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Review

Benefits and Trade-Offs of Smallholder Sweet Potato Cultivation as a Pathway toward Achieving the Sustainable Development Goals

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Abstract: The 2030 Agenda for Sustainable Development, including the 17 Sustainable Development Goals (SDGs), will shape national development plans up to 2030. SDGs 1 (No Poverty), 2 (Zero Hunger) and 7 (Affordable and Clean Energy) are particularly crucial for the poor, given they target the basic human needs for development and fundamental human rights. The majority of poor and malnourished people in the developing world live in rural areas and engage in farming as a key part of their livelihoods, with food and agriculture at the heart of their development concerns. Crops that can provide both food and energy without detrimental impacts on soil or water resources can be particularly beneficial for local development and smallholder farmers. Sweet potato, in particular, is starting to attract growing attention from researchers and policymakers as it has the potential to address these global problems and promote a sustainable society. We systematically review the literature to assess how sweet potato can support smallholder farmers to make progress towards the SDGs. We find that sweet potato has important untapped potential to advance progress, particularly linked to its versatility as a crop and its multiple end-uses. However, further research is paramount in order to better recognise and harness its potential to address the issues of food, nutrition and energy security in the context of a changing global climate. Further investigation is also needed into the trade-offs that occur in the use of sweet potato to support progress towards the SDGs.

Keywords: resilience; agriculture; biofuels; bioethanol; food security; poverty; energy; nutrition; livelihoods; synergy; trade-offs

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1. Introduction

The adoption of the Millennium Development Goals (MDGs) in 2000 signalled a global consensus around the imperative of reducing poverty and improving the lives of people in developing countries [1]. However, as the 2015 deadline for the MDGs drew nearer, progress was falling short of international expectations. Even though the proportion of undernourished people in the developing world had fallen by almost half since 1990 [2], food security still proved elusive for several developing countries. In 2018, for instance, 850 million people were hungry and one in three people were malnourished [3], with the current COVID-19 crisis anticipated to raise that figure further. Despite tangible progress in reducing poverty and improving lives, almost 27% of the world's population were still classified in 2017 as poor according to the Global Multidimensional Poverty Index [4]. Finally, even though energy-related targets were absent from the MDG framework, it was acknowledged that addressing energy needs constituted an essential element to the fulfilment of the MDGs. Even so, the energy needs of hundreds of millions of people around the world remained unmet, with close to 1.1 billion people in 2016 unable to access electricity [5].

For the international community to sustain momentum and tackle the pressing environmental, political and economic challenges facing our planet [6], the MDGs were replaced in 2015 by the Sustainable Development Goals (SDGs), with a deadline of 2030. Consisting of 17 goals and 169 targets, the SDGs are universal, inclusive, integrated and indivisible in nature, and put forward a transformational and holistic plan to guide efforts of all stakeholders toward sustainable development [7]. The SDGs emphasise inclusive growth and commit to leaving no one behind [8,9]. From the 17 goals, we focus on SDG 1 (No Poverty), SDG 2 (Zero Hunger) and SDG 7 (Affordable and Clean Energy), given their focus on food and energy, aspects that constitute basic human needs and fundamental human rights [10,11] (Table 1).

Table 1. Sustainable Development Goals (SDGs) 1, 2 and 7 and their targets.

	SDG 1: End Poverty in All Its Forms Everywhere
1.1.	By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day.
1.2.	By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions.
1.3.	Implement nationally appropriate social protection systems and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable.
1.4.	By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.
1.5.	By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.
	SDG 2: Zero Hunger
2.1.	By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.
2.2.	By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons.
2.3.	By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.
2.4.	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
2.5.	By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to fair and equitable sharing of benefits arising from the utilisation of genetic resources and associated traditional knowledge, as internationally agreed.
	SDG 7: Ensure Access to Affordable, Reliable, Sustainable and Modern Energy
7.1.	By 2030, ensure universal access to affordable, reliable and modern energy services.
7.2.	By 2030, increase substantially the share of renewable energy in the global energy mix.
7.3.	By 2030, double the global rate of improvement in energy efficiency.

