Adaptation Pathways for African Indigenous Vegetables' Value Chains

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1 Introduction

Climate change generally poses unequivocal risks for food systems, and in particular for tropical agro-climatic zones (ACZ) in sub-Saharan Africa, due to their high exposure and low adaptive capacities (Niang et al. 2014; FAO 2015a). Food production in sub-Saharan Africa largely depends on smallholder rain-fed agriculture, highly vulnerable to seasonal shifts in precipitation patterns and extreme weather events (Lotze-Campen 2011; Anyah and Qiu 2012). Increasing variations in precipitation patterns, temperature rises and increased frequency and severity of weather-related extremes consequently cause heat and water stress and shortened cropping seasons, leading to yield reductions (Burke and Lobell 2010). Model-based estimates using the Agricultural Model Intercomparison and Improvement

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Project (AgMIP) indicate production declines for the main staple foods, maize and beans, of up to 20% for East Africa (Ramirez-Villegas and Thornton 2015). A crop simulation meta-analysis indicates that even with incremental adaptation measures maize crop losses cannot be avoided, with severe consequences for sub-Saharan African food systems (Challinor et al. 2014). There are no comparable simulation models to predict the risks for tropical horticulture in the face of climate change (Ayyogari et al. 2014; Midmore 2015). Compared to cereal crops, fruits and vegetables have very fixed climatic requirements for their physiological processes, resulting in high sensitivity to high temperatures or low soil moisture (Masinde and Stuetzel 2005; Ngugi et al. 2007; Muthomi and Musyimi 2009; Adebisi-Adelani and Oyesola 2013; Ayyogari et al. 2014). A changing climate also influences the nutritional value of vegetables: less ascorbic acid due to water deficiency and a sharp decrease in iron content due to the CO_2 fertilisation effect have been reported (Jain et al. 2007; Luoh et al. 2014).

Parts of sub-Saharan Africa are exposed to multiple stressors, and have therefore been termed hotspots of climate change, sharing a triple burden of (1) high exposure to the effects of climate change, (2) high poverty rates, and (3) high population densities (Müller et al. 2014). This study focuses on one of the hotspots, the densely-populated regions of Kenya, located in or adjacent to the Lake Victoria region. Kenya, despite being a middle income country, shows high rates of chronic food insecurity, with an estimated 30% of children under the age of 5 being stunted. According to Grace et al. (2012) increased stunting correlates with increased temperature and decreased rainfall in Kenya. High urbanisation and population growth together with crop yield reductions will exacerbate food insecurity in Kenya, where a doubling of the population to 97 million, with the rate of urban dwellers increasing from 25 to 46%, is projected for 2050 (FAO 2015b). A global simulation on regional undernourishment in the face of climate change estimates increased stunting rates in East and South sub-Saharan Africa by 55% (Lloyd et al. 2011).

Vegetables and fruits are protective foods, being rich in micronutrients and therefore a viable solution to fight undernourishment and hidden hunger. Studies show that 80% of vitamin A consumption in African diets derives from vegetables and fruits (Ruel 2001). Kenya's vegetable intake, at 88 kg/capita/year is high compared to other sub-Saharan countries. However, vegetable consumption among poorer rural households is lower compared to the better-off urban population (Okado 2001). African indigenous vegetables (AIVs) have the potential to improve food security in the face of climate change, for several reasons. AIVs are mainly produced by resource-poor smallholders, are nutrient-denser than exotic vegetables, have various health benefits, contribute to identity and authenticity, and offer a range of agronomic advantages (Ngugi et al. 2007; Abukutsa-Onyango 2010). There is a growing demand for AIVs, and planting areas have increased from 17,000 to 40,000 ha over 3 years (HCDA 2015). African nightshade (*Solanum scabrum*), spiderplant (*Cleome gynandra*), amaranth (*Amaranthus* spp.) and recently cowpea leaves (*Vigna ungulculata*) are the most common (HCDA 2013, 2015). Overall, there are more than 210 species with nutritional value (Maundu et al. 1999). Compared to spinach, AIVs contain twice the amount of protein and 1.5–2 times as much vitamin A and more than 4 times as much vitamin C (Oniang'o et al. 2008; Yang and Keding 2009; Abukutsa-Onyango et al. 2010; Luoh et al. 2014). 100 g of fresh AIV contain 100% of the daily requirements of iron, vitamins, and calcium, and 40% of protein (Lenné et al. 2005; Abukutsa-Onyango 2010; Keatinge et al. 2010; Afari-Sefa et al. 2012). The potential of AIVs is largely underutilised as they are often overlooked in food policies and programs due to their antiquated image as a "poor man's crop" or "backward" food (Abukutsa-Onyango 2010; Gevorgyan et al. 2015). This attribute largely derives from the colonial past, when exotic vegetables were highly promoted and indigenous species entirely neglected.

