Climate Change Resilient Crops to Combat Food and Nutrition Insecurity in Marginal Lands

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1 Introduction

Climate change and food security are two of the world's most pressing issues, with multiple interconnected risks and uncertainties affecting food security and the livelihoods of those involved in production systems and value chains. Despite doubling food production in the last three decades, global hunger has risen since 2014 (FAO 2020), significantly impacting African countries and the rest of the world's water resources, food security, and human health. Food security refers to (i) the availability of sufficient quantities of suitable quality food, whether produced at home or imported; (ii) individual access to the resources for purchasing appropriate foods for a nutritious diet; and (iii) utilization of food through adequate diet, clean water, sanitation, and health care to reacquaint individuals with food (FAO 2006). The food system will be under additional strain as the world's population exceeds 9 billion by 2050, the food system will face increased strain. Because of the tremendous rise in global population, concurrent, strategic investments in climate-resilient

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agricultural production systems, resource efficiency, low-waste supply chains, adequate nutrition, and healthy eating choices are necessary (UNPD 2011).

A prime impact of food insecurity is malnutrition, a lack of dietary energy needed to live a normal, active, and healthy life. Undernourishment happens in the form of nutritional deficiencies in vitamins (e.g., vitamin A) and minerals (e.g., iron, zinc, iodine). Recent studies based on data collected from 53 countries show that more than 27 countries reduced their calorie consumption due to climate change (Ray et al. 2019). The good news is that nutrient-rich, underutilised, neglected crops are extremely resilient to harsh environments (drought, salinity, and extreme temperature) and yield well with limited resources. This is true even though it has been anticipated that the productivity of major crops will be lower under marginal lands. (Mabhaudhi et al. 2019). According to FAO projections, most food required to feed 2 billion mouths by 2050 must come from marginal lands (FAO 2017). Many people in Sub-Saharan Africa (SSA) rely heavily on underutilised, neglected crops (leguminous, leafy, grain, root, and tuber crops) for their main source of food and nutrition. This is also due to their role in food security, owing to their ability to withstand drought in changing climates. These crops are also well known for serving as significant subsistence farming systems in SSA, where they have played a significant role in household food security and income generation owing to their ability to reach the maturity stage within a short period, which renders them very useful in supporting nutrition-intervention programmes (Mampholo et al. 2016). According to (Jaenicke and Höschle-Zeledon 2008), over 7000 underutilised, neglected crop species have been discovered and extensively used as food sources throughout human history. Underutilized, neglected crops are well positioned to offer strategic food options with the potential to improve nutrition, increase dietary diversity, and adapt to climate change, given the need for dietary variety and persistent concerns about environmental impacts. The consumption of underutilised, neglected crops significantly contributes to poverty. Future agriculture necessitates tailored solutions that integrate fundamental shifts in current knowledge and enabling technologies and consider the need to protect the environment and meet societal demands.

Climate change is a menace posing an extreme threat to the environment and human beings. Climate change is linked to rising temperatures, more intense precipitation, and changes in the interactions between crops, pests, pathogens, and weeds. It also exacerbates several trends, such as the decline of pollinating insects, growing water scarcity, rising air pollution (such as tropospheric ozone), and declining fisheries. Agriculture is the key economic enterprise at the centre of the food security dilemma because of abiotic stresses, both direct and indirect. The emission of dangerous gases, especially CO_2, is the main factor for the greenhouse effect and rising average global temperatures. The number of stress spells, their impact on everyday living, and crop damage are the primary indicators of climate change and environmental variation. Abiotic stresses, such as water scarcity and temperature extremes, significantly impact plant development and yield due to climate change. Plants are frequently subjected to various stressors in natural climate conditions, including waterlogging, drought, heat, cold, and salinity. UV-B, light intensities, flooding, gas emissions, and physical and chemical factors that cause additional stress are all abiotic factors. A dynamic balance of suitable biophysical resources, such as soil quality, water availability, sunlight, CO_2, and temperature, ultimately determines agricultural output quantity and nutritional quality. Crop yields are extremely susceptible to temperature and water supply fluctuations and are generally coupled with high temperatures because low soil moisture decreases evaporative cooling from the landscape and because high temperatures increase crop water loss (Malhi and Kaur 2021). Climate change has detrimental effects on agriculture, particularly the produced crops.

Africa is one of the continents most at risk from persistent climate variability with strong adverse economic effects. This vulnerability is worsened by development challenges, particularly ecosystem degradation and endemic poverty, facilitated by constrained access to resources like capital, infrastructure, markets, and technology (IPCC 2007). Reduced crop productivity is the primary threat to food security, especially given the world's rapid population growth. Slow production growth and sharp annual fluctuations in output have remained chronic problems due to climate change affecting the poorest households, the most vulnerable since they devote the major share of their income to food. Hungry people are less able to concentrate and have diminished physical strength. Reduced food supply and higher prices undercut child nutrition, early childhood development, and education.

Climate change can affect prices, potentially leading to increase and greater volatility. Furthermore, increased temperatures may increase the risk of heat stress during postharvest transportation, resulting in a reduced availability of fresh products, deteriorated quality, reduced nutritional quality, and sensory appeal, as well as worsening storage conditions, which may result in reduced shelf-life. A lack of agricultural resilience to climate change critically underlies SSA food insecurity quality and distribution. Furthermore, the transition of SSA agriculture to producing crops that are more resilient to abiotic stresses like drought, heat and flooding is crucial in the face of the climate change predicted for shorter- and longer-term future by building climate resilience for food and nutrition security. Climate change is expected to have a wide range of negative effects on plant physiology, ultimately limiting plant growth, productivity, and food supply. As a result, excess food must come from marginal lands considered unsuitable for growing main staple crops under the adverse climate change scenario. Because of their high nutritional profile and improved resilience to several abiotic stresses, underutilized, neglected crops are suitable crops to improve food and nutritional security. This book chapter comprehensively reviews the multifaceted relationships between climate change and its impacts on crops, food, and nutrition insecurity, demonstrating the need for expanding populations to adjust to shifting climatic conditions (Fig. 1). Additionally, it identifies the key success factors and challenges that must be addressed to bring about the widespread use of climate change-resilient crops to combat food insecurity and ensure adequate nutrition in marginal lands. Researchers must make strategic investments at the same time to create climate-resilient agricultural production systems, effectively use resources, create low-waste supply chains.