The majority of poor and malnourished people live in rural areas [12,13] and are dependent on smallholder agriculture [14]. It is well recognised that growth and development in the agriculture sector can play a critical role in reducing poverty and improving both food and energy security [10,15,16]. Smallholder farmers provide more than 80% of the food supply in Asia and Africa, where poverty and hunger are widespread [17]. Yet, the energy needs of smallholder farmers are often overlooked, with many dependent on woodfuel and/or charcoal. To improve the conditions and productivity of smallholder farms, and therefore raise the living standards of smallholder farmers, there is an urgent imperative to address the huge deficit in access to modern energy services they currently face. One intervention for doing so involves incentivising smallholder farmers to produce bioenergy crops from their land in a sustainable way, which they can then sell or use themselves. The recent expansion in liquid biofuel production using crops as feedstock in both developed and developing countries has opened new roles for agriculture in the energy sector [18], particularly in the context of climate change concerns. Using crops for energy rather than food, however, is a contentious proposition, with recognition of the need to assess the trade-offs (see e.g., [19]). Paying closer attention to smallholder farmers' livelihoods and development prospects, as well as assessing the trade-offs and opportunities offered by energy crops, could provide important insights to advance progress towards the SDGs [7].

Improving food and energy security, as well as reducing undernutrition, necessitates investment in higher on-farm crop diversity, alongside improvement of smallholder farmers' access to markets [14]. As the authors of [14] (p. 10657) note, "nutritional deficiencies are not only the result of low food quantities consumed, but also of poor dietary quality and diversity". Further benefits for local development and smallholder farmers that could materialise from crops that can provide both food and energy include, among others, increased agrobiodiversity, diversification of farmers' income streams, as well as improved energy security [20]. Yet, constraints of climate change, land scarcity, rising global population, food and energy demand, and environmental degradation mean that there is a need for crops that are not land- and water-intensive, are resilient and can produce high yields of food and fuel. Most of the major crops used for both food and fuel do not address these needs. For example, sugarcane and maize are land- and water-intensive and are horizontally expanding over new lands [18,21]. Their large-scale monoculture production has not only reduced the resilience of the food system by promoting cultivation of only a few varieties, but is also working against the idea of inclusive growth by failing to provide better livelihoods, affordable food and access to clean sources of energy for the rural poor [22]. At worst, large-scale monoculture production has displaced local communities and their traditional livelihoods [23].

Alternative crops to sugarcane and maize have been put forward as an underexplored option with considerable untapped potential to support rural development [24]. Various studies have looked at the potential of several crops, e.g., sweet potato, cassava, soybean, cowpea and pigeonpea, to diversify diets, support food security and provide beneficial ecosystem services [25,26], as well as enhance energy security [27]. Sweet potato, in particular, is starting to attract growing attention from researchers and policymakers, as it presents a number of potential opportunities for smallholder farmers in terms of improving agricultural productivity [24]. Sweet potato is among the most important food crops in the world for human consumption. It is mainly produced in developing countries with low per capita incomes, which is why increasing production of sweet potato is considered as a means to improve food security and reduce poverty among the poorer segments of rural and urban populations [28].

Interestingly, however, sweet potato is also one of the most underexplored food crops in the world [29]. The majority of research on sweet potato has been conducted from a biotechnological and agronomic point of view, to improve its quality and characteristics, such as colour, nutritional composition, yield and resistance to various diseases [30–32]. There is nevertheless a small but expanding corpus of research that looks at it from a development perspective, providing evidence as to how sweet potato can support smallholder farmers to make progress towards the SDGs.

This paper systematically reviews this literature to determine the possible roles of sweet potato in attaining SDG1 (No Poverty), SDG2 (Zero Hunger) and SDG7 (Affordable and Clean Energy). To the best of our knowledge, we report the first systematic review on this topic. After Section 2 on research design and methods, Section 3 presents the findings of our systematic literature review. Section 4 discusses the policy and academic relevance of our findings, while Section 5 presents our concluding thoughts.