Climate change is a global phenomenon, whereas vulnerabilities are highly contextual. Adaptations are expected to be carried out by local people in their specific settings (Sada et al. 2014). The need for adaptation action is gaining more importance, as highlighted in the IPCC AR5, which differentiates between incremental and transformative adaptation (Noble et al. 2014). Incremental adaptation practices are adjustments addressing proximate causes by building resilience into specific systems. Transformative adaptation pursues broader and systematic change by addressing the underlying roots of vulnerability. In agricultural and food value chain systems incremental adaptation includes a range of climate-smart, no-regret activities from the crop, land and water management spectrum, whereas transformative adaptations in the AIV value chain system include increased social inclusiveness, bargaining power, access to markets, information, land, and water resources. The process of adjustment is based on local decision making and therefore often referred to as adaptation pathways (Wise et al. 2014). Adaptation pathways are trajectories of no-regret actions, whether incremental or transformative, in a given adaptive space. A precondition for suitable adaptation action is the awareness of local decision makers, such as smallholder farmers, of local climate variation risks and sensitivities. Farmers' perceptions of weather and system sensitivity are therefore an entry point for planning farm-level adaptation practices (Teka et al. 2013).

The triple-win framework of climate-smart agriculture (CSA) aims at (1) sustainably increasing agricultural productivity to boost incomes and food security; (2) building resilience to climate change; and (3) reducing greenhouse gas (GHG) emissions from agriculture (FAO 2011, 2013; World Bank et al. 2015). Climate-smartness has been recently operationalised as a group of criteria (weather, water, nitrogen, carbon, energy, and knowledge) for assessing various farm-level practices in a number of countries, including Kenya (World Bank and CIAT 2015). Climate-smartness would serve as a reference model for proposing adaptation pathways for AIV value chains.

Overall, climate variability and change pose currently unknown risks to AIV value chains. Neither their sensitivity, nor the adaptation strategies of AIV farmers are adequately known. The aim of this study is to document local perception of climate risks and its impact on AIV systems, particularly agronomic sensitivities in the wet and dry seasons. For three distinct ACZs, semi-arid, semi-humid, and humid, site-specific features are broken down. The study answers four specific questions: (1) How do farmers perceive climate variability and change in their local situation and how closely do these perceptions match historical weather data? (2) How sensitive are the various AIVs to changing climate in dry and wet seasons? (3) Which farm-level adaptation strategies are pursued in different agro-climatic zones? (4) Which factors are hindering the implementation of adaptation strategies, i.e. what are the adaptation gaps?

2 Materials and Methods

2.1 *Study Area*

Kenya is divided into seven ACZs based on vegetation characteristics, amount of rainfall, and soil ecological potential. The study was conducted in Kakamega, Nakuru and Kajiado counties, representing the humid, semi-humid, and semi-arid zones, respectively (Table 1 and Fig. 1). The high to medium potential areas are the humid, sub- and semi-humid ACZs. They allow arable agriculture because they have an annual rainfall of more than 800 mm (MAFAP 2013). The low potential areas are the arid and semi-arid lands. AIV production is concentrated in the high and medium potential areas, as vegetables need well-watered soils. Horticultural land is prevalent in Western Kenya, as in Kakamega (Table 1).