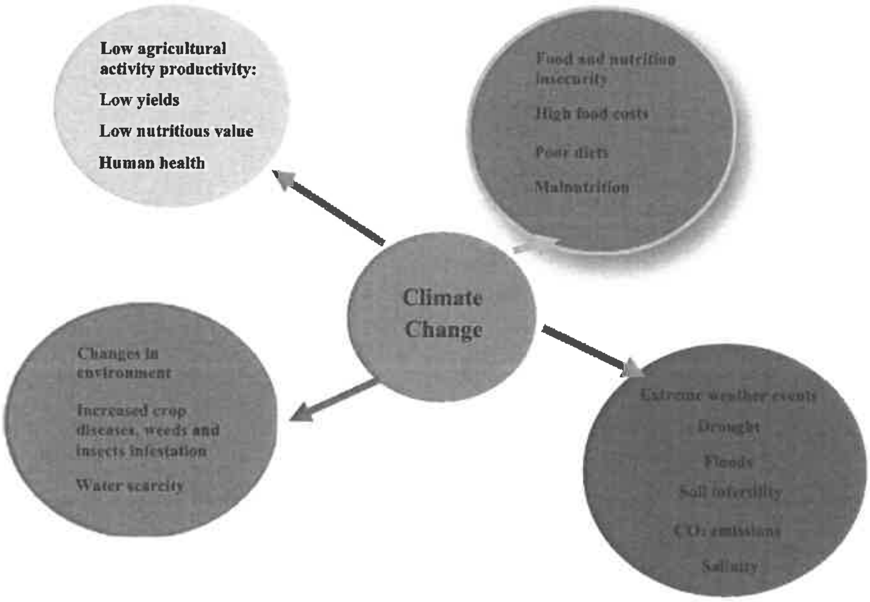

Fig. 1 Overall negative effects of climate change on agricultural production systems

2 Crop Diversity in Climate Change Adaptation

Humans have domesticated thousands of plant and animal species via deliberate selection over centuries and generated a stunning array of foods using their local biodiversity,. Traditional diets have long relied heavily on gathering and hunting wild vegetables and animals (Heywood 2013). Wild, semi-wild, or domesticated plants have always been a significant source of nourishment for civilizations. According to RBG (2016), the number of plant species used for food is small, with approximately 70,000 species possessing edible parts. Despite this tremendous diversity, only three crop species (rice, wheat, and maize) produce half of the world's plant-derived calories, and 82% of agricultural land is dedicated to growing only 20 key plant commodities (Schmidt et al. 2010). Crop diversity in food systems is disappearing due to various variables, including increased production intensity and mechanization, marketing homogenization, and consumer disengagement from traditional food cultures (Koohafkan and Altieri 2017). These trends, which began with the Green Revolution and have been reinforced by agricultural market globalization, have pushed many conventional crops to the periphery of research and development. As a result, their market competitiveness has declined, and farmers have abandoned them, resulting in genetic loss (Tripp and van der Heide 1996). There are a variety of underused crops in rural regions that are used as a staple meal, a primary source of income, and medicinal herbs for treating human diseases (Van Rensburg et al. 2007) (Fig. 2). However, due to a lack of necessary expertise in their

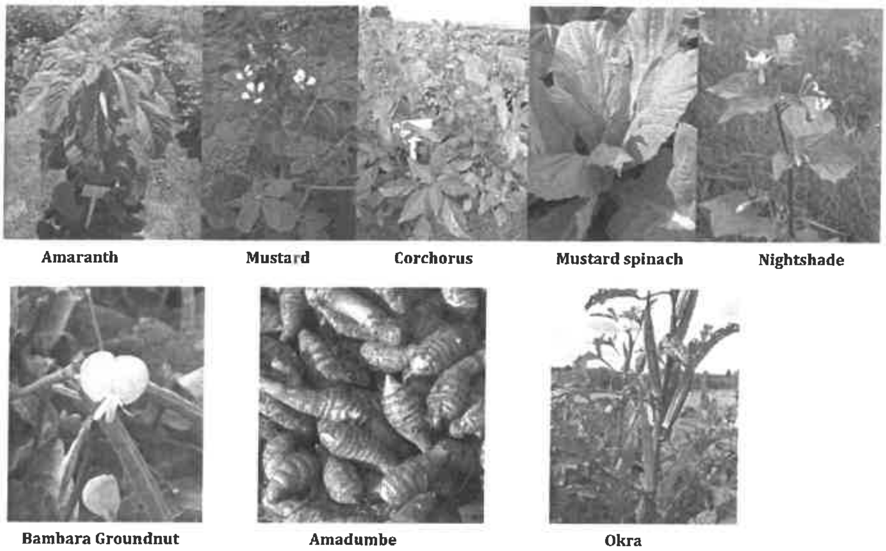

Fig. 2 Various indigenous vegetables cultivated at the Agricultural Research Council-Vegetables Industrial and Medicinal Plants, South Africa (Source: Hintsa Araya)

cultivation, smallholder farmers and homestead gardeners cannot produce these crops. Despite their multifaceted relevance, these crops are underutilized, and many are unaware of their significance (Luoh et al. 2014), including their potential to improve food and nutrition security in marginal lands.