2. Materials and Methods

A systematic literature review methodology was adopted. A keyword search was conducted during October to December 2019, using the electronic database Scopus, one of the largest and most comprehensive publication databases covering journal publications in both natural and social sciences. We considered titles, abstracts and keywords, focusing on English and peer-reviewed literature. The following search string was used: "Sweet potato OR sweet potatoe AND hung* OR malnutri* OR food* OR nutri* OR poverty OR livelihood* OR poor OR energy OR biofuel* OR fuel OR ethanol OR biodiesel OR bioethanol OR bioenergy".

The establishment of specific inclusion and exclusion criteria at the beginning of the systematic review process is a vital step that clarifies why certain studies were chosen for data extraction and others were not [33]. Such criteria are determined after setting the research question and, usually, before the actual search is conducted. For our study, the inclusion and exclusion criteria were the following. First, no time restrictions were applied to the literature. Second, only studies linking sweet potato with poverty, hunger or/and energy were included, and a decision was made to only consider developing countries, given that greater progress is needed there to advance towards the SDGs. Papers that mentioned opportunities and challenges for smallholder farmers were also included. Finally, studies focusing on purely technological or agronomical aspects were excluded.

The search revealed 3411 papers, which were imported into EndNote X9 in order to facilitate the application of inclusion and exclusion criteria. After removal of duplicates, we were left with 3401 papers. All papers were subjected to a sequence of filters in order to determine their relevance. The first filter involved reviewing all the article titles and excluding those papers whose titles we considered irrelevant according to the criteria above. Following title screening, 540 papers were retained. The second filter involved reading the abstracts of those 540 papers to determine their relevance. Following this step, 115 papers were retained. Reasonable efforts were made within the time and resources available to secure paper or electronic copies of full articles. However, this was not possible for 10 studies, which were consequently excluded from the final list of articles due to inaccessibility. The third filter involved reading the full papers to determine their relevance to our study. Following this step, 61 papers were retained for data extraction. To identify papers which were not included in, or did not turn up in, our search of the database, Google Scholar was used to complement the search results. This led to the identification of a further 50 papers that were added to the list, leaving us with a total of 111 papers to review (see Supplementary Material File S4).

Data were analysed using narrative synthesis to summarise and explain the findings [34]. All papers were reviewed by the lead author using thematic analysis, a data analysis method for identifying, analysing, organising, describing and reporting themes and patterns of meanings across a dataset in relation to a particular research question(s) [35]. To conduct our thematic analysis, we followed steps outlined by [36]. First, documents were carefully read to ensure familiarisation with the depth and breadth of their content. Second, documents were coded, identifying all data within the entire dataset deemed relevant to answering the research question(s). According to [37] (p. 207), "a code is a word or brief phrase that captures the essence of why you think a particular bit of data may be useful". Our analysis centred on determining the extent to which text referred to uses and attributes of sweet potato that could contribute towards the achievement of one or more of the three SDGs under study. Third, all the potentially relevant coded data extracts were sorted and collated into themes (e.g., poverty reduction, energy security, etc.) and those that were relevant to SDGs 1, 2 and 7 were recorded and categorised in relation to their potential to contribute to each of the targets of these goals. Fourth, we reviewed the coded data extracts for each theme to ensure that there were no inadequacies that would require any changes.

3. Results

3.1. Contribution of Sweet Potato to SDGs 1, 2 and 7

Our results reveal that sweet potato can help achieve all thirteen targets associated with the three SDGs under study (see Table 1), except SDG 1.3, which deals with national social protection systems. It should be noted at this point that each of the first 16 SDGs include number-designated outcome targets (e.g., 1.1, 1.2) and two to four letter-designated MoI (Means of Implementation) targets (e.g., 1a, 1b). The latter are specifically directed towards international co-operation and the development assistance responsibilities of developed countries and are hence excluded from our analysis. The characteristics of sweet potato that are important for each target are elaborated in Table 2 (see also Supplementary Material Table S1).

Table 2. Links between specific features of sweet potato and SDG targets linked to goals 1, 2 and 7.

