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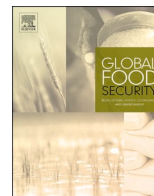
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Determining appropriate interventions to mainstream nutritious orphan crops into African food systems

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ABSTRACT

Nutritious 'orphan' crops could (re)diversify African food systems, but appropriate means to bring this about are required. A review of the literature on crop intervention options suggested success and failure factors in promotion, but indicated little about the relative importance of production-versus consumption-based measures and how these interact. An analysis of secondary crop production data indicated that addressing food policies could be valuable for orphan crop mainstreaming, but, as with literature review, did not provide clear guidance on the importance of different interventions. A survey of experts suggested that cross-disciplinary teams are important for developing mainstreaming strategies, but revealed no clear consensus on the importance of particular measures for specific orphan crops. We discuss the implications of these findings.

1. Introduction

Low- and middle-income regions of the world are undergoing rapid structural transformation and face significant challenges in achieving food and nutrition security (Willett et al., 2019; IFPRI, 2020). Among the continents, Africa experiences the highest level of malnutrition-related disease (Development Initiatives, 2018; FAO, 2018). More effective ways to address malnutrition on the continent are thus widely recognised as required (Covic and Hendriks, 2016; Development Initiatives, 2018). The problem of malnutrition is intertwined with climate change and environmental degradation that worsen the already poor dietary situation (Díaz et al., 2019; IPCC, 2020).

Complementary approaches to improve dietary quality include crop 'biofortification' (de Brauw et al., 2015) and 'diversification' (Kumar et al., 2015). Both approaches, sometimes applied together in the same intervention, are being promoted widely in Africa (African Union, 2014). Biofortification is based on the breeding of more nutritious

varieties of crops (Bouis and Saltzman, 2017), while diversification is founded on increasing the range of nutritious crops grown (Keatinge et al., 2010). Diversification spreads the risks caused by single crop failure and as a result is recognised to have a particular role to play in promoting food system resilience under the variable weather caused by anthropogenic climate change (Renard and Tilman, 2019). In addition, diversification supports synergies in production through crop nutrient cycling and other processes that help deal with and reverse environmental degradation (Dawson et al., 2019a).

One opportunity to support food system diversification in Africa is through the greater inclusion of 'orphan' crops (Frison et al., 2006; Mabhaudhi et al., 2016). These crops, which include a range of fruits, vegetables, legumes, grains and roots (AOCC, 2020), are often highly nutritious (Stadlmayr et al., 2013, 2019) and can fit well into existing agricultural systems to support production synergies (Dawson et al., 2019a). They also have rich (though depleting; Stévant et al., 2019) reservoirs of genetic diversity that can be used to genetically improve

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them (Dawson et al., 2019b; Jamnadass et al., 2020). As attested by their name, African orphan crops have mostly been little researched in the past. However, there has recently been a re-evaluation of their roles in food systems as the dangers of focusing on the cultivation of nutritionally-limited and often resource-intensive major crops have become increasingly recognised (Khoury et al., 2014).

Just because their potential is now more widely appreciated, it does not follow that (re)diversifying African food systems with orphan crops is straightforward (Dawson et al., 2018). Addressing several issues has been suggested to be required. 'Potential solutions' involve work on: the appropriate 'biophysical' design of farming systems to integrate orphan crops (Dawson et al., 2019a; Timler et al., 2020); the genetic 'tailoring' of orphan crops to fit more optimally in production designs (Dawson et al., 2019b; Jamnadass et al., 2020); the development of processing procedures so that orphan crops can be more readily used as ingredients in processed foods increasingly consumed by expanding urban populations (Popkin et al., 2012); and the appropriate messaging of how orphan crop foods can help achieve healthful diets (e.g., to support specific recommendations in food-based dietary guidelines; Bekele et al., 2019).

In this review, we explore underlying issues that help inform 'mainstreaming' approaches for orphan crops in Africa. Our primary approach is to undertake a systematic review of the relevant literature on orphan crop mainstreaming methods applied to date in the continent (described in Section 2). Our objective is to see if clear patterns for effectiveness are recorded that help prioritise particular production and/or consumption interventions going forward. Because this literature review revealed only limited information, we supplement it with an analysis of secondary time series data sets on crop production for the African continent (Section 3). In this analysis, we investigate incentives for crop production (farmer 'revenue') and crop consumption (consumer 'price') to see if there is any evidence that one is more important than the other for supporting mainstreaming. To further supplement these findings, we conduct a survey of experts working in the crop sector to gain insight into possible tacit knowledge on the needed mainstreaming interventions for specific orphan crops (Section 4). Our primary purpose in the survey is to see if consensus exists on the most important interventions. We summarise the implications of our findings in the final section of our review (Section 5).

In our review, the focus is mainly on food systems with relatively short production-to-consumption chains (including crop self-consumption by producers). However, our findings also have implications for the redesign of more complex food systems. In our own research, we have designed an approach to support the diversification of African food systems based on 'food crop portfolio' development (McMullin et al., 2019). This approach is currently applied to subsistence production, but the intention is to expand it to include production for the market. Thereby, other consumers could benefit from healthier diets and farmers improve their livelihoods through the sale of portfolio crops. We will therefore (in Section 5) discuss the finding of our review for the future development of the portfolio approach. More widely, our intention in writing this review is to help guide policy makers and practitioners in the design of more effective interventions to support food system diversification.

2. How does the literature on crop mainstreaming in sub-Saharan Africa inform on appropriate orphan crop promotion interventions?

In this section, we describe results from a systematic review of the available literature on orphan crop promotion interventions in sub-Saharan Africa. This literature review is to see if it is possible to prioritise from different production- and/or consumption-oriented options for action to support more effective mainstreaming. Our analysis indicates that the relevant literature is very limited. However, for a small number of crops a number of case studies of suitably-documented

interventions do exist. Although these case studies provide useful information to support future mainstreaming efforts, they do not tell us much about the relative importance of production-versus consumption-based interventions and how these interact. This is because interventions were not designed in a way that would allow these points to be tested. Our literature review is detailed below.

2.1. Approach to literature review

For our literature review we began with a panel of 30 crops from the African Orphan Crops Consortium list of under-utilised and/or under-researched crop species in Africa (AOCC, 2020; list of crops in Appendix 1). The 30 crops that we settled on for review were chosen by us from the full AOCC list of 101 crops on the basis that we considered them most likely to reveal intervention information. The extent to which panel crops have been researched varies: they are all relatively under-researched in Africa compared to major staples; however, examples such as sweet potato (*Ipomoea batatas*) have been more researched than other crops. Nevertheless, because of their place in traditional African farming systems, we consider that all of our panel crops could hold particular lessons for future orphan crop mainstreaming.

A description of our approach to literature review is given in the legend of Fig. 1 (and in Fig. 1a). In brief, we searched the titles, abstracts and keywords of publications listed in the Scopus database for crop names, their synonyms and a range of other search terms related to the use and value of the crops. Search terms included 'consumption', 'production', 'nutrition', 'income', 'scaling up' and 'adoption'. We searched for mentions in 48 named sub-Saharan African countries and for documents published between 1960 and 2018.

