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ORIGINAL PAPER

Food security impacts of industrial crop production in sub-Saharan Africa: a systematic review of the impact mechanisms

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Abstract

A number of industrial crops have been promoted in sub-Saharan Africa (SSA) to meet a range of policy objectives including economic growth, rural development, agricultural modernization and energy security. The food security impacts of industrial crop production have received extensive policyattention and have been widely discussed in the academic literature. There is, however, an overall lack of a clear understanding of these impacts due to thelarge diversity of industrial crops, and their varied modes of production, expansion areas, and impact mechanisms. This systematic review synthesizes theavailable knowledge on the interface of industrial crops and food security in SSA. In particular we identify key patterns with how different industrial cropsand impact mechanisms are represented and studied in the current literature, and how they intersect to affect food security. The current literature isfragmented, as most studies focus on single or small subsets of crops and impact mechanisms. Most studies capture mechanisms related to food access andavailability, rather than to food utilization and stability. A clustering analysis identified the main literature clusters that combine mechanisms related to foodavailability, access to food, and environmental impact. The overall analysis presented in this systematic review allowed us to identify priority policy andpractice domains that need to be targeted in order to improve the food security outcomes of industrial crop production in SSA.

Keywords Biofuels · Cash crops · Cluster analysis · Impact mechanism · Sub-Saharan Africa

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12571-019-00988-x) contains supplementary material, which is available to authorized users.

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1 Introduction

Industrial crops have non-food uses such as for fibre, and feedstock for bioenergy and other industrial products (Singh 2010). Industrial crops include crops that cannot be used for food consumption (e.g., cotton, tobacco, jatropha) and crops that have non-food uses but are also integral components of the food industry without being staple crops (e.g., oil palm, sugarcane) (Wiggins et al. 2015; Singh 2010).[1] Some industrial crops can be mono-functional, for example used only for fibre (e.g. cotton), recreation (e.g. tobacco) or energy (e.g. jatropha). Other industrial crops such as sugarcane can have

[1] Some major staple food crops in sub-Saharan Africa (SSA) such as maize and cassava can also be considered as industrial crops in some contexts, as they can have non-food uses (such as for ethanol). However, these other uses are minor for maize as it is by far the main staple food crop across most of SSA. For other staple crops with industrial uses such as cassava, very few papers track the final end use. Hence it is difficult to understand whether these crops are used for industrial uses in a given context. In SSA, industrial crops are essentially cash crops, as they are cultivated overwhelmingly for income generation rather than household use.

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multiple functions including as food supplements (i.e. sugar), fuel (i.e. ethanol), and industrial products (i.e. as bioplastics). In this respect, industrial crops are defined by their functionality and end use, rather than the mode of production. The production of industrial crops is undertaken in different farming systems ranging from extensive smallholder farms to large-scale intensive plantations (Singh 2010) (see Section 2).

Industrial crop cultivation has traditionally been a major agricultural activity in many parts of sub-Saharan Africa (SSA). Thus, it intersects with food crop production, rural development, and environment sustainability, and as a result has important ramifications for food security[2] (Wiggins et al. 2015) (see Sections 3–4). Such intersections are particularly important in SSA where agriculture is the main source of livelihoods (Niang et al. 2014), and chronic undernutrition, food insecurity and low food self-sufficiency (FAO, IFAD, UNICEF, WFP, WHO 2018; Akombi et al. 2017; FAO and ECA 2018) combine with high and endemic poverty (Beegle et al. 2016; World Bank 2019). These linkages become even more important considering the rapid environmental change throughout the region (Niang et al. 2014; IPBES 2018), which has important ramifications for agricultural production (e.g., Reynolds et al. 2015; Onyutha 2018a; van Ittersum et al. 2016).

The impacts of industrial crops on food security is a relatively new research topic. Economic narratives dominated the early debates about industrial crop impacts in SSA (e.g., prior to the 2000s). Some scholars viewed industrial crop production as a capitalistic means for the continued exploitation of SSA countries following colonial rule (Darkoh and Ould-Mey 1992; Timberlake 1985). Conversely other scholars perceived industrial crop production as one of the few competitive economic advantages for many countries in the region, and an avenue to integrate them into the global economic system (Mellor and Malik 2017; Timberlake 1985; Van Vliet et al. 2015). Gradually, the environmental and social impacts of industrial crop production have become more visible within the academic literature, particularly that related to bioenergy (e.g. Gasparatos et al. 2015; German et al. 2011).

Food security has emerged in the past 10–15 years as one of the most widely debated impacts of industrial crop production in SSA, largely following the proliferation of biofuel projects and the prominence of the land grabbing, land dispossession, and “food vs. fuel” debates (Kuchler and Linnér 2012; Tenenbaum 2008; Tomei and Helliwell 2016). In these debates, industrial crops (especially bioenergy crops) were perceived to be major risks to food security at the local and national level mainly though competition for land (e.g. Molony and Smith 2010; Matondi et al. 2011; HLPE 2013). Conversely, other studies focused on the economic potential of industrial crop production, identifying them as an important driver of economic growth and rural transformation that could have positive food security outcomes if undertaken sensibly (Arndt et al. 2012; Hartley et al. 2019; HLPE 2013).

However, it is extremely complicated to unravel comprehensively the food security outcomes of industrial crop production, as they are mediated by different mechanisms (Wiggins et al. 2015). For example, as with other agricultural activities, industrial crop production is a major driver of land use change, and is bound to compete for land with food crop production in SSA (Gasparatos et al. 2018a). Land competition is one of the most significant mechanisms mediating the food security outcomes of industrial crop production (Wiggins et al. 2015). Another mechanism is the generation of formal and stable income and employment opportunities that are often lacking in poor rural areas of SSA (Darkoh and Ould-Mey 1992; Tosh 1980). The income generated through engagement in industrial crop production could be used to buy food, thus having a positive effect on some aspects of food security (e.g., Bosch and Zeller 2013; Strasberg 1997). Such income-related positive effects can be particularly pronounced during periods of high food insecurity (von Maltitz et al. 2016).

In reality, industrial crop production can catalyse a very diverse constellation of impact mechanisms that ultimately mediate the actual food security outcomes in SSA (Wiggins et al. 2015). These mechanisms can depend on diverse factors such as the type of crop, the mode of production (e.g., large-scale plantations or smallholder settings), the environmental and socioeconomic context of industrial crop production, and the institutions that govern industrial crop production, use and trade (e.g., Gasparatos et al. 2015; FAO and ICAC 2015).

Studies at the intersection of food security and industrial crops have used different methodologies and indicators.[3] The existing literature offers a mosaic of information for different crops, modes of production, geographic areas, and impact mechanisms. Despite some comparative studies (e.g., Silvestri

[2] Different interpretations and definitions of food security have been proposed (Clay 1997; Gibson 2012; Jones et al. 2013). For this systematic review we adopted the four-dimension definition proposed by the UN Food and Agriculture Organisation (FAO 2006), namely food availability, stability, access, and utilization. Food availability generally relates to the food supply side, and addresses issues of food production, stock levels and trade. Access to food (both economic and physical) reflects the sufficient supply of food at the local, national and international levels. Food utilization relates to nutrient utilization within the human body. It covers various nutritional practices such as food intake and preparation, diet diversity, food distribution and the general nutritional status of individuals. Food stability reflects the stability of the three aforementioned dimensions over time, which is necessary for sustaining a stable food intake and overcome periodic risks and food insecurity. The stability dimension depends on various economic, socio-political, and environmental factors, and is occasionally considered as the dimension that integrates food availability, access and utilization (Ericksen 2008). Food security is a scale-depended multi-dimensional concept that relates to different levels such as the national, local and the household level (Pinstrup-Andersen 2009). At the national level, food security relates mainly to the supply side, and describes the availability and distribution of food to ensure healthy and nutritional diets. At the intra-household level food security represents a state where all household members have sufficient amount of food for their needs.

[3] This has also been observed in other SSA contexts, such as in urban areas (Haysom and Tawodzera 2018).

et al. 2016; Achterbosch et al. 2014; Baiphethi and Jacobs 2009), we have only a piecemeal understanding of the issues usually through individual case studies focusing on specific industrial crops, locations, and/or impact mechanisms.

Nevertheless there is an emerging strand of literature that has explored the interface of industrial crops and food security in SSA in recent decades. This literature is both conceptual and empirical, and has adopted different perspectives such as the land-sharing and land-sparing debate, agroecology, and equity and social justice. However, to our best knowledge no study has synthesized comprehensively these viewpoints or delineated the different mechanisms through which industrial crop production mediates food security in SSA. Considering the increasing global demand for industrial crops and land allocated for their production in SSA (see Section 2), this possibly limits the efficacy of current literature to inform policymakers and practitioners.

Accordingly, this paper aims to systematise the existing evidence about the different mechanisms through which industrial crop production affects food security in SSA. The objectives are to unravel: (a) the key literature patterns for different industrial crops and impact mechanisms (e.g., which food security pillars are studied the most) (Sections 4.1, 5.1); (b) how mechanisms intersect and affect food security (e.g., which mechanisms combine to affect food security and how) (Sections 4.2, 5.1); (c) the underlying factors affecting the food security outcomes of industrial crop production (e.g., main themes related to each mechanism) (Section 5.2); and (d) the possible key priority areas to reduce the negative food security outcomes of industrial crop production (Section 5.3). We focus on industrial crops that strictly have non-food uses and/or are important components of the food industry without being staple food crops (see Footnote 1). Such crops have received substantial attention in academic, policy and practice debates.

Section 2 outlines the history and production patterns of industrial crops in SSA. Section 3 outlines the systematic review protocol, including the impact mechanisms, and the methods for paper selection, review and analysis. Section 4 highlights the main literature patterns, especially the main represented crops and mechanisms, and how they intersect to affect food security. Section 5 synthesizes the main review findings, makes recommendations how to improve the food security outcomes, and proposes future research priorities at the interface of industrial crops and food security.

2 Historical patterns and modes of production

Several regions in SSA have a long tradition of industrial crop production that predates the colonial period, e.g. see Kriger (2005) for cotton. During the colonial era, industrial crop production expanded rapidly in different parts of the subcontinent to meet the large demand in Europe for crops such as cotton, cocoa, coffee, and rubber (Brun 1991).

In the post-colonial era, industrial cropping became a major economic cornerstone in several SSA countries (Achterbosch et al. 2014). For example, tobacco and sugarcane have become the major exports for Malawi, contributing significantly to foreign exchange earnings (Chinangwa et al. 2017). Cocoa has been the backbone of the national economies of Ghana and Ivory Coast (Breisinger et al. 2008), while sugarcane has practically dominated the economies of small countries such as Swaziland and Mauritius (Terry and Ogg 2016; Kee Kwong 2005). Cotton has underpinned the national economies of several countries in western Africa, including Burkina Faso and Mali (Tschirley et al. 2009; Vitale 2018).

The long-standing effort to modernize the agricultural sectors of SSA countries and integrate them into the global economic system has been one of the major drivers of industrial crop expansion in the post-colonial era (Mellor and Malik 2017; Timberlake 1985; Van Vliet et al. 2015). More recently, the prospects of socioeconomic development, economic growth through exports, and energy security have driven the rapid expansion of bioenergy crop production (Gasparatos et al. 2015), particularly following the 2008 food and fuel price crisis. Many national governments view industrial crops [and the foreign direct investments (FDI) they can attract], as engines of national economic growth and rural development (Gasparatos et al. 2015; German et al. 2013; Schoneveld 2014). Thus, many countries have opened their rural frontiers for FDIs related to industrial crops (Giovannetti and Ticci 2016; FAO 2012), especially during the land rush around the 2008 food and fuel price crisis (Schoneveld 2014).

Bioenergy crops such as jatropha and sugarcane have accounted for most of the industrial crop expansion since the mid-2000s, often through foreign-led large-scale land acquisitions (Schoneveld 2014). However, despite the heavy promotion of jatropha, it is not clear how much land was allocated and converted to its production before its widespread collapse in the last few years (Gasparatos et al. 2015; von Maltitz et al. 2014). Jatropha investments possibly accounted "*for 31.1% of the total area acquired; with the largest areas acquired in Madagascar (979,610 ha), Zambia (707,476 ha), and Ghana (671,951 ha)*" (Schoneveld 2014: 39), but less land was actually converted in most of these countries (Locke and Henley 2013).

