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## Possible implications of climate change on the medicinal properties of *Bulbine* species with a particular focus on *Bulbine abyssinica*, *Bulbine frutescens* and *Bulbine natalensis* in South Africa

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### Abstract

*Bulbine abyssinica*, *Bulbine frutescens* and *Bulbine natalensis* of the *Asphodelaceae* family have been used for many years, traditionally for the treatment of skin related conditions such as wounds, scars, burns and rashes. To date, these plants have been studied for various medicinal properties, including antioxidant, antimicrobial, anti-inflammatory, anti-diabetic and even anti-platelet activity. This review article aims to discuss the ethnobotanical uses and medicinal activity from the perspective of abiotic stress impacts, specifically elevated carbon dioxide and high temperature. Literature sources obtained from Google Scholar, Science Direct, theses and books were used to search for the ethnobotanical, traditional uses, and pharmacological studies of the species. In addition, articles around the concurrent and separate studies of elevated CO<sub>2</sub> and temperature impacts on medicinal activities of other medicinal plant species were also sourced for reference purposes because there have not been any reported studies discussing the impacts of the aforementioned abiotic factors on the species.

**Keywords:** ethnobotany, carbon dioxide, high temperature, *Bulbine*, pharmacological activity

### Introduction

The *Bulbine* genus is a member of the family *Asphodelaceae*, which is native to the southern and tropical regions of Africa, as well as in parts of Australia and New Zealand<sup>[1]</sup>. The species are described to have thick storage roots and mesomorphic or occasionally succulent leaves with centrally or unbranched inflorescences<sup>[2, 3]</sup>. The genus have characteristic yellow flowers borne on long stems, with plants ranging in a variety of sizes from bushy caulescent to dwarf groups<sup>[4, 5]</sup>. Traditionally, the uses of *Bulbine* plants was limited only to wound healing and other skin-related conditions such as burns, scars and rashes but since the 18<sup>th</sup> century, the plants have been used to treat other ailments such as stomach ailments, diarrhoea and mouth ulcers<sup>[6]</sup>.

The *Bulbine* species are rich in phytochemicals such as the abundant anthraquinones, isofuranonaphthoquinones, triterpenes, saponins, tannins, alkaloids, phenolic acids and flavonoids which are responsible for their healing properties, of which multiple compounds have been identified under each group<sup>[5]</sup>. Numerous studies have been conducted on the pharmacological potential of the abovementioned phytochemicals, and many of the studied species have shown antiplasmodial, antitrypanosomal, antiviral, anti-inflammatory, antioxidant, antibacterial, antifungal and cytotoxic properties<sup>[5]</sup>. A recent review article by Bodede *et al.* (2020)<sup>[5]</sup> has been greatly referenced in this review particularly on the pharmacological potential of the *Bulbine* species, however, one factor that is often overlooked in medicinal plant analyses is the impacts of abiotic stress, such as high temperature and elevated carbon dioxide stress, on the phytochemical constituents and their efficacy on treating ailments.

The sessile nature of plants makes them vulnerable to all forms of environmental stress. It has been reported that elevated temperatures can affect plant development and growth parameters and inhibit photosynthetic activity<sup>[7, 8]</sup>. Projections show that heat waves are also becoming more frequent and last longer periods, with short-term events spanning over a few days and temperatures increasing over 5 °C above average<sup>[9-11]</sup>.

Atmospheric carbon dioxide plays a vital role in primary metabolic functions such as photosynthesis, with reports of increased biomass in aerial and underground plant organs due to cellular expansion and growth<sup>[12]</sup>. Evidence shows that elevated CO<sub>2</sub> increases carbohydrate

utilization via respiration, resulting in the increase in carbon fixation, further increasing energy and biochemical precursors to promote leaf growth<sup>[12]</sup>. Although carbon dioxide seems to have a positive effect on overall plant growth, changes in climate could potentially cause carbon dioxide to produce negative effects on plants<sup>[12, 13]</sup>. Although there has been sufficient studies documented on the ethnobotanical and medicinal properties of *B. abyssinica*, *B. frutescens* and *B. natalensis*, to date, no available studies have been recorded on the impacts of abiotic stress impacts, particularly elevated CO<sub>2</sub> and high temperature stress. This review will discuss the ethnobotany and medicinal activity of three commonly traded and used *Bulbine* species in South Africa i.e. *Bulbine abyssinica*, *Bulbine frutescens* and *Bulbine natalensis*, in the perspective of the possible impacts of elevated carbon dioxide and high temperature stress. This review will aim to promote awareness of climate change impacts on medicinal plants and hopefully increase the amount of studies on the phytochemical impacts and pharmacological potential of medicinal plants exposed to environmental stress conditions.