2.2 *Data Sources*

The study used a mixed method approach, combining quantitative and qualitative data sets collected in the three ACZs. The different data sets come from a representative household panel survey conducted by the HORTINLEA project in 2014 (Kebede et al. 2015). In addition, in-depth information on climate perception and

Table 1 Study area

County	Kakamega	Nakuru	Kajiado
Agro-climatic zone	Humid	Semi-humid	Semi-arid
Rural-urban character	Rural	Peri-urban	Peri-urban
Horticultural land in ha/% of crop land	8,627/3.4%	33,734/0.1%	3,494/0.03%
Population	1,660,651	1,603,325	687,312
Poverty rate (%)	53	40.1	11.6
Mean temperature max (°C)	29	20	34
Mean temperature min (°C)	18	15	22
Mean precipitation p.a. (mm)	2,000	800	500

Source HCDA (2013), ASDSP (2014), CIA (2013)

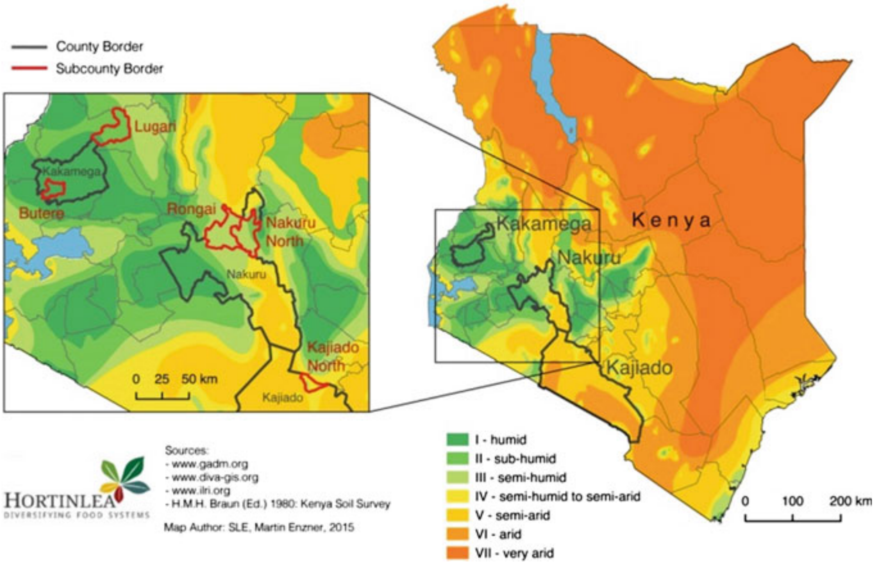

Fig. 1 Agro-climatic zones in Kenya and main study areas (sub-counties)

the sensitivities of AIVs to climate variability and change was gathered in focus group discussions (FGDs) with farmers. Farmers' perceptions of climate change were compared with empirical historical weather data obtained from the Kenya Meteorological Office (KMO).

The household panel survey data were analysed for three counties (Table 1), consisting of 610 growers, among whom the humid and semi-humid ACZs are well represented with 590 growers. The results for the semi-arid ACZ Kajiado must be interpreted carefully, as the sample contains only 20 respondents. The household survey section about "weather perceptions and effects of climate change" contains mostly categorical variables, for which cross tabulation procedures have been run to display contingency tables and their associations with Chi-Square test and Cramer's V (Figs. 3 and 6).

The household survey results on perceptions of climate change and adaptation strategies were compared to the information gained during 18 FGDs in which 189 AIV farmers participated. Local extension officers, trained in the research design and non-biased interview techniques, facilitated the discussions. Most of the participating farmers (60%) cultivate AIVs in a semi-commercial way, i.e. they produce for their own consumption and sell the surplus on local markets. 32% produce only for home consumption and 8% primarily for sale. 68% of the farmers were female, and 32% were male. Each discussion started with shifts and variability in temperature and precipitation. All assertions were recorded. Then, a sensitivity ranking of all AIV species grown by the farmers was conducted. The ranking was done for each season separately. Agreement was reached among farmers on the species which are least sensitive, which come second, third, and which are most sensitive to rainy and dry seasons respectively. Agreement was only reached after all arguments for their ranking decisions were provided. The adoption rate of climate-smart farm-level adaptation strategies in land and water, soil fertility, and crop management were assessed by simply adding up the practices of each farmer from a prepared list. At the end of the FGD, all farmers were asked to identify the three most important gaps in adapting to climate change. These statements were categorised into knowledge, technology, institutional and funding gaps, following a generic structure as proposed by UNEP (2014). The qualitative data obtained was processed by coding procedures according to content analysis (Mayring 2015). In this study, the impacts of adaptation strategies and adaptation gaps were not deeply explored.