Cocoa is the most extensively cultivated industrial crop in SSA in terms of land area, amounting to 11.37 million ha harvested in 2012, surpassing coffee by a wide margin (Fig. 1). Sugarcane has experienced a steady increase in harvested area (Fig. 1), becoming the leading industrial crop in terms of tonnage (94.6 million t in 2012) (Fig. 2). Other industrial crops, such as cocoa, coffee, cotton, oil palm, rubber, tea, tobacco and vanilla amounted to a combined production of 11.2 million t in 2012. Palm oil production has been increasing sharply in Central and Western Africa to meet the ever-rising regional

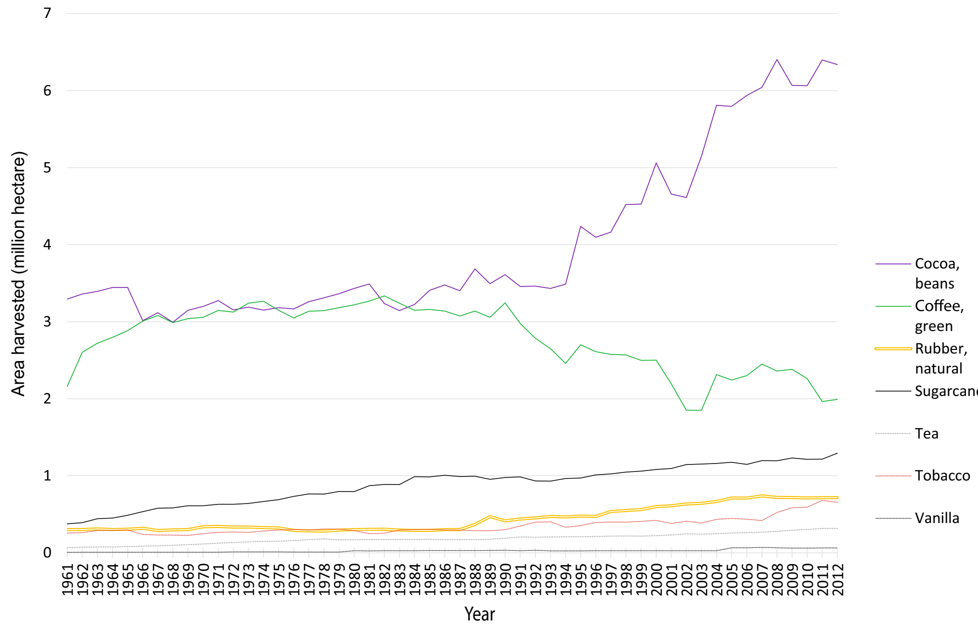

Fig. 1 Harvested area for major industrial crops in sub-Saharan Africa. Source (FAOSAT 2019)

and global demand (Ordway et al. 2017; Carrere 2010). Similarly, the export revenues generated from major industrial crops have also increased rapidly, reaching an annual value of USD 19.6 billion in 2011 across the region (Fig. 3).

In some SSA countries, industrial crop production has been considered a success in terms of delivering the anticipated economic growth and rural development (e.g. see World Bank 2011). However, that has not been the case in many other SSA countries due to various interconnected reasons such as fluctuations in exchange rates, high export taxes and inefficient markets (Achterbosch et al. 2014; Amigun et al. 2011; Boafo et al. 2018).

Furthermore, the dynamics of industrial crop expansion and national food security have varied widely across SSA counties. Figure 4 highlights patterns of industrial crop production (in terms of allocated land) and food security (in terms of depth of food deficit and hunger) for major producing countries. These are Burkina Faso (cotton), Cameroon (cocoa, oil palm), Ethiopia (coffee, sugarcane), Ghana (cocoa, oil palm), Malawi (tobacco, sugarcane), and Swaziland (sugarcane). The long-term expansion of industrial cropping has been relatively moderate in some countries (even reaching a plateau), and has coincided with the constant reduction of hunger and food deficits (Fig. 4). In some countries, the reduction of hunger and food deficits has been rapid (e.g. in Ghana, Cameroon), while in others more gradual (e.g. Ethiopia, Malawi).[4]

In contrast, industrial crop expansion has been very aggressive in some other countries, such as Burkina Faso and Swaziland, and eventually dominated those national economies (Vitale 2018; Terry and Ogg 2016) (Fig. 4). In these countries, rapid industrial crop expansion (or contraction) tends to coincide with rapid changes in hunger and food deficit (Fig. 4). This may indicate a closer linkage between industrial crop production and national food security in these countries, and possible effects of other related factors such as reforms in the industrial crop sector (Kaminski et al. 2009), as well as international commodity prices and trading regimes (Terry and Ryder 2007).

Additionally, industrial crop production is rarely uniform within individual countries and tends to be concentrated in specific areas, especially for crops such as sugarcane and oil palm that require large investments to achieve economies of scale. For example, sugarcane production in Malawi and Swaziland is concentrated in just two relatively small areas in each country; Nchalo and Dwangwa in Malawi (Chinangwa et al. 2017), and Big Bend and Northern Lowveld in Swaziland (Terry and Ogg 2016). Conversely, industrial crops that have been geared towards smallholders (e.g., coffee, cocoa, cotton and tobacco) or experienced large unregulated expansion (e.g. oil palm in Cameroon) tend to be produced in larger areas with conducive agro-ecological conditions.[5] In this respect, industrial crop production can have more pronounced and easily tracked outcomes on local food security (rather than national food security) (see list of mechanisms in Section 3.2).

[4] Such food security trends might reflect broader national socioeconomic processes, with industrial crop expansion being one of these (de Graaf et al. 2011).

[5] Tobacco in Malawi is mainly produced in the Central, Northern and Southern regions (Chinangwa et al. 2017). Coffee is produced in many parts of Ethiopia, and mainly in the southern regions such as Sidamo, Harrar, Ghimbi and Limu (Moat et al. 2017). Cotton is grown in most regions of Burkina Faso (with the exception of the arid north regions), with the eastern cotton zone of Bobo-Dioulasso accounting for most of the production (Boafo et al. 2018). Cocoa production spans large parts of Ghana and Cameroon, and especially southern Ghana and western Cameroon. Oil palm in Cameroon was mainly concentrated in the Southwest region, but substantial recent expansion driven by informal mills occurs in the Littoral and Central Regions (Ordway et al. 2019).

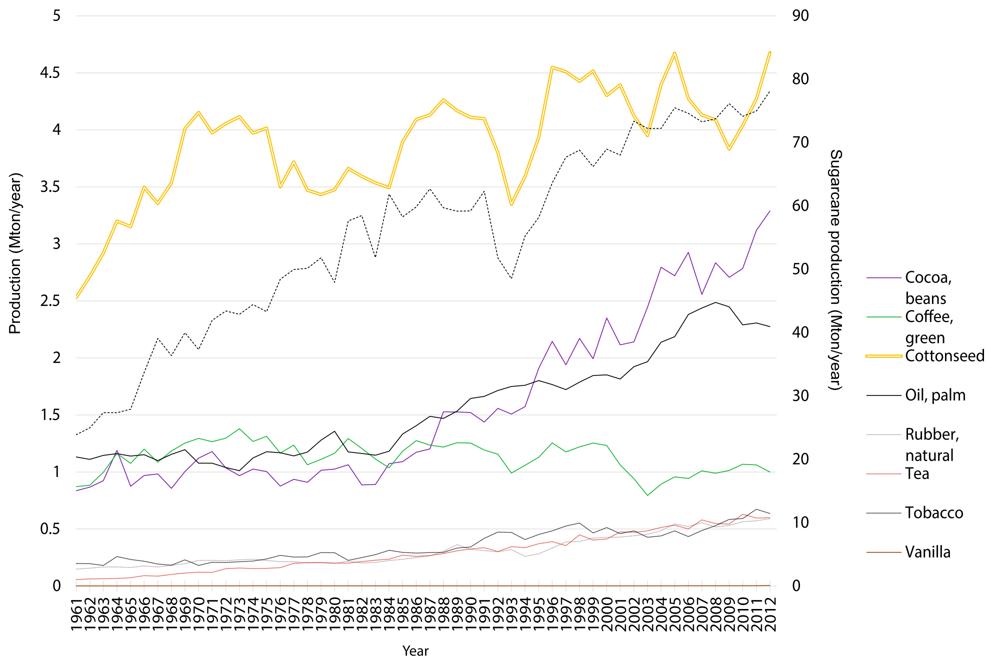

Fig. 2 Production of major industrial crops in sub-Saharan Africa. Source (FAOSAT 2019). Note: The secondary y-axis in the right-hand side denotes sugarcane production.

The mode and socio-ecological context of industrial crop production dictates their local food security outcomes (Gasparatos et al. 2015; Gasparatos et al. 2018a). It is thus necessary to understand some key features of the different production modes, namely (a) smallholder-based production, (b) large plantations, and (c) hybrid systems (Fig. 5). Such schemes are integrated in radically different land uses, usually representing a mosaic of agricultural land and natural ecosystems (Gasparatos et al. 2018a).

Smallholder-based industrial crop production can take many forms. Typically it is mostly integrated into current farming practices or totally displaces prior cropping practices, e.g. through the creation of small industrial crop plantations, which is common in sugarcane production in southern Africa (Von Maltitz et al. 2019). However, smallholder-based agricultural systems are very heterogeneous across SSA. Even though generalisations must be made with caution, there are some common characteristics across much of the reviewed literature. In particular:

- Land holdings and family farms for food and industrial crop production are generally very small. They are

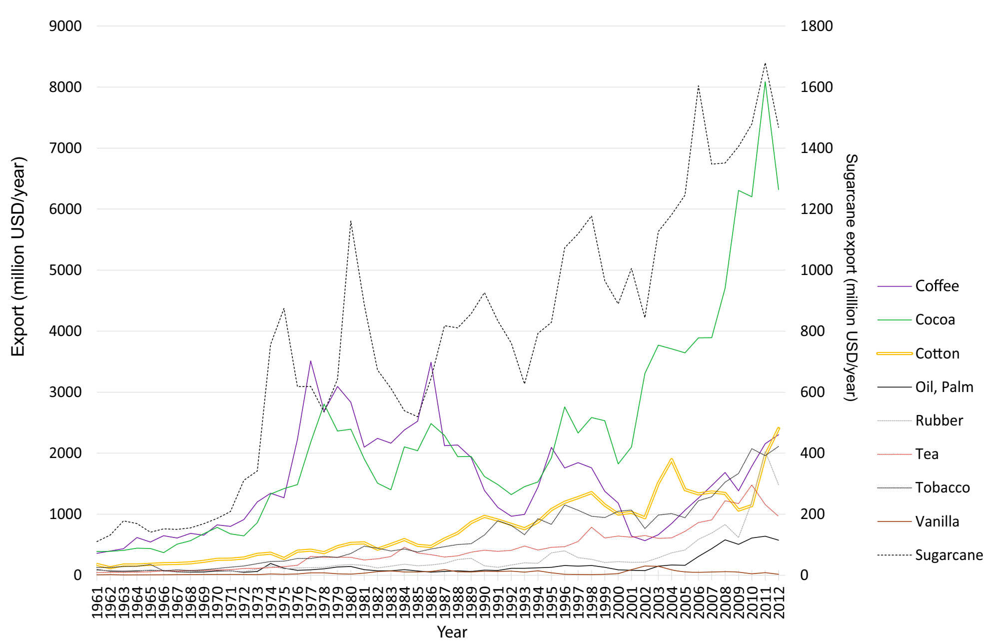

Fig. 3 Export value of industrial crops in sub-Saharan Africa Source (FAOSAT 2019). Note: Estimates include raw materials, refined materials and by-products of cocoa, coffee, cotton, oil palm, rubber, tea, tobacco, vanilla and sugarcane.

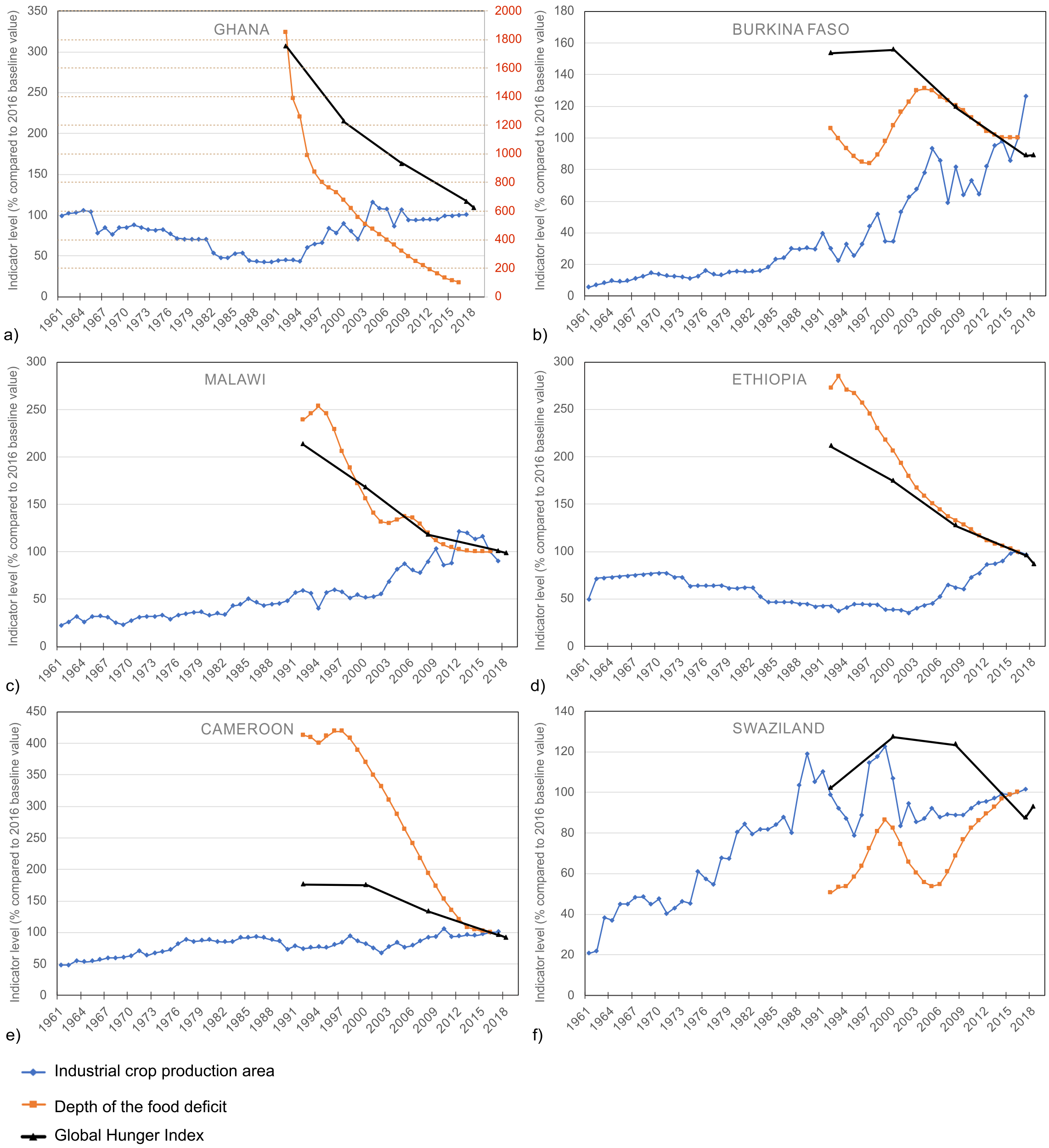

Fig. 4 Patterns of industrial crop production and food security in selected countries. Note: The right-hand y-axis in Fig. 4a (Ghana) reports values for the "Depth of Food Deficit". Data points represent annual indicator values compared to the base indicator value for the year 2016. Hence data points do not report absolute indicator values, but increases or decreases compared to the 2016 baseline. "Industrial crop production area" is aggregated production area figures for all industrial crops considered in this study (Section 3.3), with the exception of jatropha (FAOSAT 2019). This indicator is likely underestimated for countries that have experienced large jatropha expansion such as Ghana (Schoneveld 2014). Data for "Depth of Food Deficit" and "Global Hunger Index" are collected from (World Bank 2018; von Grebmer et al. 2018).