### Methodology

Literature research was conducted using Google Scholar, Science Direct, theses and books to attain review and scientific articles from a wide collection of journals. These sources were used to search for the ethnobotanical and pharmacological studies with keywords “*Bulbine*”, “*abyssinica*”, “*frutescens*”, “*natalensis*”, “antioxidant”, “antimicrobial”, “antiviral”, “cytotoxic”, “antidiabetic”, “anti-inflammatory”, “anti-platelet”, and “wound healing” being used for the literature search. In addition, studies on abiotic stress impacts on medicinal activity, including elevated CO<sub>2</sub> and temperature aspects, were searched to elaborate on the possible impacts that could be afflicted on *B. abyssinica*, *B. frutescens* and *B. natalensis*.

### Morphology and ethnomedicinal uses

#### *Bulbine abyssinica*

*Bulbine abyssinica*, commonly referred to as bushy *Bulbine* (English), intelezi (Xhosa), ibhucu (Zulu), of which the latter two are also used to refer to *B. frutescens* and *B. natalensis*, moetsa-mollo (Sotho) and geelkatstert (Afrikaans)<sup>[14, 15]</sup>, is a perennial herb with a rhizomatous base that grows in small clusters<sup>[15]</sup>. The leaves are described as soft, dark green and grass-like which grow up to 35 centimetres in length<sup>[15]</sup>. This plant bears black fruits of about four millimetres in diameter when mature and are often covered with a faded perianth<sup>[15]</sup>. This species grows on rocky grassland and shallow soil overlying rock, as well as in woodlands<sup>[14, 15]</sup>. *B. abyssinica* can be found in the Eastern Cape Province, Kwa Zulu Natal Province, eSwatini, Lesotho and as far as Ethiopia and Angola<sup>[3, 15, 16]</sup>. *Bulbine abyssinica* is used to treat various ailments including rheumatism, dysentery, bilharzia and cracked lips<sup>[15, 17]</sup>. Van Wyk *et al.* (2008)<sup>[17]</sup> reported that the decoction of *B. abyssinica* roots are used to treat infertility and back pain, and the leaves are administered as tea for the treatment of coughs, vaginal and bladder infections<sup>[15]</sup>. *B. abyssinica* is well known and studied for its use in the management of diabetes mellitus<sup>[15, 18]</sup>. In the Eastern Cape Province, the plant is one of the two most traded *Bulbine* species<sup>[5, 19]</sup>, and its leaves are also used in ethnoveterinary medicine as an anti-helminthic for cattle<sup>[20]</sup>.

#### *Bulbine frutescens*

*Bulbine frutescens* is a perennial subshrub with a woody base and mainly subterranean roots<sup>[3]</sup>. The leaves are said to be

onion-like and green with either an erect or slightly erect inflorescence<sup>[3, 16]</sup>. The plant grows well in sandy soil and flowers all year round<sup>[2, 3]</sup>. *B. frutescens* is mostly found in the Eastern Cape Province but they are also common in the western parts of South Africa<sup>[3, 16]</sup>.

*Bulbine frutescens* is commonly known as intelezi, burn jelly plant, ingelwane (Zulu), ibhucu, ithethe elimpofu (Zulu) and rankkopieva (Afrikaans)<sup>[17, 21, 22]</sup> and is the most used *Bulbine* species by traditional healers<sup>[6]</sup>. The leaves contain a gel fluid that is used as an anti-clotting agent as well as for the treatment of acne, burns, cold sores, insect bites, rashes, mouth ulcers and ringworms<sup>[23]</sup>. Similar to *B. abyssinica*, *B. frutescens* is also used as an anti-helminthic for cattle<sup>[20]</sup>.

#### *Bulbine natalensis*

*Bulbine natalensis*, commonly known as rooiwortel (Afrikaans) and ibhucu, is described as a frost tender evergreen plant characterised by its broad, aloe-like fleshy yellow-green leaves<sup>[24]</sup>. The stems bearing yellow flowers are curved erect and grow up to three times longer than the leaves<sup>[3]</sup>. The plant thrives in rocky areas with nutrient-poor soil<sup>[3, 25]</sup>. The distribution of *B. natalensis* ranges across central, eastern and northern South Africa as well as Zimbabwe and Mozambique<sup>[3, 16, 24]</sup>.

The leaf gel is mostly used to treat skin-related ailments much like most *Bulbine* species, such as wounds, rashes and ringworms and the roots are infused and administered orally to treat vomiting and diarrhoea, convulsions, venereal diseases, diabetes and blood disorders<sup>[24, 26, 27]</sup>. The underground stem or corm has been greatly studied for its potential use as a fertility booster for men<sup>[28]</sup>.