Indigenous leafy vegetables are increasingly recognized as having the potential to grow in marginal lands and improve food security due to their adaptability to various environmental conditions (Mabhaudhi et al. 2019). Leafy vegetables are considered a rich source of nutrients, including pro-vitamin A, vitamin C, folic acid, riboflavin, and minerals such as iron, zinc, calcium, and magnesium needed for an adequate human diet (Mabhaudhi et al. 2019). In sub-Saharan Africa, micro and macronutrient deficiencies are a severe health problem, particularly for women and children (Galani et al. 2020). Indigenous vegetables have been an essential food source for years, providing vital nutrients and vitamins in South African rural communities. Many of these crops are not in today's formal markets as they are mostly collected from backyard gardens. Little is known about their production practices, while today's agricultural economy dictates producers to fine-tune their farming practices to maximize yields and minimize production costs. To reintroduce these crops to farming communities with cost-effective production methods, one must understand the plant with considerable precision. Several studies were conducted in two small-scale farmers' fields in South Africa to evaluate the sustainability and profitability of nutritionally important indigenous vegetable crops (Fig. 3). Several production inputs and management practices were evaluated. Results indicated that the engagement of farmers and adoption of the crops for optimizing profitability and promoting nutritious indigenous food crops was successful. Low-cost inputs such as

Fig. 3 A Farmer harvesting nutritious indigenous vegetable (*Cleome gynandra*) in South Africa (Source: Hintsa Araya)

organic fertilisers like manure improved the productivity of indigenous vegetable crops and were comparable in yield with commercial production norms. Supporting smallholder farmers to produce important nutritional indigenous vegetables could expand the diversity of our food basket; in addition to this, as most of the indigenous vegetables are wild species that could grow in harsh environments as weeds, they could bring the benefits of resilience to climate change.

3 Legumes for Food Production and Climate Change Mitigation

Legumes provide several crucial services to communities in different regions in South Africa. The root-nodule bacteria (collectively called "rhizobia") can infect roots and form N_2-fixing nodules in members of the Leguminosae (Pule-Meulenberg and Dakora 2009). By fixing atmospheric N_2 in symbiosis with the soil bacterium rhizobia, they can supply nitrogen (N) to agro-ecosystems, boost soil carbon content, and increase the productivity of succeeding crops. The role of legumes has hardly ever been considered in terms of their potential to help mitigate climate change by reducing the use of fossils. Ecosystems in natural and agricultural settings benefit from the mutualistic relationship between the Leguminosae and the Rhizobiaceae. Therefore, symbiotic legumes can potentially significantly increase the N economy of ecosystems. Legumes are a significant source of protein and minerals required for human and animal nutrition and contribute to soil N development. Therefore, symbiotic N_2 fixation by rhizobia offers a more affordable, environmentally friendly, and sustainable nitrogen source for resource-poor farmers in developing countries.

Given the broad distribution of N_2-fixing Leguminosae in Africa, biological N_2 fixation must be the main route for N intake into that region's desert and natural ecosystems. In Africa, food legumes such as cowpea (*Vigna unguiculata* L. Walp.), groundnut (*Arachis hypogaea* L.), soybean (*Glycine max* Merrill), common bean (*Phaseolus vulgaris* L.), and Bambara groundnut (*Vigna subterranean* L. Verdc.) form a major integral part of the traditional cropping system, and thus, offer a great opportunity for increasing N supply for resource-poor farmers (Hirsch et al. 2003). These grain legumes improve soil N fertility and benefit intercrops or succeeding cereal crops (Dakora and Keya 1997; Hardarson and Atkins 2003; Herridge et al. 2008). The most widely cultivated edible legumes in various parts of Africa include cowpea, Bambara groundnut, and groundnut, presumably due to their relative adaptability to this environment of frequent drought and low nutrient availability. Studies have demonstrated the beneficial impacts of fixed-N from symbiotic legumes on cereal crops like sorghum, whether in rotation or as an intercrop.

Numerous limitations, such as high soil temperatures, low levels of mineral nutrients, and low soil pH, limit research on biological nitrogen fixation in various parts of Africa and South Africa (Pule-Meulenberg 2014). Estimates of N_2 fixation in laboratory settings demonstrate that grain legumes can give a sizable quantity of nitrogen to the continent of Africa's conventional cropping systems (Mokgehle et al. 2014; Pule-Meulenberg and Dakora 2009; Belane and Dakora 2009). Several research studies have utilized various methods to assess the symbiotic N_2 fixation by groundnuts under experimental circumstances in Africa, and the results have been highly variable. For instance, Gathumbi et al. (2002), observed that groundnut production in Kenya averaged 8 kg N. ha^1. According to Sanginga (2003), the amount of nitrogen fixed by groundnuts varied between 11 and 63 $kg.ha^{-1}$ in Nigeria and 19 to 79 $kg.ha^{-1}$ in Zambia. Several biotic and abiotic factors, including the quantification method, genotypes examined, the number of reference plants used, and others, could all contribute to the difference in the amounts of N this legume contributed. Due to its significant N contribution to soil fertility, other legume crops, such as groundnut, have an advantage over grain legumes like a common bean (*Phaseolus vulgaris* L.) as an N_2-fixing crop.

