Enhancing legume crop pollination and natural pest regulation for improved food security in changing African landscapes

|Review paper

Enhancing legume crop pollination and natural pest regulation for improved food security in changing African landscapes

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[+]denotes studies done outside the African continent but relevant in providing baseline for understanding legume pollination and pest control.

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Abstract

Legumes are important crops for food security, consumed by millions of people especially in Africa where they are an essential proteins source and provide key vitamins and minerals. Most legumes depend on insect pollination and natural pest regulation for sufficient yields, however, there is emerging evidence that yield gaps caused by lack of pollination and/or pest pressure may be common. Here we review the literature reporting on pollinators and natural enemies contributing to legume crop yields, and the impact of land-use change on the services provided by these beneficial organisms. We identify strategies for enhancing the benefits of pollination and natural pest control in legumes and propose policy and practice interventions for better utilization of pollinators and natural enemies in legume cropping systems in Africa.

Key words: Africa, ecosystem services, food security, legumes, natural pest enemies, pollination

1) Introduction

Legumes (Family Fabaceae, also referred to as Leguminosae) are a multipurpose crop and are consumed in both fresh and dry forms either directly as food or in various processed forms as animal feed or used as bio-energy crops (Merga and Haji, 2019; Snapp et al., 2019; Vanlauwe et al., 2019). Legumes (e.g. pigeon pea, groundnuts, cowpeas, and dry beans) are essential in the diets of millions of people across the world especially those in developing countries where they provide essential proteins, key vitamins, and minerals (Nedumaran et al., 2015). Legume consumption in sub-Saharan Africa is estimated to be approximately 4-6 kg/person per year

(Nedumaran et al., 2015). These crops are a particularly important protein sources for vegans and vegetarians as well as those with limited access to meat (Nedumaran et al., 2015; Ojiewo et al., 2015; Bradbury et al., 2017[+]). Furthermore, legumes also provide amino acids, fiber, minerals and other nutrients for livestock (Gulzar and Minnaar, 2016). An increasing human population has led to rising demand for legume based foods (Stagnari et al., 2017) with increases seen in both North America and Europe where prices have also risen (Nedumaran et al., 2015). These trends are set to continue (Islam et al., 2019) and a significant shift towards legume production will be needed in the near future in order to match this increasing demand.

In Africa, legumes are important for food and nutritional security as well as being a revenue source for small-holder farmers (Vanlauewe et al., 2019). These crops provide food, feed, and fuel to many rural communities (Muoni et al., 2019), while farmers also benefit from the enrichment of soil fertility and reduced erosion because of the legume's nitrogen-fixing abilities and erosion control particularly provided by the dense root network of perennial legumes. Legume production in Africa (as in the other parts of the world) has been increasing since the year 2000 largely due to increasing groundnut, cowpea and common dry bean production (Fig. 1). Other legume crops (pigeon pea, broad beans, and green peas) have remained below 2 million tons for 19 years (2000 – 2018) (Fig. 1 and Appendix 1). However, soybean production has been increasing since 2010 (Fig. 1).

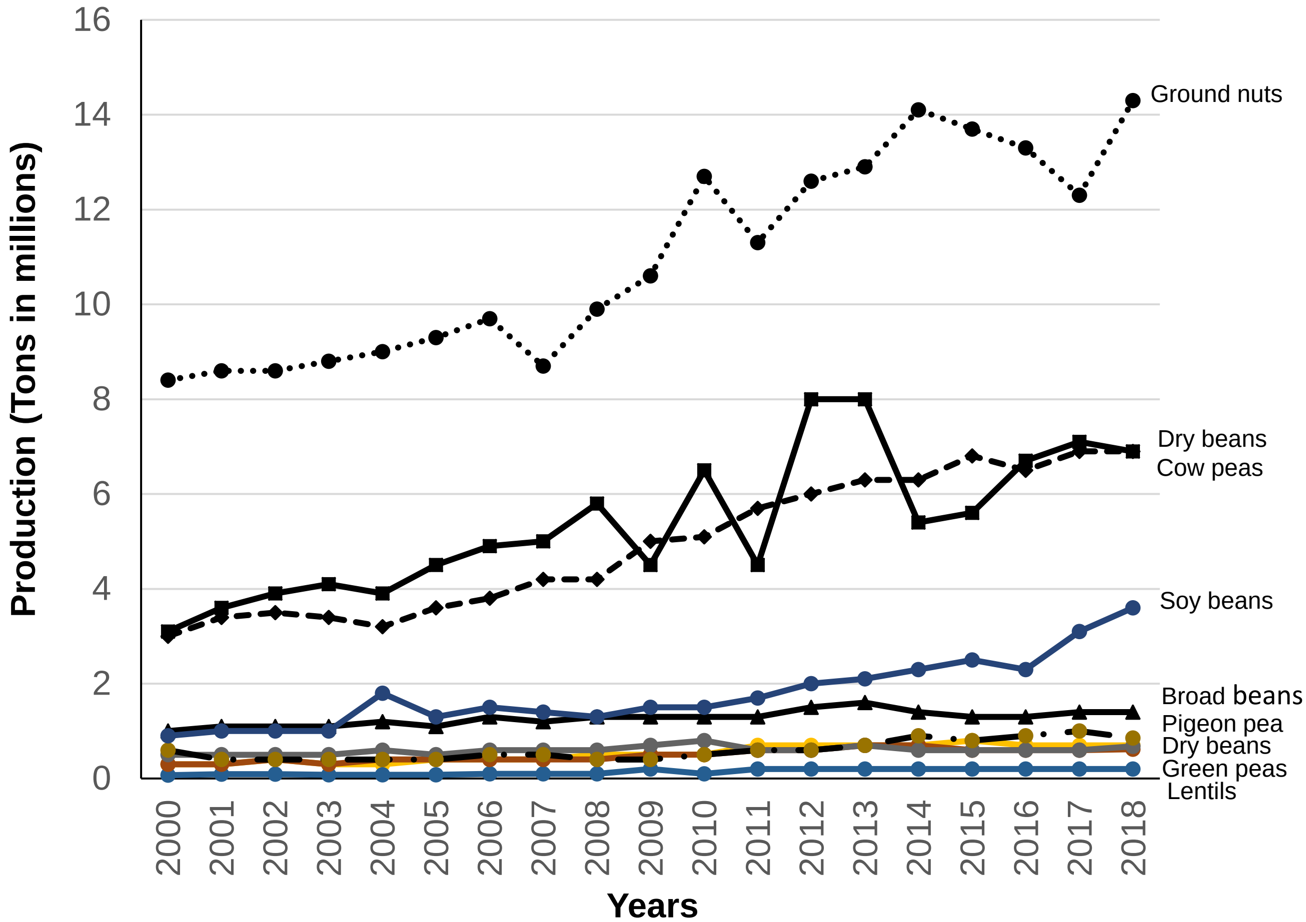

Figure 1: Trends in legume production by crop (millions of tons) in Africa from 2000 to 2017 (*Source: FAOSTAT, 2020*).