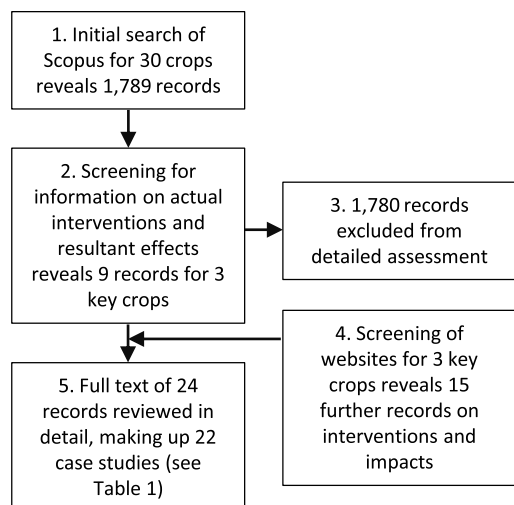
The results of our initial literature search, which revealed 1789 documents, are summarised in Fig. 1b. Our next task was to determine which of these documents reported directly on the results of crop mainstreaming interventions. To do this, we (SMcM, BS or IKD) read the abstracts of all the documents to look for evidence that intervention effects had been recorded. We focused on whether there was mention of changes in production, in incomes, in consumption and/or in consumers' nutritional status. This screening revealed only three crops (or crop groups) with multiple relevant publications: common bean (*Phaseolus vulgaris*), orange-fleshed sweet potato; and African leafy vegetables (various species). In further analysis we therefore focused on these three crops. For these crops, only nine relevant publications describing interventions and the effects achieved were revealed by our screening of initial Scopus search results (i.e., a return rate of 0.5%). This indicated that the testing of production and consumption interventions to determine the factors supporting orphan crop mainstreaming in sub-Saharan Africa is very limited.

To supplement the above nine Scopus-identified references for our three focus crops and to gain deeper insights into the mainstreaming approaches, we screened the websites of institutions and initiatives known to actively promote the crops in Africa (as described in the legend to Fig. 1). These further searches identified an additional 15 relevant references for the three crops. Thus, when pooled, we obtained a final set of 24 references that could be explored in more detail. For each of these references, one of us (BS) read the document in full and summarised the following information: the type(s) of intervention made for crop mainstreaming; the metric(s) applied to assess the impact(s) of intervention; the success and/or failure factors considered by the authors of the piece to condition the effectiveness of intervention; and any recommendations for further intervention action or research.

2.2. Findings of detailed literature review

The 24 references we reviewed in detail represented 22 case studies of intervention: six were for common bean; ten for orange-fleshed sweet potato; and six for African leafy vegetables. The details of our findings are presented in Table 1 and are summarised below.

(a) Literature review



(b) Initial findings

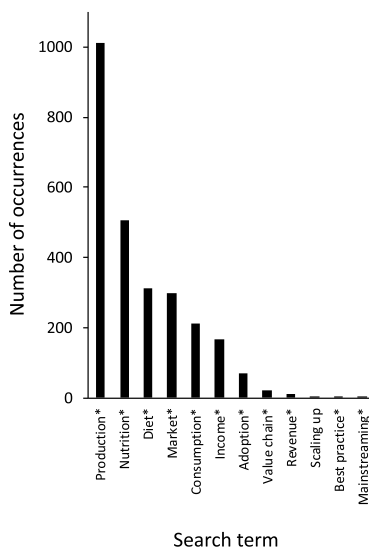


Fig. 1. Literature review of mainstreaming interventions for a panel of 30 crops. (a) Review strategy, (b) initial findings. (a), Box 1: we initially searched the Scopus database for accepted Latin binomials and common synonyms of the 30 chosen crops in our panel (Appendix 1), in combination with any of the following terms: ‘consumption*’, ‘diet*’, ‘production*’, ‘nutrition*’, ‘income*’, ‘revenue*’, ‘best practice*’, ‘mainstreaming*’, ‘scaling up’, ‘adoption*’, ‘market*’ and ‘value chain*’. This was in combination with the names of any of 48 sub-Saharan African countries (according to <https://data.worldbank.org/region/sub-saharan-africa>). Searches were made for peer-reviewed articles, conference papers, online reports and technical notes. Box 4: to supplement the nine references identified through Scopus for three focus crops (common bean, sweet potato and African leafy vegetables), we reviewed the websites of Bioversity International, the International Center for Tropical Agriculture (CIAT), the International Potato Center (CIP), and the World Vegetable Center. These institutions are part of or are affiliated with the CGIAR consortium on agricultural research and development and undertake crop adoption research in Africa. The websites of the HarvestPlus initiative and the CGIAR’s Independent Science and Partnership Council were also reviewed, in the latter case specifically screening the information reported by their Standing Panel on Impact Assessment. The screening of websites was based on the common names of crops as well as their Latin binomials. During website searches we looked for relevant documents that were published between 2000 and 2019. If website searches revealed reviews that had been published between 2014 and 2019, we further screened these to identify any additional primary references that reported on crop-based interventions. In (b), the number of occurrences of specific search terms in all of the initial identified 1789 references is given (note that some individual references report multiple terms).

For common bean, the case studies we identified focused on production interventions. In particular, researchers emphasised the impacts achieved by: developing new varieties (especially iron-rich varieties, designed to help combat iron-deficiency-related anaemia); supporting seed multiplication; and facilitating seed distribution. The nutritional impacts for individual community members of these production interventions were neither described nor tested in any detail. However, it was considered that nutritional benefits would primarily be realised through farmers’ home consumption of the beans they produced (though markets also link bean production to wider consumption).

For orange-fleshed sweet potato, the case studies we identified revealed a wider portfolio of intervention testing than for common bean, in which the effects of production- and consumption-oriented measures were often explored together. The provision of planting material to farmers and guidance on production management practices (e.g., in order to avoid pests and diseases) were common production-oriented interventions. Nutrition education and market development and/or market information were common consumption-oriented measures applied in parallel to production measures. The possible beneficial nutritional impacts of interventions were directly explored in some cases

by measuring the concentration of serum retinol in individuals in intervention communities (orange-fleshed sweet potato is an important source of provitamin A; Low et al., 2007; Hotz et al., 2012a). A unique feature of research on orange-fleshed sweet potato among our three focus crops was the attempt to explore the cost effectiveness of different intensities of intervention for realising impacts (Hotz et al., 2012a, 2012b; de Brauw et al., 2015). This work suggested agronomic training and nutritional education measures should not be ‘overdone’ compared to other promotional inputs such as planting material provision.

For African leafy vegetables, as for orange-fleshed sweet potato, the case studies we identified revealed a wider portfolio of intervention testing than for common bean. As for sweet potato, the effects of production- and consumption-oriented measures were generally explored together. The provision of planting material and agronomic training were common production-based interventions, while the provision of nutrition and health education, and market development, were common consumption-oriented measures applied in parallel to production measures. The nutritional impacts of interventions for individual community members were mostly indirectly explored, although some post-intervention measures of the dietary diversity of

Table 1

Results of detailed literature review of mainstreaming interventions for three focus crops in sub-Saharan Africa. Data on 22 case studies of intervention were compiled (based on 24 references in total; two case studies each comprised of two references reporting on the same intervention).