Most legume crops encourage using high-intensity cropping systems, including intercropping, which, depending on the situation, might be a practical way to boost agricultural productivity and production overall (Maitra et al. 2020). Intercropping gives farmers access to a greater range of crops to harvest, which helps farmers fight food and nutrition poverty and diversify household food baskets. Intercropping is growing two or more crops concurrently on the same field for sufficient time to cover the vegetative stage (Bele et al. 2014; Gebru 2015). Intercropping is connected to agricultural techniques like double cropping and mixed cropping, which allow for more effective use of resources on the farm and sustainable crop output (Maitra et al. 2020; Li et al. 2020). Figure 4 illustrates intercropping a leguminous crop (cowpea: *Vigna unguiculata*) with a cereal crop (maize: *Zea mays*). Cowpea can offer affordable symbiotic nitrogen as a biofertilizer to improve soil fertility in cropping systems, just like most N_2-fixing legumes. Implementing sustainable methods like intercropping is necessary to boost agricultural output and increase

Fig. 4 Cowpea (*Vigna unguiculata*) and Moringa (*Moringa oleifera*) intercropped at the Agricultural Research Council—Vegetable, Industrial and Medicinal Plants field site (Source: Hintsa Araya)

resource use efficiency due to the changing climate (temperature, rainfall, etc.) (Gebru 2015; Khanal et al. 2021).

4 The Resilience of Non-Leguminous Crops to Climate Change

Non-leguminous cover crops can improve soil organic matter by increasing biomass production and scavenging nutrients, particularly N, left behind from earlier crops (Singh et al. 2020). It has also been noted that non-leguminous cover crops can lower nitrate leaching losses (Nouri et al. 2022). Non-leguminous cover crops have become more important since their crop residues in conventional systems are insufficient to compensate for the loss of soil organic matter caused by high mineralization rates. Furthermore, non-leguminous cover crops could supplement the scarce supply of farmyard manures by being sown before cereal crops like maize (*Zea mays)*. Pearl millet (*Pennisetum glaucum* L.), fodder maize, and sorghum (*Sorghum bicolor* L.) are a few of the common non-leguminous cover crops (Singh et al. 2020). Cutting crops before planting subsequent maize has been reported to benefit non-leguminous cover crops as fodder crops. While research has demonstrated the importance of flower removal on non-leguminous crops, their effects on yield and quality have not been researched extensively.

4.1 Non-Food Crops Contribution to Combat Food Insecurity

A crop grown for industrial purposes only, as opposed to producing food for human consumption, is referred to as a non-food crop or industrial crop. Non-food crops include crops such as cotton (*Gossypium hirsutum*), jute (*Corchorus capsularis*), sisal (*Agave sisalana*), and flax (*Linum usitatissimum*) (Heidari et al. 2021). Non-food crop products promote their increased usage as industrial raw materials, for instance, through fostering collaborative efforts between researchers and the agriculture sector. Non-food crops are employed as industrial raw materials for various reasons, including their capacity to provide higher technical performance or a more economical raw material and their frequent ability to promote sustainability and the environment. Cotton production in South Africa is associated with weaving yarns (used for towels, denim, and sheets) and knitting yarns (e.g., fabrics and underwear). Some major cotton products associated with cotton from the seeds include oil, soaps, and hulls (Bennett 2001). Some non-food crops, such as cotton, have high-value, low-volume ones used in pharmaceuticals where supply quality and traceability are crucial and can be produced profitably without government assistance. Jute (*Corchorus capsularis*) has different parts used as medicine to treat many ailments in different regions of the world (Biswas et al. 2022). For example, in South Africa, the leaves treat gonorrhoea, tumours, and aches and pains (Mahwasane et al. 2013). Jute production in some countries, such as India and China, is associated with fibre (Saleem et al. 2020). The previous research on jute also described the characteristics of lignin and carbohydrates. Despite the contribution of the previous studies on jute, there is still a need to maximize the exploitation of fibre to have a complete understanding of the crop's composition. Standards can ensure bio-based goods achieve a quality equivalent to or better than requiring a minimum proportion of renewable content or encourage non-food uses of crops more easily met by natural products than competitors. In terms of sisal, products such as plastic and rubber can be produced from the plant due to its potential as reinforcement in polymer composites due to its low density.

4.2 Agro-Ecological Approaches to Climate Change

Improving crop productivity, even in marginal lands, is the main aim of agricultural production. Ecological-based alternatives combining multiple components in one system may provide a robust path to increase agricultural productivity, sustainability, and resilience (Burgess et al. 2022). Conventional farming has detrimental effects on the environment due to the excessive use of fertilizer, which degrades water and soil quality and disrupts the global nitrogen cycle by promoting the emission of reactive nitrogen gases into the atmosphere (Fung et al. 2019). The effects on the environment include detrimental declines in forest area. For example, 53% of the total land in the Philippines is classified as forest lands; however, only 19% is adequately covered with forest vegetation due to the destructive conversion of forest land to permanent annual cropping areas (Magcale-Macandog et al. 2010). This has ultimately led to alarming declines in land productivity as it resulted in massive soil degradation or erosion (Magcale-Macandog et al. 2010). In India, approximately 120.8 million ha of previously arable- and forest land is declared degraded (Sarvade and Singh 2014). Agriculture must sustainably contribute to food and nutrition security and the rural economy while reducing the negative impacts on or improving the environment (Chimonyo et al. 2020).