Despite being an important food security crop to many millions of rural people and smallholder farmers in Africa, legumes have not received as much attention as cereals with regards to research and development, particularly through plant breeding (Foyer et al., 2016). Based on recent production and yield trends, legumes are far below cereals, and yields are increasing at a much slower rate of 2.0% per annum (p.a.) compared to 3.8% p.a. for cereals (FAOSTAT, 2020) (Fig. 2).

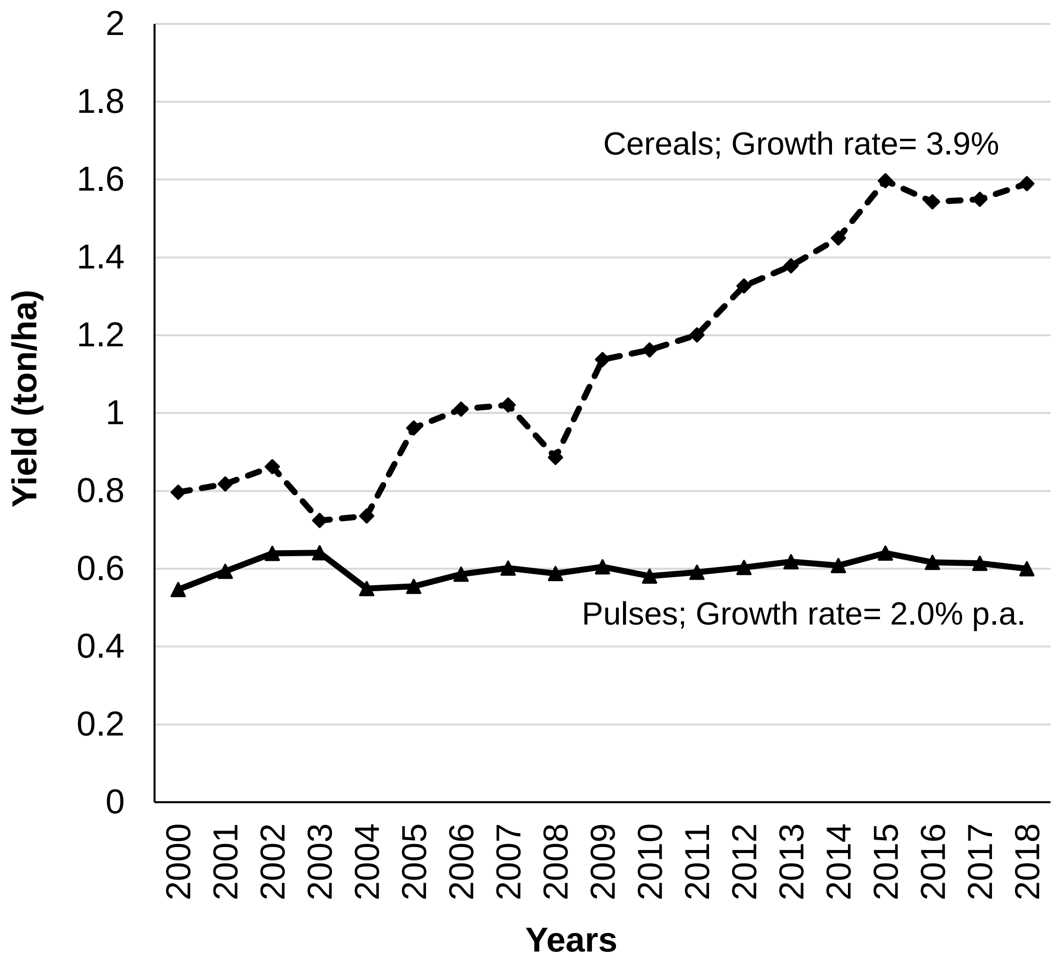

Figure 2: Yield/ha trends for cereal and pulse crops in Africa from 2000 to 2018 (*Source: FAOSTAT, 2020*)

Legume yield is partly dependent on arthropods, especially pollinating insects and natural enemies of pests (Suso et al., 2016; Delaplane and Mayer, 2000[+]; Grzywacz et al., 2014[+]). This includes important crops such as Bambara nuts (*Vigna subterranea*) (Kasina et al., 2009b), cow pea (*Vigna unguiculata*) (Pasquet et al., 2008), faba beans (*Vicia faba*) (Garratt et al., 2014[+]; Nayak et al., 2015[+]), pigeon peas (*Cajanus cajan*) (Otieno et al., 2011 and 2015) and forage legumes such as alfalfa (*Medicago sativa*), clover (*Trifolium* spp) and vetches (*Vicia* spp) (Snapp et al., 2019). If legume production is going to continue to increase in Africa, it is essential to explore how pollinators and natural enemies can be used to support this increase in production and keep pace with rising demand in changing African landscapes. This is particularly important if yield is already constrained more by limited pollination or pest regulation than other crops in Africa.

Globally, pollination is provided to legume crops by both managed (mainly honeybees) and wild pollinators including the naturally occurring ‘native bees’ (Erickson et al 1978+, Benachour et al., 2007+; Garratt et al., 2014). Likewise, in Africa honeybees are both managed (mainly for honey production) and wild and both likely contribute to the pollination of legumes. In cropping systems around the world, the abundance of native bees as crop pollinators is driven by farm management practices and landscape context (Dainese et al., 2019[+]). However, relatively few studies on the factors driving pollination services to crops derive from Africa and yet yield limitations linked to a shortage of insect pollination has been found in smallholder farming systems, including those in Africa (Garibaldi et al., 2016[+]).

Natural pest control is another important ecosystem service delivered to crops mostly by invertebrates commonly referred to as natural enemies (den Belder et al., 2002[+]). The presence of natural enemies in crop fields can be an important factor in managing pest populations (Dainese et al., 2019[+]) and similar to insect pollinators, farm management and local landscape context are important determinants of natural enemy populations and the pest control services they provide (Karp et al 2018 [+], Martin et al 2019[+]). Natural and semi-natural areas are used by natural enemies as a refuge from undesirable on-farm conditions such as during pesticide sprays or they provide alternative forage resources (Blitzer et al., 2012[+]; Balzan et al., 2014[+]; Ramsden et al., 2014[+]). Further, local crop rotation and crop diversity at the landscape scale can promote natural pest control (Schneider et al. 2015[+], Redlich et al. 2018[+]), but comparable studies for Africa are currently lacking.

In North America and Europe, the pollination requirements of many legume crops and the contributions of pollinators to legume production have been established for example in soybeans (Erickson et al., 1978[+]) and field beans (Bartomeus et al., 2014[+]; Garratt et al., 2014[+]). Similarly, pests and associated natural enemies are relatively well known for most temperate crops. However, in developing countries, including those in Africa, knowledge of the pollination requirements, pests and natural enemies of most legume crops is not well understood despite the potential for using pollinators and natural enemies to safeguard legume production.

