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Review

Diversity and Conservation Through Cultivation of *Hypoxis* in Africa—A Case Study of *Hypoxis hemerocallidea*

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Abstract: Africa has the largest diversity of the genus *Hypoxis*, accounting for 61% of the current globally accepted taxa within the genus, including some endemic species. Using *Hypoxis hemerocallidea* as a case study, this review addresses the conservation concerns arising from the unsustainable, wild harvesting of a number of *Hypoxis* species. *Hypoxis hemerocallidea* is one of the wild-harvested, economically important, indigenous medicinal plants of southern Africa, with potential in natural product and drug development. There are several products made from the species, including capsules, tinctures, tonics and creams that are available in the market. The use of *H. hemerocallidea* as a "cure-all" medicine puts an important harvesting pressure on the species. Unsustainable harvesting causes a continuing decline of its populations and it is therefore of high priority for conservation, including a strong case to cultivate the species. Reviewing the current knowledge and gaps on cultivation of *H. hemerocallidea,* we suggest the creation of a platform for linking all the stakeholders in the industry.

Keywords: African potato; conservation; commercialization; cultivation; Hypoxidaceae; medicinal plant; unsustainable harvesting; wild harvesting

1. Introduction

The African continent is known for its rich floral biodiversity, high levels of endemism [1] and increasing reliance on its natural resources based on its indigenous knowledge systems, for economic growth and development. The increasing reliance of a growing population coupled with other factors such as habitat destruction, alien species invasion and other anthropogenic factors has resulted in an increasing strain on African plant diversity, creating the need for urgent biodiversity conservation interventions [2]. Globally, there are 119 accepted taxa, including species and infra-species levels within the genus *Hypoxis* [3]. Using the latest information from the African Plant database [4], there are 72 of these taxa with accepted names [3,5] that are naturally distributed in tropical Africa, southern Africa, North Africa and Madagascar (Table 1). According to Balogun et al. [6], about 40 *Hypoxis* species are known in southern Africa, which is regarded as the main center of the species diversity and endemism [7]. Some of the species have been grouped into another genera following recent taxonomic reclassification [3,5]. About 32 *Hypoxis* species were recorded in Tropical East Africa including Uganda, Kenya, and Tanzania [8]. *Hypoxis* species are regarded as valuable medicinal plants for the treatment of numerous ailments in most parts of Africa [9]. In southern Africa, *Hypoxis* *hemerocallidea* is the top *Hypoxis* species with commercial value, seconded by *H. colchicifolia* [10,11]. This review therefore focuses on *H. hemerocallidea* as a case study of species within the genus although other African *Hypoxis* species of medicinal importance are also highlighted.

Hypoxis hemerocallidea Fisch., C.A.Mey. & Avé-Lall. (family: Hypoxidaceae), commonly known as African potato, iLabatheka, iNkomfe, moli and star flower, is listed in southern Africa as one of the indigenous medicinal plants with potential in natural product and drug development [12–14], hence being one of the commercially important medicinal plants in the region. It is the only *Hypoxis* species listed among the 51 plant species in the African Herbal Pharmacopoeia [15]. The commonly used part is its corms. Thus, during harvesting the corms are dug out, killing the plant [16,17]. This has most likely led to a decline in its wild populations and thus the need for conservation strategies [15]. The current review paper aims at discussing the cultivation of *H. hemerocallidea* as a conservation strategy, research work and information generated in the cultivation of the species, and recommendations going forward, which can be applicable to other *Hypoxis* species.

Hypoxis Species in Africa

The African continent alone accounts for 61% (N = 72) of the current globally accepted taxa within the genus *Hypoxis*. Some of the taxa such as *H. fischerii* var. *hockii* (De Wild.) Wiland & Nordal, *H. fischerii* var. *zernyi* (G. M. Schulze) Wiland & Nordal, *H. gregoriana* Rendle, *H. kilimanjarica* subsp. *kilimanjarica*, *H. kilimanjarica* subsp. *prostrata* E. M. Holt & Staubo and *H. urceolata* Nel are endemic to East Tropical Africa [8]. Many *Hypoxis* species are used in the management of HIV/AIDS, cancer, tuberculosis, sexually transmitted diseases and infertility (Table 1), because of their similarity in chemical constituents [18]. As a result, some of these taxa are used interchangeably in African Traditional Medicine [8]. For example, *H. angustifolia* Lam, *H. goetzei* Harms, *H. nyasica* Baker, and *H. obtusa* Burch. ex Ker Gawl. are all used in traditional medicine for similar purposes in Tanzania [7]. The corm is often the plant part used and its harvest is rather unsustainable and might lead to decimation of natural populations. At present, only *Hypoxis malaissei* Wiland has been listed in the IUCN Red List of Threatened Species [19] as 'Data Deficient'. However, this species and *H. fischeri* var. *katangensis* (De Wild.) Wiland & Nordal are suggested to be in the East Tropical Africa 'Critically Endangered' list [8]. Most species only appear on National Red List Data as 'Least Concern', but *H. fischeri* var. *colliculata* (Wiland) Wiland & Nordal, *H. kilimanjarica* Baker, *H. kilimanjarica* subsp. *Prostrata.*, and *H. polystachya* Welw. ex Baker are listed as 'Vulnerable' in the East Tropical Africa [8], and five other species are listed as 'Near Threatened' (Table 1).

Table 1. *Hypoxis* species diversity in Africa (adapted from African Plant Database [4]).