4.3 Agroforestry as an Approach to Climate Change

Agroforestry addresses issues of ecological and economic strategies for climate change adaptation and mitigation (Newaj et al. 2013). The increase in food shortage due to reduced productivity caused by land degradation and climate change has increased interest in agroforestry to improve soil conditions and enhance local climate conditions (Mbow et al. 2014). Agroforestry is a system where woody perennial trees are used in the same land-management unit with crops and animals for ecological and economic benefits (Everson et al. 2011; Maponya et al. 2021). The interaction between trees and other components of agriculture may be important at various scales, such as at a field scale where trees and crops are grown together, at a farm level where trees may provide fodder for livestock, and at a landscape level where the system is used for ecosystem services (Coulibaly et al. 2017). One of the ecosystem services may be a scenario where tree canopies and leaf litter protect the soil against erosion and high temperatures (Alfaia et al. 2004). In the apiculture system, pollination is an important ecosystem service as it positively impacts biodiversity and food production (Etxegarai-Legarreta and Sanchez-Famoso 2022) (Table 1).

Table 1 Various agroforestry systems used around the world

Land use system	Description	Reference
Agrisilviculture Agrosilviculture	Integration of trees with other woody perennial	Sarvade and Singh (2014) Uleh and Usman (2020)
Agrisilvipasture Agrisilvipastoral	Combining trees with crops and livestock	Sarvade and Singh (2014) Tolunay et al. (2007)
Silvopastoral	Combining trees with pasture and livestock	Sarvade and Singh (2014) Dwivedi et al. (2007)
Agrihorticulture	Integration of fruit trees with crops	Sarvade and Singh (2014)
Apiculture	Integration of trees with honey bee-keeping	Sarvade and Singh (2014) Tolunay et al. (2007)
Aqua forestry	Includes cultivation of aquatic plants or production of fish in water bodies within tree forests	Sarvade and Singh (2014) Tolunay et al. (2007)

Agricultural land faces several environmental threats, such as land degradation by erosion, invasive alien species and overgrazing (Zerihun 2020). Agroforestry is a potential tool for managing harsh environments, creating favourable microclimate conditions, improving soil health, and conserving biodiversity (Newaj et al. 2013). Agroforestry-based adaptation to climate change is based on reversing negative trends in diverse tree cover and a targeted shift in resource capture to adjust to the changing climatic conditions (Van Noordwijk et al. 2021). Everson et al. (2011) mentioned that an improvement in the efficiency of land use systems is required to maximize the use of scarce resources, such as water, to increase productivity and minimize resource degradation. Climate change mitigation strategies, in most cases, focus on reforestation and forest protection and conflict with the need to expand agricultural production to meet the growing food demand (Mbow et al. 2014). However, agroforestry can provide a good strategy to address forest protection and food security needs. For example, a study in Tanzania indicated that farmers were growing tree species used for food (*Cocos nucifera*), fruits (*Mangifera indica, Persea americana*), timber production (*Tectona grandis*), shading (*Ficus stuhlmannii*), and other trees for animal fodder (Nnko et al. 2022). Land-based economic development strategies, including agroforestry, are major in livelihood improvement and economic development (Zerihun 2020). In a study by Maponya et al. (2021), rural community members reported increased food access and reduced food insecurity due to the agroforestry project they were involved in.

Magcale-Macandog et al. (2010) reported that agroforestry increased farm benefits by 42–137%, while during the same period, farmers practicing monoculture incurred losses in the Philippines. One farmer in India increased farm total return by 16.5–136.2% through agri-horticulture, compared to monoculture (Dwivedi et al. 2007). Growing annual crops such as corn in combination with fruit trees increased household food security, and corn yield increased annually under agroforestry compared to monoculture, where there was a gradual decline in corn yield in 9 years (Magcale-Macandog et al. 2010). Apiculture provides farmers with innovative new products with economic and income generation opportunities, thus improving their economic food access and security (Etxegarai-Legarreta and Sanchez-Famoso 2022). Devkota et al. (2016) found that apiculture had a higher benefit-cost ratio and provided higher opportunities for farmers to earn a better living by earning additional revenue from selling bee products.

Agroforestry can improve soil fertility by increasing the soil organic matter content and N_2 fixation, especially by leguminous trees, facilitating nutrient cycling, improving the soil structural properties, and conserving soil moisture (Mbow et al. 2014). Trees contribute to more efficient nutrient cycling and prevent nutrient losses due to leaching, as they have a dense, deep and permanent network of roots (Alfaia et al. 2004). Leguminous trees can contribute to the supply of N into the soil by fixing atmospheric N into the soil (Coulibaly et al. 2017). In a bamboo-maize, bamboo-cassava, and bamboo-cowpea agroforestry study, soil moisture and cation-exchange capacity were significantly improved in year three (Akoto et al. 2020). Atapattu et al. (2017) studied the effects of eight forest plant species on soil physical properties under agroforestry and reported significant increases in soil organic matter, exchangeable potassium, and total nitrogen concentration in leguminous tree species. The soil microbial activity was also improved in the agroforestry system (Atapattu et al. 2017). Zakes et al. (2015) studied a banana-coffee agroforestry system and reported that the system significantly increased total soil organic matter and N compared to banana mono-cropping, and total C was increased by 26%.

4.4 Intercropping for Improved Crop Variety

Intercropping is the cultivation of two or more crop species, or genotypes, simultaneously to maximize productivity per land area using a few resources (Burgess et al. 2022; Hinamen et al. 2016). The benefits of intercropping include maintaining and improving soil quality and fertility, reduced pathogen and insect infestation levels, reduced need for nitrogen fertilizers where nitrogen-fixing species are used as intercrops, increased profit margins, and reduced input costs (Hinamen et al. 2016). With appropriate management practices, Chimonyo et al. (2020) concluded that intercropping maize and Bambara groundnut can adapt when water resource decreases are projected. Intercropping can also improve land-use efficiency, where fewer land areas are required to improve yield (Fung et al. 2019).