The objectives of this review with a focus on Africa are to; (i) examine the contributions of pollination a nd natural pest control services to legume crop production (sections 2.1 and 3.1), (ii) highlight the current effects of agricultural intensification and land-use change on pollinators and natural enemies and the ecosystem services they provide to legume crops in Africa (sections 2.2 and 3.2), (iii) identify key gaps in our knowledge and propose avenues for future research (section 4), and (iv) highlight regulations and policies that could be adopted for enhancing the benefits delivered by pollinators and natural enemies in legume cropping systems (section 5).

We performed a systematic literature search using Web of Science and Web of Knowledge (ISI Thompson-Reuters (www.webofknowledge.com)) and Google Scholar (https://scholar.google.com/) to identify studies that examined pollination or natural pest control in legume crops in Africa. At the onset, we found no specific continent-wide studies on either pollination or pest control in legumes. We, therefore, narrowed our search further to specific regions and countries. We used search term combinations such as; "Legume" AND "pollinators"

AND "East Africa" OR "Kenya" OR "Uganda" OR "Tanzania" for instance and repeated this for the other regions in the west, south, central, and north of Africa (Appendix 2). We repeated the search criteria for natural enemies by replacing "pollinators" with "natural enemies" OR "natural pest enemies" OR "biocontrol" OR "biological control". (An expanded list of all search terms is presented in Appendix 2). This criterion list produced only a limited number of studies so, we expanded our search by performing an extensive literature search of online databases and repositories of African academic and research institutions listed in the International African Institute's Digital Research Repositories for African studies (https://www.internationalafricaninstitute.org/repositories) and used a combination of keywords relevant to this article, which yielded the 54 studies cited in Tables 1 – 3 and elsewhere in this paper. Some studies outside Africa have been included in specific sections of this paper denoted by a superscript + sign. A decision was made to include these studies because they provide a critical baseline in understanding legume pollination and pest control.

2) Pollination services underpinning legume crop production in Africa

2.1 Pollination of legume crops

The effect of insect pollination on legume yield depends on whether the species or variety is self-fertile or self-sterile. Self-fertile crops (e.g. soybeans and peanuts) generally do not require external vectors for pollination, however self-sterile crops (e.g. alfalfa) are up to 100% reliant on external agents for pollination. In some of the self-fertile species, however, it has been established that animal pollination can boost seed set when compared to purely self-pollinated plants e.g. 20 – 90% of pigeon pea fruit set is contributed by bees (Otieno et al., 2011; Pando et al 2011a; Fohouo at al. 2014; Mazi et al., 2014) and honeybees, carpenter bees, and leaf cutter bees enhance fruit set of cow pea by 10 – 100% (Fohouo et al., 2009; Kasina et al., 2009a; Ige et al., 2011; Musa et al., 2013; Stephanie et al., 2015; Wousla et al., 2019) (Table 1). It should be noted, however, that for any crop type there are often major varietal differences in dependency on pollinators (Bishop et al., 2020).

The literature on crop pollination in Africa is generally limited (Gemmill-Herren et al., 2014), and studies focusing on legumes are particularly rare although research conducted outside the continent is relevant in some contexts. Overall, a very small proportion of crop-pollinator relationships have so far been characterized for legumes and even fewer studies have considered the community level and comparatively little applied work exists, either with regards to agriculture or conservation (Rodger et al., 2004). To date, a majority of pollination studies in Africa have focused on non-crop plant species investigating evolutionary relationships or breeding systems (Gemmill-Harren et al., 2014) and many studies which do exist are not traceable or accessible because they are locked in grey literature (Rodger et al., 2004, Gemmill-Harren et al., 2014).

Our review indicated that pollination studies in legume crops grown in Africa have generally focused on seven pulse crop species spread across the continent, namely; pigeon peas (Otieno et al., 2011; Pando et al., 2011a; Martins, 2013; Fohouo, 2014; Otieno et al., 2015), French beans (Valk et al., 2012; Masiga et al., 2014), cowpea (Pasquet et al., 2008; Fohouo et al., 2009; Kasina et al., 2009b; Ige et al., 2011; Wousla et al., 2019), runner beans (Pando et al., 2011b), bambara nuts (Kasina et al., 2009b), dry common beans (Kasina et al., 2009b), green grams (Kasina et al., 2009b) and, faba beans (Benachour et al., 2007) (see Table 1). Studies on pollination of other legume crops in Africa are not available. However, based on legume production data for Africa from the Food and Agricultural Organization, we included chickpeas, lentils, dry peas and soybeans in Table 1 and provided their pollination requirements based on studies done elsewhere in the world.

Pigeon pea (*Cajanus cajan*)

Pigeon pea pollination has been studied more extensively than other legume crops (Table 1). The consensus across all the studies considered is that in general insect pollinators increase yields. In a study assessing the impact of a megachilid bee (*Chalicodoma cincta*) on pod and seed set of pigeon peas, Pando et al., (2011a) found an increase in fruit set of between 19.65% and 96.72% on flowers visited by the bees compared to those not exposed to bee visits in a study from Cameroon. Another study by Fohouo (et al., 2014) found carpenter bees increased pigeon pea fruit set by 22.26%. Martins (2013) reviewed case studies linking wild pollinators of crops (including pigeon pea), natural habitat, and rural farmers and linked increased pigeon pea yield to wild bee pollination, particularly by the carpenter and leafcutter bees in Mwanza, Tanzania. The authors noted that the bees were extremely vulnerable to habitat degradation and loss. Carpenter bees were also found to be important pollinators of pigeon pea in Kenya by Otieno et al., (2015) where the abundance of bees was found to be correlated with pigeon pea fruit set.

French beans (*Phaseolus vulgaris*)

French beans, although largely thought to be self-fertile, were found to undergo outcrossing aided by bees in Kenya, mostly dominated by honeybees and carpenter bees (Table 1) (Masiga *et al.*, 2014). Potential pollination deficits in this crop among small-scale farms was also found and associated with proximity to natural habitats. Bean yield was also significantly correlated with the mean abundance of carpenter bees.

Cowpea (*Vigna unguiculata*)

A study by Fohouo et al., (2009) investigating the foraging behavior of pollinators and pollination of cowpea by *Apis mellifera adansonii* found the number of seeds per pod to be significantly greater in openly pollinated flowers (62%) when compared to those protected from insects (48%), mainly due to carpenter bees, leafcutter bees and honeybees (Table 1). Wousla et al., (2019) also found that bees increased seed set in cowpea by between 1 - 10% in Kenya. This was mainly attributed to leafcutter (*Megachile* spp.) and carpenter bees (*Xylocopa* spp.).

Faba beans

An increase in faba bean yield was associated with insect floral visitors. A study by Benachour et al., (2007) in Algeria recorded that plants visited by insects produced more pods per plant, more seeds per pod, and the seeds were heavier and of better shape than the plants receiving no bee visits.