Sweet Potato Characteristics	Contribution to SDG Targets
Sweet potato can create sustainable income generation opportunities due to its low-input requirements, high multiplication rate, high consumer acceptability and its potential for diversification into different uses.	1.1, 1.2, 1.5, 2.1 and 2.3
Sweet potato can enhance food security by addressing hunger, malnutrition and micronutrient deficiency due to its high nutritional content.	1.1, 1.2, 2.1 and 2.2
Sweet potato increased resilience during food shortages and mitigated the adverse impacts of disasters and famine.	1.1, 1.2, 1.5, 2.1 and 2.2
Sweet potato can reduce risks and promote sustainable agricultural production.	1.5 and 2.4
Sweet potato can empower women and girls and promote gender equality.	1.4 and 2.3
Sweet potato can safeguard biodiversity as it can encourage sharing of benefits among the farmers from the utilisation of sweet potato genetic diversity.	2.5
Sweet potato has important potential for biofuel production due to its high starch content and high bioethanol yield.	7.1, 7.2, 7.3, 1.2 and 1.4

First, sweet potato can contribute positively to reducing poverty by creating sustainable income generation opportunities for small farmers. This is due to its profitability [38,39], potential for biofuel production as a result of its high starch content [40–42], the selling of vines due to their high multiplication rate [43,44], low production costs due to low input requirements [28,45,46], and the potential for high yields [47]. Cases from Uganda, Malawi and Nigeria demonstrate that the sale of sweet potato roots and vines can be profitable, thereby raising the income of farmers and ultimately allowing them to perform other important household functions, including paying for children's education, clothing and medication [48–53]. This shows how benefits can cascade across several SDGs. For example, farmers in the Phalombe and Chikwawa districts of Malawi who multiplied sweet potato vines were able to buy livestock and new land, install electricity and ultimately raise their standard of living [43]. However, upscaling such small-scale successes so that they have an impact on national SDG progress remains challenging.

Diversification of sweet potato into multiple uses through the development of processed products and value addition also has potential to increase crop utilisation and generate income. Diversification therefore can play a role in the attainment of SDG by augmenting incomes and improving livelihood outcomes [43,54–57]. Sweet potato is used in animal feed, as well as for making industrial and other processed products [51,58]. Purple-fleshed sweet potato, rich in anthocyanins, is used in food-processing industries as food colorant for making noodles, snacks and bread [30]. Similarly, sweet potato roots are used for producing fuel, liquid glucose, textiles and can be bio-fortified [44,59]. As the authors of [43] note, farmers in Malawi that cultivated orange-fleshed sweet potato (OFSP) reported that due to its short maturity period and availability in lean months, they not only had enough food, but could buy food using money gained through the sale of OFSP, or exchange it for other items. Nevertheless, at present, these opportunities are largely untapped by poor, rural smallholders (see also [60]).

Second, sweet potato can offer protection against hunger and malnutrition [28,32,44,48,49,54], being a staple crop in many African and Pacific Island countries such as Tanzania, Malawi, Uganda, Mozambique, Rwanda, Burundi and Papua New Guinea [61–64]. It is kept for reliable supply and is available during lean months. It is only harvested when needed and the rest is left in the soil, so it can play a role in buffering food shortages and ensuring food availability [65–73]. Even in countries such as India where sweet potato is not an important crop, it is cultivated by the tribal people in Madhya Pradesh, Orissa and Bihar districts, who are the poorest rural people of India [74]. Poor farmers grow sweet potato due to its robustness, growth on marginal soils, low-input requirements and short harvesting period [51,75]. Given that the poor are already familiar with this crop, it offers a useful starting point for its further application to tackle hunger.

Importantly, sweet potato can help reduce malnutrition and micronutrient deficiency, and address the nutritional needs of various age and gender groups due to its high nutritional content [51,76,77]. Sweet potato is among the world's major food crops that produce the highest amount of edible energy per hectare per day [51,78,79] and contains large amounts of carotenes, dietary fibre, vitamins A and C, folate, zinc and iron [51,68,73,76,80–82]. Varieties such as OFSP contain high amounts of beta-carotene, which is important in overcoming vitamin A deficiency (VAD) [44,51,57,83]. VAD limits child growth, weakens the immune system, causes xerophthalmia which leads to blindness, and increases mortality rates among children and pregnant women [84,85]. Use of high beta-carotene varieties, such as OFSP, is cost-effective in fulfilling vitamin A requirements and reducing VAD in vulnerable populations [86] (also contributing to SDG Target 3.2). These features indicate that it can play a significant role in improving nutrition [87]. Only 100g to 125g of OFSP is enough to fulfil the recommended vitamin A dietary requirement for children under six years old [88].