Energy yield was calculated by Sun et al. (2020) to determine the yield advantage of a maize-based intercropping system, and it was reported that the system increased the energy yield compared to the sole cropping system. The study further reported an increase in the maize-based intercropping system's economic benefit (input-output evaluation) (Sun et al. 2020). Fung et al. (2019) found that maize-soybean intercropping reduced the nitrogen need of maize by 33%, producing the same maize yield compared to the sole maize system, in addition to the soybean yield.

Intercropping of maize and potatoes resulted in reduced yield of both crops when assessed individually and compared with sole cropping; however, a combined yield of one row of maize and two rows resulted in an increased total land yield (Kidane et al. 2017). Intercropping can increase the availability of a variety of food for nutrition purposes. Intercropping of cotton and peanuts with various plant populations increased field utilization efficiency and a significant increase in net profits, 127.8% higher than cotton monoculture (Wang et al. 2022).

4.5 Crop Rotation as a Sustainable Strategy for Resilience

Crop rotation is the recurrent succession of crops on the same land in consecutive seasons, and this method suggests that crops generally follow a pre-determined order, and this is a farmer's decision on what type of crops to grow in the current and coming growing seasons (Barbieri et al. 2017; Chongtham et al. 2017). Considering the history of agriculture, crop rotation has emerged as one of the first sustainable agricultural practices, which improved yields by taking advantage of niche complementarity, optimising nutrient use, and reducing pests and pathogen loads (Dias et al. 2015).

Crop rotation is frequently used as an alternative technique to combat the harmful side effects of intense cropping (Xuan et al. 2012). Compared to conventional farming, crop rotation is particularly importance in organic farming because of the restrictions on using easily soluble mineral fertilisers and the prohibition of synthetic chemicals to control weeds, pests, and diseases (Chongtham et al. 2017). Crop rotation can bring agronomic benefits in conservation agriculture and, in addition to economic gains, bypassing edaphoclimatic difficulties in the region (Volsi et al. 2020). According to Shah et al. (2021), crop rotations with various crops benefit the farmers, reduce production risk and uncertainty, and enhance soil and ecological sustainability.

4.6 Mixed Farming to Increase Food Production

Mixed farming is one of the basic agricultural modes that appeared during the middle and late Peiligang Culture and became a common subsistence economy at the end of the Neolithic (YuZhang et al. 2016). In order to ensure sustainable agriculture, Mekuria and Mekonnen (2018) define mixed farming as the simultaneous production of crops and livestock rearing. This type of enterprise balances and integrates crop and livestock enterprises to spread economic risk and capture synergies in terms of forage supply, but in many parts of the world, these have become increasingly separated and specialized (Bell et al. 2015).

Mixed crop-livestock systems are the predominant farming system throughout the semi-arid and sub-humid zones, with important contributions to meat and milk production, to crop productivity through the provision of manure, and to livelihoods for millions of rural people (Descheemaeker et al. 2018). This farming system is important as it accounts for almost half of world food production and is present in all edaphoclimatic areas. In addition, it provides sound alternatives to progressively achieve world food production by sufficiently utilizing available natural resources. Agriculture is supported by a substantial role and the prevalence of mixed agricultural systems, particularly in the humid tropics (Stark et al. 2018).

4.7 Drought-Tolerant and Water-Efficient Crops

According to Shanker et al. (2022), "drought-tolerant crops" are cultivars of plant species with coping mechanisms that allow them to escape, avoid, or survive drought stress. Developing drought-tolerant crops for improved water utilization in agriculture is one of the most important areas of plant breeding. The agricultural industry consumes the most water globally, and as a result, in arid areas—which include many developing nations—the amount of water used for crop cultivation might surpass 90% of total consumption (ISAAA 2022). Selecting or developing drought-resistant crops becomes crucial to tackle this challenge, particularly in water-scarce environments. Such crops have particular morpho-physio-anatomical characteristics, including, but not limited to (1) early stomata closure; (2) increased photosynthetic efficiency; (3) low cuticular transpiration rate; (4) deposits of lipid layers; (5) reduced leaf area; (6) waxy leaf area; (7) higher number of stomata found at a lower leaf surface and located in deep cavities or depressions of leaf tissues and (8) efficient water uptake and transport mechanisms (Ortiz et al. 2019). Modi and Mabhaudhi (2013) listed several underutilised, neglected crops in South Africa which possess such drought-tolerance characteristics, namely amaranth, Bambara, cowpea, maize landraces, pearl millet, taro, wild mustard and wild watermelon. The drought tolerance of these crops was evaluated by testing their response to different planting periods (early—August to September mid -mid-October to November, or late season planting—January to February) or soil water supply regimes (irrigated and rainfed cultivation). The study demonstrated that maize requires sufficient water supply for increased productivity and, as a result, it may be less drought-tolerant than other traditional crops investigated concurrently. Wild watermelon, on the other hand, performed the best with early planting, suggesting that the crop is tolerant to water stress during the early vegetative stages, making it suitable for early planting and possibly obtaining high yields. Cowpea and amaranth demonstrated superior performance under relatively low soil water supply, while taro and Bambara groundnut were quite sensitive to water stress. Modi and Mabhaudhi (2013) investigated the water use and water use efficiency of amaranth, taro, and Bambara groundnut. The highest water use efficiency of Amaranth was observed under the least irrigation water regime (up to 30 kg m^{-3}), taro under 60% actual evapotranspiration (up to 0.49 kg m^{-3}), while Bambara groundnut under 30% actual evapotranspiration (up to 0.262 kg m^{-3}). However, taro and Bambara groundnut yield were significantly compromised with reduced water supply, which shows that these crops are better cultivated under limited to non-existent water stress conditions.