Country	Interventions	Measures of impact	Success/failure factors noted	Recommendations for further mainstreaming	Reference(s)
Common bean					
Uganda	<u>Production:</u> improved variety seed distribution, over previous few years to publication date (from 1995)	Yield, income, food security	<u>Success:</u> greatest benefits went to households of average wealth. Access to markets for sale, and high soil fertility for improved yields, are important factors. Variety yield is the most important production characteristic mentioned by farmers for encouraging adoption. <u>Failure:</u> poor households were unable to increase production significantly, absence of a reliable seed supply system	Explore replicability for elsewhere in Uganda. Explore shorter value chains and farmer cooperatives that benefit farmers better in the market. Improve farmer access to market information. Support storage approaches to allow timing of market entry to maximise good sale prices	David et al. (2000)
Malawi	<u>Production:</u> improved variety seed multiplication support to NGOs, 1995 to 1997	Level of production adoption	<u>Success:</u> farmers' membership in seed multiplication groups. <u>Failure:</u> lack of access to seed. Gender, literacy, education and prior knowledge were all associated with adoption levels	Strengthen the linkages between researchers, extensionists and farmers to better understand farmers' constraints and priorities. This could be done through joint research-extension meetings, among other means	Masangano and Miles (2004)
Uganda, Rwanda	<u>Production:</u> improved variety breeding and release over decades	Level of adoption, yield, income, food security, dietary diversity at household level	<u>Success:</u> wide availability of agricultural extension services (Rwanda). <u>Failure:</u> poorer bean-producing households less likely to adopt new bean varieties (Uganda)	Limited information given, but promote access to improved seed and information (Uganda)	SPiA (2014), Larochelle et al. (2015)
Rwanda	<u>Production:</u> active dissemination of improved (iron-rich) varieties through multiple means from 2010	Level of adoption, yield. Local use or sale (as measure of nutrition)	<u>Success:</u> targeting women and using farmers' social networks for seed dissemination are important. <u>Failure:</u> farmers report low yield as a factor in discontinuing production of improved varieties (even though these varieties' yields are reported to be higher than a baseline)	Explore the yield issue (why the 'low yield' of higher-than-baseline-yield improved varieties is a factor limiting adoption)	Asare-Marfo et al. (2016a, 2016b)
Malawi	<u>Production:</u> improved variety breeding and release over decades	Level of variety adoption, yield, food security, dietary diversity at household level	<u>Success:</u> presence of extension services (including through mobile phone communication), markets, education. <u>Failure:</u> lack of access to seed, especially for poor farmers, that raises transaction costs	Strengthen seed systems. Use village-level variety demonstration to promote improved varieties. Carry out research to allow the appropriate redesign of extension services. Analyse the dynamics of adoption and test whether impacts persist over time	Katungi et al. (2017)
Uganda	<u>Production:</u> participatory variety selection trials, 2012 and 2013. Impact measured in 2014	Level of new variety adoption	Limited information, but farmers' length of history of bean production influences variety adoption/retention	Limited information given, but need to explore the dynamics of local seed systems	Wilkus et al. (2018)

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women and children within households were made (Ochieng et al., 2018).

In total, our three case study crops provided useful insights into wider orphan crop mainstreaming (Table 1). The presence of extension services, access to markets and the availability of nutrition education were commonly identified as important factors conditioning successful crop promotion; conversely, an often-identified factor resulting in failure was the inability to deliver to farmers appropriate planting material of crops (e.g., improved varieties). Our case studies also, however, indicated limitations in the intervention-oriented research that has been done to date on African orphan crops. A particular feature we noted was an absence of intentional testing of the relative importance of production-versus consumption-oriented interventions (and how these interventions interact) in determining success, with case studies not designed in a way that would allow such issues to be explored. Consideration for consumer food preferences and behaviours to inform

interventions was also not widely evident. In addition to this, we noted that the range of indicators applied by most case studies to measure project success was relatively restricted. Measurements generally focused only on immediate household effects and had only limited relevance for exploring the sustainability and scaling of interventions.

3. Can analysis of longitudinal data sets of crop production in Africa inform appropriate orphan crop mainstreaming interventions?

Given the only limited information revealed by our literature review on the best approaches for orphan crop mainstreaming, we supplement it by assessing longitudinal data sets of crop production in Africa. Our objective is to see if there is evidence that focusing on increasing farmers' crop production incentives ('revenue') or increasing consumers' economic accessibility to food crops (decreasing 'price') is likely

Table 1 (continued)

Country	Interventions	Measures of impact	Success/failure factors noted	Recommendations for further mainstreaming	Reference(s)
Orange-fleshed sweet potato (OFSP)					
Kenya	<u>Production plus consumption</u> (but testing only of consumption intervention): +/- nutritional education over a 1-year period, along with provision of OFSP planting material and agronomic support (at planting, mid-season and harvesting) to 'control' and 'test' women's groups. Impact measured the following year to intervention	Child dietary intake (food frequency) of OFSP and other foods rich in provitamin A	<u>Success</u> : simply providing planting material and agronomic support is not sufficient to increase children's frequency of consuming provitamin A-rich foods; nutritional education was needed to bring about significant increases in children's consumption. <u>Failure</u> : limited availability of OFSP planting material, conflict in timing of farm activities	Increase drought resistance of OFSP varieties. Explore women's income generating opportunities with OFSP. Work with local authorities on subnational-specific dietary change recommendations. Train appropriate extension workers in basic health and nutrition messages	Hagenimana et al. (2001)
Mozambique	<u>Production plus consumption</u> : provision of OFSP planting material and agronomic support (unspecified), nutrition training, market development. Over a two-year period, 2003 to 2005. No testing of production vs. consumption interventions (and interactions)	Level of production adoption, production output, child dietary intake (food frequency and 24-hr recall), child serum retinol concentration, child anthropometry, nutritional knowledge, sale	Limited information provided, though success attributed to being an integrated intervention	Explore if a less intensive package of activities could have reached the same effects more cost effectively. Investigate the longer-term sustainability of interventions. Identify the challenges in scaling to larger areas and other contexts	Low et al. (2007)
South Africa	<u>Production plus consumption</u> : provision of planting material and promotion of cultivation of OFSP and other nutritious crops, cooking and nutrition education. Measurements of impact three years after project initiation. No testing of production vs. consumption interventions (and interactions)	Gardening practices, nutritional knowledge, child dietary intake (food frequency), child morbidity	<u>Success</u> : involvement of the local Departments of Health and Agriculture were critical. <u>Failure</u> : lack of inputs for production, such as irrigation and planting material	Limited information given	Laurie and Faber (2008)
Uganda	<u>Various production and consumption interventions</u> : including provision of OFSP planting material and agronomic support (unspecified), food processing innovations, social capital development, nutritional education	Include level of production adoption, farmers' incomes	<u>Success</u> : markets for OFSP planting material and value-added foods are important, as are long term investment and integrated partnerships in interventions. Farm-based planting material supply to other farmers is also an important success factor	Limited information given	Mwanga and Ssemakula (2011)
Uganda	<u>Production plus consumption</u> : provision of OFSP planting material and agronomic support (e.g., avoidance of pests and diseases, vine conservation across seasons), nutritional and health training to farmer groups, promotion to wider community of health benefits, market information, marketing training. Two intervention levels, identical in year one, but either scaling back or maintaining some agriculture, market and nutrition training activities afterwards (lower intensity vs. higher intensity models, respectively). Two years between baseline and impact measurement, 2007 to 2009. No testing of production vs. consumption interventions (and interactions)	Dietary intake (24-hr recall) and serum retinol concentration of children and women	<u>Success</u> : a similar magnitude of impact on consumption was observed for both low- and high-intensity intervention models, suggesting that some training activities can be excluded after initial intervention, without compromising impact	Limited information given, but the study supports the use of more cost-effective intervention models	Hotz et al. (2012a)
Mozambique	<u>Production plus consumption</u> : provision of OFSP planting material and agronomic support (e.g., avoidance of pests and diseases, vine conservation across seasons), nutritional and health training of women, promotion to wider community of health benefits, trader training and market development. Two levels of	Level of production adoption, dietary intake (24-hr recall, food frequency) by children and women, anthropometry (weight and height) of children and women	<u>Success</u> : a similar magnitude of impact was observed for both low- and high-intensity intervention models, suggesting that training in agronomy, nutrition and health could be limited to the first project year without compromising impact	Limited information given, but the study supports the use of more cost-effective intervention models	Hotz et al. (2012b)

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Table 1 (continued)