Historical weather data on monthly mean temperature in °C and monthly precipitation in mm were obtained from the KMO. For the period 1980–2014, trends were analysed for three reference weather stations: Kakamega town for the humid zone Kakamega, the Jomo Kenyatta International Airport (JKIA) for the semi-arid zone Kajiado, and Nakuru town for the semi-humid zone Nakuru. As data were only available as monthly averages, it was not possible to exactly determine onsets and cessations as well as the intensity of rainfall. For exact rainfall distribution analysis daily data would have been needed.

3 Results

3.1 Farmers' Perceptions of Weather and Climate Variability and Change

Farmers in the **humid zone**, **Kakamega**, report a regular rainfall pattern until the year 2000, with two pronounced rainy seasons from March to May and September to December. This common pattern no longer holds, since a majority of the 90 participants have observed three major weather changes. Farmers agree on more overall rainfall, more unpredictable and more intense rainfalls. The increased frequency of hailstorms has been reported in six out of eight locations. "*If it rains, it pours down in a short time, and then for several days, we suffer from serious dry spells.*" (FGD 11) "*In the past, rains started in February, but now it rains throughout the entire year.*" (FGD 8) These observations are supported by the results from the household survey (Fig. 3), where 70% of the 373 AIV farmers stated more overall rainfall, and 18% indicated unpredictable and extreme rainfall events.[1] The perception of temperature change is less clear. Most farmers assert an increase in day and night temperatures, particularly during the rainy season, and

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[1] The Cramer's V coefficient of 0.305 indicates a strong association between rainfall perceptions and ACZ.

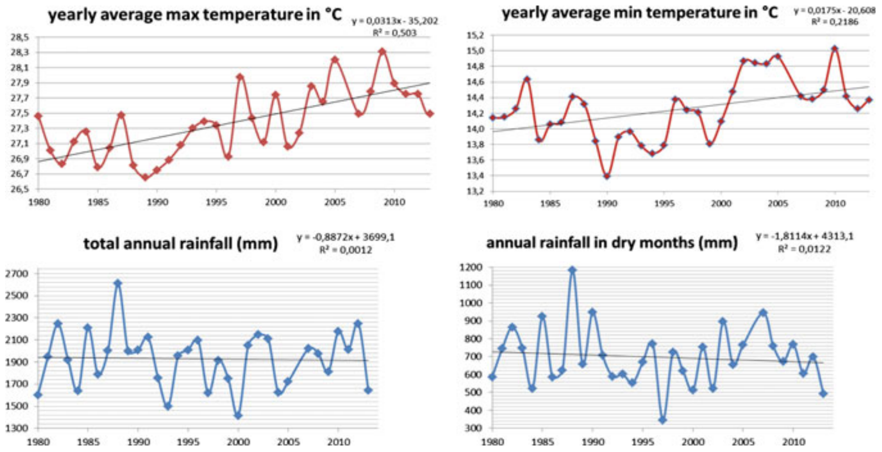

Fig. 2 Temperature and rainfall trends 1980–2013 Kakamega (humid zone)

more hot days. "*The days can be very hot now, that is different from the past.*" (FGD 7) "*In the past we were able, but now we cannot work in the field anymore at 2 PM, it is just too hot.*" (FGD 5) Farmers state that extremes in both directions are more pronounced. The results of the household survey also indicate varying perceptions,[2] such as hotter dry seasons and more hot days ranked first by 28% of respondents, followed by the opposite observation of longer cool seasons by 24.6%, and cooler dry seasons by 22.5%.

Historical data show a rather insignificant rainfall trend in terms of total annual rainfall (Fig. 2), and therefore do not support farmers' assertion of increased annual rainfall. In some monthly timelines, which are not illustrated here, monthly mean rainfall data confirm an upward trend, particularly during the short rains (September, December). For temperature, farmers' assertions of a temperature increase are supported by historical increases in maximum and minimum temperature of 0.4 and 1 °C, respectively (Fig. 2).

