes in South Africa is a field that needs to be explored in an attempt to address the water crisis and food insecurity simultaneously. As the cultivation of edible halophytic crops such as *T. cilata* has been regarded as the possible solution for the sustainability of food production in the future [4, 27, 29], it is very key to start developing hydroponic growth protocols for these plants, in order to better understand their nutrient uptake and salt tolerance.

For an efficient nutrient uptake, hydroponic cultivation is regarded as an ideal method to manipulate or optimize both the supply of nutrients and the root environments [33]. Continuous replacement of nutrients in the hydroponics system is important because it allows for efficient nutrient uptake and prevents toxins of waste nutrients [34]. Well managed periodic application of fertilizers can help achieve a desirable balance between foliage growth and reproductive growth and that is usually realized through the use of an irrigation computer [27,35]. These researchers further explain that the water supply and nutrient supply have to be matched with carbon assimilation or growth rates in order to achieve balanced growth. Likewise, it is important to understand the general hydroponic nutrient supply in order to plan protocols for the cultivation of halophytes.

The introduction of hydroponic systems has allowed for the determination of optimal requirements for the basic nutrients needed for plant growth [33]. The required concentration of nutrients in the aqueous solution is determined by the uptake rate of the plant, which differs from plant to plant [32,36]. In most cases, Potassium (K) supply is not necessary for high yields but uniform flowering and ripening, and the addition of NaCl in the solution reduces the K concentration. So that means addition of NaCl should be carried out with care as it reduces the acidity of the solution, thus reducing the uptake of K [34]. *T. ciliata* and other halophytes naturally grow in saline conditions, in which the uptake of K is limited. There is a necessity to reduce nitrate concentration in the solution as lower nitrate content of vegetable crops is recommended for health and also it is to reduce the negative greenhouse effect on the environment K [34]. Furthermore, this has called for partial replacement of KNO_3 and NO_3 by KCl, $CaCl_2$, and NaCl in the nutrient solution. The acidity and alkalinity (pH) of the nutrient solution in the cultivation of halophytes needs to be handled with care, as this may be the deciding factor on the successful cultivation of these plants [27,37].

Salinity and Electrical conductivity in relation to nutrient uptake

In recent years, electric conductivity (EC) has been increased by adding NaCl to the solution but later studies proved that NaCl-induced EC decreases the uptake of Calcium (Ca), which can result in devastating outcomes [34,37]. Adjusting the electrical conductivity of the solution is a more precise method of controlling plant development.

Measuring EC in the root zone is a practical method to adjust nutrient supply because the conductivity of the solution is directly proportional to the amount of salts dissolved in the solution [37]. This means if the solution has high conductivity, there is a high concentration of salts. The salinity of the solution has an intense effect on osmotic potential resulting in the decrease in the uptake of nutrients and water [34,38]. It has also been reported that salinity or high EC reduces the nutritional status and yield [33,37]. However, the effect of salt differs from species to species. Halophytes are a group of plants that have evolved to withstand highly saline conditions and the effect of salinity is minimal compared to normal plants. This means thorough research needs to be conducted per species in order to determine the precise tolerance to salinity.

Not all plants are sensitive to high salt levels and there are plants that have evolved in saline regions and prefer high salt levels in their root zone such as halophytes including *T. ciliata*. Growth media that are used in hydroponics usually have a neutral EC and pH [39]. It is, therefore, important not to ignore the role of growth media in ensuring the successful hydroponic cultivation of halophytes and plants in general. The growth medium plays an important role in successful cultivation as it plays the role of being an anchor and allows for gas exchange and holds water and nutrients [37,39].

The importance of growing substrates in hydroponics

Soil is a natural growth media for all plants and all plants naturally occur in different areas in which different soil types are found. However, the use of soil in the greenhouse and commercial cultivation has created many problems such as undesirable microbial activities, soil-borne diseases, and nematodes resulting in varying salinity, acidity levels, poor nutrient levels, poor drainage, and other undesirable soil characters [40]. The most innovative technology of plants growing in greenhouses, the soil has been replaced by numerous organic and inorganic substrates such as rockwool, vermiculite, perlite, peat, leca clay, silica sand, and others [33,41]. These substrates are disease and pest-free materials that can support the plants, hold sufficient moisture required by plants to grow and can be reused for many years [42]. The origin of these media is different, some of them are of natural origin and some are produced artificially and they are also different in their chemical, physical, and biological properties. Consequently, a medium selection is one of the most significant factors influencing plant growth and development in the greenhouse and affecting crop quality [41,42].

Growing substrate plays four significant roles in the plant. It supplies nutrients to the plant, allows for gas exchange to and from the roots, allows for the provision of water to the plant roots, and provides support as an anchor for the plant [39,42]. Mahjoor *et al.* [37] state that the use of soilless growing medium allows for more effective and efficient use of water and fertilizer, and thus minimize the need for use of chemicals for pests and diseases. *T. ciliata* naturally grow on the sand dunes [17], but studies have shown that plants can perform better in other soils in greenhouse cultivation compared to their natural soils [41,42].

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CONCLUSION

Highly saline and coastal lands occurring in abundance around the coast of South Africa are seen as unusable production areas for conventional crop cultivation. The potential of this land can be explored to experiment with possible salt-tolerant crops as a substitute to the conventional vegetable crops which demand high water supplies in cultivation. This also necessitates the development of more efficient technological innovations such as hydroponics to counter the predicted water crisis. This phenomenon, therefore, calls for more research studies to be conducted on edible salt-tolerant halophytic plants. Halophytic plants such as *T. ciliata* have the potential to become an important vegetable crop in the predicted dry seasons because of their resiliency to withstand highly saline and dry conditions. Based on little information from literature that the plant was consumed by the Khoi-san people who lived in the western Cape coast in the past, findings from this review are recommended as points of reference for researchers, food enthusiasts, potential farmers and policy makers. The review also suggests further studies on the hydroponic propagation of *T. ciliata* and establishment of its hydroponic growth protocol to partially address the issue of water scarcity and food insecurity. It recommends further studies on breeding of this plant to produce varieties with high yields and nutrition.

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