Country	Interventions	Measures of impact	Success/failure factors noted	Recommendations for further mainstreaming	Reference(s)
	intervention: low intensity = one year; and high intensity = three years. Both carried out all activities in year one and provided planting material and broad market support through the project. For the high intensity intervention only, further training (agronomic support, nutrition, health) was given in years two and three. Baseline collected in 2006, further survey in 2009. No testing of production vs. consumption interventions (and interactions)				
Mozambique, Uganda	<u>Production plus consumption:</u> provision of OFSP planting material and agronomic support (unspecified growing methods, vine conservation across seasons), nutritional and health training to farmer groups, promotion to wider community of health benefits. Two levels of intervention applied, with scaling back or maintaining of training and messaging activities after year one (lower intensity model vs. higher intensity model, respectively). Work spanned 2006 to 2009. No testing of production vs. consumption interventions (and interactions)	Level of production adoption, knowledge about vitamin A, child dietary intake (24-hr recall)	<u>Success:</u> nutritional knowledge appeared to play only a limited role in adoption, more important in Uganda. There was little difference between low- and high-intensity intervention models and so less intensive intervention was determined to be more cost effective. Appeared that vine access was the most important factor in explaining increases in provitamin A consumption	Develop approaches to encourage cross-farmer sharing of planting material	de Brauw et al. (2015)
Mozambique	<u>Production plus consumption:</u> provision of OFSP planting material and agronomic support (on planting, disinfecting and preserving vines), nutrition and health training of women. Work spanned 2006 to 2009. No testing of production vs. consumption interventions (and interactions)	Disease (diarrhoea) prevalence in children, child dietary intake (food frequency)	<u>Success:</u> greater education level of mothers	Limited information given	Jones and de Brauw (2015)
Tanzania	<u>Mostly production:</u> review of various promotion activities for OFSP, including breeding of improved varieties and provision of planting material. Less work available for review on demand creation (consumption)	Include level of production adoption, consumption	<u>Failure:</u> lack of profitability for supplying both improved planting material and the food market. Scattered and uncoordinated action. Little focus on commercially viable value chains. Inattention to demand characteristics	Research consumers' preferences and willingness-to-pay. Develop nutritional quality assurance measures for processed OFSP-containing foods, to signal added nutritional value. Support demand creation through marketing campaigns and food product development. Catalyse private sector involvement. Develop purchasing programmes to deliver planting materials to farmers	Waized et al. (2015)
Zambia	<u>Production plus consumption:</u> limited specific information, but interventions for OFSP made since 2011 include provision of planting material, agronomic support (unspecified good agronomic practices, multiplication and conservation of vines) and nutritional messaging. Measurements in 2015	Production adoption, procurement, knowledge on nutrition, dietary intake (food frequency) at household level	<u>Failure:</u> inability to access planting material	Sensitise households on the nutritional benefits of OFSP, targeting households with children aged under five years. Design sustainable planting material supply systems	Sakala et al. (2018)
African leafy vegetables					
Kenya	<u>Various production and consumption interventions:</u> including planting material supply, agronomic information (unspecified practices),	Production, consumption at household level, marketing, income	<u>Success:</u> increased knowledge of nutritional value led to changed perceptions, with higher demand in urban markets and increased farm household consumption.	Develop refrigeration facilities for vegetable storage. Focus on building women's capacity	Gotor and Irungu (2010)

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Table 1 (continued)

Country	Interventions	Measures of impact	Success/failure factors noted	Recommendations for further mainstreaming	Reference(s)
Kenya	processing and marketing, beginning primarily from 2001. Measurements before intervention in 1997 and after intervention in 2007		An institutional coordinator of interventions is important. Failure: problems in transportation to markets (to Nairobi), exclusion of the poorest farmers from markets		
Kenya	Production plus consumption: training in agronomy (e.g., pest management, irrigation methods), postharvest handling, nutritional and commercial value, marketing. Intervention in 2006, impact measured in 2009. No testing of production vs. consumption interventions (and interactions)	Production, consumption (not further specified), nutritional and farming knowledge, sale	Failure: limited access to planting material and other inputs, absence of transport logistics to access urban markets	Limited information given	Ndenga et al. (2013)
Kenya	Production plus consumption (but only testing consumption interventions): provision of planting material, agronomic support (unspecified), open market/supermarket linkages, cooking demonstrations, nutrition and health education. Different combinations of consumption interventions tested; all groups received production interventions. Intensities of particular interventions varied. Eighteen months of action, 2009 to 2011	Cultivation, consumption (previous week recall), market presence, sale	Success: applying more interventions together resulted in greater success. Production interventions alone had the lowest success. Familiarity to specific vegetables contributed to success. The appearance of vegetables in supermarkets fuels demand in open markets	Protect women's role in sale. Monitor changes in producers' and consumers' behaviours and attitudes	Kariuki et al. (2013)
Malawi	Production plus consumption: provision of improved planting material, agronomic support (e.g., training and technical support for irrigation), marketing, nutrition education. From 2008 to 2011. No testing of production vs. consumption interventions (and interactions)	Production, consumption at household level, income, marketing	Success: proximity to cities with a high demand for vegetables. Failure: farmers' lack of skills to exploit market opportunities	Limited information given	Gotor and Martin (2013)
Tanzania	Production plus consumption: promoting production, consumption through agricultural shows, cook shows. Various other sensitisation measures, including on health benefits. Interventions from 2014, impacts determined 2015. No testing of production vs. consumption interventions (and interactions)	Dietary diversity of women, children and households	Success: pregnant women's access to health advice in prenatal care clinics may be important	Limited information given, but should target children and women in hospitals and schools with promotion programmes	Ochieng et al. (2018)
Kenya, Tanzania	Mostly production: various interventions primarily over the preceding decade but some earlier, including breeding and provision of improved planting material, e.g., through 'seed kits' for farmers. Evaluation in 2017 and 2018	Production adoption (improved varieties) and use of best production practices, according to expert opinion. Seed suppliers' seed production and distribution	Success: promotion of seed kit distribution is an effective approach. The adaptability of the crop (amaranth) and the strength of demand in peri-urban and urban areas are also important. Failure: seed market constraints	Ensure closer collaboration between research organisations, (other) breeders and seed companies (e.g., support the Africa Vegetable Breeding Consortium). Support capacity building in agronomic practices (e.g., in integrated pest management)	Ochieng et al. (2019)

to be more effective in driving orphan crop integration in African food systems. Overall, our analysis provides ambiguous results on this point, but suggests that the policy environment around food production could be an important area for action. Our analysis is described below.

Comparable open-access country-level crop production information for most nations of the world is available through FAOSTAT. These secondary data, collected by FAO from national governments, have been used widely to explore food system trends (e.g., [Khoury et al., 2014](#); [Dawson et al., 2019a](#)). We therefore make use of these data for the period 1963 to 2016 to explore food system trends for Africa for a panel

of 63 crops that are representative of crop production on the continent as a whole (the panel contains both orphan and major crops; see legend to [Fig. 2](#)). Our analysis is based on information on unit farm gate production value (in constant 2004–2006 USD), total output, yield (production per unit area) and area planted from the FAOSTAT production domain data sets for the continent as a single geographic entity ([FAOSTAT, 2019](#)).