Runner beans

A study on foraging and behavior of carpenter bees on runner bean flowers in Cameroon established a pollination deficit (Pando et al., 2011b). This study found a 25.8% increase in fruit set following floral visitation by *Xylocopa calens*.

Bambara nuts

This crop was found to benefit from insect pollinators with a dependency ratio of 0.61 (Kasina et al., 2009b). Here, dependency ratio reflects the contribution of pollination to food production and corresponds to the quantitative relative loss of agricultural production that would be induced by the disappearance of pollinators (Klein et al., 2007; Jacquemin et al., 2017).

Green grams

Insect pollinators increased the number of seeds per pod of green grams by 37.56% and seed weight by 90.63% (Kasina et al., 2009b).

Table 1: Summary of pollinators key to legume crop pollination in Africa

	Crop									
↓Pollinator	**Bean plants (*Phaseolus vulgaris*) – French beans, dry beans green beans**	**Faba beans (*Vicia faba*)**	**Chick peas (*Cicer arietinum*)**	**Cow peas (*Vigna unguiculata*)**	**Lentils (*Lens culinaris*)**	**Dry peas *Pisum sativum***	**Pigeon pea (*Cajanus cajan*)**	**Soy bean (*Glycine max*)**	**Peanut/ground nut (*Vigna subterranea*)**	**Runner beans *(Phaseolus coccineus)***
Dependence of legumes on insect pollination	*<30%*	*<30%*	*<30%*	*30-70%*	*<30%*	*<30%*	*<30%*	*<30%*	*<30%*	*<30%*
Honey bees (*Apis mellifera*)	50 - 60%	Yes	Yes	10 – 70%				20%	10	Yes
Carpenter bees (*Xylocopa spp.*)	20 – 60%			70 – 95%			20%	10		
Leaf cutter bees (Megachilids)	Yes			30 - 100%			20 - 90%			
Halictid bees (Lipotriches)	Yes	Yes					Yes			
Digger bees (Anthrophorids and Amegillas)		Yes	Yes				Yes			
Ceratina							Yes			
Stingless bees							Yes			
Colletes	Yes									
Bumble bees		Yes		<1%						Yes
Eucera		Yes								
Flies (Syrphid and Calliphorid) and other fly pollinators)		Yes	Yes				Yes			
Beetles		Yes								
References	Roger et al, 2004; Kasina et al., 2009b; Douka et al, 2013; Douka et al., 2017; Masiga et. al, 2014, Fohouo et al., 2014	Roger et al, 2004; Benachour 2007; Aouar-Sadli et al., 2008; Kennedy et al., 2013; Gasim & Abdelmula 2018	Latif et al., 2019	Roger et al, 2004; Pasquet at al 2008; Asiwe 2009; Fatokun 2002 Fohouo et al., 2009; Kasina et al., 2009b; Ige et al., 2011; Musa et al., 2013; Stephanie et al., 2015; Wousla et al., 2019	Horneburg 2006	Naeem et al., 2018	Roubik ,1995; Roger et al, 2004; Otieno et al., 2011; Pando et al 2011a; Fohouo at al. 2014; Mazi et al., 2014; Otieno et al 2015	de Milfont et al., 2013; Blettler et al., 2018	Roubik ,1995; Kasina et al., 2009b	Pando et al., 2011b

Note: Percentages given represent the amount of fruits set by corresponding pollinators (shown in column 1) on legumes crops in Africa as reported in the literature. The percentages are rounded to the nearest 10%. "**Yes**" denotes that visitation to flowers of legumes by these insects was frequently recorded but their contribution to pollination was not quantified. Full references to the citations are provided in **Appendix 3a**.

2.2 Impacts of agricultural intensification and land-use change on pollination services to legume crops in Africa

On a global scale agricultural intensification negatively affects pollinators by reducing nesting and forage resources as well as by increasing exposure to agrochemicals (Deguines et al., 2014; Potts et al., 2016; Cairns et al., 2017) and Africa is no exception. For example, land-use change in Kenya, particularly through agricultural expansion, has contributed to habitat loss, environmental degradation, and land fragmentation, disrupting pollinator networks that are important in supporting and sustaining biological functions (Mwangi et al., 2012). Similarly, high usage of pesticides, herbicides, and fertilizers are exposing pollinators to further risk (Guenat et al., 2019).

Otieno et al., (2015) investigated the effects of agricultural intensification on pollinator guilds and found negative effects of insecticides on bee abundance and functional guilds when used on pigeon pea fields. This study also found a positive relationship between bee abundance and habitat complexity, characterized by small-holder farms interspersed with semi-natural habitats producing mosaics of heterogeneous habitats across the landscape. Pesticide use was also found to be a key negative predictor of pollinator abundance and richness, although by contrast the use of fertilizers significantly increased pollinator abundance. In another study, pesticides were also found to impact honeybee colonies by weakening their potential for crop pollination (Muli et al., 2014). This may be a result of pesticides impairing the bees' ability to learn floral associations and hence taking longer to find and pollinate flowers (Siviter et al. 2018). The extent to which this impacts legume crops reliant on honeybees is unknown. Masiga et al., (2014), while studying pollination deficits in French beans in Kenya, found that natural areas adjacent to crop fields were important for pollination service delivery and advocated area-wide habitat management to support carpenter bees which are key pollinators of French beans.

3) The role of natural enemies of pests in legume crop production in Africa

3.1 Natural enemies of legume crop pests

Insect pests are among the major challenges faced by legume crop growers in both small-holder and large scale farming systems in Africa. Our review showed that legume crops suffer a multitude of pests affecting various parts of the plant and can cause significant losses to yield including up to 100% yield losses in some cases (Table 2).