### Pharmacological activity

#### Antioxidant activity

Various authors have reported the antioxidant potential of *B. abyssinica*, *B. frutescens* and *B. natalensis* with all stating that they possess good to excellent antioxidant activity. A study by Kibiti *et al.* (2015)<sup>[29]</sup> looked into the polyphenolic content and antioxidant activity of whole plant (leaves, stems, roots and flowers) *B. abyssinica*. The results showed that *B. abyssinica* had an overall good antioxidant activity, with the aqueous extracts yielding a higher activity in comparison to the acetone extracts at various concentrations (2, 2 diphenylpicrylhydrazyl (DPPH): 0.5 mg/ml; lipid peroxide: 0.5 mg/ml; nitric oxide: aqueous - 0.025 mg/ml, acetone - 0.2 mg/ml; hydrogen peroxide: 0.025 mg/ml; 2, 2'-azino-Bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS): aqueous - 0.5 mg/ml, acetone - 0.2 mg/ml). Shikalepo *et al.* (2017)<sup>[30]</sup> assessed the antioxidant activity in *B. frutescens*. The DPPH and hydrogen peroxide scavenging assays show that *B. frutescens* exhibited excellent antioxidant activity, with IC<sub>50</sub> values showing inhibition at 17.94 and 27.03 µg/ml respectively, with increasing concentration of the extracts leading to an increase in their reducing power. Ghuman *et al.* (2019)<sup>[31]</sup> revealed that *B. frutescens* leaves and *B. natalensis* roots exhibited excellent antioxidant activity with DPPH radical scavenging showing EC<sub>50</sub> values of 0.053 µg/ml and 0.006 µg/ml respectively.

#### Antimicrobial activity

Mocktar (2000)<sup>[3]</sup> assessed the antibacterial and antifungal activity of *B. abyssinica*, *B. frutescens* and *B. natalensis*. The organic solvent and aqueous extracts of *B. natalensis* leaves showed the least antibacterial activity, whereas the stem and root extracts showed significant inhibition against *Bacillus*

*subtilis*, *Micrococcus luteus*, *Proteus mirabilis*, *Staphylococcus aureus* and *Staphylococcus epidermidis*. The organic solvent leaf extracts of *B. frutescens* showed inhibitory activity against *P. mirabilis* and *S. aureus*, however, the aqueous leaf and root extracts, as well as organic solvent root extracts showed the least antibacterial activity. The organic solvent leaf extracts of *B. abyssinica* exhibited the greatest inhibitory activity against *Pseudomonas aeruginosa*, however the roots displayed the least antibacterial activity. All the plants did not display any antifungal activity against *Penicillium*, however the underground stems and roots of *B. natalensis* showed some antifungal activity against *Aspergillus*.

Kibiti *et al.* (2015) [29] analysed whole plant *B. abyssinica* against eight diabetic status opportunistic bacteria. The results obtained showed that *B. abyssinica* acetone and aqueous extracts had positive inhibition against *Shigella flexneri*, *P. aeruginosa*, *S. aureus*, *Enterococcus faecalis*, *Klebsiella pneumoniae*, *Streptococcus pyogenes* and *Proteus vulgaris*, with zones of inhibition varying from 12 to 41 mm. The overall mean inhibition diameters of the acetone extract was slightly higher (18.95 mm) as compared to the aqueous extract (17.09 mm). Both aqueous and acetone extracts had no inhibitory activity against *Serratia marcescens*. The minimum inhibitory concentration (MIC) was also observed with varying concentrations between 5 and 0.0005 mg/ml of both extracts, with the lowest MIC of 0.31 mg/ml for the acetone extracts observed against *S. aureus*, *P. aeruginosa* and *E. faecalis* and the aqueous extract showed the lowest MIC activity against *S. aureus* (0.078 mg/ml) and *S. flexneri* (0.31 mg/ml). Three phytosterols, namely ergosterol, stigmasterol and sitosterol, isolated from the underground stems of *B. natalensis* were tested against three fungal strains (*Aspergillus flavus*, *Fusarium verticilloides* and *Penicillium digitatum*) by Mbambo *et al.* (2012) [32]. Ergosterol was discovered to have yielded the highest inhibition zone diameter across all three strains, however, stigmasterol and sitosterol exhibited better antifungal activity than the antifungal drug Amphotericin B.

The antifungal potential of whole plant *B. abyssinica* was analysed by Kibiti *et al.* (2016) [15], with recordings showing that the plant had proven to be effective against three fungi isolates, namely *Microsporum canis*, *Microsporum gypseum* and *Trichophyton rubrum* out of nine fungi isolates with zones of inhibition ranging between 19 and 33.3 mm.