Third, sweet potato can increase resilience and reduce the vulnerability of smallholder agricultural production systems to climate change effects and other disruptions. As noted previously, sweet potato can provide poor people with access to cheap food and prevent them from falling into poverty during periods of food shortage, but it can also buffer them from food price increases [89,90]. This is because less than 1% of sweet potato is traded in international markets, so it is less affected by global price fluctuations compared with other major crops [76]. During 2007–2008, rice, wheat and maize prices, as well as those of cassava and matooke, increased many-fold due to price fluctuations in international markets, higher fuel costs and diversion of crops toward biofuel production [91]. Consequently, approximately 100 million people fell into poverty, with the 1.4 billion people who were already surviving on less than $1/day even more severely impacted because these people are usually net buyers of these crops. Empirical evidence from Uganda shows that decreasing sweet potato prices helped buffer the impact of rising prices of other foods, ultimately reducing vulnerability to this economic and social shock [89]. Many people in urban Zimbabwe replaced their maize-based meals with sweet potato to avoid the higher prices of other crops, also taking advantage of its low requirements and fast growth [92]. This suggests it could play an important role as a safety-net crop.

Sweet potato has also played a critical role in mitigating disaster impacts following droughts, floods, and climate- and war-related famine, in regions such as East and southern

Africa [50,67,93–95]. Sweet potato has a short harvesting period of 3–5 months, with its leaves available for consumption after only two months. Once planted, it does not require much attention and can produce reasonable yields when other environmental and input requirements are met [50]. In many active warzones in Africa, such as northern Uganda, rebels destroy other crops, but show little interest in sweet potato. This has promoted its production in these disaster-prone areas where hunger and famine are prevalent [50]. Similarly, in Tonga, 20,000 sweet potato planting materials were distributed to farmers after they were hit by Tropical Cyclone Ian in 2014 [61]. Sweet potato production in these areas mitigated famine and hunger and improved food security by increasing the availability and accessibility of food [50]. As the authors of [96] also note, in many post-disaster areas, sweet potato production has increased, and hunger and famine have been reduced.

Sweet potato has low water requirements (500 mm on average during the growing season, compared to 1500–2500 mm for sugarcane), prevents soil erosion by creating ground cover, performs weed control, is drought-tolerant and pest-resistant, and can grow under high CO_2 concentrations [24,30,46,86,97–100]. These characteristics are explored below and not only support sustainable production, but also build the resilience of vulnerable communities against climate-related shocks. Sweet potato immediately produces adventitious roots and trailing vines, which allow it to colonise marginal soils and go deeper into the soil in search of water and nutrients [98]. However, additional irrigation might be desirable during the initiation period, depending on the climatic conditions [97,101]. Sweet potato is a cover crop, as the rapid vine growth covers the soil and, hence, prevents soil erosion and suppresses weeds [30]. Compared to rice, it has less than 50% of the nitrogen and 20% of the water requirements [102]. In a study by [103], sweet potato was grown in open-top chambers at four different CO_2 levels from 354 to 665 μmol mol^{-1}, and storage root increases between 46% and 75% at the highest CO_2 concentration were recorded. This means it can continue to thrive under projected climate change where CO_2 concentration is predicted to rise from 380 μmol mol^{-1} in 2007 to 460–560 μmol mol^{-1} by 2050 [104,105]. In terms of its impacts on ecosystems, sweet potato has not caused any large-scale land use changes in the past 20 years in countries like Brazil, unlike most other crops [46]. Biofuel production from sweet potato is highly beneficial for the production of bioethanol for clean cookstoves [106], therefore reducing GHG emissions linked to land cover change by providing an alternative fuel source to wood. This contributes to Target 2.4, ensuring sustainable food production systems and resilient agricultural practices that help maintain ecosystems and strengthen capacity for adaptation to climate change. There are further case studies from Pacific Island countries demonstrating sweet potato's success in promoting food security and livelihoods against the varying impacts of climate change, given its demonstrated drought and salt tolerance [61].