Table 2: summary of pests of legume crops and associated yield losses in Africa

Common pest orders	Bean plants (*Phaseolus vulgaris*)	Broad beans (*Vicia faba*)	Chick peas (*Cicer arietinum*)	Cow peas (*Vigna unguiculata*)	Pigeon peas (*Vicia faba*)	Lentils (*Lens culinaris)*	Dry peas (*Pisum sativum*)	Peanut/ground nut (Vigna subterranea)	Runner beans (Phaseolus coccineus)	Soy bean (Glycine max)
Percentage yield loss due to pests	100%	10 - 70%	30-100%	90 – 100%	10 – 70%	∞	80%	70%	∞	20 -40%
Isoptera	RO,LE		ST	RO,LE	ST			RO, ST		
Orthoptera	LE	LE	LE	LE	LE					LE
Coleoptera	LE,FL,PO	LE,FL,PO		RO,LE,FL,PO,SE	LE,FL,PO,SE	RO, LE, SE	RO, PO	LE	LE,PO	LE, FL, PO
Hymenoptera	LE			LE						LE, PO
Thysanoptera	FL,PO	FL		FL	LE, FL	LE, FL, PO	FL		LE,FL	
Lepidoptera	FL,PO		ST, LE,POO	ST,FL,P,SE	ST,F,P,SE	PO, SE	PO	RO	LE, FL	LE,PO
Hemiptera	LE,FL,PO	LE,FL	LE	ST, LE,FL,P	LE,FL,PO	RO, LE,FL,PO	LE	LE	LE,PO	LE, PO, SE
Diptera	LE,FL,PO		LE	LE,FL,PO	LE,FL,PO	LE	ST,LE			RO, ST
References	Abate and Ampofo 1996; Mwanauta et al., 2015; Ochilo and Nyamasyo 2011; Ojwang' et al., 2010	Hansen et al., 2008; Duan et al., 2014; Stoddard 2010	Latif et al., 2019	Karungi et al., 2000; Oyewale, and Bamaiyi 2013	Dialoke et al., 2010; Minja et al., 1999; Minja et al., 1999	Stevenson et al., 2007	Ali et al 2009	Mkandawire et al., 2007, Dike 1997	Biddle and Cattlin 2007	Hartman et al., 2011; Abudulai et al., 2012

Note: the damaged plant parts are denoted by RO = Root, FL= flower, PO = pod, SE = seed, ST = Stem and LE = leaf. ∞ denotes that yield loss attributed to pests for a particular crop was not reported. Full references to citations are provided in **Appendix 3b**.

Pest suppression by natural enemies has been recognized as an important regulating ecosystem service that can offer an environmentally benign solution to pest problems (Snyder, 2019[+]).

Furthermore, interest in the use of natural enemies in Integrated Pest Management (IPM) programs including legume cropping systems has grown in recent years, including in Africa (Pretty and Bharucha, 2015).

In legume cropping systems, predators of insect pests include; spiders (Araneae), true bugs (Hemiptera), ground beetles (Carabidae; Coleoptera), rove beetles (Staphylinidae; Coleoptera), ladybird beetles (Coccinelidae; Coleoptera), praying mantis (Mantodea), lacewings (Neuroptera), earwigs (Dermaptera), and hoverfly larvae (Syrphidae; Diptera) (Abtew et al., 2016; Brévault and Clouvel, 2019). Parasitoids are also important natural enemies of some pests in Africa (Mkenda et al., 2019a,b&c) (Table 3).

Table 3. Summary of natural enemies and the pests they can help control in legume crops in Africa

	Pests - Orders								
Natural enemies – Orders	Trombidiformes	Hemiptera	Lepidoptera	Thysanoptera	Hymenoptera	Diptera	Coleoptera	Orthoptera	**References**
Hemiptera	√	√	√						Lee and Landis, 2001; Stewart et al, 2007; Javahery, 2013;
Diptera	√	√	√			√	√	√	Stewart et al, 2007; Mahr et al., 2008; Ndakidemi et al., 2016; Pesticide Action Network (PAN) (2014)
Coleoptera	√	√	√	√	√	√			Chin and Brown 2010; Lee and Landis, 2001
Neuroptera	√	√							Lee and Landis, 2001
Araneae		√	√			√			Ndakidemi et al., 2016
Hymenoptera		√	√			√			Ndakidemi et al., 2016

Note: Full references to citations are provided in **Appendix 3c**.

In Africa, a limited understanding of the potential of natural enemies in pest control exists. In East Africa, for instance, legumes are grown and consumed by millions of people and pests remain one of the key challenges in the production process, yet the use of natural enemies to mitigate this challenge is limited (Belmain et al., 2013). Some studies however do demonstrate the potential benefits of natural enemies. A review by Ndakidemi et al., (2016) found natural enemies and pollinators within legume fields to play a key role in ensuring sustainable production, especially in smallholder farms. Furthermore, Mkenda et al., (2019b&c) identified parasitoids and hyperparasitoids of aphids (*Aphis fabae*) on bean plants (*Phaseolus vulgaris*) and proposed interventions to improve landscapes by adopting farming practices that can augment the populations of the most common parasitoid, *Aphidius colemani*, to enhance pest control.

3.2 Impacts of agricultural intensification and land-use change on natural enemies in legume crops in Africa

Changing land-use and farm management practices caused by agricultural expansion and intensification to match the needs of a fast-growing population in Africa has resulted in the loss of natural habitats in tandem with a decline in overall biodiversity (Tscharntke et al., 2005[+]; Lamarque et al., 2011[+]; Belmain et al., 2013). The human population in Africa has almost doubled since 2000 and is projected to be 2.4 billion people, compared to the current 1.3 billion, by the year 2050 (United Nations, 2019). This could potentially result in drastic land-use change leading to declines in indigenous plant species, which support beneficial native arthropod species. This increase in population in tandem with increasing pulse legume production (although with a slight decline between 2015 and 2017) (Fig. 3) is likely to cause increased pressure on remaining natural or near-natural habitats, exacerbating the problems facing natural enemies if no mitigation measures are put in place to safeguard the existence of these beneficial organisms.