Plant Species	Synonyms of the Accepted Names	[2] Distribution in Africa	Plant Part(s) Used	Nature of Diseases/Condition Plant is Used Against	Conservation Status	Main Threats	Reference
[1] ***Hypoxis abyssinica* Hochst. ex A. Rich.**	*Hypoxis boranensis* Cufod.; *Hypoxis neghellensis* Cufod.; *Hypoxis petitiana* A.Rich.; *Hypoxis schweinfurthiana* Nel; *Hypoxis simensis* Hochst.; *Hypoxis tristycha* Cufod.	TA					
***Hypoxis acuminata* Baker**		SA			LC*		
***Hypoxis angustifolia* Lam.**	*Hypoxis angustifolia* var. angustifolia; *Hypoxis biflora* Baker	MA-SA-TA	Corm	Skin ulcers, HIV/AIDS, wounds, sickle cell diseases, ringorms	LC*		[7,8,20]
***Hypoxis angustifolia* var. buchananii Baker**	*Hypoxis obliqua* var. woodii (Baker) Nel; *Hypoxis woodii* Baker	SA			LC*		
***Hypoxis angustifolia* var. luzuloides (Robyns & Tournay) Wiland**	*Hypoxis luzuloides* Robyns & Tournay	MA-TA			LC@		[8]
***Hypoxis angustifolia* var. madagascariensis Wiland**		MA					
***Hypoxis argentea* Harv. ex Baker**	*Hypoxis argentea* var. argentea	SA-TA	Corm	Stomachache, diarrhoea	LC*		[21]
***Hypoxis argentea* var. sericea (Baker) Baker**	*Hypoxis argentea* var. flaccida (Baker) Baker; *Hypoxis dregei* (Baker) Nel; *Hypoxis sericea* Baker; *Hypoxis sericea* var. dregei Baker; *Hypoxis sericea* var. flaccida Baker	SA-TA	Corm	Diabetes	LC*		[22]
***Hypoxis bampsiana* subsp. tomentosa Wiland**		TA			NT@	Overgrazing, tree cutting, soil erosion, agriculture	[8]
***Hypoxis bampsiana* Wiland**	*Hypoxis bampsiana* subsp. bampsiana	TA					
***Hypoxis camerooniana* Baker**	*Hypoxis lanceolata* Nel; *Hypoxis ledermannii* Nel; *Hypoxis petrosa* Nel; *Hypoxis recurva* (Baker) Nel; *Hypoxis thorbeckei*	TA					

	Nel; *Hypoxis villosa* var. recurva Baker						
***Hypoxis canaliculata* Baker**		TA					
***Hypoxis colchicifolia* Baker**	*Hypoxis distachya* Nel; *Hypoxis gilgiana* Nel; *Hypoxis latifolia* Hook.; *Hypoxis oligotricha* Baker	SA	Corm	Diabetes, cancer, osteoporosis, purgative	LC*		[7,20–23]
		SA					
***Hypoxis costata* Baker**		SA-TA			LC*		
***Hypoxis cuanzensis* Welw. ex Baker**		TA					
***Hypoxis decumbens* L.**	*Anthericum ensiforme* Vell.; *Anthericum sessile* Mill.; *Hypoxis breviscapa* Kunth; *Hypoxis caricifolia* Salisb.; *Hypoxis decumbens* var. dolichocarpa G.L.Nesom; *Hypoxis decumbens* var. major Seub.; *Hypoxis elongata* Kunth; *Hypoxis gracilis* Lehm.; *Hypoxis pusilla* Kunth; *Hypoxis racemosa* Donn.Sm.; *Niobea nemorosa* Willd. ex Schult. & Schult.f.; *Niobea pratensis* Willd. ex Schult. & Schult.f.	SA					
***Hypoxis demissa* Nel**		TA					
***Hypoxis dinteri* Nel**		SA-TA					
***Hypoxis exaltata* Nel**		SA			LC*		
***Hypoxis filiformis* Baker**	*Hypoxis biflora* De Wild.; *Hypoxis caespitosa* Baker ; *Hypoxis dregei* var. biflora Nel ex De Wild.; *Hypoxis malosana* Baker; *Hypoxis muenznerii* Nel	SA-TA			LC*, LC@		[8]
***Hypoxis fischeri* Pax**	*Hypoxis fischeri* var. fischeri; *Hypoxis multiflora* Nel	TA			NT@	Possible damage to its scattered, island-like habitat range	[8]
***Hypoxis fischeri* var. colliculata (Wiland) Wiland & Nordal**	*Hypoxis hockii* var. colliculata Wiland	TA			VU@	Known from only four collections in East Tropical Africa	[8]

Hypoxis fischeri **var. hockii (De Wild.) Wiland & Nordal**	*Hypoxis hockii* De Wild.; *Hypoxis pedicellata* Nel	TA	Corm	Testicular swelling	LC@		[8]
Hypoxis fischeri **var. katangensis (De Wild.) Wiland & Nordal**	*Hypoxis aculeata* Nel; *Hypoxis hockii* var. katangensis (Nel) Wiland; *Hypoxis katangensis* Nel	TA			CE@		[8]
Hypoxis fischeri **var. zernyi (G. M. Schulze) Wiland & Nordal**	*Hypoxis matengensis* G.M.Schulze; *Hypoxis zernyi* G.M.Schulze	TA	Corm	Testicular swelling	LC@		[8]
Hypoxis flanaganii **Baker**		SA			LC*		
Hypoxis floccosa **Baker**	*Hypoxis ecklonii* Baker	SA			LC*		
Hypoxis galpinii **Baker**	*Hypoxis infausta* Nel; *Hypoxis pungwensis* Norl.; *Hypoxis stricta* Nel	SA-TA			LC*, NT@	Near threatened in the East Tropical Africa due to disjunct distributions	[8]
Hypoxis gerrardii **Baker**	*Hypoxis junodii* Baker	SA	Corm	Abdominal cramps	LC*		[24]
		SA					
Hypoxis goetzei **Harms**	*Hypoxis esculenta* De Wild.; *Hypoxis rubiginosa* Nel; *Hypoxis turbinata* Nel	TA	Corm	Epilepsy, HIV/AIDS, stomachache	LC@		[7,8]
Hypoxis gregoriana **Rendle**	*Hypoxis araneosa* Nel	TA			LC@		[8]
Hypoxis hemerocallidea **Fisch. & Avé-Lall.**	*Hypoxis elata* Hook.f.; *Hypoxis obconica* Nel; *Hypoxis patula* Nel; *Hypoxis rooperi* T.Moore; *Hypoxis rooperi* var. forbesii Baker	SA-TA	Corm	Cancer, HIV/AIDS, urinary tract diseases, reproductive system diseases, prostate hypertrophy, benign prostate hyperplasia, Tuberculosis, Syphilis, Diabetes	LC*		[8,20,25–28]
Hypoxis interjecta **Nel**		SA			LC*		
					LC*		
Hypoxis kilimanjarica **Baker**	*Hypoxis alpina* R.E.Fr. ; *Hypoxis incisa* Nel; *Hypoxis kilimanjarica* subsp. kilimanjarica	TA			VU@	Human activities, does not survive in cultivated fields or after fires	[8]
Hypoxis kilimanjarica **subsp. prostrata E. M. Holt & Staubo**		TA			VU@	Increasing tourist activities	[8]

