Traditional African vegetables in modular living walls: a novel approach towards smart cities

Karen L Botes[1] **and Christina A Breed**[1]
[1] Department of Architecture, University of Pretoria, South Africa, Private Bag X20
Hatfield, Pretoria, 0028, South Africa

karen.botes@up.ac.za

Abstract. In terms of the 2030 Agenda for Sustainable Development and the United Nations (UN) Sustainable Development Goals (SDGs), sustainable cities and communities (SDG 11), combined with good health and wellbeing (SDG 3), are vital. The world is not making adequate progress in meeting the UN's targets to address food security (SDG 2). In South Africa, the growing population, rapid urbanization, poverty, and unemployment exacerbate the issue of food security; even more so considering climate change (SDG 13). The built environment needs to respond to these demands and incorporate green initiatives that can provide ecosystem services. Novel approaches are required to optimize land use and promote sustainable built environments through food production. This paper consolidates literature on local vertical urban food production with vegetable crops to enhance ecosystem services and lower the carbon footprint of buildings in the Global South. The literature review points to the potential of small-scale edible living walls that utilize local materials and traditional African vegetable (TAV) species to enhance system sustainability and resilience. TAV species offer advantages as opposed to exotic food crops as they are tolerant to extreme heat and drought, have a high nutritional value, and have low irrigation and agrochemical maintenance requirements.

1. Introduction

Food security and climate change are two of the most significant global challenges of the 21st century [1]. The world is not making satisfactory progress in meeting the UN's targets to address hunger, food insecurity, and malnutrition in terms of SDG 2, as set out in the 2030 Agenda for Sustainable Development [1]. Besides the correlation between climate change (SDG 13) and no hunger (SDG 2), food security is also interconnected with the goals of no poverty (SDG 1), reduced inequalities (SDG 10), sustainable cities and communities (SDG 11) and responsible consumption and production (SDG 12) [1].

Heatwaves in cities are intensified through the effect of the urban heat island (UHI) [2], which emphasizes the importance of addressing global warming and improving urban microclimates through greening initiatives. Cities and agriculture are major sources of greenhouse gas (GHG) emissions. Plants, as a direct or indirect source of food and one of the planet's primary sources of oxygen, play a vital role in mitigating these challenges [3]. Innovative thinking for urban greening and cooling is therefore required by policymakers and built-environment designers to mitigate the impact of global warming [4].

Outdoor living walls have been proven to provide much-needed urban ecosystem services [5]. In inner cities, the extent of the potential area for façade greenery is almost double the footprint of buildings, with the potential to offer more environmental benefits than green roofs [6]. A prime contemporary research focus is the potential of living walls to improve the urban microclimate through thermal insulation [6] and cooling by means of evapotranspiration, wind, or sun screening [7]. A second area of interest is urban small-scale, vertical outdoor food production [8]. Localized food production holds significant benefits in terms of the contribution to ecosystem services and decreased GHG emissions due to the reduced transportation of food from remote areas [9, 10]. Edible green infrastructure (EGI) holds benefits in offering provisioning ecosystem services, which is integral to sustainable cities [10, 11, 12].

Research on living wall systems (LWSs), as part of EGI, reports that, despite the psychological and aesthetic benefits, the economic feasibility of LWSs needs improvement [13, 10, 11]. A way to increase the economic feasibility of LWSs is to introduce edible crops [13, 10, 11].

Building-integrated agriculture, which involves the integration of food production in urban buildings and includes vertical food farming [3], is currently growing in developed communities. However, it is still an unfeasible option for the Global South. Disadvantages include a limited scope of suitable food crops, high start-up costs, high technical requirements for ventilation, light, temperature, and irrigation [3], high skilled labour, possible robotics usage [4], and the economic scale outcompeting small-scale producers [14].

The economic feasibility and resilience of living wall systems in the Global South require using locally produced systems, reducing energy and water usage, and using suitable plants [15]. However, limited research has been done to determine species' tolerance in urban LWSs to address food security.

A paradigm shift is necessary to reconfigure the food systems in Africa and the Global South in response to growing planetary concerns. The global food system relies on only 30 crops to provide for the nutritional requirements of the human population, which makes food systems vulnerable to climate variability [16], especially in marginalized countries such as South Africa. With the increase in the intensity and frequency of extreme climate events such as heat, drought, storms, and floods associated with climate change reducing arable areas, the need for crops that can tolerate these conditions is increasing [1, 17]. One of the strategies entails the reinvigoration of African orphan crops (AOCs) and traditional African vegetables (TAVs) to improve diets and their sustainable use [17, 18].