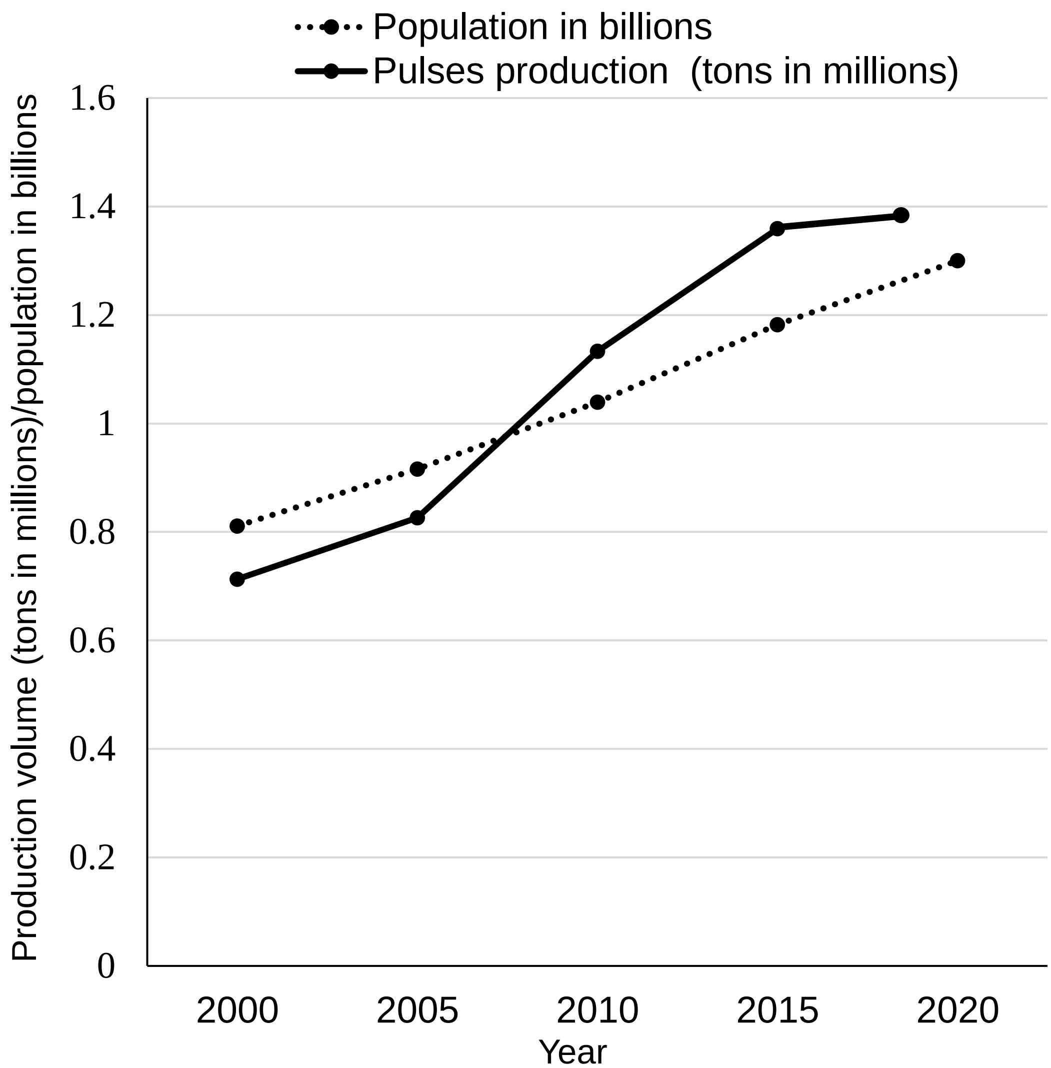

Figure 3: Trends in legume production (millions of tons) and population growth (billions of people) in Africa from 2000 to 2020 (*Source: FAOSTAT, 2020 and World Population Prospects (2017 Revision) - United Nations population estimates and projections 2019*). **Note**. Legume production data was only available up to 2018 by the time of this review.

Agricultural intensification has resulted in considerable simplification of cropping systems in terms of the diversity of crop species grown and management practices used in agricultural landscapes (Keating et al., 2013[+]). For example, it was once common practice to intercrop maize, beans and pumpkins in small-holdings in Africa, providing all-year on-farm nutritious food, however such practices are declining (Pleasant, 2016). This agricultural simplification can result in the loss of natural enemy species which are generally supported by diverse discontinuous systems, thus weakening the ability of these beneficial organisms to suppress pest species, e.g. aphids (Zhao et al., 2015[+]). As a result, pests can multiply in the absence of their natural enemies prompting farmers to adopt alternative strategies such as increasing the dosage and/or strength of pesticides resulting in reduced potential for natural pest control (Krauss et al. 2011) and associated environmental risks (Bon et al., 2014). Studies on other crops found that keeping some natural habitats in the landscape benefited natural enemies e.g. Kebede et al., (2018) and such approaches could be taken in legume cropping systems.

While there is generally only a limited body of literature on legume pollinators and natural enemies of pests in Africa, particularly those from which to deduce trends in the delivery of pollination and pest regulation services to legume crops, our review confirms the existence of three main patterns consistent with global trends, namely; (i) pollinators can significantly increase legume crop yields, and (ii) a diverse array of pests threaten legume yields but natural enemies can control these pests, but (iii) increasing agricultural intensification and human population growth has led to loss of near natural habitats on which pollinator and natural enemy communities rely and reduced crop diversity at local and landscape scales has put pressure on their populations and the services they provide.

4) Current knowledge gaps and avenues for future research

Pollinators and pollination

Studies on the pollination requirements of key legume crops (including different varieties) and how this varies between farming system, landscape and geographic regions are needed. To do this, the use of available tools for the assessment of ecosystem services such as FAO's protocol for assessing pollination deficits (Vaissière et al., 2011+) and the Toolkit for Ecosystem Service Site-based Assessment (TESSA) (Peh et al., 2013+) can be employed. These protocols involve pollinator exclusion and supplementary pollination techniques which has been effectively employed in many crops and systems to identify levels of crop dependence and potential deficits and opportunities to increase yield through the management of pollinators (Garibaldi et al 2016). Such research takes time and resources, but it could be targeted at those crops and varieties where evidence is lacking or that are of particularly high value. Furthermore, to increase geographical coverage or help with targeting management interventions, methods evaluating pollination could be implemented by farmers themselves (Garratt et al., 2019+).

Identifying individual invertebrate species or elements of the invertebrate community that are making the most important contributions to pollination based on abundance and effectiveness is also necessary to inform effective conservation and biodiversity management. The contribution of pollinators can be estimated by directly comparing the effectiveness of individual species to different crops in controlled experiments (Garratt et al., 2014+) or by considering species and community traits (Garabaldi et al., 2015+, Greenop et al., 2018+, Woodcock et al., 2019+) to identify species or groups of species with a key functional role in African legume production systems.

Finally, there is also a need to study the regional and geographical distribution of legume pollinators to help understand the impacts of possible drivers effecting pollinator populations including land-use change, anthropogenic disturbance and climate change (Kerr et al. 2015; Woodcock et al. 2016; Peters et al. 2019). Regional studies in Kenya have shown that some bee species have narrower ecological niches – in terms of activity, host preference and interspecific interactions and are therefore more sensitive to changes than generalist species e.g. honey bees (see Otieno et al. 2015). A better understanding of legume pollinator traits through targeted research will help predict the vulnerability of different pollinator species to various threats.

Natural enemies of pests

Studies establishing the role of natural enemies in controlling key pests in legume crops and identifying trade-offs in using these organisms compared to chemical pesticides are needed. These studies could, for instance, determine optimal application strategies (e.g. by pesticides) that avoid unnecessary harm to predatory arthropods e.g. spiders, hoverfly larvae, ladybirds and parasitoids. It is important to establish accurate economic thresholds for pests on legume crops so that only selective pesticides are applied when necessary as part of an IPM strategy (Gentz et al., 2010). Importantly, organic management, mixed cropping and new pest control approaches such as push-pull systems require experimental testing and tailoring to legume crops but represent huge potential for more sustainable farmland management in Africa (Hassanali et. al. 2008; Eyhorn et al., 2019).

Ecological intensification

Ecological intensification (EI) aims at increasing crop productivity by enhancing biodiversity and associated ecosystem services while minimizing the use of synthetic inputs and cropland expansion (Franke et al., 2018[+]; Garibaldi et al., 2019[+]). This practice presents a viable strategy for promoting beneficial insects important for legume crop production in Africa but currently there is a lack of evidence for the potential of EI and effective tools for its implementation.