#### Antiviral activity

A variety of *Bulbine* species have been traditionally used for the treatment of viral infections including HIV/AIDS, chickenpox and herpes simplex [5]. Of the three species, so far only *B. frutescens* has been scientifically studied for its use in HIV/AIDS treatment. Shikalepo *et al.* (2017) [30] analysed the ethanol extracts of *B. frutescens* leaves to test for *in-vitro* inhibitory activity on three HIV enzymes, namely HIV-1 protease (PR), reverse transcriptase (RT) and integrase. The extracts demonstrated a good inhibitory activity against HIV-1 PR and RT with IC50 values of 0.18 mg/ml and 0.52 mg/ml respectively. These findings could expand research on HIV/AIDS treatment with other *Bulbine* species.

#### Anti-inflammatory activity

The analysis of whole plant *B. abyssinica* was conducted by Kibiti *et al.* (2016) [15] against protein denaturation and erythrocyte membrane lysis. The acetone extract showed the highest protein inhibition effect as compared to the aqueous extract and the standard drug with IC50 values of 215 µg/ml,

330 µg/ml and 312 µg/ml respectively. The results of the erythrocyte membrane lysis showed that the aqueous extracts yielded a higher protection against membrane lysis compared to the acetone extract. The results show that *B. abyssinica* has a good anti-inflammatory properties.

Ghuman *et al.* (2019) [31] tested the anti-inflammatory activity of various medicinal plants, of which *B. frutescens* and *B. natalensis* were included and the results revealed that the leaf extracts of *B. frutescens* and the root extracts of *B. natalensis* were amongst eight out of 11 species that exhibited excellent inhibition of nitric oxide, with IC50 values of 26.32 µg/ml and 28.64 µg/ml respectively. In addition, *B. natalensis* leaf extracts exhibited significantly high lipoxygenase inhibitory activity (6.93 µg/ml).

#### Cytotoxicity/anti-cancer activity

Kuroda *et al.* (2003) [33] revealed that the anthraquinone anthrone originally isolated from *B. frutescens* roots and *B. natalensis* rhizomes [34] has shown significant tumour-specific cytotoxicity against human squamous carcinoma (HSC-2) cells. Habtemariam (2010) [35] discovered that a knipholone derivative, knipholone-anthrone isolated from *B. abyssinica* and *B. frutescens* roots [36] presented better results when tested on leukemic cell lines with IC50 values ranging from 0.5 to 3.3 µM. [5]. The bulbs from *B. frutescens* were tested for their efficacy to induce apoptosis in breast cancer cells by Kushwaha *et al.* (2019) [37]. The gas chromatography-mass spectrophotometry (GC-MS) analysis discovered that the hexane and methanol extracts significantly decreased cell viability (IC50 of 4.8-28.4 µg/ml) inducing cell cycle arrest at G1 phase in both triple negative (MDA-MB-231) and luminal (T47D) breast cancer cells. The results from fluorescent spectroscopy and confocal microscopy further showed that the extracts induced the nuclear morphology and mitochondrial integrity disruption, increasing ROS production in both cells.

#### Anti-platelet activity

Several authors have analysed *B. natalensis*' anti-platelet activities, the ability to prevent the clotting of blood, with all confirming its potential. Mosa *et al.* (2011) [38] discovered that the chloroform extracts of *B. natalensis* exhibited the highest anti-platelet aggregation activity with an IC50 value of 0.43 mg/ml. Lazarus (2012) [24] also discovered that the chloroform extracts from *B. natalensis* leaves inhibited ADP-induced clotting by 100% at doses of 1 and 3 mg/ml with IC50 values of 5.32 mg/ml.

#### Anti-diabetic activity

Of the three *Bulbine* species, to date, only *B. abyssinica* has been scientifically analysed for its use in diabetes management in South Africa. Odeyemi *et al.* (2018) [39] assessed the antidiabetic potential of *B. abyssinica* leaf extracts. The results showed that the extracts exhibited anti-diabetic activity with an IC50 value of 140 and 68.58 µg/ml for  $\alpha$ -amylase and  $\alpha$ -glucosidase inhibitory activities respectively meaning that *B. abyssinica* has anti-diabetic potential. Odeyemi *et al.* (2018) [39] reported the uses of *B. natalensis* for the management of diabetes, but according to Musara *et al.* (2020) [40], there has not been any study conducted on the antidiabetic activity of the plant.