African orphan crops include edible, under-researched crops that are adapted to the extreme climate and soil stresses of Africa [19]. Fox and Young [20] describe a plant as edible when it is eaten regularly due to its taste and texture, and its ability to add flavour and variety to traditional dishes without causing any ill side effects. These crops are still used in traditional local diets, and are locally indigenous to Africa, or had been introduced to Africa centuries ago [19]. For good reason, these species are also referred to as understudied, neglected, and underutilized crops for the future [21, 22]. Vegetables, together with cereals, legumes, fruit, and root crops, form a category of AOCs [22, 23]. Towns and Shackleton [24] proposed the term traditional African vegetables to describe species that are nutrient-dense, compared to dark leafy green vegetables. Adapted to local conditions, TAVs are considered to have the potential for sustainable and resilient small-scale agriculture and food systems in the Global South [17, 18].

This paper aims to investigate the potential of building future cities in South Africa and the Global South, including edible living wall systems, to contribute to food production and provide ecosystem services. Former research is reviewed to analyse the factors that affect the efficiency of living walls, investigate the potential of urban vertical food production as EGI to provide ecosystem services and determine the potential of TAVs as an alternative to commercial crops to address food security.

2. Research Methodology

An integrative literature review process was followed. The aim of collecting data was to combine different perspectives and fields of research rather than cover all published information on the topic [25]. The review allowed for the inclusion of experimental and non-experimental research [26]. The review process entailed the following steps: problem identification, literature search, data evaluation, selecting studies for inclusion, data analysis, and presentation in line with a framework [26].

An initial search was conducted of publications between 2017 and 2021 using the Scopus and ScienceDirect databases and Google Scholar with keywords on living walls with food plants. Peer-reviewed publications were identified from Scopus (n = 0), ScienceDirect (n = 15) and Google Scholar (n = 179) as being relevant to this study and were included in the review. A second search to assess research on the relevant plant species involved keywords on African vegetables. The results entailed peer-reviewed publications selected from Scopus (n = 0). ScienceDirect (n = 69) and Google Scholar (n = 696). Titles and abstracts were scanned for relevance, after which a primary list of two books and 126 articles were selected for this study. These primary sources were divided into subgroups to facilitate analysis. Subgroups entailed the efficiency of LWSs, exterior edible LWS benefits and ecosystem service provisioning, and TAVs as food plants. The review list was extended with additional publications [27] during the review process, based on citations in the primary list. A final number of 127 publications was included in the review.

In line with the objectives of this paper, the following three research questions guided the analysis: Which factors affect the efficiency of edible living walls as EGI? What is the potential of urban edible living wall systems to provide ecosystem services? What are the factors affecting the potential of TAVs for urban agriculture as an alternative to commercial crops?

Three limitations need to be acknowledged. First, only English peer-reviewed publications were included. Second, grey literature was excluded, which might have led to some novel research not being captured. Third, the research of the peer-reviewed papers was assumed to be of sound quality. To meet the required page limits of this paper, the least-used studies were omitted where several studies confirmed the same information.

3. Findings and Discussion

3.1 Factors affecting the efficiency of edible living walls as edible green infrastructure

The review on the efficiency of living walls points out that limited empirical studies have been conducted relating to their benefits, with social and educational benefits being the least researched [28]. The literature suggests that the cost efficiency of LWSs, as well as their low resilience and high maintenance, health risks, and carbon footprint, are still negatively impacting their efficiency in food production. These four factors are discussed below.

3.1.1 Cost efficiency

It should be noted that LWSs’ appreciation for biodiversity, noise reduction [29, 5], aesthetic and wellbeing or biophilic benefits [13, 11] have been recorded but are difficult to include in cost-benefit analyses.

A life cycle analysis of LWSs concluded that the environmental burden of LWSs exceeds their cooling benefits [30]. Perini and Rosasco [31] also conducted a life cycle cost-benefit analysis, comparing the installation, maintenance, and disposal costs to the social benefits (including real estate value, energy demand reduction, durability, and air quality improvement). They concluded that economic feasibility can be improved through cost-effective installation and maintenance and ensuring a wider use to increase social benefits through the improvement of environmental conditions in cities, which could lead to government incentives [31]. A life cycle cost study to compare three different systems in Singapore confirmed that maintenance in the operational phase contributed to the highest expenditure, the most cost-efficient being support systems that comprise climbers at the base growing on a frame [32]. The findings of the study showed that modular systems with individual pots were more efficient than framed modular systems [32]. Another Global South study recommends unsophisticated technology with a lower financial and embodied cost, besides a reduction in energy and water usage [15]. In addition, crop selection is confirmed to be important for increasing feasibility, with small crops that have short production cycles reported as being more suitable selections [33].

Limited studies to improve affordability and durability were found. Riley *et al.* [34] developed a LWS with an integrated *in-situ* pervious cast concrete layer in front of the structural backup layer. However, the study requires further research to address optimal plant growth on exterior walls and other factors with a negative impact on people or food crops [34].