A fourth contribution of sweet potato relates to achieving gender equality and empowering all women and girls. Sweet potato is primarily cultivated and harvested by women in most African countries, offering a useful route to enhance the role of women in agricultural production and grant them more equitable access to resources, if supported by appropriate property rights and cultural practices [49,63,67,107]. Women who grow sweet potato generally have control over small areas of land and decide when to plant (local contextual derivations notwithstanding). They usually also decide whether to consume it at home or to sell it and earn some income that stays under their control. However, they commonly have to inform their husband prior to taking such action [69].

Fifth, genetic diversity of sweet potato is maintained in the various gene banks around the world and the benefits generated by using this diversity have been shared with sweet potato farmers [108]. The gene bank at the International Potato Centre (CIP) maintains 5526 cultivated accessions [44]. These genetic resources are freely available for sharing, as clonal materials, either in in vitro plantlet form or in storage root form, and as true-seed lots [44]. Notably, 45 new sweet potato varieties were released in Africa in five years by African institutions collaborating with CIP [44]. Moreover, farmers usually plant various sweet potato varieties and do not just rely on one [67,96]. Vegetative propagation also ensures that the various desirable genetic traits are maintained generation after generation without the use of advanced technology for monitoring or relying on seed supply systems [90]. This allows it to be quickly and easily shared locally among farmers, thereby maintaining genetic diversity and preventing its privatisation by a few transnational seed companies [108], therefore supporting SDG Target 2.5.

Finally, the literature discusses sweet potato as a solution to alleviate energy poverty in developing countries, though investigations are less well developed than studies of its food uses. Sweet potato is a renewable and abundant resource, making it a very promising feedstock for biofuel production and electricity generation [109,110]. It has a high sugar content, as 80% of its dry matter content is made up of carbohydrates, is composed of simple fermentable sugars, and produces very high bioethanol yields [111–113]. Biofuel production from sweet potato can provide access to affordable, reliable and modern energy services and increase the proportion of renewable energy in the world [114–116]. High bioethanol yield of 5859 to 10,467 L/ha (46% and 149% higher when compared to sugarcane and corn, respectively), combined with low input requirements, can further improve the overall energy efficiency of biofuel energy production [42,102,117]. In China, various pilot production units with intensive cultivation practices have been constructed to supply high-yielding cultivar feedstock for commercial bioethanol production [112]. Biofuel production from starch-rich sweet potato can help overcome energy poverty and reduce fuelwood use by providing, in particular, poorer people with few other options, access to clean, affordable and modern energy [84,118,119], assuming it is accompanied with use of relevant technologies (stoves, infrastructure, etc). However, using biomass as an energy source can compete with food and feed production [120], so this remains a major challenge.

3.2. Trade-Offs and Co-Benefits

Our analysis identified various trade-offs and co-benefits between sweet potato usage as food or fuel, and between SDGs 1, 2 and 7. Multiple trade-offs and co-benefits were identified even within the same target of some SDGs. Lack of access to clean and affordable energy results in fuel-wood dependence among poor people (fuel poverty), deforestation, GHG emissions and increases vulnerability of poor people to climate-related disasters [114,115,118,119,121]. Use of sweet potato as an energy source could mitigate against these impacts. If sweet potato is used solely for food, these benefits may no longer be viable. Furthermore, using sweet potato as food alone would act as a barrier to engagement in income-generating opportunities from small-scale biofuel production, thereby restricting people in diversifying their livelihoods and increasing their resilience.