Hypoxis kraussiana **Buchinger ex C. Krauss**		SA			LC*		
Hypoxis lata **Nel**		SA			LC*		
Hypoxis lejolyana **Wiland**		TA					
Hypoxis leucotricha **Fritsch**		TA					
Hypoxis limicola **B. L. Burtt**		SA			LC*		
Hypoxis longifolia **Baker**	*Hypoxis longifolia* var. thunbergii Baker	SA	Corm	Gynaecology and obstetric disorders	LC*		[29]
Hypoxis ludwigii **Baker**		SA			LC*		
Hypoxis lusalensis **Wiland**		TA					
Hypoxis malaissei **Wiland**		TA			Data Deficient#,CE@		[8]
Hypoxis membranacea **Baker**		SA			LC*		
Hypoxis monanthos **Baker**		TA					
Hypoxis muhilensis **Wiland**	*Hypoxis muhilensis* subsp. muhilensis	TA					
Hypoxis multiceps **Buchinger ex Baker**		SA-TA			LC*		
Hypoxis neliana **Schinz**		SA			LC*		
Hypoxis nyasica **Baker**	*Hypoxis campanulata* Nel; *Hypoxis engleriana* Nel; *Hypoxis engleriana* var. scottii Nel; *Hypoxis ingrata* Nel; *Hypoxis probata* Nel; *Hypoxis retracta* Nel	TA	Corm	Coughs, HIV/AIDS	LC@		[8]
Hypoxis oblonga **Nel**		SA			LC*		
Hypoxis obtusa **Burch. ex Ker Gawl.**	*Hypoxis angolensis* Baker; *Hypoxis iridifolia* Baker; *Hypoxis nitida* Verd.; *Hypoxis obtusa* var. chrysotricha Nel; *Hypoxis villosa* var. obtusa (Burch. ex Ker Gawl.) T.Durand & Schinz	SA-TA	Corm	Diabetes, ulcers, HIV/AIDS, abdominal pains	LC*, NT@	Near threatened in the East Tropical Africa due to disjoint distribution, and regular gathering for herbarium collections	[7,8,30]
Hypoxis parvifolia **Baker**		SA-TA			LC*		
Hypoxis parvula **Baker**	*Hypoxis brevifolia* Baker; *Hypoxis parvula* var. parvula	SA			LC*		
Hypoxis polystachya **Welw. ex Baker**	*Hypoxis orbiculata* Nel; *Hypoxis polystachya* var. andongensis Baker; *Hypoxis subspicata* Pax	TA	Corm	Testicular swelling, fungal infection of scalp	VU@	Strong antropogenic pressure, collection for medicinal purpose	[8]

***Hypoxis protrusa* Nel**		TA					
***Hypoxis rigidula* Baker**	*Hypoxis cordata* Nel; *Hypoxis elliptica* Nel; *Hypoxis laikipiensis* Rendle; *Hypoxis rigidula* var. rigidula; *Hypoxis volkmanniae* Dinter	SA-TA	Corm	Gall sickness	LC*, LC@		[8]
***Hypoxis rigidula* var. pilosissima Baker**	*Hypoxis arnottii* Baker	SA-TA			LC*		
***Hypoxis robusta* Nel ex De Wild.**		TA					
***Hypoxis sagittata* Nel**		SA			LC*		
***Hypoxis schimperi* Baker**	*Hypoxis macrocarpa* E.M.Holt & Staubo	TA	Corm	Coughs	NT@	Limited and scattered island-like distribution; possibility of being used as a substitute for other more commonly used *Hypoxis* species	[7,8]
***Hypoxis setosa* Baker**		SA			LC*		
***Hypoxis sobolifera* Jacq.**	*Hypoxis canescens* Fisch. & C.A.Mey.; *Hypoxis krebsii* Fisch.; *Hypoxis pannosa* Baker; *Hypoxis sobolifera* var. accedens Nel; *Hypoxis sobolifera* var. pannosa (Baker) Nel; *Hypoxis villosa* var. canescens (Fisch. & C.A.Mey.) Baker; *Hypoxis villosa* var. pannosa (Baker) Baker; *Hypoxis villosa* var. sobolifera (Jacq.) Baker	SA	Corm	Immune boosting	LC*		[31]
***Hypoxis stellipilis* Ker Gawl.**	*Hypoxis lanata* Eckl. ex Baker	SA	Corm	Immune boosting	LC*		[31]
***Hypoxis suffruticosa* Nel**		TA					
***Hypoxis symoensiana* Wiland**		TA					
***Hypoxis tetramera* Hilliard & B. L. Burtt**		SA			LC*		
***Hypoxis uniflorata* Markötter**		SA			DDT*		
***Hypoxis upembensis* Wiland**		TA					