3.1.2 Low resilience and high maintenance

Living wall systems for food production face maintenance challenges such as equal water provision on all levels, the availability of light, and accessibility for harvesting crops if the system is too high above ground level [33]. A case study conducted in a high-rise environment in Singapore found that crops that prefer higher light saturation levels were more resilient, although crops also showed extreme photosynthetically active radiation (PAR) variability (as well as annual PAR variability) due to the sun's north-south oscillation and high-temperature levels during midday hours [35]. Although associated with leaf chlorosis, increased photoperiods (of more than 12 hours) led to increased biomass in both photoperiod-sensitive crops such as tomato and non-photoperiod-sensitive crops such as sweet pepper [35]. Depending on suitable PAR and crop selection, the study concluded that edible LWSs could potentially address food production in city environments [35].

3.1.3 Health risks

The health risks of edible living walls in city environments are due to pollution from contaminated soil, water and air. Inadequately treated water in the case of grey water, or water and air pollution when in the proximity of roads, can lead to the contamination of crops [36, 33]. High concentrations of heavy metals such as arsenic, cadmium, copper, and lead in soils in inner city areas are of concern [37, 38]. The trace metal content in the crop biomass in inner city areas, and especially high traffic areas, is argued to be mitigated through the erection of barriers between food crops and roads [36].

3.1.4 Carbon footprint

Natarajan *et al.* [27] suggest that water usage during the operational phase of LWSs should be targeted to reduce life-cycle energy usage and GHG emissions through measures such as water harvesting, drip irrigation, a pumpless gravity-fed watering system, and drought-tolerant plant species.

3.2 The potential of edible living wall systems to provide ecosystem services

The production of edible plants and, in particular, TAVs, in modular LWSs can potentially offer a resilient solution to increase agricultural productivity and income, in combination with other advantages such as the reduction of emissions and the UHI effect [1]. Mabhaudi *et al.* [39] determined that non-major crops contribute to food and nutrition security, human health and wellbeing, climate change adaptation, a healthy environment, and employment creation in poor rural communities. A pilot study of an exterior 7.5 m^2 LWS on a south-facing wall with edible crops delivered a harvest that could provide more than the daily vegetable allowance of 400 g recommended by the World Health Organization (WHO) [40] for a healthy adult diet [8].

A literature review and research to analyse the social impact of a residential-scale LWS prototype in Sri Lanka also demonstrated that edible LWSs in urban environments offer psychological, aesthetic, health, and social advantages, i.e. they impact human behaviour [41]. Positive impacts were found to exceed negative impacts, although it was argued that more research was required to address the full life cycle [41]. Other recorded positive behaviour includes the increased consumption of vegetables and fruit by urban community gardeners [38].

3.3 Factors affecting the potential utilization of traditional African vegetables as an alternative to commercial crops

African orphan crops and TAVs have numerous advantages as opposed to exotic food crops due to their tolerance to local climate conditions, their high nutritional value, the short growing season required, and the low maintenance requirements in terms of irrigation and agrochemicals [42]. African vegetables are more resistant to pathogens in comparison to exotic vegetables [43]. However, the utilization of TAVs is hampered by several factors.

Taste is argued to be the most important criterion in terms of selecting TAVs for cultivation, followed by marketability, biomass yield, and ease of collection and processing, based on a study in Ethiopia [44]. Exotic vegetables are preferred over local vegetables in South African urban areas. This is due to several reasons. Traditional African vegetables were replaced by exotic crops in colonial South Africa, which resulted in the relegation and neglect of AOC species [16]. Factors that impact negatively on the potential use of TAVs are elaborated on below.

3.3.1 Taste.

Besides availability, recipes and ease of preparation, taste, consistency, and appearance play a significant role in the acceptance of TAVs [45, 46]. Taste preferences differ among different geographic areas, i.e. the bitter taste of the spider flower (*Cleome gynandra*) and nightshade (*Solanum retroflexum*) are preferred in the northern parts of South Africa, compared to preferences of sweet amaranth in the southern parts of the country [47, 45]. Studies conducted to determine the taste preferences of young consumers suggested that canned amaranth and cowpea leaves have potential as commercial products and that cleome leaves need further research [48].

3.3.2 Social perception.

A study conducted on the availability, cost, and popularity of TAVs in markets in Ghana showed that six TAV crops were sold fresh at four markets throughout the year, and that popularity was high among 88% of the respondents [49]. These vegetables included the purple amaranth (*Amaranthus cruenthus*), jute mallow (*Corchorus olitorius*), roselle (*Hibiscus subdariffa*), African eggplant (*Solanum macrocarpon*), waterleaf (*Talinum triangulare*) and cocoyam (*Xanthosoma sagittifolium*) [49].