typically less than 5 ha, and most often less than 1–2 ha (FAO 2018; Lowder et al. 2016);

- Food crop production in family farms is usually geared towards domestic consumption, with the opportunistic sale of surplus output (e.g. AGRA 2017). Industrial crop growers tend to convert portions of their family farms for industrial crop production, but even when extensive conversion occurs some food crop production is still undertaken (e.g. Achterbosch et al. 2014);
- Agricultural input use (e.g. fertilisers, pesticides) is typically very low and as a result yields are low, with large gaps between realised yields and potential yields (e.g. Moyo 2016; Chianu et al. 2012).
- Farm labour typically comes from within the household, with occasional hiring of labour depending on the area and time of the year (e.g. Rapsomanikis 2015).

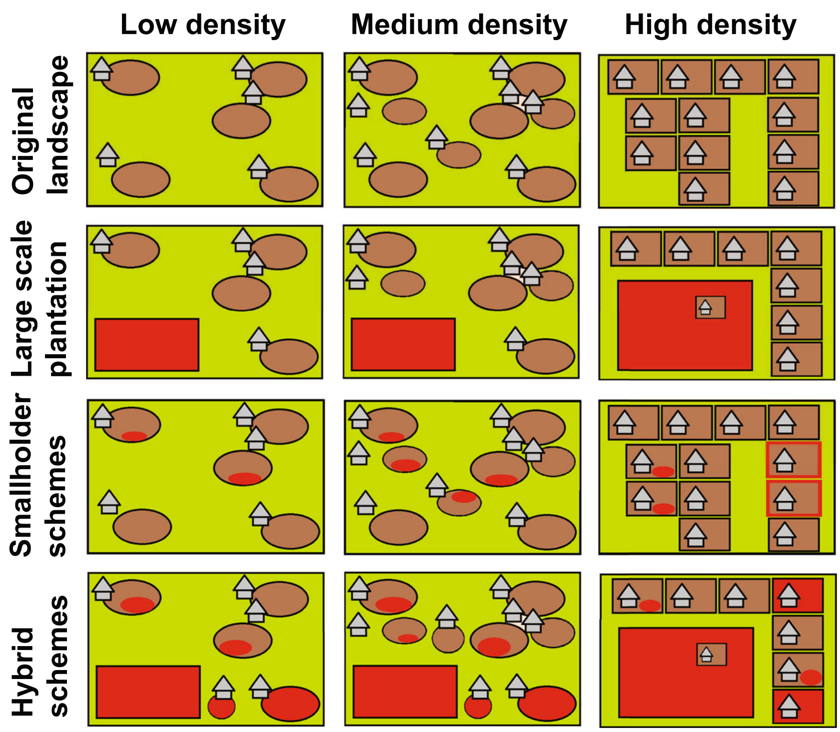

Fig. 5 Main modes of industrial crop production in sub-Saharan Africa. Source: (Gasparatos et al. 2018a). Note: Green denotes natural ecosystems (e.g. woodland, grassland), brown denotes agricultural land, and red denotes industrial crop land.

Large plantations in SSA can extend from a few tens of hectares to several thousand hectares depending on the crop and the region (e.g., Hall et al. 2017; Smalley 2013). Often large plantations adopt intensive monocultural practices, require large-scale land consolidation, displace many smallholders and convert extensive land areas (Hall et al. 2017). Large plantations often generate employment and income, and develop infrastructure (e.g. roads) in poor rural areas that lack such options (Smalley 2013). Plantation employment has very context-specific characteristics, ranging from insecure, precarious and lowly paid (Ahmed et al. 2019a), to highly beneficial and appreciated by local communities (Hall et al. 2017). However, plantation employment can divert labour from other local activities (including food crop production), often through questionable working practices. Plantation owners and investors are usually private companies, state agencies, parastatal bodies, or joint partnerships.

Hybrid industrial crop production systems comprise of core large plantations surrounded by hundreds or thousands of smallholders (Brüntrup et al. 2018). These smallholders can be contractually linked to a single buyer that is usually the core plantation (i.e. outgrowers), or sell to multiple buyers depending on markets signals (i.e. independent producers) (von Maltitz et al. 2019). Hybrid systems are more common for crops such as sugarcane and oil palm that are perishable and whose production benefits from economies of scale (von Maltitz et al. 2019; Carrere 2010).

Various stakeholders are involved in the initiation and operation of industrial crop projects in SSA. Many of the large plantations are operated by companies that are either fully privatised, parastatal or state entities (von Maltitz et al. 2019). Smallholder- and outgrower-based initiatives are usually developed by civil society organisations and government agencies (von Maltitz et al. 2019).

3 Methodology

3.1 Research approach

Our systematic review classifies and assesses the evidence about the impacts of industrial crops on food security based on clear variables and not perceived knowledge (Hagen-Zanker et al. 2012; Kelly 2015). We selected this approach because most current studies at the interface of industrial crops and food security in SSA use different conceptualisations of food security and different indicators for each underlying mechanism. This makes impossible their consistent analysis through a meta-analysis approach. However, systematic reviews have important advantages over narrative reviews due to the more transparent review methodology, which makes it possible to replicate the results of the review, thereby improving academic rigor (Kelly 2015; Mallett et al. 2012). Our systematic review comprised of three methodological steps:

(a) identification of mechanisms and selection of evaluation criteria (Section 2.2);

(b) identification, selection and review of literature (Section 2.3);
(c) statistical analysis and identification of literature patterns (Section 2.4).

3.2 Identification of mechanisms and selection of evaluation criteria

Table 1 summarizes the selected mechanisms for each of the four pillars of food security. To evaluate consistently the reviewed literature, we developed a series of full statements about how each mechanism affects the respective food security pillars.

Mechanism selection was informed through (a) a series of literature reviews (Wiggins et al. 2015; Gasparatos et al. 2015; Gasparatos et al. 2018a), and (b) experience gained through extensive empirical work of the research team in many industrial crop sites in SSA in the past decade (e.g. von Maltitz et al. 2016; Von Maltitz et al. 2019; Mudombi et al. 2016; Ahmed et al. 2017, 2018, 2019a; Dam Lam et al. 2017; Gasparatos et al. 2018a, 2018b; Boafo et al. 2018).

We used various criteria and variables to categorize and evaluate the literature, including study characteristics (e.g. author affiliation, crops and study scale), methods, mechanisms and food security outcomes (Table 2). The food security outcomes implied or stated in each study were identified based on the presence of one or more mechanisms, and whether the mechanism(s) had the predicted effect on food security, the opposite effect, or a bi-directional effect (e.g., for some study groups/areas these had the predicted effect and for others the opposite effect) (Table S1, Supplementary Electronic Material).

3.3 Identification, selection and review of the literature

To identify the literature we conducted an exhaustive search of all relevant publications following common principles of systematic review in qualitative research (Gentles et al. 2016). We focused our review on peer-reviewed literature (i.e. journal papers and relevant book chapters), complementing them with appropriate grey literature. Considering the wide variety of crops and impact mechanisms (Table 1), we used for keywords combinations of industrial crops and the names of SSA countries that are the major producers of these crops as identified from the database of the Food and Agricultural Organization of the United Nations (FAOSAT 2019). The geographical scope of the study included all countries south of the Sahara desert, including South Africa (see also Section 4.1). The main studied crops were cocoa, coffee, cotton, jatropha, rubber, sugarcane, shea, tea, tobacco, oil palm, and vanilla. The list of keywords and search terms is included in Table 3.

We used Elsevier Scopus and Web of Science to identify journal papers and book chapters, and Google Scholar to identify publications not indexed in these portals such as technical reports (Gentles et al. 2016). Other relevant literature was also identified through snowball sampling (e.g. through the references of reviewed papers). The literature search, and its systematic review, reflected the state of relevant literature in October 2017.

After locating relevant documents, we screened their abstracts to ascertain relevance to the objective of the review (i.e. relevance to at least one industrial crop and food security mechanism). If the document was considered relevant, we proceeded with a full review. If the abstract did not allow us to conclusively determine relevance, we undertook a full review of the publication to ensure that we did not miss relevant literature.

In total 116 studies were fully reviewed and included in this systematic review, of which 90 were peer-reviewed publications. In total, 126 observations were extracted from the 116 reviewed papers. We elicited a single observation from 111 studies and multiple observations (15 observations in total) from five studies. A single observation denotes the effect of a single crop on one or more food security mechanisms (Table 1). The elicited observations accounted for a total of 132 mechanisms. The full list of the reviewed manuscripts is included in the Supplementary Electronic Material (Table S2 and List S1: References for clustered studies).

3.4 Statistical analysis

We categorized each paper for each variable using categorical or ordinal values. Categorical values represent two or more categories, without any intrinsic ordering between categories (e.g. crop, methodology). Ordinal values represent ordered values such as the magnitude of the mechanism reviewed (Table 2).

We analysed the data using simple descriptive statistics (Section 3.1) and cluster analysis (Section 3.2). For the cluster analysis, we re-coded the results of each reviewed study (i.e. effects of mechanism on food security). This is because the impact mechanism covered in each study could either have the predicted direction of effect on food security (i.e. increase or decrease it), the opposite effect, or a bi-directional effect depending, for example, on the crop or the year in studies that studied multiple crops and years. Understanding the direction of the impact is important for understanding whether there is consensus within the literature about the possible food security outcomes of each mechanism. The specific codes used were:

- 1 – high negative impact (single direction mechanism).
- 2 – medium negative impact (single direction mechanism).
- 3 – low negative impact (single direction mechanism).
- 4 – two-way impact (bi-directional mechanism).

Table 1 Food security impact mechanisms for each pillar of food security

Pillar A: Food availability		Food security impact
A1. Food crop area	Industrial crop expansion reduces areas that provide food crops, possibly reducing the production of food crops (land use change: food crop farms converted for industrial crop production), Wider economy effects can influence this mechanism, e.g. by promoting large-scale land acquisitions causing extensive land allocation for industrial crops production.	↓
A2. Wild food area	Industrial crops expansion reduces areas that provide wild food such as plants, mushroom and game, possibly reducing wild food availability for household use. (land use chance: forest area converted for industrial crop production) Wider economy effects can influence this mechanism, e.g. by promoting large-scale land acquisitions, causing extensive land allocation for industrial crops.	↓
A3. Livestock grazing area	Industrial crops expansion reduces grazing areas for livestock, possibly reducing livestock production (land use change: grazing area converted into areas for industrial crop area) Wider economy effects can influence this mechanism, e.g. by promoting large-scale land acquisitions, causing extensive land allocation for industrial crops.	↓
A4. Labour/capital diversion	Involvement in industrial crop production (e.g. as plantation workers, industrial crop smallholders) diverts labuor and capital from activities related to food production (e.g. food crop cultivation, livestock rearing), reducing thus the production of food crops and livestock	↓
A5. Farming inputs	Industrial crop production increases access to farming inputs, such as seeds, fertilizers, pesticides and herbicides, which can be used/diverted for food crop production increasing food crop yields Wider economy effects can influence this mechanism, e.g. by affecting energy prices and/or subsidies for farming inputs	↑
A6. Technology	Industrial crop production (and related investments) can introduce new farming technologies (e.g. irrigation, mechanization), which can be used/diverted for food crop production increasing food crop yields Wider economy effects can influence this mechanism, e.g. by affecting energy prices and/or subsidies for technology adoption	↑
A7. Other	Other mechanism linking industrial crop production to food availability	↑ or ↓
Pillar B: Access to food		
B1. Infrastructure	Industrial crop production can catalyse infrastructure development especially in plantation settings (e.g. opening/enhancing roads and local/public transportation for large-scale production), increasing access to markets to purchase food Wider economy effect can influence this mechanism, e.g. by facilitating the contribution of the state to the development of this infrastructure	↑
B2. Market linkages	Industrial crop production facilitates market linkages (e.g. enhances access of local food/industrial crop producers to buyers), which gives incentive to local farmers to expand food crop production for sale Wider economy effects can influence this mechanism, e.g. by facilitating the viability of agricultural markets, and strengthening and maintaining these linkages.	↑
B3. Food prices	Industrial crops expansion can increase food prices, making it less affordable (and thus accessible) particularly to urban poor and rural landless households Wider economy effects can influence this mechanism, e.g. by mediating food prices through multiple channels related to land allocation, prices of agricultural inputs, and prices of agricultural commodities	↓
B4. Income generation	Income generated directly through the involvement in industrial crop production (e.g. as plantation workers or smallholders) can be used to purchase food Wider economy effects can influence this mechanism, e.g. by mediating income levels through setting standards for salaries or industrial crop prices	↑
B5. Job creation	Employment generation by industrial crop estates, processing plants, and other downstream activities can become a dependable and stable source of livelihoods, ensuring a dependable and stable access to food Wider economy effects can influence this mechanism, e.g. by giving incentives for industrial crop investments with employment-generation potential	↑
B6. Land compensation		↓