In the advent of habitat loss and land degradation leading to low habitat quality (Kennedy et al., 2013[+]; Ferreira et al., 2015[+]; Nemésio et al., 2016[+]), community stability and processes such as pollination and natural pest regulation are weakened and networks destroyed (Kovács-Hostyánszki et al., 2017[+]). With these foregoing impacts, the employment of EI practices that either restore or maintain semi-natural and natural habitats achieved through effective habitat management or establishment of boundary features, fallows, etc. can therefore greatly increase the complexity and connectivity within legume agricultural landscapes required by many species of pollinators and natural enemies (Mkenda et al., 2019b).

Sufficient control of pests may not always be achievable by natural enemies alone in cases where pest populations are beyond the control of natural enemies. In such cases it is important to employ a measured approach to pesticides use by following guidelines and, most importantly, adopting Integrated Pest and Pollinator Management (IPPM) as part of an ecologically intensive strategy. This encompasses better training, use of the correct application equipment, utilizing less toxic alternatives, spraying outside blooming period and pollinator activity times. These approaches limit risks to pollinators, natural enemies and the environment while increasing the benefits of these pesticides to crops (Biddinger and Rajotte, 2015[+]).

5. Regulations and policies to protect and promote pollination and natural pest regulation

Protecting pollinators and natural pest enemies could be through the development of regulations and legislations using policy interventions that incentivize good practices (such as habitat protection and IPM) among farmers and citizens. Implementing policies that promote the utilization of pollinators and natural enemies of pests through a regulatory framework could be a viable tool for improving the sustainability of legume production. However, African countries generally (apart from a few such as South Africa (Fabricius et al., 2003)), lack policies to formally guide the use of ecosystem driven natural resources, but regulations on how pollination and natural pest control services should be managed are urgently needed. Mirroring approaches taken by countries such as the Philippines, a comparatively low to middle-income country not unlike many in Africa, including institutionalization of farmer field schools and training on IPM (Furlong et al., 2019). However sufficient investment is needed from regional and national governments.

Many farmers in Africa already practice organic farming (Epule, 2019). Organic approaches could be further supported through incentives and policies that provide the necessary guidelines and framework within which organic farming can take place effectively to safeguard the environment and ecosystem services. This could be achieved through the provision of subsidies to farmers who practice environmentally-friendly farming or certification of products from such farms combined with facilitation to access suitable markets.

As identified in this review, multiple factors are acting together to impact the future of legume crop production in African agricultural landscapes. These impacts have knock-on effects on the well-being of pollinators and natural enemies of pests. This calls for adequate regulations and policies that will not only promote the production of legume crops but also safeguard pollinator and natural enemy species and guide the utilization of these ecosystem service providers.

In summary, six policy directions can benefit both pollinators and natural enemies of legume pests in Africa;

1. Development of beneficial insect friendly pesticide policies. This would result in the restriction of some of the most harmful pesticides affecting pollinators or natural enemies

either directly or indirectly. This would be supported through better training for growers on using alternative pesticides and biological control approaches.

2. Extension of protected area policies to include key habitats that support pollinators and natural enemy communities essential to the production of legumes and other crops. These policies could provide information for the enhancement of beneficial insect habitats either through plantings or management in ways that ensure beneficial insects thrive. Extension services also need to include narratives of pollinator and natural enemy conservation practices in their encounters with farmers.

3. Development of a framework to incentivize farmers through programs such as payment for ecosystem services i.e. for farmers that grow pollinator-friendly crops to have a built-in incentive to manage their habitats for native pollinators (Rose et al., 2015[+]). Governments could also consider tax benefits extended to farmers who practice pollinator-friendly farming.

4. Provision of a framework for ensuring representation in empowerment programs, certification of farmers who practice environmentally friendly farming (whether public or private-led) and market access for all stakeholders involved in legume crop production. This also includes indigenous farmers. Packages for protecting beneficial species need to be developed together with all stakeholders building on local knowledge gained from participatory encounters.

5. Recognition of the role of research in training experts and developing solutions to environmental problems especially those that threaten the existence of beneficial species. On this policy front, it is important to provide a framework for implementing research

findings from pollination and natural pest regulation studies in advancing legume crop production.

6. Improved knowledge exchange between farmers, extension workers, researchers, NGOs and policymakers to highlight the multiple values of pollinators and natural enemies for improved nutritional, food and economic security. This could take the form of national training programmes, farmer field schools, participatory research, and evidence-based policy development.

6) Conclusion

Our review has demonstrated the important role played by pollinators and natural enemies in legume crop production in Africa and contributions of these organisms to food security. The review identifies agricultural intensification and population growth as the key drivers changing the landscapes used by beneficial organisms and threatening their future existence and the services they provide. Ecological intensification and organic farming offer novel solutions to safeguarding the ecosystem services provided by pollinators and natural enemies of pests. The application of ecological intensification through practices such as effective habitat management or establishment of boundary features, fallows, etc. in legume cropping systems can restore or maintain semi-natural and natural habitats suitable for beneficial insects. These habitats provide the much needed connectivity required by beneficial organisms within legume agricultural landscapes to sustain viable populations.

Finally, African countries need a holistic approach to raise awareness among farming communities and move towards the use of policies in the utilization of naturally occurring ecosystem services of pollination and natural pest regulation to formally protect these ecosystem services by reducing the environmental impacts of agriculture and its dependence on nonrenewable resources to safeguard the legume crop base. This can be done through a more promising avenue of ecological intensification using biodiversity-mediated ecosystem services to support legume production.

Declaration of conflict of interest

None.

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Appendix 1: Table showing harvested area, production and yield of major legume food crops in Africa from 2000 to 2018 (*Source: FAOSTAT 2020*)