***Hypoxis urceolata* Nel**	*Hypoxis apiculata* Nel; *Hypoxis arenosa* Nel; *Hypoxis bequaertii* De Wild.; *Hypoxis crispa* Nel; *Hypoxis cryptophylla* Nel; *Hypoxis textilis* Nel	TA	LC@	[8]
***Hypoxis villosa* L. f.**	*Fabricia villosa* Thunb.; *Hypoxis decumbens* Lam. [Illegitimate]; *Hypoxis fabricia* Gaertn.; *Hypoxis microsperma* Avé-Lall.; *Hypoxis obliqua* Jacq.; *Hypoxis scabra* Lodd.; *Hypoxis tomentosa* Lam.; *Hypoxis villosa* var. fimbriata Nel; *Hypoxis villosa* var. obliqua (Jacq.) Baker; *Hypoxis villosa* var. scabra (Lodd.) Baker; *Hypoxis villosa* var. villosa	SA-TA	LC*	
***Hypoxis zeyheri* Baker**		SA	LC*	

[1] Boldly written taxa are accepted names according to The Plant List [5] and World Checklist of Selected Plant Families [3]. [2] Distribution in Africa: TA: Tropical Africa Area (EPFAT Area, country-based, south of the Sahara, complementary to the following); SA: Southern Africa Area (South Africa, Namibia, Botswana, Lesotho, Swaziland); NA: North Africa (Mauritania, Morocco, Canary Isl., Algeria, Tunisia, Libya, Egypt, Madeira); MA: Madagascar (Malagasy Republic). [#] Global conservation status according to IUCN [32]. * Conservation status according to The Red List of South African Plants (SANBI) [33]; LC: Least Concern; DDT: Data Deficient—Taxonomically Problematic; VU: Vulnerable. @ East Tropical Africa Conservation status [8]; CE: Critically Endangered; VU: Vulnerable; NT: Near Threatened; LC: Least Concern.

2. Natural History and Distribution of *Hypoxis hemerocallidea*

Hypoxis hemerocallidea, previously known as *H. rooperi* [3,5], is a perennial corm with long, broad, and slightly hairy leaves [34,35] (Figure 1). Some species have a close morphological resemblance with *H. hemerocallidea*, such as *H. acuminata* Baker, *H. colchifolia* Baker, *H. galpinii* Baker, *and H. obtusa* [36]. The long, hairy and sickle shaped leaves of *H. hemerocallidea* differentiate it from the other species [36].

(a) **(b)** **(c)**

Figure 1. The yellow flowers (**a**), hairy leaves and black seeds (**b**) of *Hypoxis hemerocallidea* and its corm (**c**).

Hypoxis hemerocallidea has yellow star-shaped flowers [36], of which between one to three open within an interval of an hour per day, a strategy to encourage cross-pollination [37]. Although *H. hemerocallidea* plants produce many seeds, very low germination percentages were reported [38], due to the hard, shiny, black seed coat which may be impermeable to water and may restrict oxygen movement to the embryo, thus delaying germination [37,38]. Most mature corms, which are dark-brown to black outside and yellow inside, are approximately 10–15 cm in diameter and about half a kilogram in weight [39]. The fleshy corm is a survival mechanism that enables the plant to withstand cold conditions, drought, and veld fire [40]. In South Africa, *H. hemerocallidea* grows naturally in the savanna grasslands in KwaZulu-Natal, Eastern Cape, Mpumalanga, Limpopo, Gauteng, and Free State Provinces, and also grows in other countries such as Lesotho, Swaziland, Mozambique, and Zimbabwe [41].

3. Uses and Chemical Composition of *Hypoxis hemerocallidea*

Hypoxis hemerocallidea is traditionally used as a tonic, purgative, diuretic or to treat infertility, inflammation, prostate gland disorder, wounds and burns [14,42]. Promising anticancer activities of *H. hemerocallidea* have also been reported [43], which support the listing of *H. hemerocallidea* as one of the species used for the treatment of cancer in the Eastern Cape Province of South Africa [44]. Furthermore, it is also used for the treatment of diabetes in Eastern Cape and Eastern Free State [6,16]. The species was made famous by the South African Health Ministry when it was recommended as an immune booster for people living with HIV/AIDS [16,44,45]. The 14 member states of the Southern African Development Community (SADC) supported the use of 'African potato' in HIV management [46]. *Hypoxis hemerocallidea* was found to be a good source of trace elements such as zinc, copper, and manganese, which could account for its use as a pro-fertility ingredient and for boosting the immune system [47]. However, there are warnings of a potential herb-drug-interaction if *H. hemerocallidea* is used with conventional drugs for the management of HIV/AIDS [45]. It was also mentioned as one of the three most used plant species in the treatment of sexually transmitted diseases, in KwaZulu-

Natal and Limpopo Provinces of South Africa [48,49]. In support of its traditional use as an anti-miscarriage medicine, apart from being used for bronchial asthma [50], a study by Nyinawumuntu et al. [51] showed that *H. hemerocallidea* corm extracts possess uterolytic activity. *Hypoxis hemerocallidea* is mentioned as one of the species used for the treatment of tuberculosis in Limpopo Province of South Africa [52]. The species was one of the most cited medicinal plants in the medicinal markets [53], used for treatment of malaria and venereal diseases in Mozambique [26,54]. Different *Hypoxis* spp. are used in the treatment of prostate cancer in Zimbabwe [55]. A description of the history, first research reports and prominent promotion of commercial uses of *H. hemerocallidea* [43] is adapted in Figure 2. Traditional uses and chemical constituents of 11 *Hypoxis* species, including 14 *H. hemerocallidea* herbal formulations indicating the commercial importance of this species, are summarized in other reports [56].