From the data, we generated two simple proxies for potential production and consumption drivers. The first, which we term 'revenue', was calculated as farm gate value per unit area of production. We

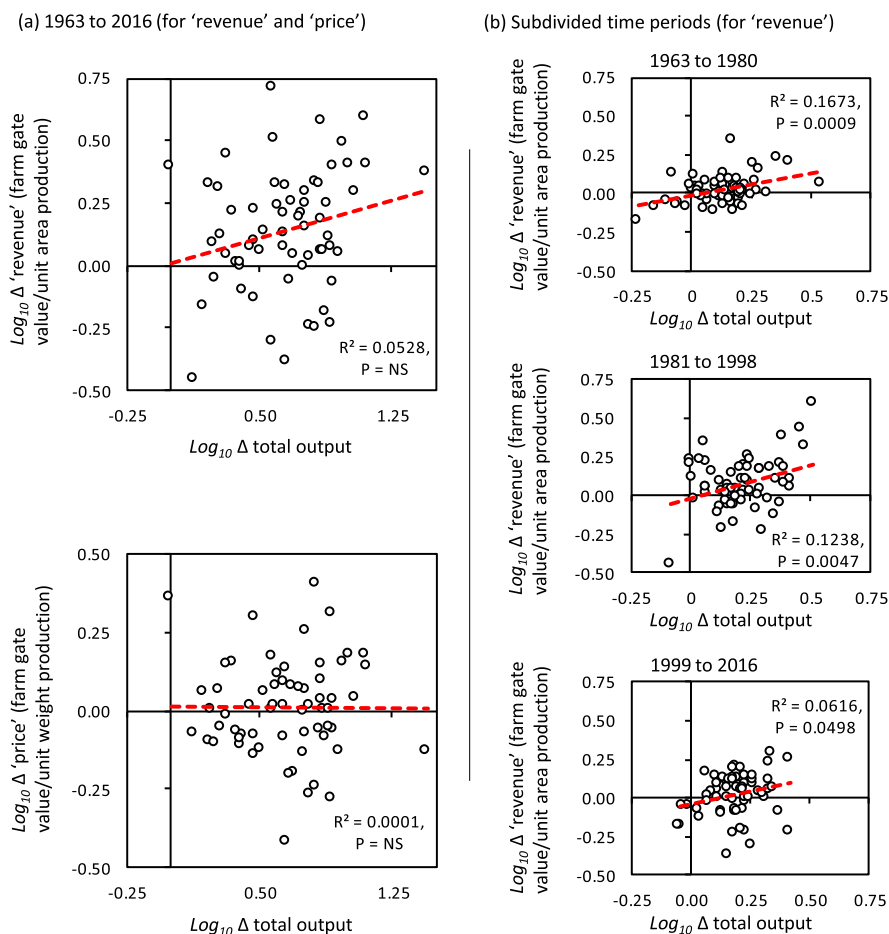


Fig. 2. Comparisons of crop 'revenue' for farmers and 'price' for consumers (1/consumer accessibility) with changes in total output for a panel of 63 crops grown in Africa. Comparisons (a) for the 1963 to 2016 time period and (b), for 'revenue' only, for three subdivided time periods (1963–1980; 1981 to 1998; and 1999 to 2016). For both (a) and (b), profiles are based on FAOSTAT (2019) production data. Graphs show \log_{10} changes in revenue or price comparing five year means for the start and end of the time period (so, e.g., between mean 1963–1967 and mean 2012–2016). Linear regressions across crops indicate no statistically significant correlations between variables in (a) but statistical significance at varying levels in (b). Production values used to approximate revenue and price are based on constant 2004–2006 USD. Crops (crop groups) for which data were extracted from FAOSTAT were as follows (crop labels as given in the FAOSTAT production domain data sets): Almonds, with shell; Apples; Apricots; Avocados; Bambara beans; Bananas; Barley; Beans, dry; Beans, green; Broad beans, horse beans, dry; Cabbages and other brassicas; Cashew nuts, with shell; Cassava; Chick peas; Chillies and peppers, dry; Chillies and peppers, green; Cocoa, beans; Coconuts; Coffee, green; Cow peas, dry; Dates; Eggplants (aubergines); Figs; Fonio; Grapefruit (inc. pomelos); Grapes; Groundnuts, with shell; Karite nuts (sheanuts); Kola nuts; Lemons and limes; Lentils; Maize; Mangoes, mangosteens, guavas; Melons, other (inc. cantaloupes); Millet; Oil palm fruit; Okra; Onions, dry; Onions, shallots, green; Oranges; Papayas; Peaches and nectarines; Pears; Peas, dry; Peas, green; Pepper (piper spp.); Pigeon peas; Pineapples; Plantains and others; Potatoes; Pumpkins, squash and gourds; Rice, paddy; Sorghum; Soybeans; Sugar cane; Sweet potatoes; Tangerines, mandarins, clementines, satsumas; Taro (cocoyam); Tea; Tomatoes; Watermelons; Wheat; Yams. Of this crop panel, 35 are annual crops and 28 are perennial crops. Linear regressions calculations were undertaken in Excel.

consider this as a loose proxy for farmers' crop production incentives. The second, which we term 'price', was calculated as farm gate value per unit weight of production. We consider this as a loose proxy for consumers' accessibility (1/accessibility) to crop foods. Note that both these proxies are limited in application as they do not take account of a wide range of other factors that will affect revenue and price and that may have changed in strength over the tested time period. Nevertheless, the availability of these measures over a greater than 50-year period within which significant agricultural transformations have occurred could be a starting point for providing useful insights into food system drivers.

For each of the 63 crops in our panel, we plotted changes in our two proxy measures against the change in total output over the sampled time series. We then calculated linear regressions across crops to determine relationships between variables (see legend to Fig. 2 for more information). By exploring the slope of the regression of our indicators across crops against output expansion over time, it should be possible to obtain information on the relative importance of revenue and price factors in crop expansion.

The results of our analysis are shown in Fig. 2. They indicate that, for the 1963 to 2016 time period as a whole, there is no statistically significant relationship between either of our proxies and output expansion across our crop panel (Fig. 2a). However, if the overall tested time period is divided into three equal 18-year subperiods (1963–1980; 1981 to 1998; and 1999 to 2016), statistically significant positive relationships ($P < 0.05$) do become evident for 'revenue' (Fig. 2b), though still not for 'price' (results not shown). These subperiods roughly correspond with different phases of subsidy provision to farmers in African

agriculture: subsidised inputs for agriculture were introduced widely prior to the mid-1970s; structural adjustment programmes introduced in the 1980s and 1990s often removed these; while since the early 2000s there has been gradual reintroduction, mostly related to the provision of (staple) crop seeds and fertilisers (Kato and Greeley, 2016). Our findings thus support a view that crop-specific varying subsidy environments over the 1963 to 2016 period had a role in determining food production profiles.

Revenue, price and food crop output expansion are complexly interrelated in food systems, so it is perhaps not surprising that the results of our analysis involving them were largely ambiguous. Clearly, crude indicators from FAOSTAT production data alone offer only limited insights for mainstreaming orphan crops. Nevertheless, they do suggest that removing or redirecting production subsidies could play an important role.

4. How can experts' perspectives on Africa's orphan crops guide mainstreaming efforts?

Given the limited information revealed both by literature review and our analysis of secondary data sets of crop production, we explore a further approach to determine orphan crop mainstreaming interventions. This involves a survey of experts working in the crop sector in Africa to gain insights into interventions for specific orphan crops. Our survey reveals that there is a relationship between respondents' area of expertise and their views on the priority constraints to be addressed for crops. However, the survey does not reveal anecdotal consensus on

the most important interventions for specific crops. Our survey is described below.

Through our institutional networks we identified and contacted a group of experts of different disciplines working in the crop sector across Africa. We asked each expert to complete an online survey on African orphan crops (approach described in Appendix 2). As part of the survey, we asked participants to rank three potential bottlenecks for orphan crop use, with reference to the specific crops on the AOCC crop list (AOCC, 2020). We also asked participants to address a series of questions about the particular characteristics of each of these crops.