Table 1 (continued)

Pillar A: Food availability		Food security impact
	Lack of compensation for land loss due to industrial crop production does not compensate for the loss of income opportunities and food crop production, causing short- or long-term loss of access to food	
B7. Other	Other mechanism linking industrial crop production to access to food	↑ or ↓
Pillar C: Food utilization		
C1. Time diversion	Female engagement in industrial crop activities (e.g. plantation employment, smallholder production) diverts their time from child care, nutrition and unpaid care work, taking a toll on food preparation and especially child nutrition	↓
C2. Energy security	Engagement in industrial crop production value chains can affect household energy choices and the adoption of clean and improved energy options through multiple pathways, improving food preparation practices	↑
C3. Other	Other mechanism linking industrial crop production to food utilization	↑ or ↓
Pillar D: Food stability		
D1. Natural disasters	Engagement in industrial crop activities acts as a buffer against food security risks posted by natural disasters, especially by offering a stable source of livelihoods that can help households cope during such events	↓
D2. Market stability	Industrial crops increases risks of food price fluctuation (i.e. unpredictable increases and decreases) thus reducing food stability	↓
	Wider economy effects can influence this mechanism, e.g. by mediating both food and industrial crop prices through multiple channels related to land allocation, prices of agricultural inputs, and prices of agricultural commodities	
D3. Food imports	Industrial crop production and export generates foreign exchange that can enable food import, enhancing thus the stability of food within the country	↑
D4. Food assistance	Industrial crop plantations/companies can provide food assistance, reducing incidence of seasonal hunger during periods of high food insecurity	↑
D5. Political stability	Industrial crop production can contribute manifold to the national economy and prosperity, catalyzing political stability that can have a stabilizing effects for multiple other mechanisms and the wider economy	↑
D6. Women empowerment	Involvement in industrial crop value chains can increase women's access to land, income, and training/education opportunities, enabling them to provide better for their families.	↑
D7. Environmental impacts	Industrial crop introduction can affect local environmental conditions through land use and cover change, soil quality degradation, water quality degradation, and depletion of water resources depletion, among others. Collectively such effects reduce the capacity of local agro-ecosystems to produce food in a stable manner	↓
D8. Other:	Other mechanism linking industrial crop production to food stability	

Note; "↑" denotes a positive effect of the specific indicator on food security, while "↓ "a negative effect

- 5 – low positive impact (single direction mechanism).
- 6 – medium positive impact (single direction mechanism).
- 7 – high positive impact (single direction mechanism).

We excluded from this analysis studies that show no effect on food security or no conclusive outcome, but we highlight them in the descriptive analysis. Out of the 126 observations, we excluded 10 observations this way, producing finally only one valid observation per reviewed paper (116 in total).[6] We assigned the level of these effects based on our expert judgment after reading each study, and from our own experience undertaking extensive empirical research on this topic. This is because the reviewed studies tend to use widely different conceptualisations of food security and different indicators for the same mechanism, making impossible the consistent quantitative elicitation of the magnitude levels (Section 3.1).

We identified literature patterns using two different clustering approaches. Clustering A group studies according to combinations of impact mechanisms and their similarities in terms of magnitude and direction of effect on food security. It indicates which type of impact industrial crop production is likely to have on food security. Clustering B group impact mechanisms according to their co-existence, magnitude and direction of effect. It indicates which mechanisms or groups of mechanisms are likely to co-occur in the reviewed literature.

[6] We exclude these observations consistent with the aim of this paper, which was to systematize the existing evidence about the different mechanisms through which industrial crop production affects food security in SSA. Observations with no effect or conclusive impact do not provide any information that could serve to understand this interface.

Table 2 Variables and ranges used in the systematic review

Variable	Range of values
Study characteristics	
Peer-reviewed	1 = Yes 2 = No
Crop	1 = Oil pam 2 = Rubber 3 = Sugarcane 4 = Coffee 5 = Jatropha 6 = Shea 7 = Tobacco 8 = Tea 9 = Cotton 10 = Cocoa 11 = Vanilla
Author affiliation	1 = Local (affiliated with institution in the study SSA country) 2 = Regional/African (affiliated with institution in another SSA country) 3 = Outside Africa (affiliated with an institution outside SSA) 4 = Collaboration of African and non-African institutions 5 = Not specified/not known
Research funding	1 = Local (offered by an institution within the study SSA country) 2 = Regional/African (offered by an institution from another SSA country) 3 = Outside Africa (offered by an institution outside SSA) 4 = Co-funded by African and non-African institutions 5 = Not specified/not known
Spatial scale of study	1 = Local 2 = Sub-national 3 = National 4 = Regional 5 = Continental 6 = Global 7 = Not specified
Methodology	1 = Qualitative 2 = Quantitative 3 = Mixed-method
Use of direct measure of food security	1 = Yes 2 = No 3 = Both 4 = Not applicable
Type of outcome	1 = Historical/baseline (current state) 2 = Predictive (future state) 3 = Both 4 = Not specified
Impact mechanism	
Presence and direction	1 = Hypothesized direction (see Table S1) 2 = Opposite direction (see Table S1) 3 = Bi-directional (see Table S1) 4 = Cannot conclude 0 = Not covered; magnitude effect scale
Magnitude	1 = Low 2 = High 3 = Cannot conclude
Spatial scale of effect	1 = Local 2 = Sub-national 3 = National 4 = Regional 5 = Continental 6 = Global 7 = Not specified

To select the most appropriate clustering algorithms we use the ‘clValid’ package (Brock et al. 2014) of R Project (R Core Team). This pre-analysis allows for the identification of the most appropriate clustering methods. Thus for Clustering A

Table 3 Search terms for literature identification

First term (industrial crop)	Second term (region)
"Cocoa"	"Angola" OR "Cameroon" OR "Central African Republic" OR "Comoros" OR "Congo" OR "Côte d'Ivoire" OR "Democratic Republic of the Congo" OR "Equatorial Guinea" OR "Gabon" OR "Ghana" OR "Guinea" OR "Liberia" OR "Madagascar" OR "Nigeria" OR "Sao Tome and Principe" OR "Sierra Leone" OR "Togo" OR "Uganda" or "Tanzania"
"Coffee"	"Angola" OR "Benin" OR "Burundi" OR "Cabo Verde" OR "Cameroon" OR "Central African Republic" OR "Comoros" OR "Congo" OR "Côte d'Ivoire" OR "Democratic Republic of the Congo" OR "Equatorial Guinea" OR "Ethiopia" OR "Gabon" OR "Ghana" OR "Guinea" OR "Kenya" OR "Liberia" OR "Madagascar" OR "Malawi" OR "Mauritius" OR "Mozambique" OR "Nigeria" OR "Rwanda" OR "Sao Tome and Principe" OR "Sierra Leone" OR "Togo" OR "Uganda" OR "United Republic of Tanzania" OR "Zambia" OR "Zimbabwe"
"Cotton"	"Angola" OR "Benin" OR "Botswana" OR "Burkina Faso" OR "Burundi" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Côte d'Ivoire" OR "Democratic Republic of the Congo" OR "Swaziland" OR "Ethiopia" OR "Gambia" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Kenya" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mozambique" OR "Namibia" OR "Niger" OR "Nigeria" OR "Rwanda" OR "Senegal" OR "Somalia" OR "South Africa" OR "Togo" OR "Uganda" OR "United Republic of Tanzania" OR "Zambia" OR "Zimbabwe"
"Jatropha"	No specific geographical area
"Sugarcane"	"Angola" OR "Benin" OR "Burkina Faso" OR "Burundi" OR "Cabo Verde" OR "Cameroon" OR "Central African Republic" OR "Chad" OR "Congo" OR "Côte d'Ivoire" OR "Democratic Republic of the Congo" OR "Swaziland" OR "Ethiopia" OR "Gabon" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Kenya" OR "Liberia" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mauritius" OR "Mozambique" OR "Niger" OR "Nigeria" OR "Réunion" OR "Rwanda" OR "Senegal" OR "Sierra Leone" OR "Somalia" OR "South Africa" OR "Uganda" OR "United Republic of Tanzania" OR "Zambia" OR "Zimbabwe"
"Shea"	No specific geographical area
"Tea"	"Burundi" OR "Cameroon" OR "Democratic Republic of the Congo" OR "Ethiopia" OR "Kenya" OR "Madagascar" OR "Malawi" OR "Mali" OR "Mauritius" OR "Mozambique" OR "Réunion" OR "Rwanda" OR "Seychelles" OR "South Africa" OR "Uganda" OR "United Republic of Tanzania" OR "Zambia" OR "Zimbabwe"
"Oil palm"	"Angola" OR "Benin" OR "Burundi" OR "Cameroon" OR "Central African Republic" OR "Congo" OR "Côte d'Ivoire" OR "Democratic Republic of the Congo" OR "Equatorial Guinea" OR "Gabon" OR "Gambia" OR "Ghana" OR "Guinea" OR "Guinea-Bissau" OR "Liberia" OR "Madagascar" OR "Nigeria" OR "Sao Tome and Principe" OR "Senegal" OR "Sierra Leone" OR "Togo" OR "United Republic of Tanzania" OR
"Vanilla"	"Comoros" OR "Kenya" OR "Madagascar" OR "Malawi" OR "Réunion" OR "Seychelles" OR "Uganda" OR "Zimbabwe" OR
"Cocoa" OR "Coffee" OR "Cotton" OR "Jatropha" OR "Sugarcane" OR "Shea" OR "Tea" OR "Oil palm" OR "Vanilla"	"Africa"

Note: The FAOSTAT database does not contain production statistics for jatropha and shea. The main study countries were identified through other relevant studies (e.g., Schoneveld 2014; Bup et al. 2014).

we used the k-mean with gap statistic plot method, and for Clustering B we used the hierarchical clustering method with average distance measure.

For Clustering A, clusters are denoted as CL and are determined through the 'factoextra' package of R Project (R Core Team) (Supplementary Electronic Material, Fig. S1) (Kassambara and Mundt 2017). Robustness is evaluated by finding whether the number of the identified clusters produces clusters at their best cohesion within a given cluster and distance between clusters. For this purpose, we applied the Calinski-Harabasz (CH) index (Calinski and Harabasz 1974; Liu et al. 2010). To calculate the CH index we used the 'fpc' *package* of R Project (R Core Team) (Hennig 2018). Based on the highest value of the CH index we identified that three clusters was the most optimal size (Table S3, Supplementary Electronic Material).

For Clustering B, clusters are denoted as MA and are determined through the 'pvclust' package (Suzuki and Shimodaira 2015). The hierarchical clustering method does not require the definition of an optimal number of clusters prior to the analysis. However, rectangles around groups were highly supported by the data at a significance level of 0.05 (Kassambara and Mundt 2017).

4 Results

4.1 Descriptive statistics

The literature at the interface of industrial crops and food security in SSA increased substantially in the 2010s (Fig. 6). More than half of the reviewed studies came from institutions located outside of SSA (55%), 18% were from collaborative work between SSA and non-SSA institutions, and only 15% came solely from SSA institutions (Fig. 7a).

Most studies focused on the local (52%), sub-national (i.e. province or region level) (17%) and national (19%) scale (Fig. 7b). Qualitative, quantitative, and mixed-method research approaches were represented relatively evenly between studies (Fig. 7c). However, an increasing number of publications after 2010 applied qualitative and mixed-method research approaches (Fig. 5). Most studies focused on historical and baseline trends, with only a few providing predictive assessments of the food security outcomes of future industrial crop expansion in SSA (Fig. 7d).

Ghana was the most studied country (13 studies), followed by Uganda (9 studies), Mali (8 studies) and Ethiopia (8 studies) (Fig. 8). Overall, most studies came from Eastern Africa (50 studies), Western Africa (39 studies), and Southern Africa (7 studies), with fewer from Central Africa (5 studies), but greater numbers of studies covered more than one SSA region (15 studies). Jatropha (23 studies), cotton (20 studies), oil palm (15 studies) and sugarcane (15 studies) were the most studied crops, while cocoa (5 studies), vanilla (5 studies), and tea (2 studies) were the least studied (Fig. 9a).

"Access to food" and "food availability", were by far the most widely studied pillars of food security, with 80 and 93 studies respectively (Fig. 9b). "Food stability" was also relatively well-represented (in 58 studies), whereas "food utilization" was the least represented (20 studies) (Fig. 9b). Jatropha and cotton were represented in a relatively large number of studies spanning the four pillars of food security, with, however, far fewer studies falling in the "food utilization" pillar. Most of the tobacco, sugarcane and cocoa studies focused on mechanisms related to "food availability" and "access to food", whereas most rubber and oil palm studies covered "food availability" and "food stability" (Fig. 9a–b).