In the **semi-arid zone, Kajiado,** all 31 farmers consistently assert increased temperatures, increased frequency of very hot days, and a sharp decline in, and more unreliable rainfall. "*In the past, when I walk up the hill to the fields, it was warm, but now it is sometimes so hot, that I need to rest.*" (FGD 3) Likewise, the household survey reveals that the majority of farmers perceive higher and more extreme temperatures and less rainfall (Fig. 3). Overall, farmers' assertions are in line with the trends. Historical weather trends strongly support the perceived increase in night and day temperatures (Fig. 4). Rainfall shows a sharp decline with a slight rising trend in the dry months, indicating a less distinct rainy season.

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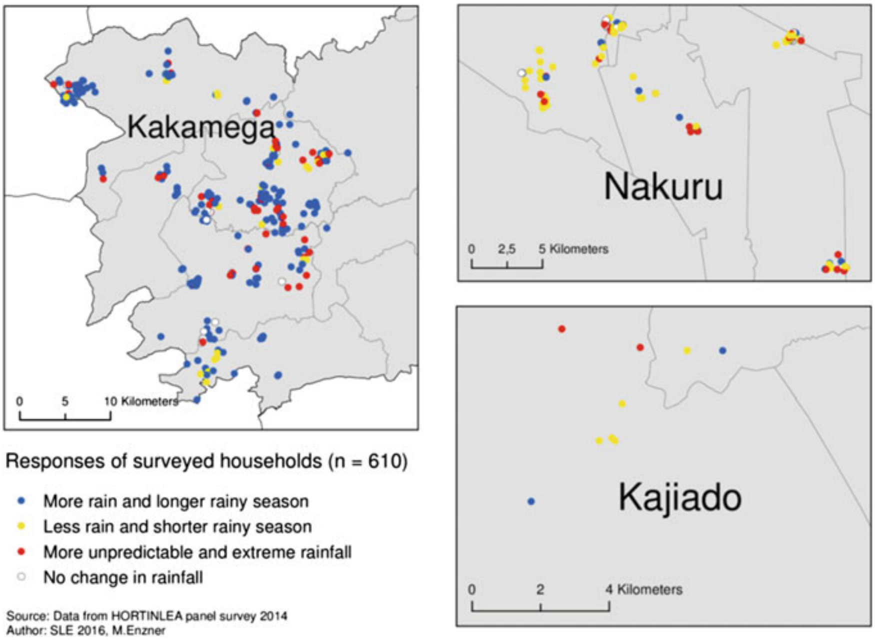
[2] The Cramer's V coefficient of 0.209 indicates a medium association between temperature perceptions and ACZ.



Source: Data from HORTINLEA panel survey 2014
Author: SLE 2016, M.Enzner

Fig. 3 Farmers' perceptions of changes in rainfall

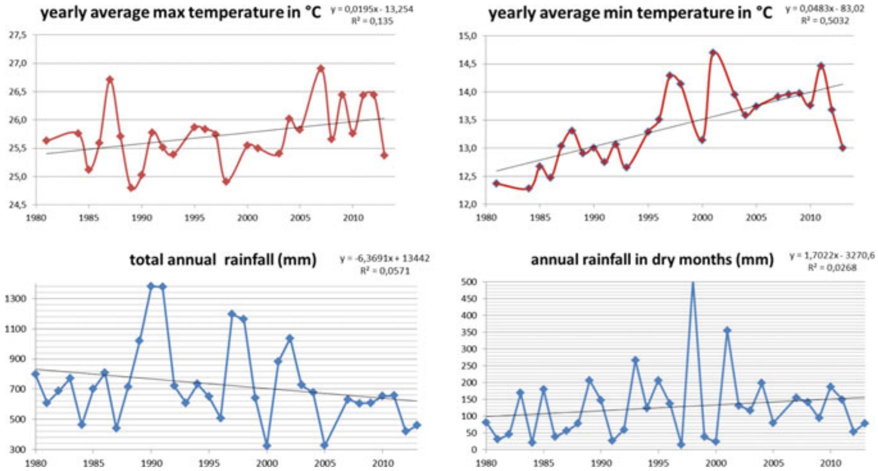


Fig. 4 Temperature and rainfall trends, JKIA (Kajiado, semi-arid zone)

In the **sub-humid zone, Nakuru**, the majority of the 68 participating farmers describe climate change as increased unreliable and unpredictable rainfalls and more frequent and severe dry spells with hotter temperatures. "*During the dry*