In South Africa, TAVs play a vital role in the economy and subsistence of poor communities, but trade remains informal and low [50]. The urbanized youth has a negative perception of TAVs as old-fashioned and “poverty crops” associated with foraging from the wild [51, 47]. The viewpoint of “poverty crops” is, however, challenged in a small survey conducted in KwaZulu-Natal, where all respondents disagreed with the perception [52]. The youth, in particular, should be educated on agronomy, nutritional value, and modernized healthy preparation methods to enhance the taste of TAVs and encourage their consumption [52].

Some beliefs among African people affect consumption levels; for example, the belief that reddish or purple leaves, such as the genus Amaranthus, can lead to insanity. High levels of nitrates in amaranth, which are carcinogenic and can make anaemia sufferers susceptible to methemoglobinemia (blue baby syndrome), also affect consumption levels [53]. This is despite the plant’s nutritional benefits due to the high levels of protein, minerals, and Vitamin C [53].

3.3.3 Marketability.

A recent resurgence in the popularity of TAVs is evident in their availability in markets, some supermarkets, and at informal traders. This initiated the commercialization of some species [54]. The South African market is mainly limited to dried products and amaranth leaves at informal markets by street traders. In KwaZulu-Natal and Gauteng, however, the municipal fresh produce market and selected greengrocers also sell fresh leaves [51, 47]. In Limpopo, Chinese cabbage and pumpkin leaves were traded, with nightshade (*Solanum retroflexum)* sold in large supermarket outlets in the Vhembe district [55].

The South African Venda and Southern Sotho cultural groups, with 265 and 203 used food plant species recorded respectively, are the two most prominent cultural groups preferring TAVs [56]. In rural and lower-income communities, the consumption of TAVs is higher than in urban areas [57], especially during periods of drought and unemployment [47].

Rural households have better access to the natural locations of these vegetables [45]. Indigenous knowledge of the impact of TAVs on consumption preferences. Vorster *et al.* [51] reveal that elderly decision-makers prefer vegetables with medicinal benefits [57]. The income generation of TAVs through crop production among small-scale family farmers should not be underestimated [1, 16]. A limiting factor is the shortage of quality seeds and improved cultivars.

3.3.4 Research to improve genetic traits.

Research to enhance exotic crops and their genetic enhancement has surpassed that of TAVs, which has resulted in a decline in their use [50]. The development of genetic traits to improve the quality and quantity of yields, and efficient agricultural and processing practices are imperative in the development of TAVs [21, 23]. Additional undesirable constraints of some AOC species that need to be altered include toxic compounds in some species [21, 23]. Research to improve seed production and cultivars is endorsed by the World Vegetable Center [58].

3.3.5 Policy documents and governance.

The absence of policy documents to guide decisions for food production with AOCs also impacted the potential of these crops in Africa [21]. Mabhaudi *et al.* [16] maintain that South African policies need to promote underutilized indigenous and traditional crops to support all food system stages and represent the interests of all role players, including smallholder farmers and women as producers of TAVs to counteract existing inequalities. Mabhaudi *et al.* [39] emphasize the role of individuals in the indigenous knowledge of non-major crops to rank and compare these crops to expand their potential use to address the SDGs.

4. Conclusions and Further Research

Following the COVID-19 pandemic, the importance of a healthy planet with an equilibrium between the human population and our natural environment cannot be stressed enough. The pandemic has underpinned the importance of meeting the UN’s targets to address the SDGs. In view of the link between food security, climate change, poverty, and urbanization, novel approaches to promote sustainable urban development through food production are vital. This study maintains that food production with local crops through living walls in urban environments can be explored for increased urban ecosystem services.

From the literature review, the authors conclude that the efficiency of LWSs needs to be improved by reducing installation costs, the carbon footprint and maintenance requirements, and increasing resilience, crop performance, and social benefits. This could be achieved by reducing reliance on high technology, water, and electricity, and increasing the use of local production and recycled or reused materials.

TAV species offer advantages as opposed to exotic food crops, as they are tolerant to extreme heat and drought conditions, have a high nutritional value, require a short growing season, and have low irrigation and agrochemical maintenance requirements. However, quality seeds and cultivars need to be developed through research to ensure higher yields and improve negative traits, which currently hamper marketability through social perceptions. The perceptions of TAVs as “poverty crops” must be challenged, along with preparation methods to improve their taste. Policies are needed that address better governance of inequality and include all role-players, especially those in marginalized countries.

Edible LWSs with TAVs potentially offer a resilient approach for climatic conditions in the Global South, which is mostly semi-arid to arid, with intense weather extremes due to global warming. However, research is required to gain a comprehensive understanding of the application of TAV crops in different living wall systems.

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