4.8 Effect of Climate Change and Soil Salinity

Soil salinization has become one of the world's most severe environmental and socioeconomic problems, and it is expected to worsen due to climate change. Climate trends affect the salinization process. According to the Soil Science Society of America, saline soil is a non-sodic soil with enough soluble salt to harm most horticultural crops (SSSA 2008). Soil salinization is a land degradation process that causes an excessive buildup of soluble salts in the soil. Low rainfall, native rock weathering, sea level rise, and poor farming methods, such as irrigation with extremely salinized water, are all factors that contribute to soil salinization. (Bleam 2016).

Climate change and increasing temperatures are fundamentally the reason for soil salinization (Hassani et al. 2021). Changes in rainfall caused by global climate change may impact surface moisture availability, which is critical for germination and crop stand establishment in rainfed regions. Salinity slows the germination rate and, at higher levels, reduces germination percentage. At low concentrations, the only effect is on the germination rate, not the total percentage of seeds germinated. Microbes have also surfaced as significant contributors. As the primary intermediates of carbon turnover in the soil, they consume glasshouse gases (Patil and Lamnganbi 2018). Increased soil temperature results from increased air temperature, accelerating diffusion-controlled reactions and solutions chemical reaction rate. Typically, salinity is determined by averaging the electrical conductivity of a saturated soil paste extract collected from the plant's root zone over time and depth (Spiteri and Sacco 2024). Different values of EC, varying from 2 dS m^{-1} to even 30 dS m^{-1}, are used as the minimum salinity threshold for characterizing the saline soils, depending on the soil classification scheme.

Soil salinity in the root zone can occur due to decreased water availability in irrigated farming regions, upward movement of salts from shallow water tables, reuse of degraded water, and salt-water intrusion. The development of salinity in the root zone can increase nitrogen leaching from the soil and decrease crop yields. Under salt duress, plant biomass, leaf area, and development have all decreased. Salt buildup in the root zone causes osmotic stress and breaks cell ion homoeostasis by inhibiting the uptake of elements such as K^+, Ca^{2+}, and NO_3 and causing the accumulation of Na^+ and Cl. (Paranychianakis and Chartzoulakis 2005).

Salinity will impact 50% of the world's arable land by 2050. Soil salinity reduces the yield of many agricultural goods, including most vegetable harvests. However, a global concern is a substantial increase in yield and consumption of vegetable crops comprising edible portions of herbaceous species (roots, tubers, shoots, stems, leaves, fruits, and flowers). In reality, fruits and vegetables are critical to our everyday survival. There are undeniable health advantages to eating a variety of fruits and vegetables. This is mainly because fruits and vegetables are high in antioxidants. Phytochemicals found in these vegetables include vitamin C, thiamine, niacin, pyridoxine, folic acid, minerals, and nutritional fibre. A lack of vegetables has been related to some of the world's most prevalent and debilitating nutritional diseases, such as micronutrient deficiencies.

4.9 Climate Change, Food Production and Postharvest Technologies to Combat Food Insecurity

All sustainable agriculture growth programmes include research and investment components to reduce waste. Postharvest food wastage is known as "food losses" or "spoilage." Food loss is a decline in quantity or quality that renders it unfit for human consumption. (Parfitt et al. 2010). According to the FAO, UNICEF, WFP, WHO (2012), one-third of all food produced for human use is lost or discarded and ends up in landfills. Global losses in the food supply chain are expected to be around 1.3 billion tonnes per year along the food supply chain, with Sub-Saharan Africa accounting for 230 million tonnes per year. Fruits and vegetables account for most food losses. (FAO, UNICEF, WFP, WHO 2012). Understanding the causes of food loss and waste is a critical step towards increasing resource efficiency and, in the long run, contributing to the achievement of the three Sustainable Development Goals: Goal 2 is to end hunger; Goal 12 is to promote sustainable usage and production; and Goal 13 is to combat climate change.

Food waste also involves wasting the water and energy used to grow, harvest, transport, and package it. Methane, a glasshouse gas even more potent than carbon dioxide, is released when food rots in a landfill. Food loss and waste negatively impact the environment and speed up climate change. Additionally, it states that the agri-food sector is responsible for around 31% of all greenhouse gas emissions contributing to global warming (FAO 2019). Methane emissions may drop by 45% by 2030 if food loss and waste are reduced. Methane, it is noted, has an initial 20-year warming potential that is more than 80 times greater than that of carbon dioxide. It claims that human activity is to blame for at least 25% of the methane-related global heat we are currently experiencing (Shivanna 2022).

Moreover, methane primarily contributes to ground-level ozone (tropospheric O_3) formation, a hazardous air pollutant and greenhouse gas directly harmful to human health (Fig. 5). Tropospheric O_3 is a secondary air pollutant associated with adverse health effects, including asthma, reduced lung function and chronic obstructive pulmonary disease. According to Huangfu and Atkinson (2020), short- and long-term exposures are linked to detrimental health effects and early mortality. Methane also harms plants by causing cellular damage within the leaves, adversely affecting plant production, reducing the rate of photosynthesis, and requiring increased resource allocation to detoxify and repair leaves (Ashmore 2005; Sitch et al. 2007).