The results of our survey are summarised in Fig. 3. The compilation of responses from all respondents as a single group indicated that lack of knowledge about crops and how to use them, and lack of planting material availability, rated approximately equally as the top-ranking bottleneck to use (Fig. 3a). More interesting, however, was how particular categories of expert ranked bottlenecks (Fig. 3b). These observations indicated that specialists do not necessarily consider their ‘own’ discipline as key for achieving mainstreaming. As an illustration, plant breeders did not top-rank the lack of availability of high-quality planting material as the key constraint as often as would be expected based on the overall pool of responses. The same pattern applied for extension specialists, who did not top-rank the lack of knowledge about

crops as the key constraint as often as expected based on the overall pool.

To explore if there was consensus on the importance of particular interventions for individual orphan crops, we had asked respondents to define the characteristics of specific crops. Our survey provided at least four responses for each of nine of the crops on the AOCC list (Fig. 3c). The results for these crops showed that how their particular characteristics were scored by individual respondents was often very different. In addition, for each of seven of these nine crops, some of the respondents favoured a production-oriented intervention and others a consumption-oriented intervention as the most important step to take in mainstreaming.

5. Recommendations for diversifying African food systems

To understand better how to diversify African food systems through the mainstreaming of orphan crops, we have undertaken three activities: first, we reviewed the relevant literature on interventions to date in the sub-Saharan Africa region; second, we analysed crop production time series data sets for the continent; and third, we conducted a survey of experts working in Africa in the crop sector. Below, we will further relate the lessons of findings from each of these three activities. We will also

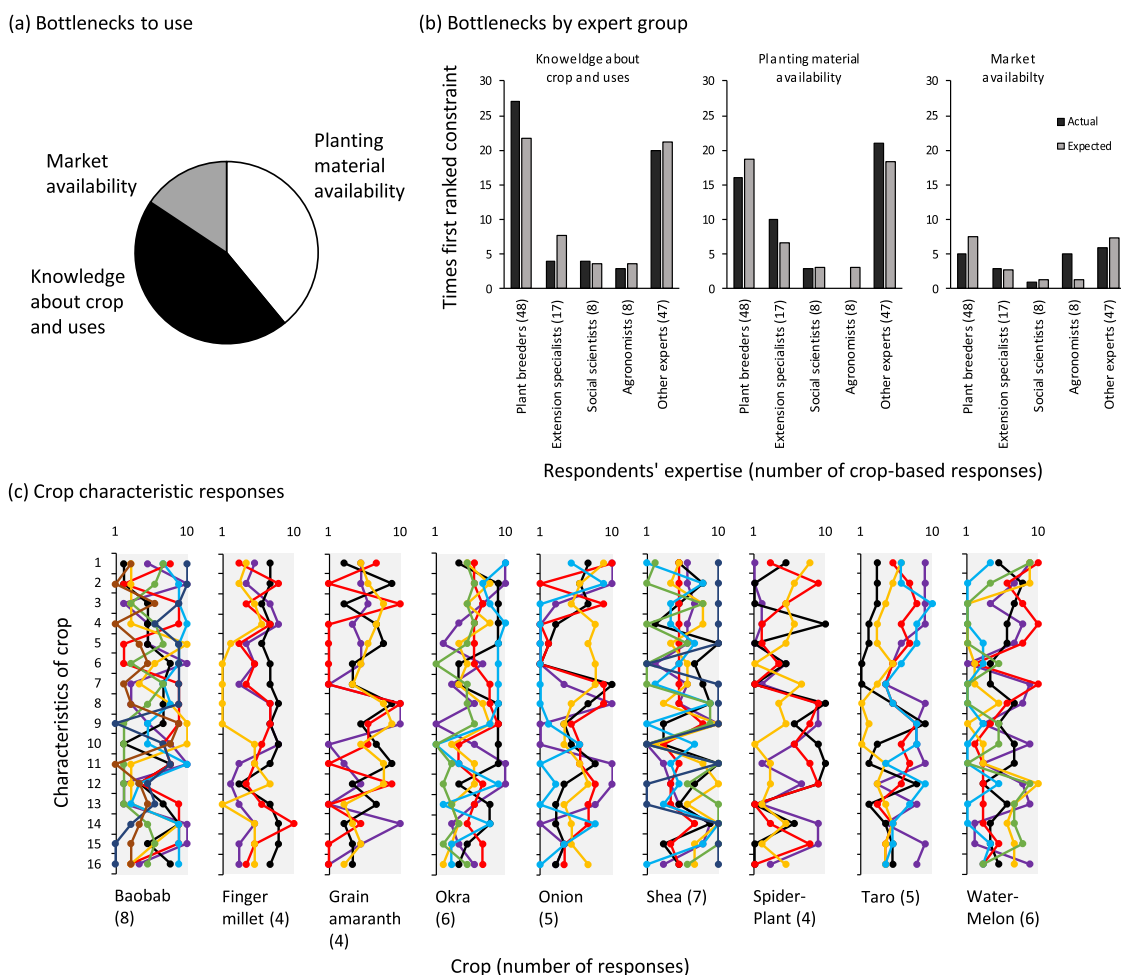


Fig. 3. Results of a survey of the perspectives of experts working in the crop sector in Africa on orphan crop mainstreaming in the continent. (a) pie diagram showing which of three bottleneck response options were ranked first for orphan crops (from a total of 128 crop-based responses). (b) bar chart showing how specific expert groups top-ranked the three bottlenecks, compared to expectations based on overall pooled responses. (c) Respondents’ scores (on a 1 to 10 scale) for 16 characteristics of nine crops that had ≥ 4 survey responses, showing the variation in score between respondents for individual crops. Nomenclature for the nine crops is as follows: baobab, *Adansonia digitata*; finger millet, *Eleusine coracana*; grain amaranth, *Amaranthus cruentus*; okra, *Abelmoschus caillei*; onion, *Allium cepa*; shea, *Vitellaria paradoxa*; spider plant, *Cleome gynandra*; taro, *Colocasia esculenta*; and watermelon, *Citrullus lanatus*. For each crop in (c), each respondent is represented by a different coloured line, the ‘shape’ of which helps illustrate the varying responses received across respondents. For further information, including on particular crop characteristics (the specifics of which could in future be explored further to understand response heterogeneity in [c]), refer to Appendix 2.

discuss the implications of our findings for the further evolution of the food crop portfolio approach that we have developed in our own work. We will finish by discussing additional areas for research to support orphan crop mainstreaming that are suggested by our review.

5.1. Lessons from literature review of crop interventions to date

Our review of the literature to determine the effects of promotion interventions that have been applied to orphan crops in sub-Saharan Africa revealed only limited examples. We studied in detail three focus crops for which multiple case studies were nevertheless available. Each of these focus crops has been promoted somewhat successfully to reach hundreds of thousands of African farmers (see Bouis and Saltzman, 2017 for common bean and orange-fleshed sweet potato; and Aworh, 2018 for African leafy vegetables). The authors of the case studies we examined for these three crops suggested a number of factors determining intervention success and failure, with the inability to deliver appropriate planting material to farmers a recurrent theme behind failure – supporting other findings that interventions do not always have to get everything right but have to avoid getting critical things wrong (Verkaart et al., 2019). However, it was clear that the availability of planting material was only one condition for success, illustrating the importance of consumption-as well as production-oriented interventions.