Similarly, fuel production from sweet potato can compete with food security, local food production and availability, and might cause food shortages [122,123]. Large-scale biofuel production from sweet potato might displace smallholder farmers and exacerbate their poverty. It might also compete with food production over resources such as land, water and energy, and could also negatively impact water and soil quality and biodiversity [124–128]. Biofuel production might make sweet potato unavailable and prevent its use as a food crop in times when other staple crops, such as maize and rice, become expensive and scarce due to price fluctuations [89,90]. Large-scale biofuel production might cause farmers to lose control over their land and production and the choice of variety to be planted [41,46]. Similarly, using sweet potato for biofuel production will not help overcome malnutrition, including vitamin A deficiency in children under the age of five (Target 2.2) [30,48].

However, using unmarketable, damaged and bruised sweet potatoes supplied by the local farmers for fuel production would not only help to reduce food vs. fuel concerns, but would also lower production costs and reduce food waste [116]. Similarly, breeding sweet potato specifically for biofuel production and not for food use can be carried out by increasing its dry matter content to produce up to 50% higher fermentable sugar yields [121,129]. This will reduce its attractiveness as a food crop in terms of appearance, colour and taste, and hence reduce its direct competition with sweet potato for use as food, decreasing any risks of price fluctuations, common with other biofuel feedstocks (see Supplementary Material Tables S2 and S3 for a full overview of synergies and trade-offs).

4. Discussion

The SDGs have the potential to completely transform development by shifting the focus towards human development and ensuring basic needs are met [8]. The majority of the world's food is produced on small farms, which currently make up 90% of the total 570 million farms in the world [7]. Smallholder farming, given its multi-dimensional nature, can strongly contribute to the social, environmental and economic dimensions of the SDGs [130].

The rise in food demand due to population growth, increased income per capita, biofuel production and low food prices cannot be met by many of the major crops [131–133]. Other crops face difficulties due to productivity losses. Climate change is projected to reduce wheat yield by up to 72% and maize, rice and soybean yield by up to 45%, in regions such as sub-Saharan Africa [134]. Such challenges create opportunities for alternative crops, like sweet potato, to diversify economic activities and improve the development situation of smallholder farmers. Our systematic review demonstrated that improving sweet potato production and competitiveness in developing countries could offer a possible pathway to alleviate poverty, improve food security, reduce malnutrition and provide access to modern energy sources, through inclusive growth (see Table 2). Recent data reveal that sweet potato production has increased by more than 150% from 1994–2011 in sub-Saharan Africa and has experienced growth in China, with both regions producing about 87% of the total sweet potato production in developing countries [32,44,104]. Varieties, such as OFSP, are well accepted by both producers and consumers due to its attributes, such as its dry matter content [53,108,135]. Increased sweet potato production would be most effective in reducing poverty in developing regions due to high growth-poverty elasticities [77].

Sweet potato, however, is under-researched relative to its contribution to healthy human nutrition. Consequently, the authors of [29] posit that sweet potato should become a high priority for future investigation, as well as receive additional investment, given its adaptation potential to climate change and its importance for food and nutrition security. Our findings revealed a variety of trade-offs stemming from using sweet potato for food, related to access to energy and various social and environmental impacts. Similarly, fuel production from sweet potato can compete with food and feed production. However, many of these trade-offs remain unexplored. A recent study by [24] concluded that not much is known about the potential and sustainability implications of sweet potato's by-products or waste streams. Moreover, they note that there are several varieties of sweet potato, each with different characteristics, suited to the delivery of certain outputs (and related by-products) and thus offering various market opportunities for smallholder farmers. Each of these varieties, however, will have its own particular set of trade-offs that require full exploration to ensure that smallholders are not negatively impacted. A study by [136] (p. 48) has also highlighted the need for further multidisciplinary, integrated research and development activities aimed, among others, "at improving production, storage, postharvest and processing technologies, and quality of the sweet potato and its potential value-added products".