Food waste and loss can be decreased by implementing low-cost postharvest technology, such as improving cold chains, educating consumers, and donating

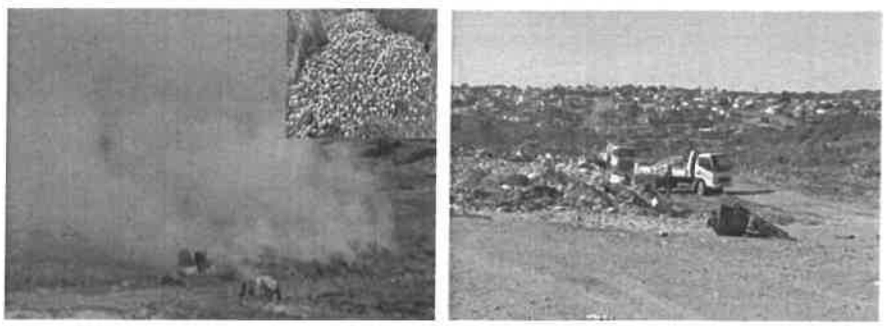

Fig. 5 Measures to prevent and reduce food waste and formation of methane greenhouse gas-emission (Image: Beverly Mampholo)

excess food. Postharvest technology involves all treatments or processes that occur from the time of harvesting until the foodstuff reaches the final consumer. Efficient harvesting, carrying, transportation, handling, storage, processing, preservation, packaging, marketing, and utilization techniques. According to Garcia-Benitez et al. (2020), handling procedures, including harvesting, pre-cooling, cleaning and disinfecting, sorting and grading, packaging, storage, and shipping, were crucial to maintaining quality and increasing shelf life. The efforts to prevent vegetable and fruit losses between harvesting and consumption are meagre. Several factors influence the postharvest losses of vegetables. The losses due to physical, physiological, mechanical, and microbial conditions are characterized by high metabolic activities (Mampholo et al. 2015). With a loss of about 10–15% in fresh weight, vegetables appear shrivelled and stale, considerably lowering their market value and consumer acceptability (Yahaya and Mardiyya 2019). Fruits and vegetables are perishable crops with a limited shelf life of about 48 h in tropical climates due to their high moisture content. Postharvest handling practices are needed to extend the crop's shelf life after harvest. Failure to adhere to handling practices can result in a high loss (Mampholo et al. 2015). It is, therefore, important to know the appropriate handling practices and treatment methods needed for harvested vegetables to reduce postharvest losses, thereby increasing profitability for handlers in developing countries (Arah et al. 2016).

Packaging is a food container that guards against mechanical harm and maintains sanitation. It also serves as a practical instrument for extending storage life and keeping bioactive ingredients and volatile molecules linked to flavor (Chandra et al. 2018). Packaging decreases post-harvest losses, which increases food availability for the expanding human population, lowers the production area needed, and protects natural resources. Utilizing genotypes with a longer postharvest life, an integrated crop management system that results in good keeping quality, and proper postharvest handling procedures that protect the quality of the goods are all examples of loss prevention strategies. Consumers desire fruit and vegetables with good flavour and nutritional quality and ornamentals with attractive appearances and long post-production life (Kader 2003). Strategies for delaying the browning and softening of wounded plant tissues and for maintaining their safety by minimizing microbial growth have been developed (Lamikanra 2002), but more research is needed to enable the extension of post-cutting life based on flavour and nutritional quality (Kader 2003).

Packaging separates the product from its surroundings and works to maintain conditions that, if not sterile, at least minimize exposure to pollutants and pathogens, hence extending the shelf life of goods (Hailu et al. 2014). Packaging effectively prevents water loss; however, it also modifies the packaging atmosphere. If the storage temperature cannot be kept low, high oxygen transmission rate (OTR) is recommended, as too low permeability causes quality loss due to anaerobic respiration (Lokke 2012). Packaging fresh produce in polyethylene bags has become a common practice nowadays. According to Hailu et al. (2014), packaging alters the composition of the air to provide the ideal environment for preserving the produce's quality. By decreasing respiration rate, enhancing moisture retention, and preventing physiological deterioration, a modified environment produced by packaging increases the storage life of produce (Sharma et al. 2018).

Packaged and marketed in plastic bags or films is to reduce water loss, with any atmospheric modification of O_2, CO_2 and C_2H_4 concentrations being incidental. Modified atmosphere packaging is very effective in retaining freshness and extending the shelf life of fresh produce by maintaining the colour, inhibiting water loss, reducing loss due to product respiratory heat, and maintaining the natural fresh taste of produce (Caleb et al. 2013). Storage circumstances influence leafy vegetables' physiological and visual quality from harvest to consumption. Low temperature is an important element in quality maintenance because it reduces respiration, reduces overall metabolism, and extends shelf life. (Spadafora et al. 2016). Good harvesting techniques can decrease mechanical damage and following waste due to microbial attack. (Wills et al. 1989). Food loss levels for a particular crop vary at various stages of the postharvest system. Even losses at a particular stage of the crop in the postharvest system may vary across nations, depending on climate and postharvest methods used.

5 Conclusion

Rising temperatures and an increase in the frequency of heat waves, droughts, and heavy downpours demonstrate that climate change is no longer a mirage but a reality. Rising poverty and food insecurity levels have also revealed the absence of social safety nets. However, underutilised crops are commonly considered future crops because of their ability to withstand extreme weather conditions, and they can be a valuable resource for tackling climate change, food and nutrition security, and food and nutrition security. Therefore, there is an urgent need to broaden the food basket of Sub-Saharan Africa by revisiting the cultivation of underutilised, neglected food crops and adapting to climate change. Despite being neglected, there is proof that these resilient crops can better adapt to extreme climatic conditions and are more resistant to abiotic stresses. Adaptation measures will aid in improving food security to climate change and allow them to generate more harvestable yields in marginal soils. Future perspectives on understanding population size trends are critical to estimating future food demands. Climate change has complicated and still-evolving effects on food systems. Agriculture is a sensitive sector that relies heavily on land, water, and other natural resources that climate affects. Access to safe and nourishing food is a fundamental human need, and food systems must be designed with this in mind. To adapt, it will be necessary to set up water conservation measures, employ water-use efficiency strategies to deal with higher temperatures and alter production methods where significant climate change will make it impossible to grow certain crops.

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