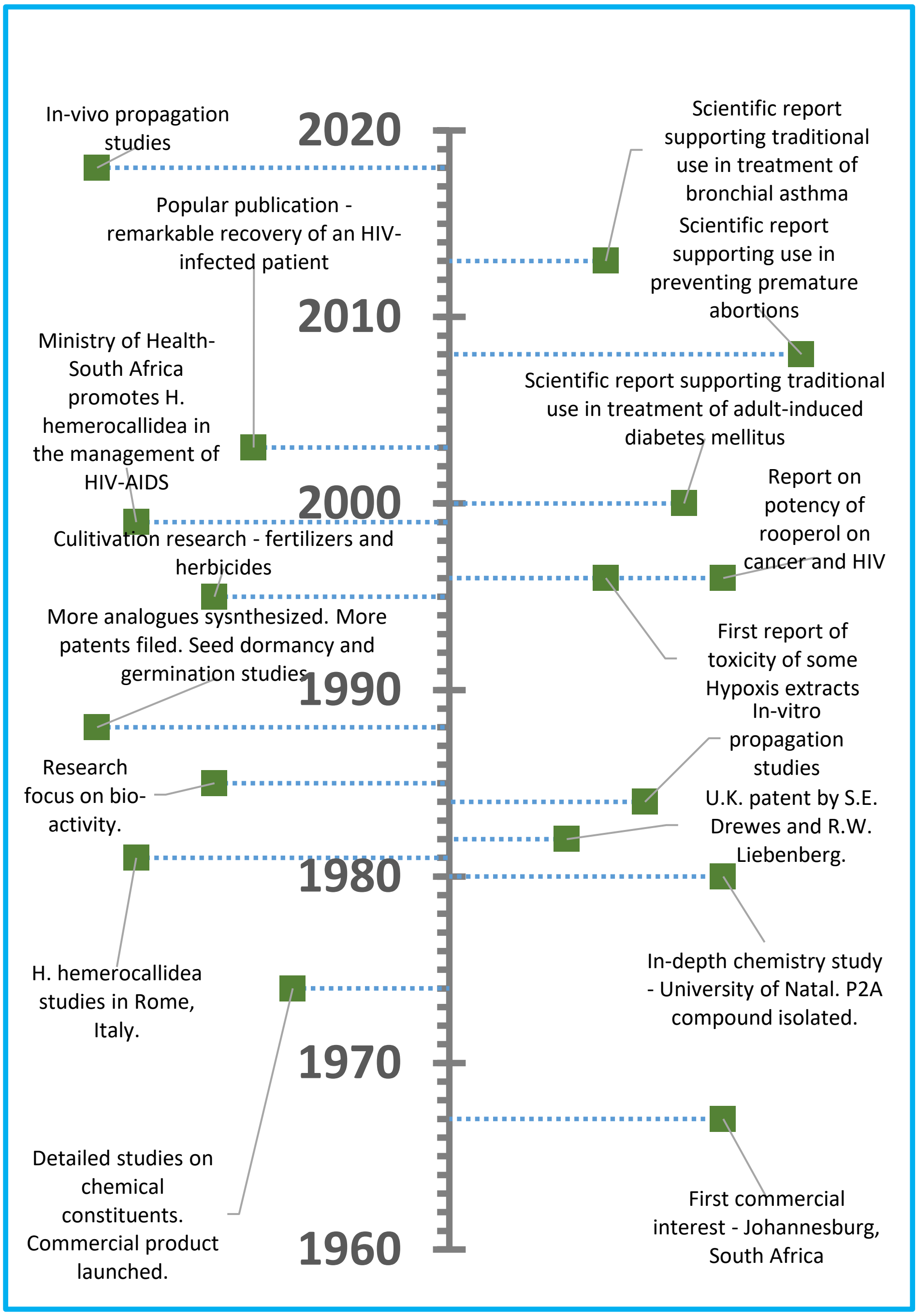

Figure 2. The timeline (1960–2020) of research and commercial use of *Hypoxis hemerocallidea*.

A glycoside called hypoxoside is mentioned as the main component of *H. hemerocallidea*, with sterols (stigmasterol, β-sitosterol, campesterol), sterolins, norlignan, daucosterols and stanols (stigmastanol) as additional constituents [42,46,57–59]. Amongst these phytochemicals, daucosterols, β-sitosterol, and hypoxide are associated with the plants' therapeutic activities [60]. Phenylalanine and *t*-cinnamic acid are reported to be precursors of hypoxoside in whole *H. hemerocallidea* plants [61]. Although some studies have proved that *Hypoxis* extracts with 45% hypoxoside are not toxic [41], even after long-term use of *H. hemerocallidea* products [56], treatment of diabetic rats with a high dose of 800 mg/kg resulted in abnormal kidney function [58].

Hypoxis hemerocallidea, H. rigidula Baker, H. galpinii, and *H. obtusa* showed similar phytochemical profiles, although further studies were recommended to confirm their safety [60]. A higher concentration of ergosterol and stigmasterol was reported in *H. rigidula* when compared to *H. hemerocallidea* [62]. When *H. hemerocallidea* was compared to *H. stellipilis* Ker Gawl. and *H. sobolifera* Jacq., it was found that both sterol and hypoxoside contents varied amongst the species, which questions the indiscriminate use of *Hypoxis* spp. in traditional medicine [60]. Several studies have been conducted to investigate the hypoglycaemic effects [63,64], typhlocolitic effects [65] and its effects on pharmacokinetics of efavirenz [57], antibiotic and immune modulation phytotherapies [66].

The common name 'African potato' is misleading, as many perceive *H. hemerocallidea* as edible. *Hypoxis hemerocallidea* has been reported as one of the indigenous and traditional food crops consumed in the North West Province of South Africa [67]. This species could be confused with the edible *Plectranthus esculentus* N.E.Br. as they both share the same common name of 'African potato' [67]. *Hypoxis hemerocallidea* has low crude protein value and low accumulation of selected elements [68], compared to human daily requirement, but its high iron content makes it a good candidate for use in overcoming iron deficiencies [47]. Some geophytes of *Hypoxis* were found in the caves in South Africa, evidence for cooking of edible rhizomes centuries ago [69].