The most frequently represented mechanisms in terms of number of studies were (in descending order): "Income generation" (B4), "Food crop area" (A1), "Job creation" (B5), "Labour/capital diversion" (A4), "Market linkages" (B2), "Farming inputs" (A5), "Environmental impacts" (D7), "Market stability" (D2), "Women empowerment" (D6), and "Technology" (A6) (Fig. 10). Of these mechanisms A1, A4, B2, A5, D2, and D7 tended to have a negative outcome on food security, while B4, B5 and A5 a positive outcome (Fig. 11).

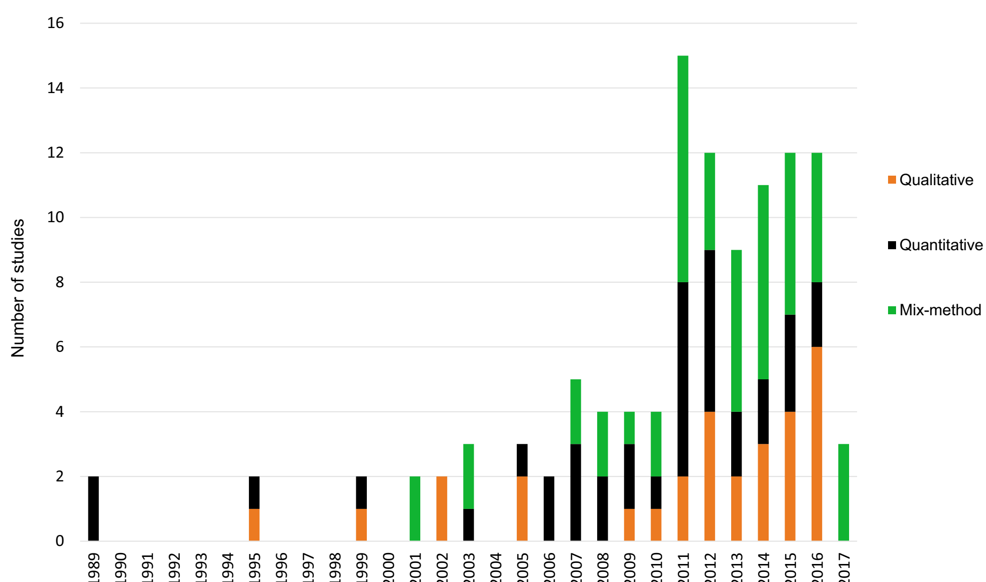

Fig. 6 Number of publications for each year

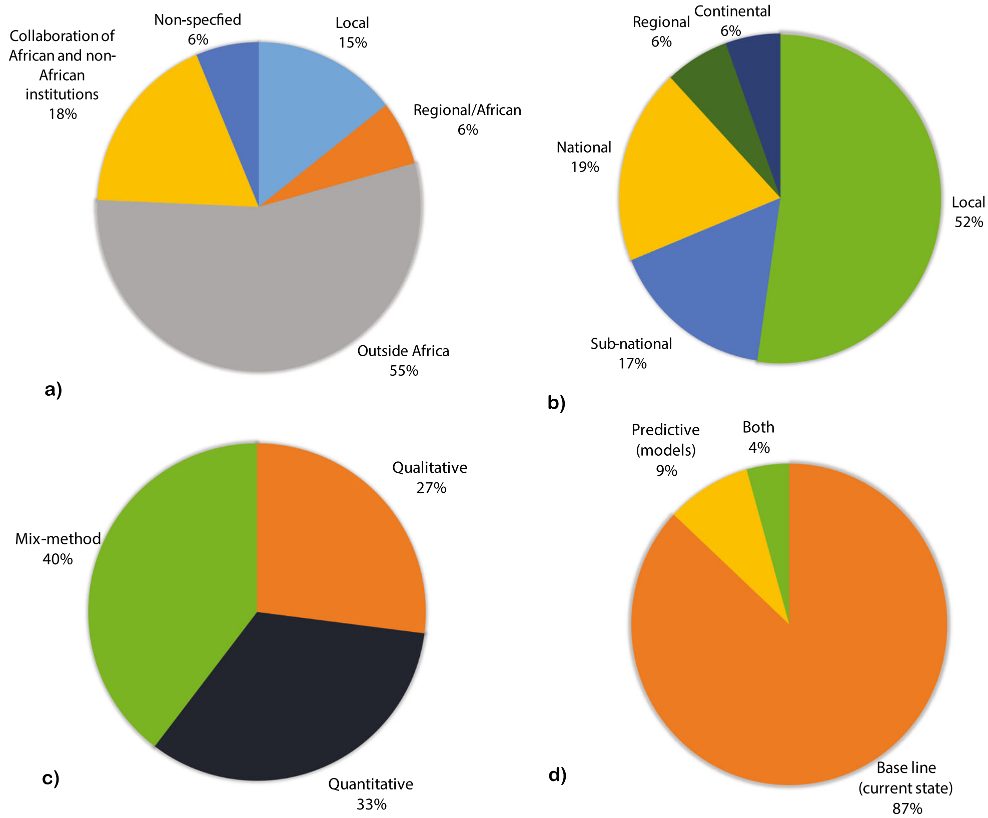

Fig. 7 Key characteristics of the reviewed studies

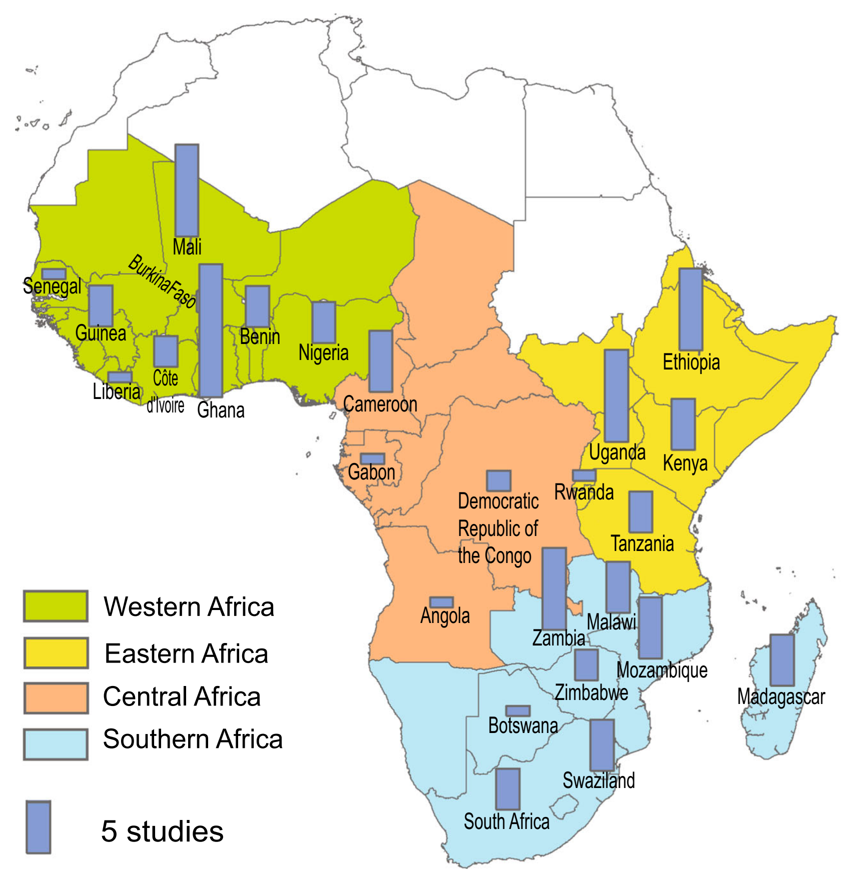

Fig. 8 Number of reviewed studies for each country

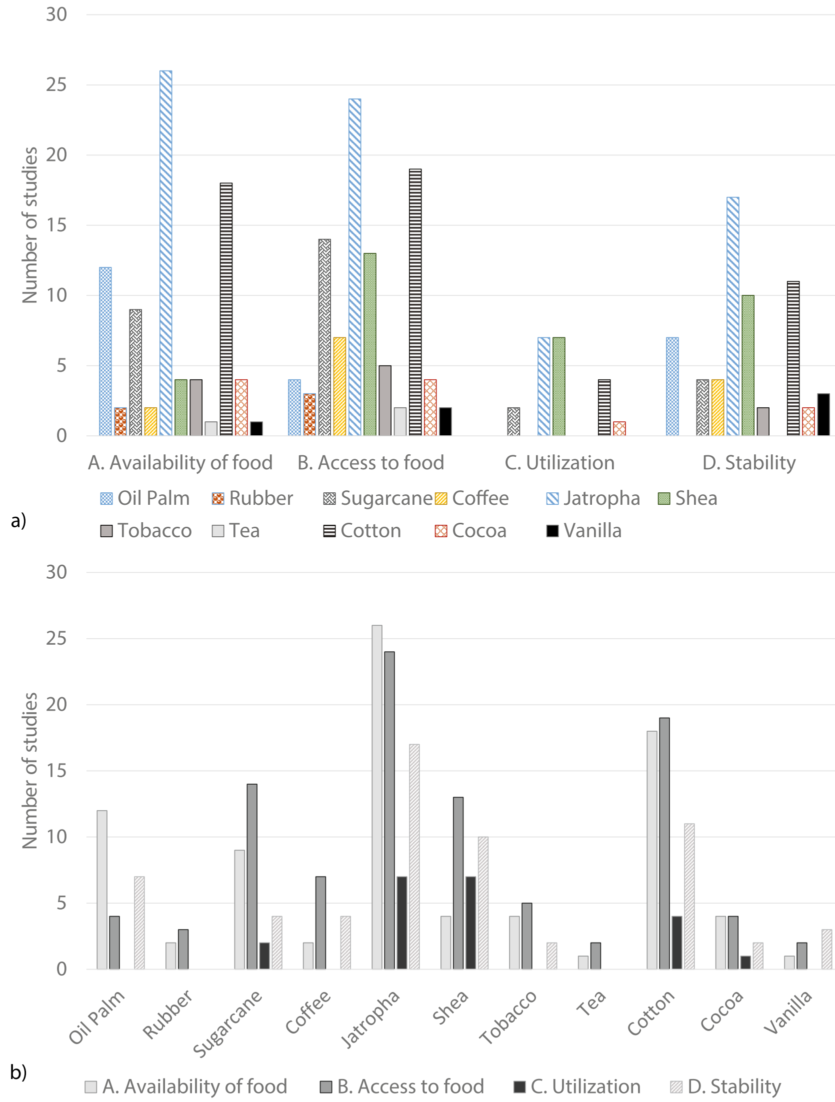

Fig. 9 Number of reviewed studies for each food security pillar by industrial crop (**a**), and for each industrial crop by food security pillar (**b**)

However, the type of represented mechanism differed substantially between individual crops, with jatropha, cotton, shea and sugarcane studies tending to capture the most diverse set of mechanisms (Fig. S2-S12, Supplementary Electronic Material). It is not clear why this is the case, but it might reflect the fact that these crops have been included in relatively more studies. The mechanisms represented in shea and vanilla studies tend to have a largely positive effect on food security (Fig. S7 and S12, Supplementary Electronic Material). On the contrary, many of the mechanisms covered in cotton and tobacco studies have a negative effect on food security (Fig. S9 and S10, Supplementary Electronic Material). Sugarcane and jatropha studies consider a very diverse set of impact mechanisms, while rubber studies have a relatively small but evenly distributed number of impact mechanisms with positive and negative effects on food security (Fig. S4, S6, S3, Supplementary Electronic Material). Mechanisms in oil palm and tea studies tended to have largely negative effects on food security (Fig. S2 and S8, Supplementary Electronic Material).

4.2 Cluster analysis

Clustering A identified three clusters (CL1-CL3 in Fig. 12 and Table 4), with CL1 and CL2 containing the most studies (see Table S4 in Supplementary Electronic Material for a list of the studies in each cluster). Studies in Cluster CL1 demonstrate that industrial crop production has an overall negative effect on food security due to declining food availability through loss of food crop area (A1), wild food area (A2), labour/capital diversion (A4), and negative environmental impact (D7), with some positive effect due to improved access to food though income generation (B4) and job creation (B5). Cluster CL2 contains studies that report an overall high positive impact of industrial crop production on food security through income generation (B4), market

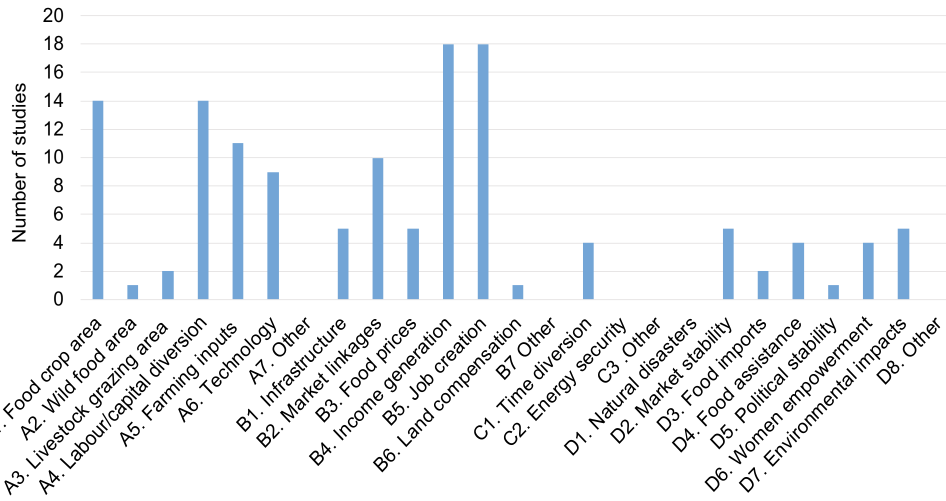

Fig. 10 Number of studies for each impact mechanism across all spatial scales. Note: Studies are double counted if they consider more than one food security pillar.

linkages (B2), job creation (B5), farming inputs (A5) and technology (A6), and women empowerment (D6), with some negative effects in food availability due to loss of food crop area (A1) and labour/capital diversion (A4). Cluster CL3 contains studies that indicate the bi-directional effect on food availability due to either (a) loss of food crop area (A1), wild food area (A2) and labour/capital diversion (A4), (b) improved access to food due to job creation (B5), income generation (B4), infrastructure (B1), food assistance (D4) and in women empowerment (D6), but (c) negative environmental impacts (D7).