#### Wound healing

The wound healing abilities of *B. frutescens* was analysed against *Centella asiatica* by Widegrow *et al.* (2000) [41]. The

findings showed that *B. frutescens* increased hydration, leaving behind a glycoprotein layer on the skin surface which assisted wound recovery time. Pather (2009) [42] tested the effectiveness of *B. frutescens* and *B. natalensis* leaf extracts on wound contraction using pig skins with results showing that both plant extracts enhanced wound contraction, increasing collagen deposition and the presence of myofibrils which both play an important role in wound healing. Pather *et al.* (2011) [43] further discovered that the leaf gels positively affect collagen synthesis leading to faster wound healing.

All the aforementioned scientific findings prove the ethnomedicinal uses of *B. abyssinica*, *B. frutescens* and *B. natalensis* for a wide variety of illnesses and diseases. As useful and important as these findings are, not just to the science and indigenous communities, but to pharmaceutical and cosmetic industries, it would be much more beneficial to continue pharmacological research in the perspective of environmental stress, because these plants are exposed to a range of abiotic and biotic factors which could potentially affect their overall medicinal activity.

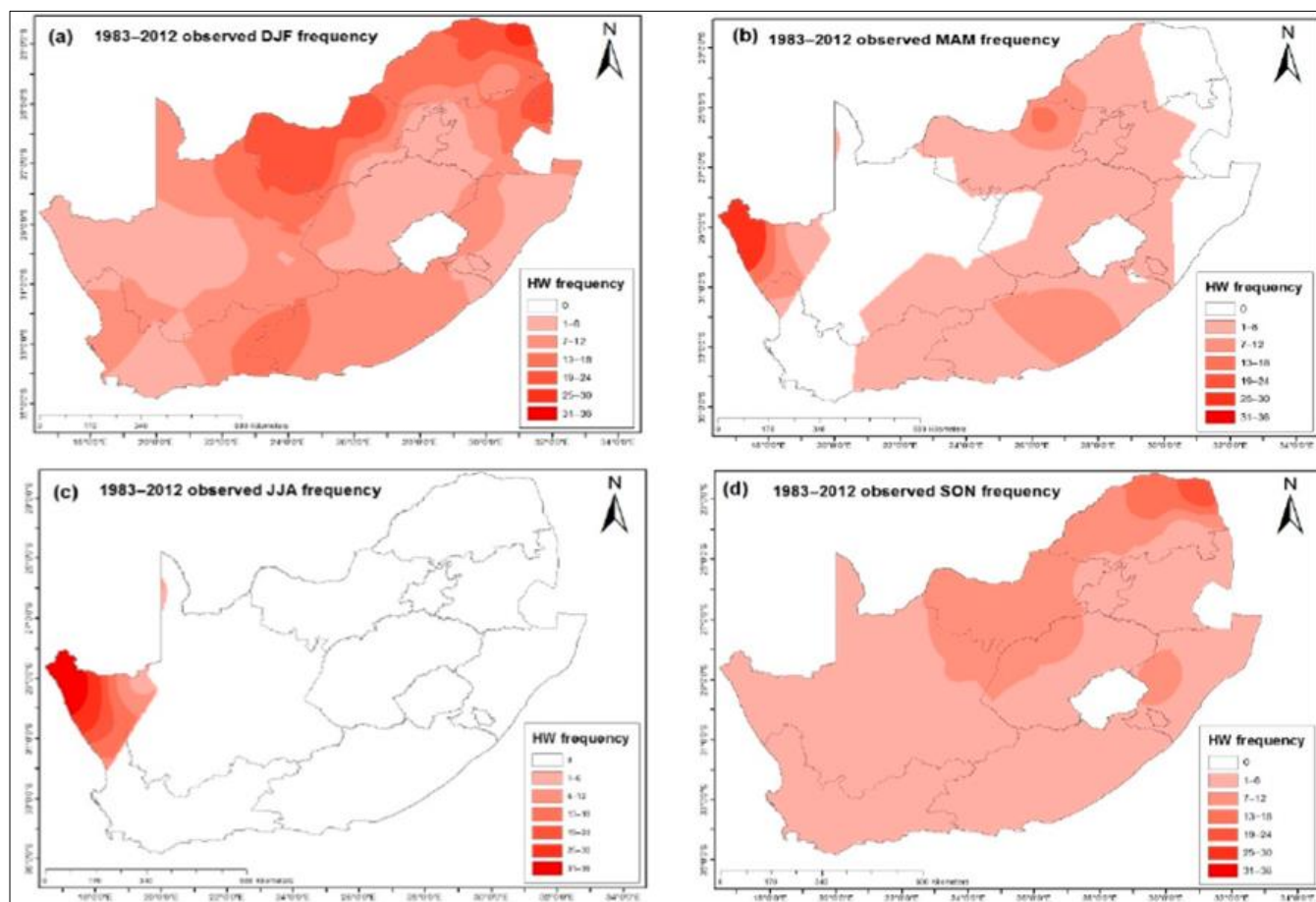
### Abiotic stress: how do high temperatures and elevated carbon dioxide impact medicinal plant pharmacological activity?