4. Market Demand of *Hypoxis hemerocallidea*

Products incorporating extracts of medicinal plants such as *H. hemerocallidea*, which were used solely in traditional medicine are increasinlgy becoming commercialized [70]. The first *Hypoxis hemerocallidea* product was developed in 1967, in Johannesburg, South Africa and was successfully marketed in Germany [71]. An increase in the market share of *H. hemerocallidea* and *H. colchifolia* in 2001 was attributed to the publicity of the species received after several media releases proclaiming its healing properties [72]. Even before this increase in consumption, it was found that 77% of the *Hypoxis* corms sold in the Witwatersrand informal medicinal plant markets were 2–7 cm in diameter, with traders compensating for the smaller size by selling a large number of smaller corms [72]. This could be an indication of the depletion of bigger corms in the wild, leading to smaller immature bulbs being harvested. For example, the size of *Eucomis autumnalis* (Mill.) Chitt bulbs sold in the market, decreased in size between 1995 and 2001, indicating the negative impacts of harvesting for trade [72]. Nevertheless, pressure on this resource continues as *Hypoxis* spp. (*H. hemerocallidea* and *H. colchifolia*) were ranked fourth in terms of volumes sold in 2007, at the Faraday market in Johannesburg [72] and was one of the 19 species that had a high demand in Zululand market [73]. 'African potato' was one of the top 10 most frequently sold medicinal plant species, reaching 11,000 kg/annum to the value of R 322,500 (approximately 21,930 USD; at the 2019 average rate of R 1.00 = 0.068 USD), in Eastern Cape Province of South Africa [74]. Approximately 31,300 corms of *H. hemerocallidea* were sold annually from 54 outlets in Durban, South Africa [75]. A factory in KwaZulu-Natal (South Africa) was reported in 2004 to be processing 1.5 tons of *H. hemerocallidea* derived products and this was expected to increase annually [29]. In Lesotho, *H. hemerocallidea* was mentioned as one of the medicinal plants frequently used for a wide range of ailments [76]. This plant was the second most commonly used species in Kimberly, South Africa [77]. In Maputo, Mozambique, *H. hemerocallidea* topped the list of medicinal plant species mentioned by 71% of traders interviewed [78]. Figure 3 shows *H. hemerocallidea* corms displayed at an informal market in northern KwaZulu-Natal, South Africa.

Many products made from *H. hemerocallidea*, which include capsules, tinctures, tonics and creams, are available in the market [79]. *Hypoxis hemerocallidea* is exported, in a preprocessed form, to

Asia and Europe, where the extracts are used for treatment of prostate problems [14]. In a review on medicinal plants with potential in the development of drugs, *H. hemerocallidea* is mentioned as one of the famous African medicinal plants [80] with an ever-increasing demand.

Figure 3. *Hypoxis hemerocallidea* corms displayed (red arrow at middle bottom of the picture) at an informal market in northern KwaZulu-Natal, South Africa, with other medicinal plants.

5. Conservation Status of *Hypoxis hemerocallidea*

The conservation status of *H. hemerocallidea* is described as declining, and although not endangered with extinction, harvesting would cause a continuing decline of its populations and it is therefore of priority for conservation [40,81], with frequent monitoring warranted [74]. The only conservation effort was reported in KwaZulu-Natal, South Africa, where 250 hectares of land has been reserved for protection of *H. hemerocallidea* [81].

The use of *H. hemerocallidea* as an "all-purpose", "cure-all", or "wonder plant" medicine [37,50] has put pressure on wild populations because it presents an opportunity for income generation, through species-specific trade network [56]. During harvesting, the whole plant is uprooted, resulting in total destruction of the plant [75]. There is a need for urgent propagation intervention [73] as their populations in the wild are declining [1]. For example, in Swaziland, *H. hemerocallidea* has become threatened with extinction [82]. In an effort to come up with sustainable harvesting strategies, Katerere and Eloff [83] found that *H. hemerocallidea* leaves cannot be used as a substitute for the corms due to lack of similarities in phytochemical content and bioactivity. However, it was suggested that the leaves of *H. hemerocallidea* might be used as substitutes for the corm in the treatment of some bacterial and fungal diseases as there seemed to be a shift in activity between plant organs in different seasons [56]. Hypoxoside was reported to be hydrolysed in the leaves and then transported to the corms [61], with this activity shifting from the leaves to the corms in summer [56]. Du Toit et al. [84] reported that harvesting season affected the concentration of active ingredients produced from the corms during the year. Therefore, the correct timing of collection of *H. hemerocallidea* leaves could ease the pressure off wild populations. The activity was higher in the leaves in spring [56], a period in which the corms are regrowing the leaves after a period of dormancy when there are fewer or smaller leaves available. In summer, when there is a greater number of bigger leaves, the activity is shifted to the corms and this could be another reason for continued use of the corms than the leaves.

6. Propagation and Cultivation of *Hypoxis hemerocallidea*

Due to the value of *H. hemerocallidea* in traditional medicine and the likely diminishing wild populations, there is a strong case to cultivate the species for sustainable supply of good quality corms

[35,45,75], agreeing with Katerere and Eloff [83] who mentioned that the only viable alternative to unsustainable wild harvesting of *H. hemerocallidea* is propagation and domestication. In essence, cultivation will not only alleviate pressure on natural resources, but it also has practical implications on optimising secondary metabolite production, facilitating standardisation, and increased safety by reducing inconsistency in quality and composition of plant material, reducing the risk of adulteration and increasing yield through management practices [85]. Encouragement of cultivation of wild harvested medicinal plants and development of nurseries to propagate the species will take off the pressure on wild stocks [44]. Cultivation of medicinal plants is becoming popular, with increasing government support to meet the high demands for plant materials [86]. The bioprospecting economy and related strategies in South Africa have put an important drive to mass propagation and cultivation of commercially important medicinal plants, of which *H. hemerocallidea* is within the top 25. However, one of the major factors hindering the improvement in cultivation of *H. hemerocallidea* is lack of knowledge of its agronomic and quality traits [40].