For Clustering B we performed a cluster analysis for all studies (regardless of spatial scale) to establish which mechanisms tend to co-exist and have significantly similar effects for food security both in terms of direction and magnitude (Fig. 13). We identified three clusters indicated as MA1-MA3. These clusters consist of five (MA1), three (MA2) and six (MA3) mechanisms each, which shared significant similarities ($p < 0.05$) in the way that they co-exist in studies and affect food security (Fig. 13). MA1 contains mechanisms such as farming inputs (A5), market linkages (B2), food imports (D3), and technology (A6), indicating positive impacts on food security, whereas food prices (B3), technology, and food imports were associated with negative impacts on food security (Table 5). MA2 contains mechanisms that are concerned with areas outside of croplands that provide wild food (A2), grazing (A3) and energy security (C2). The third cluster (MA3) contains mechanisms such as women empowerment (D6), income generation (B4), job creation (B5), infrastructure (B1), land compensation (B6) and market stability (D2). Whereas, these mechanisms tend to co-exist in studies (and have a generally positive effect on food security), smaller clusters in this branch suggest the stronger association between some mechanisms, particularly B4-B5 and B1-D6.

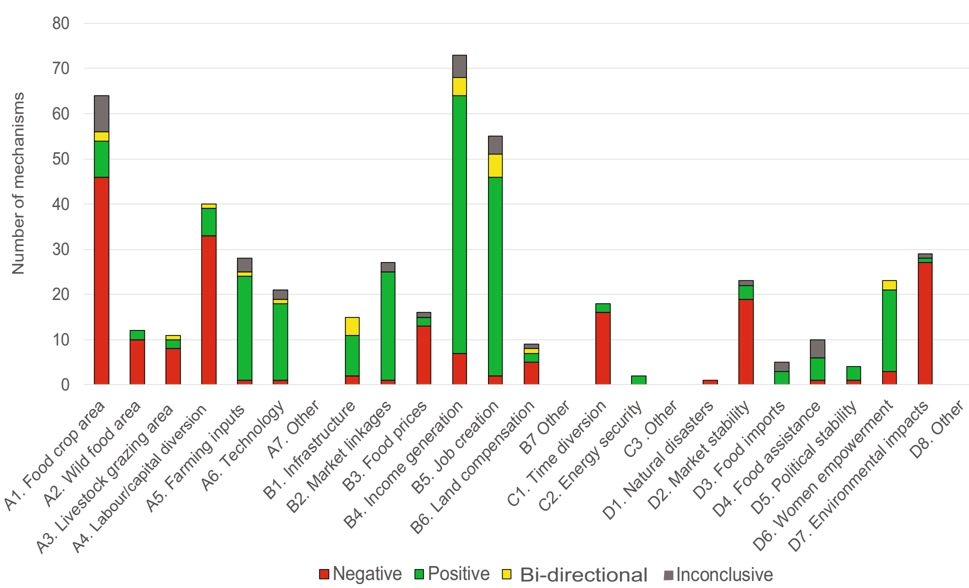

Fig. 11 Effect of different mechanisms on food security for all studies. Note: The total number of studies in this figure is lower to that reported in Fig. 9. This is because some studies focus on multiple crops and/or impact mechanisms.

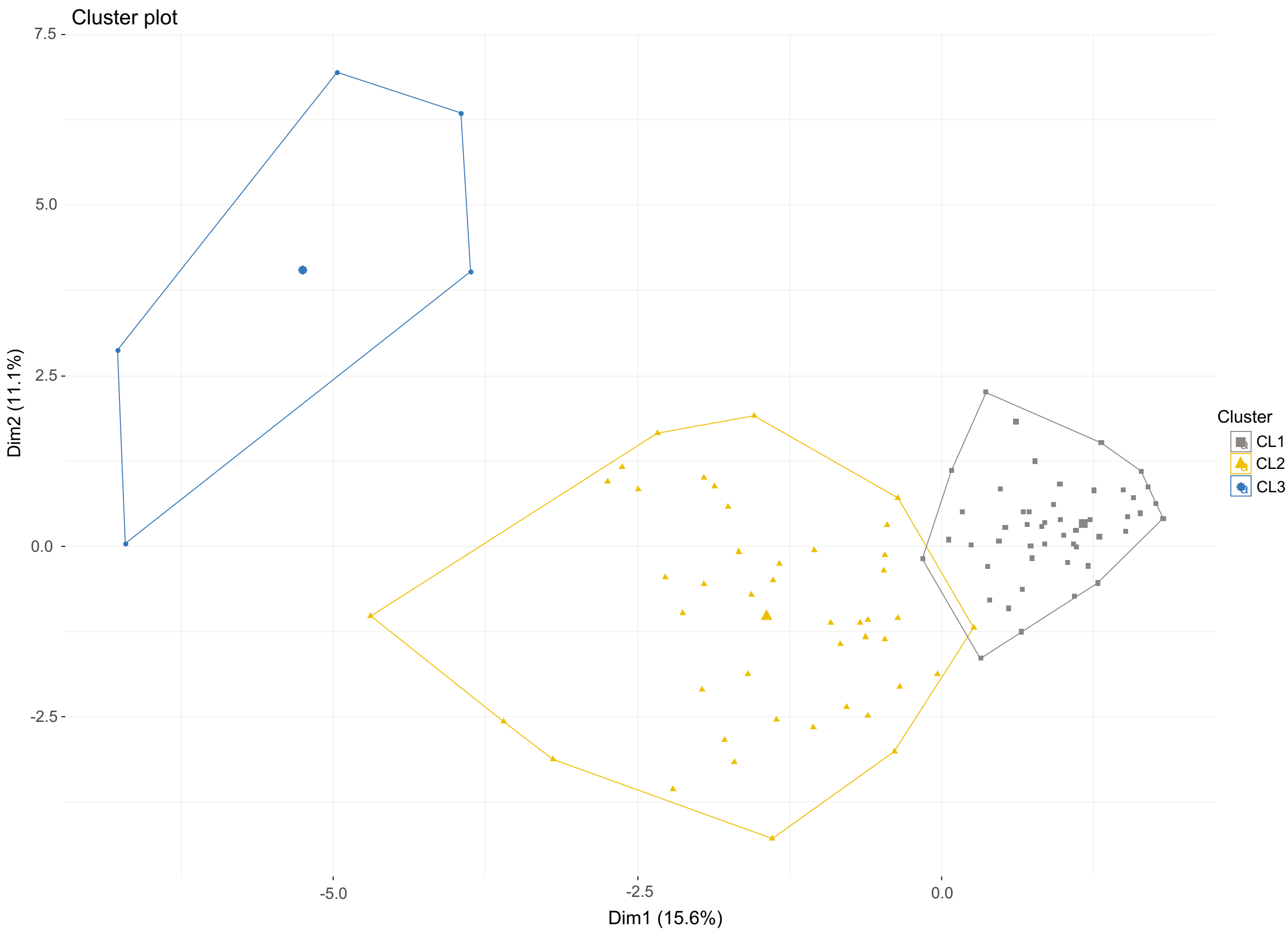

Fig. 12 Clusters of studies by impact mechanism and magnitude of effect on food security. Note: Refer to Table 1 for a clear description of each impact mechanism.

5 Discussion

5.1 Main research themes

Overall, a growing number of studies have focused on the interface of food security and industrial crop production in SSA, especially since the early 2010s (Fig. 6). This implies that the recent global land rush (Schoneveld 2014) possibly shaped substantially the recent literature on industrial crops and food security. Indeed common narratives associated with the recent land rush such as land-grabbing, land competition and "food vs. fuel" have been key underlying themes in the reviewed literature (see also Borras and Franco 2013; Kaag and Zoomers 2014; Kuchler and Linnér 2012; Tenenbaum

Table 4 Clusters of studies by impact mechanism and magnitude

Cluster	Number of studies	Main mechanisms and patterns
CL1	78	**(A1. Food crop area ↓)** (A4. Labour/capital diversion ↓) **(B4. Income generation ↑) (B5. Job creation ↑) (D7. Environmental impacts ↓)**
CL2	43	**(A1. Food crop area ↓) (A4. Labour/capital diversion↓) (A5. Farming inputs ↑) (A6. Technology ↑)** (B1. Infrastructure ↑) **(B2. Market linkages ↑)** (B3. Food prices ↓) **(B4. Income generation ↑) (B5. Job creation ↑)** (C1. Time diversion ↓) (D2. Market stability ↓) **(D6. Women empowerment ↑)**
CL3	5	**(A1. Food crop area↑↓) (A2. Wild food area ↑↓)** (A4. Labour/capital diversion ↑↓) (B1. Infrastructure ↑) **(B4. Income generation ↑) (B5. Job creation ↑)** (D4. Food assistance ↑) (D6. Women empowerment ↑) **(D7. Environmental impacts ↓)**

Note: ↑ - positive impact, ↓ - negative impact, ↑↓ - bi-directional impact. Impacts which are in **bold and underlined** are common mechanism throughout majority of studies grouped into the respective cluster. Studies that reported more than one crop were double-counted to represent mechanisms per crop. Refer to Table 1 for a clear description of each impact mechanism

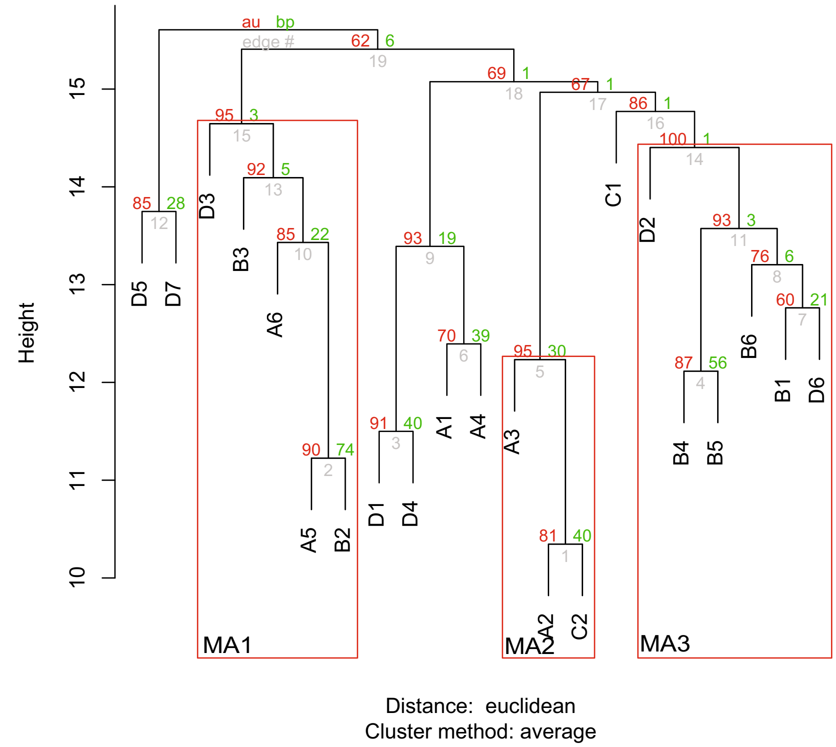

Fig. 13 Clusters of mechanisms for all crops. Note. Values on the dendrogram are AU *p*-values (red, left), BP values (green, right), and cluster labels (grey, bottom). AU denotes the approximately unbiased (AU) probability values (p-values). Clusters with AU >= 95% are indicated by rectangles, and are considered as strongly supported by data. BP denotes the bootstrap probability value, which corresponds to the frequency that the cluster is identified in bootstrap copies (Suzuki and Shimodaira 2015). Refer to Table 1 for a clear description of each impact mechanism.

2008). Much of the reviewed literature comes from countries that were targeted extensively for large-scale land-based commercial agricultural investments, such as Zambia, Mozambique, Ghana and Ethiopia (Schoneveld 2014) (Fig. 8). Additionally, many studies since the early 2010s have focused on jatropha, which was a relatively new and untested crop at that time that received very sudden attention in SSA (Fig. 9).

Our systematic review suggests that the majority of relevant studies focus on a sub-set of mechanisms that mainly fall in the "access to food" and "food availability" pillars of food security (Fig. 10). This reflects other reviews at the interface of industrial crops and food security, which have indicated that most current studies do not employ a comprehensive conceptualisation of food security that encompasses all food security pillars (Locke and Henley 2013; Wiggins et al. 2015). There is also a wide variation in the number and type of mechanisms captured for the different crops, with cotton, jatropha, shea and sugarcane being the crops featuring in most studies and having most mechanisms captured. Conversely, important industrial crops such as oil palm, rubber, cocoa and coffee feature in comparatively fewer studies, despite their extensive history and ongoing expansion in the continent (Section 2).

Most studies reporting positive food security outcomes tend to focus on livelihood-related mechanisms such as income and employment generation (including for women) (Fig. 11, Section 4.2). In practice, these two mechanisms reflect the most important reasons and incentives for most households to engage in industrial crop cultivation in SSA. Conversely, studies reporting negative food security outcomes tend to focus on mechanisms related to competition for land and labour (Fig. 11).