#### High temperature stress

Plants have specific temperature limits or thresholds when they can optimally function, and should temperatures rise

above this threshold that could possibly cause irreversible damage to their growth and development [7, 44]. It has been reported that by the end of the 21st century, there will be an increase in average global temperatures between 2.6-4.8 °C, and with this being said, the balance between ROS production and elimination in plants could be disrupted [45, 46]. In South African context, temperatures are expected to increase up to 6 °C before the end of the 21st century [47-49]. Although these predictions are estimated to occur decades later, certain areas in South Africa are already experiencing high average temperatures such as Port Elizabeth in the Eastern Cape Province (38.7 °C), Bloemfontein in the Free State Province (40 °C), Beaufort West in the Western Cape Province (42.3 °C) and Upington in the Northern Cape Province (42.4 °C) in 2019 [50].

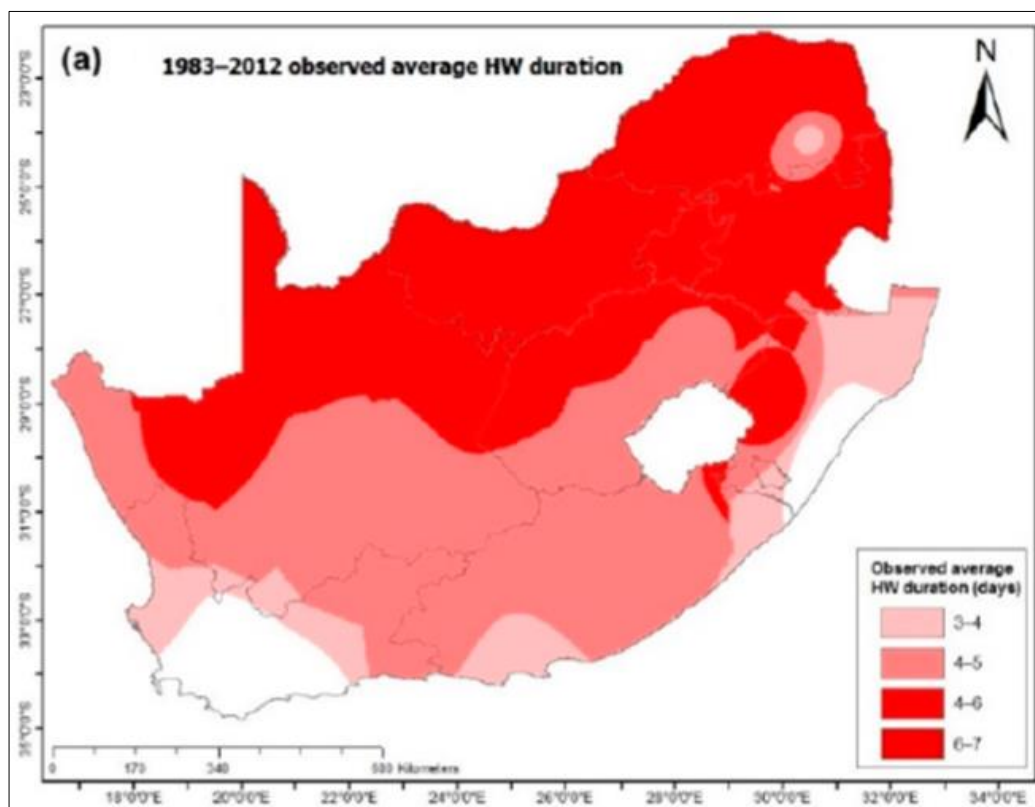
Heat waves are also a concerning issue in relation to the rise in average maximum temperatures. A heat wave, according to the South African Weather Service, is described as an event when the observed or simulated temperature is 5 °C or higher than the daily average maximum temperature of the hottest month and lasts for a minimum of three consecutive days [51]. Heat waves are mostly common and intense during the summer period between December and February in South Africa, however they do also occur during other seasons (Figure 1) [51].



**Fig 1:** Observed heat wave frequencies in South Africa between 1983 and 2012 [51].

During the period of 1983-2012, the northern, and north-western parts on South Africa have experienced between four to seven consecutive days of heat waves, whereas the rest of the country experienced between three to five days of heat waves (Figure 2) [51]. It has been projected that the frequency

of heat waves will be much higher in the next decade, with the eastern and northern parts of South Africa experiencing over 80 heat wave events and the western parts having less than 10 events [51].