The literature we reviewed told us little about the relative importance of production-versus consumption-based interventions for orphan crops and, perhaps more importantly, how these interact. In large part, this was because the case studies of intervention we reviewed were not designed to allow such testing. Thus, of our three focus crops, case studies of intervention for common bean were based only on production measures. While case studies for orange-fleshed sweet potato and African leafy vegetables did apply production- and consumption-oriented interventions, they did not aim to estimate the effectiveness of these two types of intervention one against the other and compared to the magnitude of their interaction. In theory, this point could be addressed by the adoption of factorial designs in which production interventions are – and are not – applied with – and without – consumption interventions. However, in practice, many complexities could exist in the design and interpretation of such research, which may reflect why the approach has not been applied to date. A possible further reason for the non-adoption of such designs could be limited interdisciplinarity in teams conducting intervention research. Nevertheless, factorial designs might be useful in the future if the consumption and production options for testing have already been sufficiently ‘narrowed down’ in previous work, and in such cases could be considered.

5.2. Lessons from the analysis of longitudinal data sets of crop production

Our analysis of longitudinal data on crop production did not reveal a clear picture of whether farmer ‘revenue’ or consumer ‘price’ should be prioritised for attention in orphan crop mainstreaming into African markets. This could reflect the limitations of the proxies we applied in our analysis and the wider constraints of our initial FAOSTAT data sets; other research has, for example, shown the importance of reduced prices in supporting crop demand (e.g., Gruère et al., 2006; Revoredo-Giha et al., 2018). Our analysis was based on FAOSTAT production data for Africa as a single entity. Analysis of the same data disaggregated at a national level (similar to Rakshit et al., 2014 for the single crop sorghum) would likely be more informative for understanding the relationships between revenue, price and crop output changes; such research should therefore be a future priority for our crop panel.

Despite the constraints to our analysis, it did indicate that, as would be anticipated, the policy environment around food production could be an important area for action to support orphan crop mainstreaming. There are a number of policy options around removing or redirecting food production subsidies that could be relevant that are suggested in

the literature. Making sure that the high ‘hidden’ environmental costs of ‘business-as-usual’ food production are properly accounted for would help ‘level the playing field’ for orphan crops (Pingali, 2015). Considering the food system as a whole, revenues from taxes on unhealthy food consumption could be used to subsidise healthy orphan crop consumption, in urban markets especially (Garrett et al., 2019). Supporting access to finance for small and medium-sized enterprises (SMEs) to deliver nutritious foods is a crucial aspect. Here, blended finance, where public or philanthropic capital is used to spur private sector investment, may be key (Garrett et al., 2019).

5.3. Lessons from expert survey on orphan crops

Our survey of experts working in the crop sector in Africa revealed that particular specialists did not necessarily consider their ‘own’ discipline as most important for achieving successful orphan crop mainstreaming. A positive view of this finding is that specialists are cognisant of the need for cross-disciplinary engagement for devising mainstreaming solutions. An alternative, more negative, view is that different disciplines ‘blame’ each other for any lack of success. From our survey we were not able to distinguish between these options, but further research on this would be advisable.

Further questioning of experts revealed that there was no clear consensus on the interventions most important to support the mainstreaming of specific orphan crops. We were not able to identify if this reflected a lack of understanding by individual respondents on relevant mainstreaming pathways or if it was due to specific locational contexts of crop production and consumption. However, as a starting point, these findings would suggest that cross-disciplinary teams from the research and development communities, and from different countries, should be drawn together to develop potential mainstreaming strategies, rather than relying on individual experts.

5.4. Lessons for the food crop portfolio approach

One reason why we undertook the current review was to understand how it could inform our own work. The food crop portfolio approach is a method we have designed to support the diversification of African food systems in subsistence settings, but there is the intention to also expand it to embrace markets (McMullin et al., 2019). As currently practiced, a common set of tools is used to determine within an annual calendar the crops that are grown by farmers and the foods that farming household members consume. These data are used to determine, at monthly resolution, periods of food insecurity and the key nutrient gaps that individuals and local communities face. Recommendations for nutrient-rich crop promotion are then devised that are location-specific. These recommendations consider the crops that farmers hold as priorities, when in the year crops produce food and their nutrient compositions. Based on this information, interventions to further promote portfolio crops include support in the delivery of appropriate planting material and nutrition education (see McMullin et al., 2019 for further information).

Our literature review of mainstreaming interventions reinforces the view that proper attention to delivering appropriate planting material is important for portfolio crops. Clearly, the composition of this planting material may need to change if and when portfolios become more oriented toward supplying markets than to self-provision, so new approaches for crop priority setting may be required in the future that balance direct food use with market needs. Although our review has shed only limited light on the relative intensity for intervention in production- and consumption-oriented measures that would be appropriate for the mainstreaming of portfolios, our survey of crop experts suggests that this may be context specific by crop and location. If sufficient information were to become available on the ‘best bet’ production- and consumption-oriented measures to support portfolio mainstreaming at particular locations (e.g., a particularly effective way

of supplying planting material and a particularly useful approach to nutrition education), it might be relevant to adopt factorial designs to test these together. As already noted, however, the use of such designs is unlikely to be straightforward. Finally, our analysis of longitudinal data on crop production suggests that to support the expansion of the portfolio approach to embrace markets it may be important to promote policies that level the playing field between orphan and other crops.

5.5. Future research directions

Our three-pronged approach to explore orphan crop mainstreaming solutions suggests additional avenues for research to explore producers' and consumers' behaviours and preferences. First, we need to expand our understanding of the incentives that guide the production activities that different groups of farmers adopt (Tittonell et al., 2010; Gassner et al., 2019). Though farmers' decisions are in part determined by the profitability of different production options (Michler et al., 2019), something we explored in Section 3 of this review (though our analysis was based on 'revenues' not profits), a much wider consideration of other factors is also relevant. These factors include long-term aspirations and life goals (Mausch et al., 2018; Verkaart et al., 2018). Second, for orphan crop foods to more effectively compete with other food options in more complex market-based food systems, a better understanding is required of consumers' preferences and behaviours with respect to these foods (De Groot et al., 2018; Revoredo-Giha et al., 2018). These need to be considered along with the age of consumers, their education, income, location and access to media. With orphan crops' roles in traditional food systems, paying attention to consumers' cultural backgrounds may also be particularly important.

An understanding of these issues will allow greater alignment of orphan crop foods and their promotion to tastes and preferences. In our view, it is paying more attention to these topics that may ultimately condition successful interventions for orphan crop mainstreaming, supporting societal change to bring about scaling and sustainability (Woltering et al., 2020). This is clearly an interdisciplinary process with roles for both natural and social scientists in exploring complexities and

multi-scale drivers and their interactions.

In conclusion, our review shows that, despite some 'pointers', there is much work still to be done to understand how African food systems can better be diversified and made more healthful. Further work to mainstream African orphan crops to fulfil these objectives is not only relevant for the continent: it should also provide lessons that can be applied to counter current trends toward farm landscape and dietary homogenisation globally (Khoury et al., 2014; Dawson et al., 2019a), with the negative consequences these trends have for the health of people and the planet (Clark et al., 2019).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. List of thirty crops for initial literature review

Species were a subset of the African Orphan Crops Consortium (AOCC) list of 101 under-utilised/under-researched crops (or crop categories) considered priorities for promotion in Africa (AOCC, 2020; the AOCC initiative supports the use of advanced genetic methods for the improvement of these crops). All of the crops in our 30-crop panel for literature review have the potential to diversify African diets and enhance farmers' incomes. They provide a range of different foods and consist of a mix of annual and perennial plants that are both indigenous and exotic to Africa. The exotics on the list were generally introduced to Africa in or before the colonial period and therefore have been grown on the continent for some time.