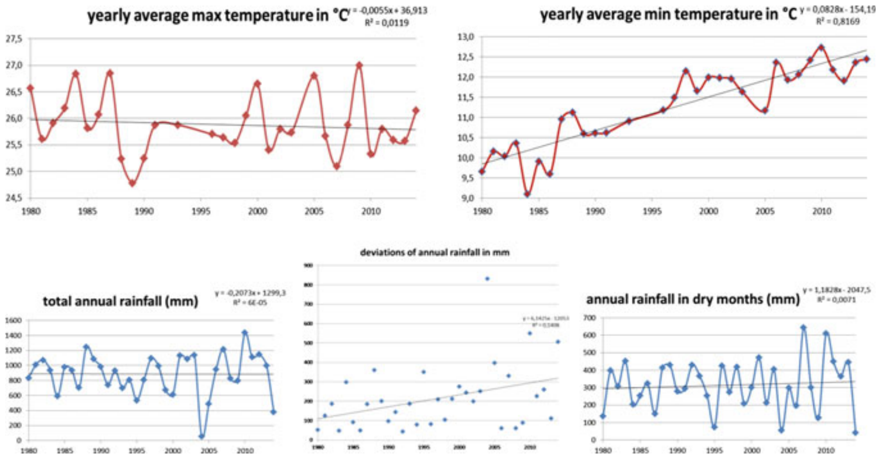


Fig. 5 Temperature and rainfall trends Nakuru (sub-humid zone)

season we abandon farming, as for the last 15 years, there have been increased droughts and unpredictable dry spells." (FGD 13) "*The temperature has increased most during the night*". (FGD 17) The representative household survey results match farmers' assertions, as many of the 183 farmers in Nakuru perceive hotter dry seasons (41.8%) and less rainfall (57.1%). Nakuru's historical weather data support a decreasing trend in total annual rainfall (Fig. 5). Figure 5 also reveals increased variability in rainfall from year to year, corresponding closely to farmers' perceptions of more unreliable and unpredictable rains.

3.2 AIV Sensitivities

As climate variability and change is real, it is important to know how AIVs respond to these changes and how sensitive they are to them. The sensitivity ranking (Table 2) provides a comprehensive overview. The table lists AIV species according to their importance on farms, as measured in size of plots per household survey. Overall, plot sizes are very small, with medians of 0.1 acre (~400 m^2). Nine different AIV species are grown in the study area, of which nightshade, cowpea, spiderplant and amaranth are the most important. The greatest diversity is found in Kakamega, where farmers grow up to eight species per farm, followed by Nakuru with six, and Kajiado with four species. Sensitivities to too much rain, water logging, dry spells, water stress and more pests and diseases are most common. The most tolerant "*survivor plants*" grown across all ACZs are pumpkin leaves and wild amaranth. Slenderleaves, jute mallow and Indian spinach are regionally important. Generally, AIVs thrive better in rainy seasons. The legumes cow pea and slenderleaves tolerate dry conditions. 15 out of 18 focus groups ranked cow peas and slenderleaves as most resistant to dry spells. Spiderplant is rather sensitive, as it is susceptible to too much and too little rain, and needs a lot of experience to grow, "*it depends on farmer's hands.*" (FGD 7) Nightshade tolerates extreme rainfall and performs well under wet conditions. However, in the dry season or during dry spells, nightshade is often affected by various pests and diseases. The results of Table 2 reveal that AIVs are not particularly sensitive, especially in the rainy season. Spiderplant, however, is more sensitive in both seasons, and requires more attention and knowledge.

3.3 Adaptation Strategies

According to the household survey, 88% of all farmers feel that climate variability and change affect their livelihoods, with the highest impacts in rural, humid Kakamega.[3] Major impacts are lower yields and more crop failure (67%), while impacts on villages, transport infrastructure and health are not prominent (2.2%). 18.8% of farmers in humid ACZs also point to positive effects of climate change, such as higher yields and less crop failure. Given the high impacts, farmers use different adaptation strategies.

Figure 6 shows that in Kajiado and Nakuru less than 50% of farmers claim that they adapt to climate change, while in rural Kakamega almost 90% of farmers pursue adaptation. Crop diversification activities are most popular (67%), whereas on-farm investments (irrigation, dams, terraces, tree planting, and ponds) and off-farm activities like non-farm employment or migration are rare strategies, due to the fact that investments and off-farm activities require capacities and resources that most farmers lack. On-farm investments are found more often in the better-off peri-urban Kajiado,[4] as farmers are more integrated into markets and cannot produce vegetables at all without irrigation due to the dry weather conditions.