**Fig 2:** Observed heat wave duration (days) in South Africa between 1983 and 2012<sup>51</sup>.

There are several documented studies that show that an increase in antioxidant activity is a result of the increase in secondary metabolites due to high temperature stress. Kumar *et al.* (2017) <sup>[52]</sup> assessed total phenolic compounds in *Aloe vera* (L.) Burm.f. from arid, semi-arid, highland, and tropical wet and dry conditions each with different temperature ranges between 7 °C and 35 °C. The results showed that the plants from highland and semi-arid areas presented the highest total phenolic content, which correlated with the increase in antioxidant activity. Boutakiout *et al.* (2018) <sup>[53]</sup> analysed the seasonal effects in phenolic compounds and antioxidant activity in the cladode juices of two prickly pear species *Opuntia ficus indica* and *Opuntia megacantha*. They reported that phenolic content and antioxidant activity were significantly higher during summer when temperatures reached highs of 48 °C compared to winter and spring. The abovementioned studies have clearly illustrated the impacts of high temperatures on polyphenolic content and antioxidant activity, which presents an idea on how plants respond to such stress. A study on the total phenols and o-diphenols of olive trees (*Olea europaea* L.) from three different temperature regions in Tunisia was analysed by Mansour-Gueddes (2020) <sup>[54]</sup>. The results showed a higher content of phenolic compounds from leaves collected in areas with higher temperatures, coupled with drought. The increase in phenolic compounds corresponded with the increase in antioxidant activity. Netshiluvhi *et al.* (2019) <sup>[55]</sup> analysed the antimicrobial activity of *B. frutescens* under temperature stress regimes of 15 and 30 °C respectively. The results showed that all the leaf extracts exhibited intermediate antimicrobial activity with MIC values ranging from 0.42 to 2.50 mg/ml across both temperature regimes, showing no statistical significant difference in the MIC values and total activity. They further stated that *B. frutescens* showed significantly higher total activity at 30 °C compared to the other two species. This means that the cultivation of

medicinal plants potentially yield better biological activity than plants harvested in the wild.

It is of great importance to carry out such research on our indigenous medicinal plant species, such as *B. abyssinica*, *B. frutescens* and *B. natalensis*, in order to determine whether their response to high temperatures follows the same trend as other plant species. This would be extremely useful in the context of understanding their adaptation, sustainability and medicinal efficacy when under stress.

### Impacts of elevated carbon dioxide

Carbon dioxide is the most potent greenhouse gas in the atmosphere <sup>[56]</sup>. Plants rely on this gas for metabolic functions such as photosynthesis. Carbon dioxide also plays a role in the production and accumulation of secondary metabolites <sup>[57, 58]</sup>. Projections state that the global CO<sub>2</sub> concentrations will have increased by 50%, reaching new highs ranging between 730-1020 ppm (parts per million) over the next 50 years <sup>[12, 13]</sup>. Numerous studies have reported on the impacts of elevated CO<sub>2</sub> on phenolic compounds and their findings appear to indicate that elevated CO<sub>2</sub> results in an increase in the production of phenolic compounds. Goufo *et al.* (2014) <sup>[59]</sup> reported an increase in total phenolic and total flavonoid compounds in mature rice plants (*Oryza sativa* L.) under a CO<sub>2</sub> concentration of 550 μmol/mol. They also suggested that the increase in the phenolic compounds could be due to the increase in photosynthetic activity in the mature rice plants. Wang *et al.* (2003) <sup>[60]</sup> discovered that elevated CO<sub>2</sub> concentrations at 300 and 600 μmol.mol<sup>-1</sup> increased non-enzymatic antioxidants such as ascorbic acid and glutathione among others, as well as flavonoids, anthocyanins and phenolic acids in strawberries (*Fragaria x ananassa* Duch.). The strawberries grown at 600 μmol.mol<sup>-1</sup> presented a higher antioxidant activity in comparison to those grown at 300 μmol.mol<sup>-1</sup>. A similar response reported by Ibrahim *et al.* (2012) <sup>[61]</sup> reported that both total phenolic and total flavonoid

contents as well as antioxidant activity increased as CO<sub>2</sub> concentration increased (400  $\mu\text{mol}\cdot\text{mol}^{-1}$ , 800  $\mu\text{mol}\cdot\text{mol}^{-1}$  and 1200  $\mu\text{mol}\cdot\text{mol}^{-1}$ ) with the latter concentration yielding the highest content of polyphenolic compounds in oil palm seedlings (*Eleais guineensis*).