Changes	**Dry beans**	**Broad**	**Chick peas**	**Cow peas**	**Lentils**	**Lupins**	**Dry peas**	**Pigeon**	**Soybeans**
Mean area harvested (ha)									
2000 - 2002	4868615.33	803568.33	503042.67	9125406.67	133829.33	46909.33	485898.00	530418.67	947208.33
2003 - 2005	5565534.67	851428.67	477593.00	9744456.00	122533.00	56411.33	554096.67	580059.67	1127680.00
2006 - 2008	5771109.67	882322.00	498695.33	11604309.00	146890.33	71807.33	554279.67	567059.67	1293698.00
2009 - 2011	6556346.00	905644.67	529249.00	10265708.67	158816.67	81605.33	661859.00	568933.00	1317029.67
2012 - 2014	7602270.67	920938.67	624007.67	11821643.00	183476.33	92688.00	733444.33	798486.33	1771850.00
2015 - 2018	7397390.00	779496.50	516803.75	12079017.50	172193.75	102512.75	657090.50	720141.5	2214297.00
Change in area (2000 to 2018)	-204880.67	-141442.17	-107203.92	257374.50	-11282.58	9824.75	-76353.83	-78344.83	442447.00
% Change	-2.69	-15.36	-17.18	2.18	-6.15	10.60	-10.41	-9.81	24.97
Growth rate per	-0.01	-0.03	-0.06	0.02	0.01	0.03	-0.01	0.01	0.05
%Growth	-0.77	-3.30	-6.21	1.80	0.87	3.29	-1.03	0.69	5.06
Mean production (tons)									
2000 - 2002	3325776.67	1069773.33	346952.33	3540293.67	80572.33	39562.00	313561.67	357054.00	1000311.67
2003 - 2005	3407923.33	1145608.00	334639.00	4180280.00	76424.33	39406.67	382376.67	387926.67	1166677.67
2006 - 2008	4082267.33	1246123.67	419926.33	5253550.67	102486.33	52863.67	411754.67	430515.33	1412246.00
2009 - 2011	5267471.00	1311391.67	552424.33	5145383.67	155586.33	59056.00	533382.00	487499.67	1555899.67
2012 - 2014	6207657.00	1477546.67	704242.67	7148536.33	194956.67	65739.33	673256.00	745091.67	2120059.00
2015 - 2018	6756959.5	1363019.5	717333	6588501.25	213987.75	72143.5	632927.75	878497.25	2861969.75
Change in production (2000-2018)	549302.50	-114527.17	13090.33	-560035.08	19031.08	6404.17	-40328.25	133405.58	741910.75
% Change	8.85	-7.75	1.86	-7.83	9.76	9.74	-5.99	17.90	34.99
Growth rate per	0.02	-0.01	-0.00	-0.01	0.04	0.03	0.01	0.08	0.09
%Growth	2.32	-1.36	-0.23	-0.53	3.77	3.17	0.51	7.55	8.81
Mean yield (ton/ha)									
2000 - 2002	0.68	1.33	0.69	0.39	0.60	0.85	0.64	0.67	1.06
2003 - 2005	0.61	1.34	0.70	0.43	0.63	0.69	0.69	0.67	1.03
2006 - 2008	0.71	1.42	0.84	0.45	0.70	0.74	0.74	0.76	1.09
2009 - 2011	0.80	1.45	1.04	0.50	0.98	0.72	0.81	0.85	1.19
2012 - 2014	0.82	1.61	1.13	0.61	1.07	0.71	0.92	0.93	1.20
2015 - 2018	0.90	1.86	1.43	0.57	1.22	0.70	1.02	1.16	1.36
Change in yield (2000 to 2018)	0.10	0.14	0.26	-0.06	0.18	-0.01	0.05	0.29	0.09
Growth rate/year	11.73	9.01	22.87	-10.57	17.24	-0.79	5.16	30.98	7.32
%Growth	0.03	0.02	0.07	-0.02	0.03	-0.00	0.01	0.07	0.03

Appendix 2a: Table of search criteria for legume pollination related studies done in Africa

S/N	Region	Search terms	Number of papers	Criteria
1	Eastern Africa	legume Pollinat* AND "**Eastern Africa**" OR "Burundi" OR "Comoros" OR "Djibouti" OR "Ethiopia" OR "Eritrea" OR "Kenya" OR "Madagascar" OR "Malawi" OR "Mauritius" OR "Mozambique" OR "Réunion" OR "Rwanda" OR "Seychelles" OR "Somalia" OR "Somaliland" OR "Tanzania" OR "Uganda" OR "Zambia" OR "Zimbabwe"	23,633	Refined search by research articles or review papers in ecology or environmental science/studies or entomology
2	Western Africa	legume Pollinat* AND "**Western Africa**" OR "Benin" OR "Burkina Faso" OR "Cape Verde" OR "Côte d'Ivoire" OR "Ivory Coast" OR "Gambia" OR "Ghana" OR "Guinea-Bissau" OR "Liberia" OR "Mali" OR "Mauritania" OR "Niger" OR "Nigeria" OR "Saint Helena" OR "Ascension" OR "Tristan da Cunha" "Senegal" OR "Sierra Leone" OR "Togo"	18,687	
3	Northern Africa	legume Pollinat* AND "**Northern Africa**" OR "Algeria" OR "Egypt" OR "Libya" OR "Morocco" OR "Sudan" OR "Tunisia" OR "Western Sahara"	17,561	
4	Southern Africa	legume Pollinat* AND "**Southern Africa**" OR "Botswana" OR "Lesotho" OR "Namibia" OR "South Africa" OR "Swaziland" OR "Eswatini"	25,993	
5	Central Africa	legume Pollinat* AND "**Central Africa**" OR "Angola" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Congo Republic" OR "Democratic Republic of Congo" OR "Equatorial Guinea" OR "Gabon" OR "São Tomé ? Principe"	2,647	

Appendix 2b: Table of search criteria for legume natural pest control related studies done in Africa

S/N	**Region**	**Search terms**	**Number of papers**	**Criteria**
1	Eastern Africa	legume "natural enemies" OR "natural pest enemies" OR "biocontrol" OR "biological control" AND "**Eastern Africa**" OR "Burundi" OR "Comoros" OR "Djibouti" OR "Ethiopia" OR "Eritrea" OR "Kenya" OR "Madagascar" OR "Malawi" OR "Mauritius" OR "Mozambique" OR "Réunion" OR "Rwanda" OR "Seychelles" OR "Somalia" OR "Somaliland" OR "Tanzania" OR "Uganda" OR "Zambia" OR "Zimbabwe"	26,459	Refined search by research articles or review papers in ecology or environmental science/studies or entomology
2	Western Africa	legume "natural enemies" OR "natural pest enemies" OR "biocontrol" OR "biological control" AND "**Western Africa**" OR "Benin" OR "Burkina Faso" OR "Cape Verde" OR "Côte d'Ivoire" OR "Ivory Coast" OR "Gambia" OR "Ghana" OR "Guinea-Bissau" OR "Liberia" OR "Mali" OR "Mauritania" OR "Niger" OR "Nigeria" OR "Saint Helena" OR "Ascension" OR "Tristan da Cunha" "Senegal" OR "Sierra Leone" OR "Togo"	24,635	
3	Northern Africa	legume "natural enemies" OR "natural pest enemies" OR "biocontrol" OR "biological control" AND "**Northern Africa**" OR "Algeria" OR "Egypt" OR "Libya" OR "Morocco" OR "Sudan" OR "Tunisia" OR "Western Sahara"	26,721	
4	Southern Africa	legume "natural enemies" OR "natural pest enemies" OR "biocontrol" OR "biological control" AND "**Southern Africa**" OR "Botswana" OR "Lesotho" OR "Namibia" OR "South Africa" OR "Swaziland" OR "Eswatini"	35,026	
5	Central Africa	legume "natural enemies" OR "natural pest enemies" OR "biocontrol" OR "biological control" AND "**Central Africa**" OR "Angola" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Congo Republic" OR "Democratic Republic of Congo" OR "Equatorial Guinea" OR "Gabon" OR "São Tomé ? Principe"	13,939	

Appendix 3a: References to pollination studies on legume crops in Africa

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