Propagation of *H. hemerocallidea* was identified as problematic since seed dormancy is difficult to be broken and the species does not propagate easily from corms; thus studies relating to reproductive biology and seed physiology of the species were recommended as a priority [12,40]. Seed germination of *H. hemerocallidea* is also a barrier because of unpredictable seed viability, combinational dormancy, poor seedling establishment, while vegetative propagation is rare [38]. Micropropagation of *H. hemerocallidea* is the only vegetative propagation method that has been thoroughly studied by many researchers [87]. Corm explants of *H. hemerocallidea* seem to take at least nine weeks to respond positively in in vitro culture compared to other *Hypoxis* species [88]. Other challenges with in vitro propagation of *H. hemerocallidea* include browning of explants and nutrient medium which necessitates regular subculturing of the shoots at six weeks' interval [81]. Endogenous contamination was also reported as a major challenge when underground organs were used as explants [75]. Ndong et al. [40] explored the regeneration potential of *H. hemerocallidea* corm explants by inoculating them on culture media with a wide range of plant growth regulator combinations and concentrations. The study concluded that no shoots were formed without plant growth regulators; shoot formation frequency and intensity were mainly dependent on cytokinin concentration and the best results were obtained with kinetin than with benzylaminopurine (BA). In a similar study, Nsibande et al. [89], reported that corm explants of *H. hemerocallidea* were very slow and relatively poor in responding to in vitro culture, with the majority of the treatments forming no callus, compared to other three *Hypoxis* spp. (*H. filiformis*, *H. argentea*, and *H. acuminata*). Direct shoot development started 10 weeks after transferring of the corm explants to a Murashige and Skoog medium supplemented with cytokinins, although growth of the shoots was prolonged [89]. Cytokinins have been reported to have a promoting effect on shoot formation in tuberous plants including *Hypoxis* spp. [40]. The stimulation of shoot regeneration, proliferation and growth by cytokinins is a species-dependent phenomenon, which is influenced by structure-activity relationship, cytokinin homeostasis, concentration of inherent endogenous plant growth regulators and auxin-cytokinin cross-talk [81]. Somatic embryogenesis, which involves the development of embryos from normal plant tissue, with the use of 2,4-D and BA produced a high number of somatic embryos while GA_3 was successful in developing the somatic embryos into plantlets [79].

Seedling emergence of *H. hemerocallidea* was observed a year after sowing [38]. Gillmer and Symmonds [90] have successfully germinated a large number of *H. hemerocallidea* seed by watering them three times in a day. In other experiments, there was no germination of intact seeds of *H. hemerocallidea* at three different temperatures (20, 25, and 30 °C), even when the seeds were treated with several chemicals [38]. Complete removal of the seed coat with incubation at 20 °C under white light resulted in 36% germination compared to dark conditions where only 6% germinated [38]. Seed coat seem to inhibit prompt germination of *H. hemerocallidea* seeds. Gibberellic acid (GA_3) at 10^{-3} mol dm^{-3} increased germination of coatless seeds, at 25 °C [37], as well as mechanical scarification and subsequent soaking for 24 h in 50 ml of GA_3 at 1200 ppm, which increased germination to 60% [38]. The scarification could have removed the physical barrier, while the GA_3 could have broken the embryo dormancy. The positive effect of GA_3 further suggests the presence of embryo dormancy in addition to the physical dormancy. For example, seeds harvested in early November (early summer) from Mountain Rise in KwaZulu-Natal (KZN), South Africa, reached a germination percentage of 52% at 25 °C, compared to 16% and 9% achieved from seeds harvested at the same site in early December and early January (mid-summer) [35]. The study by Hammerton et al. [35] suggests that microclimates and differences in soil conditions from different sites may have affected seed viability and dormancy. Seeds collected from a second site (Hayfields in KZN) in late December only achieved approximately 13% germination [35].

Although work has been done on in vitro propagation and seed germination of *H. hemerocallidea*, there is a need to develop methods that can supply the market with the material at reasonable costs [41]. In an effort to develop an easy and affordable propagation method for *H. hemerocallidea*, chipping into equal segments and scooping to remove the growth tip were found to be effective propagation methods [87].

Care is also needed as *H. hemerocallidea* plants to which herbicides were not applied grew better and had a higher hypoxoside content, compared to herbicide-treated plants [91]. Competition with weeds could have led to plant stress and thus an increase in secondary metabolite synthesis. It seems that high levels of nutrients (N, P, and K) are only required initially to produce a suitable *H. hemerocallidea* biomass and after plant establishment, fertilizer treatment can be discontinued [91]. Although *H. hemerocallidea* prefers poor soils with little nutrients, site selection for cultivation of the species is essential as exposure to cadmium (Cd) and aluminium (Al) significantly decreased the accumulation of hypoxoside [86]. Du Toit et al. [84] found that growing media and harvesting season affected the amount of compounds or active ingredients produced from the corms during the year.

7. Gaps in Cultivation Research of *Hypoxis hemerocallidea*

Currently, cultivation information, including the response of *H. hemerocallidea* to agronomic practices, is limited to few studies. Although *H. hemerocallidea* seems to be a drought-tolerant species, there is no official record of it growing in the Northern Cape and Western Cape Provinces of South Africa (Figure 4). According to the South African National Biodiversity Institute (SANBI), the species mostly grows in areas having 600 to 1000+ mm/annum rainfall, which includes the semi-arid and dry-sub humid zones of South Africa, with warm temperate climate, cool to hot summers, and humid to dry winters [92]. This indicates a need to investigate watering requirements from the seedling establishment stage to maturity. Imposing water stress at specific growth stages or even for a specific period before harvesting could increase growth while ensuring good content of active compounds. Ideally, cultivation at a commercial scale, provides an opportunity for manipulation of growing conditions to shorten the period to reach maturity, increase potency and predictability of extracts. *Pelargonium sidoides* DC. plants grown under greenhouse conditions, for example, showed equivalent concentrations of the compound of interest, umckalin, and approximately six times greater growth rates [93]. Excessive watering (twice and thrice a week) of *Dioscorea dregeana* (Kunth) T. Durand & Schinz seedlings reduced vegetative growth but significantly improved seedling weight and tuber size, while watering once a week resulted in better above ground biomass [94].