It is clear that climate change is causing drastic effects not only on the evident temperature and atmospheric CO<sub>2</sub> changes, but also on the life cycle, distribution and phytochemical composition of medicinal plants<sup>[62]</sup>. It has also been stated that climate change also increases the risk of human related illnesses and diseases ranging from temperature related illness such as heat strokes, to the increase

in vector-borne diseases like malaria (Fig. 3)<sup>[63, 64]</sup>. Therefore it is necessary to conduct more research on medicinal plants, in order to possibly develop products that can help aid this increased risk of illnesses. There are limited studies on the impacts of environmental stress such as elevated CO<sub>2</sub> and high temperatures on the medicinal efficacy of *B. abyssinica*, *B. frutescens* and *B. natalensis*. Conducting research on this aspect will contribute to the knowledge of pharmacological implications of the species in the perspective of climate change which is worth investigating, for the sake of both indigenous and scientific communities.

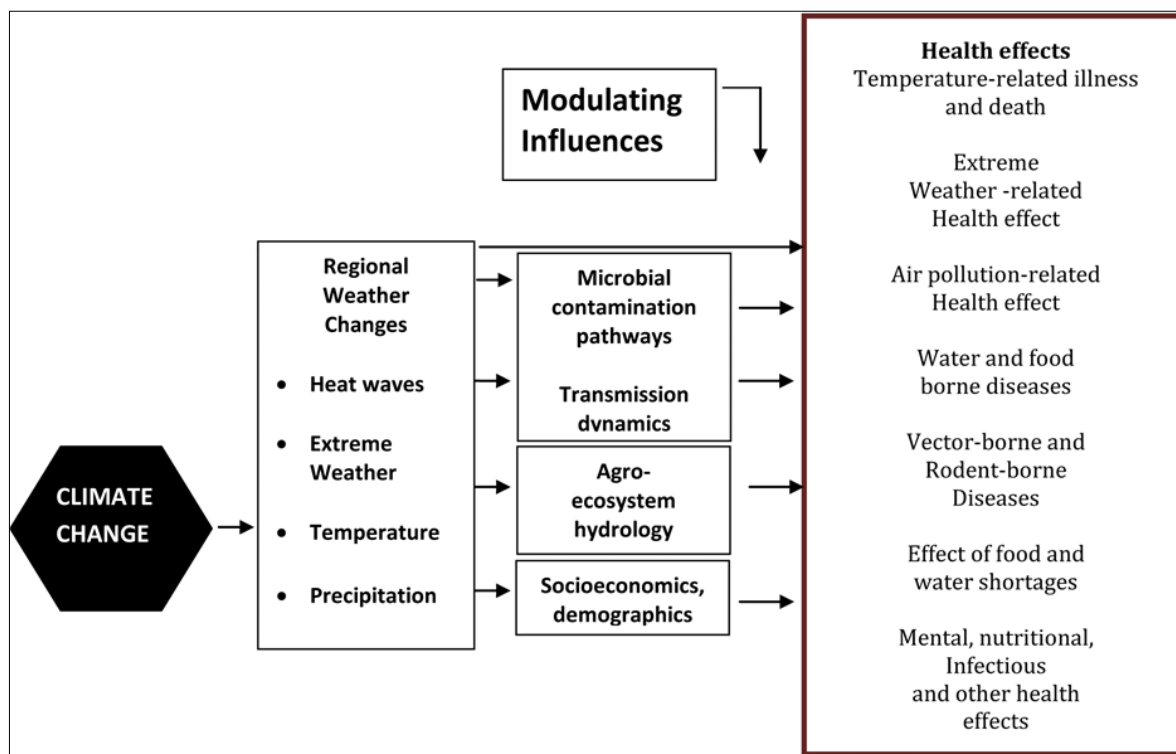


Fig 3: Impacts of climate change on weather patterns and human health<sup>[63, 64]</sup>.

## Conclusion

There has been extensive research on the morphological, physiological and biochemical responses of plants to extreme temperatures and elevated CO<sub>2</sub>, however, limited research exists on how these abiotic stress factors affect the medicinal activity of *B. abyssinica*, *B. frutescens* and *B. natalensis*, with the exception of temperature and water stress effects on the antimicrobial activity of *B. frutescens*. Although there are documented studies on the medicinal activities and phytochemical identification and isolation of these three species, to date, there have not been any available reports on how abiotic stress such as high temperatures and elevated CO<sub>2</sub> will affect their medicinal properties. Research in the general environmental stress aspect could contribute to the knowledge as to how these plants adapt under stress in natural environments, and by conducting studies on their pharmacological properties could provide new knowledge on whether a change in medicinal activity would drastically change the plants abilities to treat illness and diseases for the better or the worse.

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