This limited focus on only some crops, mechanisms and food security pillars clearly highlights the substantial

Table 5 Clusters of mechanisms across the different studies

Cluster	Mechanism combination
MA1	(A5. Farming inputs↑) (B2. Market linkages↑) (B3. Food prices↓) (A6. Technology↓) (D3. Food imports↑#)
MA2	(A2. Wild food area↓#) (C2. Adult nutrition↓#) (A3. Livestock grazing area↓#)
MA3	(B1. Infrastructure↑) (D6. Women empowerment↑) (B6. Land compensation ↑↓) (B4. Income generation↑) (B5. Job creation ↑) (D2. Market stability↓)

↑: positive impact, ↓: negative impact, ↑↓: bi-directional impact, #: under-represented mechanism. Refer to Table 1 for a clear description of each impact mechanism knowledge gaps at the interface of industrial crop production and food security in SSA. However, from our systematic review it is not easy to deduce why there is an abundance of literature for some of crops, pillars or mechanisms, and a lack for others. In our view, this narrow focus of most individual studies is not necessarily negative, as many of the reviewed studies have indeed provided very rich and detailed information about specific contexts. However, we believe that the broader uneven distribution of the literature, essentially overemphasises some aspects over others and "waters down" the evidence for some crops, mechanisms and food security pillars. This potentially limits the nuanced information available to decision-makers about the pros and cons of industrial crop production in SSA.

The three research clusters (Table 4; Fig. 12) contain studies that mainly focus on:

- negative effects on food availability and the environment, with positive effects on access to food (through income generation and job creation) (CL1, Table 4);
- positive effects on access to food (through market linkages, income generation, and job creation), positive effects on food availability (through enhanced access to farming inputs and technology), positive effect on food utilization (through women empowerment), and negative effects on food availability (through food crop area loss and labour diversion) (CL2, Table 4);
- negative or positive effects on food availability (through food crops and wild food area loss), and improved access to food (through infrastructure, job creation, income generation, food assistance and women empowerment) but with negative impacts on the environment (CL3, Table 4).

In particular, many studies tend to conflate land-based impact mechanisms such as loss of food crop area (A1), wild food area (A2) and grazing area (A3) (Figs. 12 and 13). Such mechanisms are mainly associated with negative food security outcomes and are particularly prevalent in studies related to biofuel crops (i.e. jatropha, sugarcane) and crops produced in large-scale commercial plantations (e.g. oil palm, rubber) (Figs. S6, S4, S2 and S3 in Supplementary Electronic Material). Such mechanisms are also quite prevalent in studies aiming to establish the most appropriate mode of industrial crop production to deliver the best food security and poverty alleviation outcomes (e.g. Collier and Dercon 2014; Larson et al. 2016; Mellor and Malik 2017; Van Vliet et al. 2015).

Some studies have approached the food security outcomes of industrial crops in SSA (and especially bioenergy crops) through their effect on global, regional and national food prices (Ajanovic 2011; Negash and Swinnen 2013). Furthermore, the wider economy can have important mediating effects for some of mechanisms, thus indirectly affecting food security (Table 1). Such indirect effects are often context-specific, for example, reinforcing (e.g. increased land appropriation due to FDI attraction) or suppressing (e.g. lower fertilizer use due to external economic effects) individual mechanisms. However, it is difficult to delineate such larger-scale effects due to the multiple interacting mechanisms and the (often) unreliable data to establish causal relationships at these higher scales (Tyner 2013). For example, some studies have highlighted the large discrepancy in the estimated effect of biofuel production on food prices in SSA (e.g. Sapp 2013).

As already discussed, the mode of industrial crop production affects substantially the food security outcomes (Section 2). However, the fitness of particular modes of production depends on various contextual factors such as (a) crop characteristics and agronomy; (b) production characteristics (e.g. labour intensity, returns to investment); (c) marketing characteristics (e.g. potential buyers, processing needs); (d) exogenous economic and political factors (e.g. land scarcity, population density); and (e) endogenous economic and political factors (e.g. input markets, low producer capacity, weak enforcement of property rights) (Benfica et al. 2002).

Following the above, it is safe to conclude that the deep understanding of the local food security outcomes of industrial crop production is a pre-requisite for developing policy and practice options to minimize any negative food security trade-offs. A critical reading of the reviewed literature allow us to identify some deeper underlying factors and themes for each of the 25 mechanisms that mediate their local food security outcomes. We refer to these as sub-mechanisms, and we discuss them in greater length by food security pillar in Section 5.2. More details are provided in Tables S5-S8 (Supplementary Electronic Material).

5.2 Underlying factors of the local food security outcomes of industrial crop production

5.2.1 Food availability

Most studies related to the food availability pillar tend to focus on the "food crop area" mechanism (A1) (Table S5, Supplementary Electronic Material) and point to the negative food security outcomes due to land competition for food crop production, whether through large-scale land acquisitions to develop plantations or household-level decisions to engage in smallholder production (e.g. Waswa et al. 2012; Timko et al. 2014; van Eijck et al. 2014). However, many studies have also highlighted the positive food security outcomes of industrial crop production through their complementarity with food crops in smallholder settings (e.g. Wiggins et al. 2015), especially through practices such as intercropping that minimize land competition (e.g. Duvenage et al. 2012; Grimsby et al. 2012; Romijn et al. 2014).

Studies related to the "labour and capital" mechanism (A4) overwhelmingly report negative food security outcomes. According to these studies, smallholder-based industrial crop production requires intensive labour that drastically reduces family labour availability for food crop production (e.g. Adams et al. 2016; Naughton et al. 2017; Fortucci 2002). Similarly, employment in large-scale plantations also diverts family labour from food crop production (e.g. Ismael et al. 2002; Kaminski et al. 2011; Laris and Foltz 2014). A relatively unexplored sub-mechanism is that industrial crop production (especially in large plantations) can increase local labour costs, reducing locally affordable labour options for food crop farming (Borman et al. 2013).

Many studies have ascribed positive local food security outcomes of industrial crop production to improved access to farming inputs and technology transfer (A5–6). In particular smallholder engagement in industrial crop production commonly improves access to:

- fertilizers (e.g. Brambilla and Portoy 2011; Delpeuch and Leblois 2014; Herrmann et al. 2018);
- irrigation (Negash and Swinnen 2013; von Maltitz et al. 2019);
- technical support from industrial crop companies and associations (e.g. Kalinda et al. 2015; Bello-Bravo et al. 2015);
- a high diversity of food crop and seed varieties (Bussolo et al. 2007);
- other environmentally-friendly agricultural inputs (e.g. Bassett 2010).

All of the above can enhance the yields of both industrial crops and food crops, reducing (or even reversing) to some extent, the effects of land competition. However, studies have also suggested that industrial crop production could increase local fertilizer demand, and thus its price, making it unaffordable to poorer households for food crop production (e.g. Borman et al. 2013; van Eijck et al. 2012).

5.2.2 Food access

Most studies related to the food access pillar focus on positive local food security outcomes due to income, employment and occupation generation (B4–5) (Table S6, Supplementary Electronic Material). For example, many studies have shown that involvement in industrial crop production can increase existing income sources (e.g. Banye 2014; Suleman et al. 2014; Govereh and Jayne 2003), or create additional income sources (e.g. Onoji et al. 2016; Dyer et al. 2012; Favretto et al. 2014). Even though it is often low, this income can be constant (allowing thus better planning within the household) (German et al. 2011) or can be obtained during periods of low food security (von Maltitz et al. 2016). However, such effects depend on the crop type and mode of engagement (e.g. plantation work).

Similarly, many studies have reported that industrial crop production enhances local employment opportunities, especially in poor rural areas with few formal employment options (Duvenage et al. 2012; Dyer et al. 2012; von Maltitz et al. 2016). Employment opportunities are sometimes seasonal (e.g. James and Woodhouse 2016; Matenga 2016), or can boost self-employment (e.g. Kuntashula et al. 2014; Chivuraise 2011) and women's employment (e.g. Bosch and Zeller 2013).

5.2.3 Food utilization

Studies related to food utilization mostly focus on the negative effects of female engagement in industrial crop production, and especially of paid plantation employment. This is usually linked to time loss for other household activities, and especially meal preparation, feeding children and unpaid care time (Arndt et al. 2011; Bosch and Zeller 2013) (Table S7, Supplementary Electronic Material). Some studies have reported men dominating income and employment opportunities along industrial crop value chains (e.g. paid employment), maintaining thus traditional societal structures and household roles for women (Lazzarini 2016; Waswa et al. 2009; Moseley 2001). Even though such outcomes might not be socially desirable (Section 5.3), they still reportedly had positive food utilization outcomes.

5.2.4 Stability

Most relevant studies focus on two specific mechanisms, namely women empowerment (D6) and environmental stability (D7) (Table S8, Supplementary Electronic Material). Engagement in industrial crop activities was found to occasionally empower women. For example, several studies reported that female involvement in industrial crop activities often coincides with greater control over household income allocation (e.g. Adams et al. 2016; Banye 2014). Furthermore, involvement in industrial crop activities can reportedly enhance training opportunities for women (Williamson et al. 2005; Suleman et al. 2014) and catalyse the formation of women groups that are in a better position to negotiate crop prices (e.g. Favretto et al. 2014; Annan 2013).

However, industrial crop production can have negative environmental outcomes that threaten the stability of food production locally including (a) deforestation (e.g. Grimsby et al. 2012; Naughton et al. 2017; Chivuraise 2011); (b) biodiversity loss (e.g. Senbeta and Denich 2006; German et al. 2011); (c) water depletion (e.g. Gerber 2008; Von Maltitz et al. 2016); and (d) soil degradation (e.g. Duvenage et al. 2012).

5.3 Policy and practice recommendations and pathway forward

Multiple trade-offs emerge at the interface of industrial crop production and food security, as outlined throughout this review. When viewing critically the different clusters (Section 4.2) and sub-mechanisms (Sections 5.2.2–5.2.5) it is possible to identify some priority intervention domains to enhance the positive or reduce the negative food security outcomes of industrial crop production.

Government policies should support the economic viability and the overall sustainability of industrial crop production systems. A key objective should be to achieve a better balance between competition and coordination, and provide appropriate incentives, in order to better safeguard the interests of producers (in terms of profits) and the broader society (in terms of food security). Some of the most important trade-offs and priority policy and practice domains to target government policies relate to the following interrelated questions:

- How to safeguard the long-term economic and employment benefits accruing from engagement in industrial crop production? (Section 5.3.1);
- How to enhance farm output for both industrial and food crops, while avoiding negative environmental impacts? (Section 5.3.2);
- How to enhance female participation in industrial crop production, while reducing the negative effects of time diversion from unpaid household care work? (Section 5.3.3).

5.3.1 Ensure the long-term economic benefits of industrial crop production

Industrial crop production facilitates local access to food by generating income and employment (Section 5.2.2). At the same time engagement in industrial crop production as plantation workers or industrial crop smallholders tends to divert family labour from food crop production, thus reducing local food availability (Section 5.2.1). This points to the need to ensure the generation of secure employment and income, while minimizing the negative effects of this involvement on family food crop production.

Of outmost importance would be to ensure the long-term stability and economic viability of industrial crop production in the specific areas where it has been identified to be beneficial. Sustaining the provision of income and employment benefits well into the future would make engagement in industrial crop production a worthwhile endeavour for investors, workers and smallholders. Achieving this economic viability would be very important considering the almost total collapse of the jatropha sector (Ahmed et al. 2019b; Von Maltitz et al. 2019) and the large international price fluctuations for other industrial crops such as cocoa, coffee, cotton, tobacco and rubber (e.g. Deaton 1999; FAO 2017).

To achieve this it would be necessary to provide different incentives to smallholders, plantation owners and other actors across the value chain (e.g. millers and transporters). This would go a long way towards showing strong long-term policy commitment and signals to attract sustained investments. This would most likely require coordinated national efforts, as evident in countries such as Burkina Faso, Malawi, and Swaziland where multiple policy interventions over decades have made cotton and sugarcane cornerstones of their respective economies (Terry and Ogg 2016; Johnson and Silveira 2014; Boafo et al. 2018). It would be necessary to strengthen markets and streamline the different stages of production, from land acquisition, to the economic aspects of crop production, refinement, waste valorisation, and final product use. Ultimately, the actual interventions and long-term strategies might be crop- and area-specific, so great attention should be paid to the national and local context. Some added interventions for plantation workers should ensure (a) sufficient salaries to buy food locally, (b) seasonal/part-time employment based on a standard salary rate (and not on a picking rate), (c) employment flexibility during important periods of the family farm crop calendar year (e.g. sowing and harvesting).

5.3.2 Reduce the environmental trade-offs of industrial crop intensification

Evidence suggests that industrial crop production can compete for land with food crop production (Section 4). However the actual land use change effects of industrial crop production depend on the mode of production (Section 2). Industrial crop smallholders can either choose to expand (or not) food crop production to other areas to compensate for the land allocated to industrial crops. Similarly large-scale plantations might displace farmers, who might open up farmland elsewhere. Such indirect land use effects can possibly cause the conversion of forest and pasture land (Achten and Verchot 2011). In either case such land competition can affect local food availability for some community members either through the loss of food cropland or the loss of communal pasture/forest. In smallholder settings, increasing the use of agricultural inputs (e.g. fertilisers, pesticides) and/or adopting improved production practices (e.g. irrigation, intercropping) could minimize land loss by increasing crop yields (Section 5.2.1). However, such agricultural intensification might have negative environmental impacts such as freshwater depletion, water pollution and soil degradation, all of which have been shown to have a negative effect on food stability (Section 4.2.5). The above suggests the existence of hard trade-offs between the food availability and food stability pillars.