Latin binomial	Common name (as applied by AOCC)
<i>Abelmoschus caillei</i>	Okra
<i>Adansonia digitata</i>	Baobab
<i>Allanblackia floribunda</i>	Vegetable tallow tree
<i>Amaranthus blitum</i>	Amaranth
<i>Amaranthus cruentus</i>	Grain amaranth
<i>Amaranthus tricolor</i>	Vegetable amaranth
<i>Cleome gynandra</i>	Spiderplant
<i>Corchorus olitorius</i>	Jute mallow
<i>Cucurbita maxima</i>	Pumpkin
<i>Dacryodes edulis</i>	African plum
<i>Eleusine coracana</i>	Finger millet
<i>Gnetum africanum</i>	African gnetum
<i>Ipomoea batatas</i>	Sweet potato
<i>Irvingia gabonensis</i>	Sweet bush mango
<i>Irvingia wombolu</i>	Bitter bush mango
<i>Mangifera indica</i>	Mango
<i>Moringa oleifera</i>	Drumstick tree
<i>Phaseolus lunatus</i>	Lima bean
<i>Phaseolus vulgaris</i>	Common bean

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(continued)

Latin binomial	Common name (as applied by AOCC)
<i>Psidium guajava</i>	Guava
<i>Sclerocarya birrea</i>	Marula
<i>Solanum aethiopicum</i>	Ethiopian nightshade
<i>Solanum macrocarpon</i>	African eggplant
<i>Solanum scabrum</i>	African nightshade
<i>Syzygium guineense</i>	Water berry
<i>Tamarindus indica</i>	Tamarind
<i>Vangueria infausta</i>	African medlar
<i>Vigna subterranea</i>	Bambara groundnut
<i>Vigna unguiculata</i>	Cowpea
<i>Ziziphus mauritiana</i>	Jujube

Appendix 2. Survey of the views of experts working in the crop sector in Africa on orphan crop mainstreaming in the continent

Approach

To provide information on experts' views on the promotion of orphan crops in Africa, we conducted a survey with plant breeders, agronomists, extension specialists, social scientists and other experts. We emailed these experts to invite them to complete an online questionnaire. Our email contact list was based on colleagues in Africa with whom we had previously engaged in research and development activities.

Our survey explored a number of questions relevant for orphan crop promotion. A list of survey questions is available at: <https://forms.gle/x3bpq23qJe9kSCZ6>. In the following, we refer to information collected in the survey that is relevant to the current review, though further information was also collected and awaits analysis.

In the survey we asked participants to rank perceived priority bottlenecks to orphan crop use across three options: 'planting material availability' (constraint = the inability to obtain planting material); 'market availability' (constraint = lack of availability in markets); and 'knowledge' (constraint = lack of knowledge about the crop and its uses). The first of these constraints is a production issue, the second a consumption issue, and the third relates to both production and consumption.

We also asked experts to position specific orphan crops on a scale between different paired options for characteristics relating to production, markets and use (such as: the ability to integrate into production systems vs. being highly competitive with other plants; the importance of home use vs. market sale; and the importance of local use vs. global trade). We further asked survey respondents to indicate priority interventions to promote mainstreaming for specific orphan crops.

The crop panel upon which respondents could provide information consisted of the 101 entries on the African Orphan Crops Consortium's (AOCC) priority crop list, supplemented by a small number of additional crop species (AOCC, 2020). Individual respondents were restricted to comment on a maximum of five crops in order not to overly bias sampling to particular respondents.

As part of the survey, information on respondents' backgrounds (including their area of expertise) was also collected.

Results

The full unprocessed data set of survey responses, with detailed information for individual crops, is available from the authors (KM). In total, 50 experts completed the survey and information was obtained for 57 crops. Overall, 128 crop-based responses were recorded; this represented a mean of 2.6 and 2.3 responses per respondent and per crop, respectively. Of the 128 crop-based responses, 38% were from experts who identified themselves as breeders. Another 13% were from extension specialists, 6% from social scientists, and 6% from agronomists. Thirty-seven percent of responses were from respondents who did not identify themselves as fitting within any of the above disciplines or who covered more than one discipline in their work.

The crops commented on by respondents, in alphabetic order by Latin binomial (with common names and number of responses received, respectively, in parentheses), were as follows: *Abelmoschus caillei* (Okra, 6); *Adansonia digitata* (Baobab, 8); *Adansonia kilima* (Baobab, 1); *Allanblackia floribunda* (Vegetable tallow tree, 2); *Allium cepa* (Onion, 5); *Amaranthus cruentus* (Grain amaranth, 4); *Amaranthus tricolor* (Vegetable amaranth, 3); *Anacardium occidentale* (Cashew, 2); *Annona senegalensis* (Wild custard apple, 3); *Artocarpus heterophyllus* (Jack tree, 1); *Balanites aegyptiaca* (Balanites, 3); *Carica papaya* (Papaya, 2); *Citrullus lanatus* (Watermelon, 6); *Cleome gynandra* (Spiderplant, 4); *Colocasia esculenta* (Taro, 5); *Corchorus olitorius* (Jute mallow, 2); *Cucurbita maxima* (Pumpkin, 2); *Cyphomandra betacea* (Cape tomato, 1); *Dacryodes edulis* (African plum, 1); *Detarium senegalense* (Sweet detar, 1); *Digitaria exilis* (Fonio, 3); *Eleusine coracana* (Finger millet, 4); *Faidherbia albida* (Apple-ring acacia, 1); *Garcinia mangostana* (Mangosteen, 1); *Gnetum africanum* (African gnetum, 2); *Ipomoea batatas* (Sweet potato, 2); *Irvingia gabonensis* (Sweet bush mango, 2); *Landolphia* spp. (Gumvines, 1); *Lannea microcarpa* (Tree grapes, 1); *Lathyrus sativus* (Grass pea, 1); *Lens culinaris* (Lentil, 2); *Macrotyloma geocarpum* (Geocarpa groundnut, 3); *Mangifera indica* (Mango, 2); *Momordica charantia* (Bittergourd, 1); *Moringa oleifera* (Drumstick tree, 3); *Musa balbisiana* (Bananas, 2); *Opuntia ficus-indica* (Cactus, 1); *Parinari curatellifolia* (Mobola plum, 1); *Parkia biglobosa* (African Locust bean, 2); *Passiflora edulis* (Passion fruit, 1); *Persea americana* (Avocado, 2); *Phaseolus vulgaris* (Common bean, 1); *Phoenix dactylifera* (Date palm, 1); *Psidium guajava* (Guava, 1); *Ricinodendron heudelotii* (Groundnut tree, 1); *Sclerocarya birrea* (Marula, 1); *Sphenostylis stenocarpa* (Yam bean, 1); *Talinum fruticosum* (Ceylon spinach, 1); *Tamarindus indica* (Tamarind, 1); *Telfairia occidentalis* (Fluted gourd, 1); *Vicia faba* (Faba bean, 2); *Vigna subterranea* (Bambara groundnut, 3); *Vitellaria paradoxa* (Shea, 7); *Vitex doniana* (Chocolate berries, 3); *Xanthosoma sagittifolium* (Elephant ear, 1); *Xanthosoma* spp. (Cocoyam, 1); and *Ziziphus* spp. (Jujube, 2).

To summarise the results of the survey, we tabulated responses on the rankings of crop bottlenecks, dissecting these responses by respondents' area

of expertise. We also explored the range of responses for individual crops when multiple responses were received (i.e., when a particular crop had its characteristics for production, markets and use recorded by more than one respondent; see list of survey questions for these characteristics, which are simply ordered 1 to 16 in the presentation of results). The findings are discussed in the main body of the review (Section 4 and Fig. 3).

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