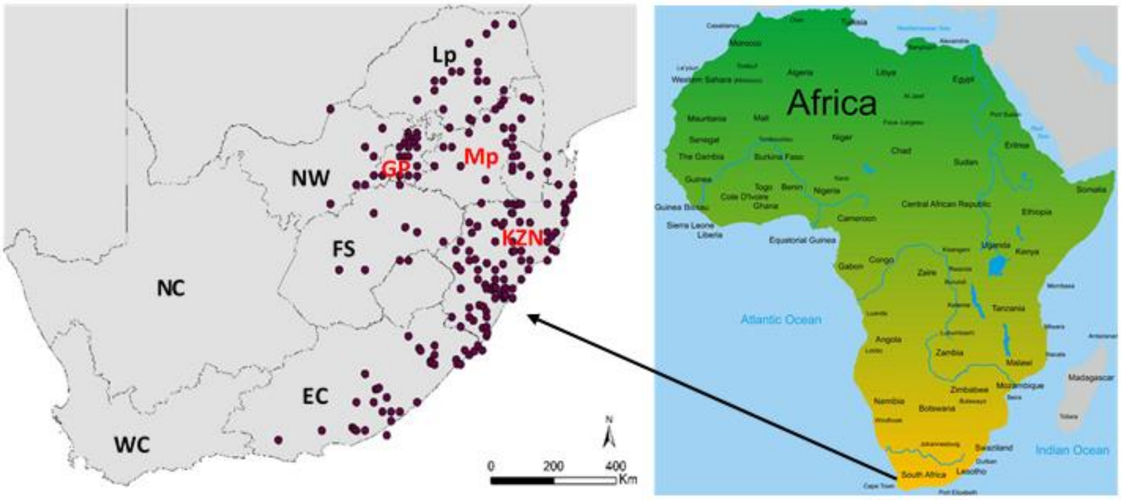

Figure 4. Distribution of *Hypoxis hemerocallidea* in South Africa, showing no records in Northern (NC) and Western Cape (WC) Provinces (Source: South African National Biodiversity Institute; SANBI). Provinces: WC: Western Cape; NC: Northern Cape; EC: Eastern Cape; FS: Free State; NW: North West; GP: Gauteng; KZN: KwaZulu-Natal; Mp: Mpumalanga; Lp: Limpopo.

The effect of fertilizers or exposure to different nutrient status on growth and medicinal activity of *H. hemerocallidea* is not fully understood. For example, in *Siphonochilus aethiopicus* (Schweif.) B.L. Burt, plants exposed to low nitrogen levels with severe water stress showed increased flavonoids, phenolics, and antioxidants indicating that fertilizer application and irrigation can alter secondary metabolite content [95]. Understanding of the strategies employed by *H. hemerocallidea* under water and nutrient stress conditions in relation to its growth, physiology, and secondary metabolite production is important.

Furthermore, field observations by Mofokeng et al. [96] showed that cultivated *Pelargonium sidoides* was susceptible to root-knot nematodes, such that root yield was negatively affected. The quality of *H. hemerocallidea* corms could be negatively affected if the species can be found to be susceptible to root-knot nematodes. Figure 5 shows a potential pest (African bollworm: *Helicoverpa armigera* Hübner) of *H. hemerocallidea*, feeding on the leaves and seeds, observed in a small scale plantation.

Figure 5. A potential pest and its potential damage on *Hypoxis hemerocallidea* plants. (**A**) African bollworm (*Helicoverpa armigera*) feeding on the leaves and (**B**) on the seed pods (Source: Agricultural Research Council-Vegetable and Ornamental Plant Research Station).

Other important aspects of commercial cultivation of *H. hemerocallidea* include optimum size and timing before harvesting the species, as it is not clear at what age or size are the medicinally active compounds available or optimum in the corm. In general, the target compounds in medicinal plants are secondary metabolites which serve as an adaptation strategy to environmental stress, infection, or herbivory. Thus, agronomic practices that can manipulate the growth and synthesis of secondary metabolites in *H. hemerocallidea* need to be fully understood if the species is to be successfully cultivated.

8. Conclusions

The decline in wild populations and the increasing demand for *H. hemerocallidea* present an opportunity to cultivate the species for conservation purposes but also as an alternative cash crop for different communities. Sustainable harvesting methods and the use of leaves as an alternative to corms should be further researched, including increasing leaf biomass and manipulating active compound content in the leaves. The main challenges for cultivation of *H. hemerocallidea*, as with many perennial medicinal plants, are the relatively long period before harvesting, in competition with wild harvest, which may reduce prices, and spatial-temporal competition with food crops. Opportunities are increasing since government legislation on wild harvesting is becoming stricter; as the demand for natural health products is also increasing, and with cultivation, pharmaceutical companies are assured of reliable supply of quality material. For example, the South African government has started to promote cultivation of commercially important indigenous medicinal plants and created a platform for linking all stakeholders in the industry. Furthermore, funding for initial investment, which is a big problem for rural poor farmers, can be made available through the abovementioned platform. As the current wild harvesting of *H. hemerocallidea* is probably unsustainable and considering its substitution with other *Hypoxis* species, it is imperative that population studies of many African *Hypoxis* species and their conservation status be reviewed for more information in order to facilitate timeous conservation and management strategies.

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