Considering the above it is necessary to understand possible trade-offs between food production and the environment due to expansion of industrial crops. Comprehensive baseline studies prior to the development of industrial crop projects would be instrumental towards this end. Such studies should elicit the land allocation decision-making processes of local farmers, and the adoption dynamics of crops and farming practices. Furthermore, it is important to rationalize both in large plantations and smallholder settings the use of fertilisers/pesticides to reduce environmental impact, and irrigation water to ensure its availability to other water users, especially during periods of water scarcity.

Such information is rarely considered during project design and in Environmental Impact Assessments (EIAs) that are the most prevalent tools used for the prediction of the possible environmental impacts of large-scale industrial crop projects in SSA (e.g. German et al. 2013). It would be necessary to require investors and project implementation teams to consider meaningfully such information prior to the approval of industrial crop projects, and identify possible mitigation options if important trade-offs are expected.

Most SSA countries require EIAs for large agricultural investments, but still more efforts are needed for the effective implementation and monitoring of mitigation options (German et al. 2013). However, EIAs cannot deal effectively with such aspects in smallholder settings, where farmers can individually decide to start and halt industrial crop production based on market signals. Even though engagement in industrial crop production improves access to agricultural inputs (and sometimes irrigation) (Section 5.2.2), smallholders often lack the capacity to use them in an environmentally and socially responsible manner (Morris et al. 2007). In these contexts, it would be necessary to provide appropriate training and promote responsible production practices as part of the support packages that smallholders receive when getting integrated in industrial crop value chains. Coordinated efforts between industrial crop companies (i.e. crop buyers), other actors in the private sector (e.g. certification companies), government agencies and civil society can go a long way toward increasing the environmental and social responsibility of smallholders. However attention should be paid to avoid overlapping the efforts of these actors and provide training that meets the needs of smallholders.

5.3.3 Improve the gender outcomes of industrial crop production

Many studies have pointed to the cross-cutting role that gender plays in mediating the positive or negative food security outcomes of industrial crop production in SSA, especially for some mechanisms related to access to food (i.e. income and employment generation, B4–5), food utilization (i.e. time diversion from unpaid care work, C1), and food stability (i.e. women empowerment, D6).

Females have traditionally been an important element of the rural labour force in SSA (Bryceson 2018). However, women are often barred from formal employment in industrial crop plantations due to lack of an appropriate skillset, cultural reasons and the fact that formal waged jobs are often perceived to be a male domain (Section 5.2.4). The entry of female-headed households in smallholder-based industrial crop production is also discouraged due to the lack of land titles or little say in family farm decision-making (Bryceson 2018). Furthermore, females by far provide most of the unpaid household care work in SSA, not the least by preparing meals and feeding children (ILO 2018).

Clearly it is not justifiable to prevent females from engaging with industrial crop value chains on grounds of safeguarding the crucial role they play in unpaid care work. However, we should also be conscious of the almost total lack of social services in rural SSA (ILO 2018). Thus, enhancing female participation (and as a consequence access to income/employment and broader female empowerment) while reducing the negative effects of time diversion from unpaid household care work is a key for maximizing the positive food security outcomes of industrial crop production.

Large-scale plantations can develop (or contribute to the development of) infrastructure that compensates for the potential loss of unpaid care work such as schools with feeding programmes, where female employees have priority access. Furthermore, flexible working arrangements and standardized salaries for seasonal and part-time employees can further ensure that female workers are not discriminated, and that food utilization trade-offs are minimized. A very promising approach specific to bioenergy crop producers (and mainly for sugarcane) would be to provide or support the acquisition of improved cookstoves and fuel. This could reduce the time invested for fuelwood collection and cooking, which takes up a substantial portion of women's time in most parts of rural SSA (Karanja and Gasparatos 2019; Köhlin et al. 2011).

Conversely, in smallholder settings it might not be as straightforward to enable gender inclusion interventions such as those mentioned above. Other possible avenues tailored for smallholder settings would be to valorise better female participation in industrial crop production by offering higher premiums from certification schemes (Parvathi et al. 2017). Supporting the development of female grower associations or increasing the decision-making power of female growers in mixed-grower associations could further improve female negotiating and decision-making power. This, in turn, could maximize gender empowerment benefits from engagement in smallholder-based industrial crop production. Furthermore, appropriate government agencies, civil society organizations and private sector actors can increase the number (and improve the quality) of training activities geared towards female growers. Such training efforts should go beyond simply offering knowledge on how to improve industrial crop production,

Table 6 Prevalence of studies for each pillar of food security for the main industrial crops

	Access to food	Food availability	Food utilization	Food stability
Cocoa	4	4	1	2
Coffee	1	2	0	4
Cotton	18	19	3	11
Jatropha	26	24	6	14
Oil palm	12	4	0	7
Rubber	2	3	0	5
Shea	6	13	7	10
Sugarcane	6	10	2	3
Tea	1	2	0	0
Tobacco	4	5	0	2
Vanilla	1	2	0	3

to further educate women about the possible trade-offs of their involvement. However, even though such interventions could possibly enhance the benefits that women receive from engagement in industrial crop production, they can have a less direct effect on food security.[7]

5.4 Methodological reflections and future research.

Despite the clear patterns outlined in the previous sections, our systematic review has some important caveats. First, it is difficult to choose a manageable set of keywords to guide study selection due to the large number of crops and producing areas, as well as the multiple impact mechanisms that tend to work in tandem. Furthermore, many studies are not indexed well with appropriate keywords to allow for the straightforward identification and elicitation of the impact mechanisms. Thus critical reading is necessary for identifying both the main mechanisms and their food security outcomes. In this study, we have sought to be as comprehensive as possible through a very broad keyword selection (Section 2.3). However, for some mechanisms (e.g. environmental impacts, D7) there are several different sub-mechanisms related to food security depending on the study context (Section 5.2.5), which can increase substantially the number of necessary keywords. In this respect future studies should aim to rationalize better keyword selection to ensure that all relevant studies are captured.

Second the quantity and quality of the available evidence varies between crops (Table 6). Cotton, jatropha, sugarcane and shea are the best-studied crops, but more scientific evidence is necessary for conclusively establishing their impacts on food security, particularly for the food utilization and stability pillars. Actually, for most crops, food utilization and stability are the least studied pillars of food security (Table 6). For example, we could not identify any studies related to food utilization for coffee, oil palm, rubber, tea, tobacco and vanilla (Table 6). For tea and rubber, we could not identify any studies related to the food stability pillar (Table 6). Future studies should aim to fill some of these knowledge gaps to achieve a more comprehensive understanding of food security impacts for all different industrial crops.

Third, we designated the magnitude of the effect of each impact mechanism on food security based on our expert judgment after reading each study (Section 3.4). This is due to the fact that the reviewed studies tend use different indicators for the same mechanisms, making impossible a consistent quantitative elicitation of impact magnitude levels. These inconsistencies were the main reason that influenced the selection of a systematic review protocol over a meta-analysis. Furthermore, as the interface between agricultural production and food security is complex and often mediated by contextual factors, narrowing down the impact mechanisms to basic information about its direction inevitably involves a degree of simplification. This reduces the nuance of the obtained results, making it impossible to understand properly the wider economic effect on some mechanisms (Table 1, Section 5.1).

One of the main observations of this systematic review is the knowledge fragmentation on the interface of industrial crops and food security. In particular we lack multi-crop assessments that (a) follow consistent protocols and (b) adopt comprehensive definitions of food security. Regarding the former, although some studies have assessed the food security outcomes of multiple industrial crops, they have often failed to distinguish between different mechanisms and impacts (e.g. Dam Lam et al. 2017; Mudombi et al. 2016). Furthermore, many studies have focused on different project stages and for different durations, thus complicating meaningful comparisons between projects, crops and studies. It is thus necessary to undertake more comparative empirical studies that adopt consistent protocols to unravel the combined effects of multiple impact mechanisms for different crops, modes of

[7] We acknowledge that access to land is gender-differentiated in SSA and that equal access to land can have a much more direct effect on food security. However the gendered aspects of land access in national legislations and informal rules across SSA go beyond industrial crops. The reader is referred to other more comprehensive publications on the matter (Doss et al. 2015; FAO 2011).

production and geographical areas. Regarding the latter, our review also reflects the general lack of assessments adopting holistic definitions and conceptualizations of food security (e.g. see Locke and Henley 2013). Studies that utilize or develop generic food security metrics that span all food security pillars (e.g. Dam Lam et al. 2017), or combine standardized metrics (e.g. the Food Consumption Score) and objective measures of food security (e.g. anthropometric measures such as child stunting) (e.g. Anderman et al. 2014), can go a long way towards bridging such gaps.

We cannot overemphasize the importance of well-designed place-based research for bridging the two gaps outlined above. Understanding food security patterns through well-described and well-designed protocols that can be replicated across sites can provide rich contextual information (e.g. Gasparatos et al. 2018b). Such information would be invaluable for the evidence-based design and implementation of appropriate industrial crop interventions at the local scale. Furthermore, such information could also be used as input to models that explain broader national food security outcomes and guide national actions on industrial crops (e.g. von Maltitz et al. 2014; Arndt et al. 2009, 2011, 2012).

Our systematic review also identifies the critical lack of literature about how future industrial crop expansion could affect food security in SSA. Although some studies have sought to assess the possible macro-economic effects of biofuel crop production in individual countries (e.g. Arndt et al. 2009, 2012; Hartley et al. 2019), there is a need for more comprehensive modelling studies that tackle this issue for multiple crops and countries, and use high quality data obtained through detailed studies at the local level. Furthermore, we need to understand better some of the operational characteristics and external factors that can catalyse the success of individual industrial crop projects, especially in the delivery of positive food security outcomes. This is particularly important considering the recent widespread jatropha collapse, which often had negative local food security outcomes (e.g. Ahmed et al. 2019b).

Finally, it is worth mentioning that climate change does not feature prominently in the reviewed studies. This is rather surprising considering that climate change is a significant pressure to many cropping systems and overall food security in SSA (e.g. Onyutha 2018a, 2018b; Rippke et al. 2016; Challinor et al. 2014). We believe that in the context of industrial crops and food security, climate change will not be a distinct impact mechanism. Rather it would increase the severity (or possibly affect the direction) of the different impact mechanisms (e.g. through effects on yields, water sources and climatic conditions). However, at this stage, this is more of a hypothesis rather than a concrete finding of the systematic review. In this respect the role that climate change plays at the interface of industrial crops and food security is a major gap in the current literature that must be further explored.

6 Conclusion

The systematic review presented in this paper has explored (a) key literature patterns for different industrial crops and food security impact mechanisms in SSA, (b) how mechanisms intersect and affect food security, (c) the underlying factors affecting the food security outcomes of industrial crop production; and (d) possible key priority policy and practice areas.

For (a) we highlighted the main literature patterns for 11 industrial crops and 25 impact mechanisms across the four pillars of food security (i.e., availability, access, utilization and stability). The quantity and quality of the current evidence varies considerably between crops, with jatropha, cotton, sugarcane and shea being the best-studied crops. Among the four food security pillars, we found a substantial body of evidence and consensus about the direction and magnitude of the different impact mechanisms only for food availability and access. Much less literature and consensus exists for mechanisms related to food stability and utilization, with relevant literature being practically non-existent for several crops.

For (b), according to the cluster analysis, some of the most common trade-offs identified in the reviewed literature contain a combination of key impact mechanisms such as land competition, access to agricultural inputs/irrigation, infrastructure development, income/employment generation, female empowerment and environmental degradation.

For (c), for each of the 25 mechanisms we identified some deeper underlying factors and themes that mediate their food security outcomes at the local level. However, these different sub-mechanisms vary significantly between crops, modes of production and social-ecological contexts.

The results for (b)-(c) suggest, that in most cases it is difficult to measure the actual food security outcomes of industrial crop production in a straightforward manner. This is because many of the mechanisms and sub-mechanisms intersect, while the type and magnitude of these trade-offs is often context-specific. The use of an array of incompatible methodologies, further compounds the clear understanding of the actual food security outcomes of industrial crop production in SSA. Furthermore, the current literature is fragmented with most studies considering only a sub-set of crops, regions, modes of production and/or impact mechanisms, while others fail to consider key stakeholders or unforeseen consequences. Even though this fragmentation is a major barrier for balanced policy and practice inferences, our systematic review has identified some priority areas for increasing the positive (or reducing the negative) food security outcomes of industrial crop production in SSA.

For (d), relevant policy and practice interventions should aim to tackle at least some of the following aspects:

- safeguard the long-term economic and employment benefits accruing from engagement in industrial crop production;

- enhance farm output for both industrial and food crops, while avoiding negative environmental impacts;
- enhance female participation in industrial crop production, while reducing the negative effects of time diversion from unpaid household care work.

Future research should fill the gaps outlined above, and especially to (a) explore the different mechanisms for which we lack strong evidence (especially related to food utilization and stability), (b) focus on multiple mechanisms and their intersection (rather than single mechanisms), and (c) understand how local impacts might conflate to induce impacts at higher scales (e.g. national, regional).

Policy-makers and practitioners should also appreciate that in a given industrial crop context many mechanisms may be at play synergistically or antagonistically. Thus future efforts seeking to promote industrial crop production in different parts of SSA should appreciate the local context, the possible trade-offs at hand, and be guided by at least some of the priority areas outlined above.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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