Our review illuminated that potential benefits and trade-offs can occur across the entire lifecycle of the crop, and that this requires further scientific research. A key challenge is to bridge the huge gap between the actual and the potential yield of sweet potato. This goes some way toward explaining why, despite all the benefits it offers, sweet potato has not yet delivered a more substantial development contribution. Average yield in Africa is 5 t/ha, which is the lowest of all developing country regions and three times lower than the average yield for developing countries as a whole (15 t/ha). This, in turn, is well below the potential yield of above 35 t/ha, as recorded, for example, in Nigeria and Ethiopia using improved varieties [28,38,44,47]. Hence, increasing productivity offers a significant opportunity to tackle a number of major development challenges, like poverty, hunger, malnutrition and energy poverty through increased income, food availability and energy supply, and reduced food prices [92,137]. However, before productivity increases can occur, a number of factors limiting the profitability and efficiency of sweet potato production must be addressed. Among the most prominent are "poor storage methods, lack of processed products, transportation problems, unstable prices, and lack of improved cultivars and planting materials" [138] (p. 314).

Turning to energy, bioenergy production from sweet potato has the potential to be advantageous from a socio-economic perspective [24]. However, there can be disincentives for incorporating smallholders in value chains, due to greater cost and complexity. Limited capital and resources, technology and information, as well as high transaction costs, are only some of the hurdles that make biofuel production for smallholder farmers a challenging proposition. As the authors of [139] also note, infrastructural support (e.g., access to water, extension services, adequate storage technology, etc.) is also key if smallholders are to be convinced of the benefits of converting sweet potato into bioethanol. Finally, the imperativeness for enabling institutional environments cannot be overstated. Such an environment should provide smallholders with a safe space for experimentation and innovation, as well as institutional support in terms of capacity building, sharing knowledge and experiences, and market development. Such an environment should also shield smallholders, to the extent possible, "from the changing context in which biofuel developments take place, preventing biofuels from becoming a threat rather than an opportunity for smallholders" [140] (p. 5127). A pertinent example here would be the Brazilian Social Fuel Seal [24].

A further challenge to harnessing benefits from sweet potato is presented by the COVID-19 pandemic. Hunger and malnutrition are expected to increase, with the poor and vulnerable being most at risk [141]. The pandemic has affected market access for smallholder farmers, as well as disrupting food chains, causing increasing food loss and falling prices, as well as weakening their purchasing power. Especially affected are those smallholders who do not produce food but, rather, other products such as flowers, cotton and fodder [142]. Several actors, such as the International Potato Center (CIP), have begun assessing the potential of sweet potato to strengthen food systems in developing countries during the COVID-19 crisis. One of the main advantages of sweet potato we have highlighted is that it is vegetatively propagated, with the seed system being characterised by a high degree of informality, with little to almost no existing private sector engagement. This informality allows sweet potato planting material to be produced and shared within village communities, an advantage major cereal crops with a high degree of formality lack [143].

5. Conclusions

Many of the major crops cannot meet the rise in food demand due to population growth, increased income per capita, biofuel production and low food prices. We therefore need to promote crops that can provide food and energy without detrimental impacts on soil or water resources, as well as provide local development benefits to smallholder farmers. Sweet potato, in particular, is starting to attract growing attention from researchers and policymakers as it has the potential to address these global problems and promote a sustainable society.

Our review has shown that sweet potato has important potential to advance progress towards the SDGs by offering multiple benefits: alleviating poverty, reducing hunger and malnutrition, enhancing resilience and reducing vulnerability, promoting gender equality, achieving more inclusive growth and improving energy security. At the same time, while sweet potato can generate development opportunities for smallholders, investments and institutional support are lacking to drive the situation forward and harness this potential. Further, sweet potato can be used for both food and fuel, presenting risks from numerous trade-offs at local to global levels. However, lack of information and knowledge means the intricacies of the trade-offs remain unexplored.

Our findings highlight the urgent need for more empirical evidence to unravel the trade-offs and to spur interest in further exploration of this crop. Our systematic literature review highlights that sweet potato is a promising crop that has less of an impact on the environment, but empirical evidence is still limited; hence, more research is required in order to unveil the detailed benefits and trade-offs. With the COVID-19 pandemic affecting food production and availability, the traits of sweet potato that make it especially suitable in post-disaster situations could outweigh some of the challenges and generate development opportunities for smallholders.

Supplementary Materials: The following are available online at https://www.mdpi.com/2071-1050/13/2/552/s1, Table S1: Data Analysis, Table S2: Food Assessment, Table S3: Fuel Assessment, File S4: Systematic Literature Review Papers.

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