The results from FGDs reveal in more detail which climate-smart farm-level adaptation strategies are applied by the farmers. Table 3 lists the adoption rates of water, land and crop management practices, which considerably differ across the ACZs. An adoption rate of more than 60% is considered high, 30–60% medium and less than 30% low. Only 10% of farmers use water management technologies; simple methods like the watering can or buckets prevail. Rainwater harvesting technologies are widely adopted only in the semi-arid county Kajiado. Few sustainable land management practices are applied; due to sloped fields, terracing in Kakamega is widespread. Integrated soil fertility management has medium adoption rates, with manure and compost being more widespread. Crop management

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[3] The Cramer's V coefficient of 0.248 indicates a medium association between impact of climate change on livelihoods and ACZ.

[4] The Cramer's V coefficient of 0.280 indicates a medium to high association between the different adaptation strategies to climate change and the counties.

Table 2 AIV relevance and sensitivities to dry spells and heavy rainfall

English/Latin/local name	No. of plots[a]	Area[b]	Sensitivities in rainy season[c]	Sensitivities in dry season[c]
African nightshade *Solanum scabrum* Managu	915 (28.1%)	0.187/0.1	*Low* Rarely affected by pests and diseases, except blight and powdery mildew; blight is increasing problem, esp. in cold season (July); tolerates waterlogging; responds well to manure	*High* Affected by aphids, sugar ants, spider mites, nematodes, esp. in high temperatures; shallow roots very sensitive to drought, wilts quickly; gets bitter under water stress; doesn't germinate well in dry spell
Cowpea *Vigna unguiculata* Kunde	607 (18.6%)	0.196/0.1	*Medium* (standing variety) Cannot withstand heavy rains; doesn't thrive when it is too cold; susceptible to a wide range of diseases and pests (leaf rust, aphids, white flies, black spot)	*Very low* (creeping variety) Drought resistant; no pests and diseases
Spiderplant *Cleome gynandra* Sage, sageti	563 (17.3%)	0.195/0.1	*Very high* Highly affected by heavy rains, flooding not tolerated, difficult to grow	*High* Affected by spider mites, white flies; affected by water stress, gets bitter and wilts; needs irrigation; difficult to grow
Amaranth *Amaranthus* spp. (*mainly blitum, lividus, graecizans*) Terrere	534 (16.4%)	0.168/0.1	*Very low* Grows everywhere; likes wet conditions; resistant to all pests and diseases; thrives also on poor soils; responds well to organic fertilizer	*Low* Resistant to drought; no pests and diseases
Slenderleaf *Crotalaria brevidens* Miro, mitoo	51 (1.6%)	0.06	*Low* Does not suffer from diseases and even less from pests	*Very low* Drought resistant due to structure and size of leaves and robust deep tap root; no diseases and pests
Jute mallow *Corchorus olitorius*	5 (0.2%)	0.06	*Very low* No pests and diseases; mucous content is bitter and keeps off pests	*Low* Deep root system is drought tolerant

(continued)

Table 2 (continued)

English/Latin/local name	No. of plots[a]	Area[b]	Sensitivities in rainy season[c]	Sensitivities in dry season[c]
Murere, mwenda, murenda				
Pumpkin leaves *Cucurbita moschata duchesne* Massaiveve, liro, seveve	12 (0.4%)	0.06	*Very low* No pests and diseases; weeds do not spread, as stems meander; tolerates a wide range of soils, grows under shade and in sunshine, tolerates high amounts of water	*Low* Self-mulching, as the leaves cover the soil; little evaporation; fairly drought tolerant, but needs water for germination; host for, but not affected by white flies
Indian spinach *Basella alba* Nderema	0	0	*Very low* No pests and diseases; tolerates high amounts of water	*Very low* Survives in any conditions; resistant to dry spell

[a] As per household survey total/in percent of all plots

[b] Mean/median area (in acre) per household as per household survey

[c] Sensitivity ranking in 18 focus group discussions (189 farmers)

Source Own compilation

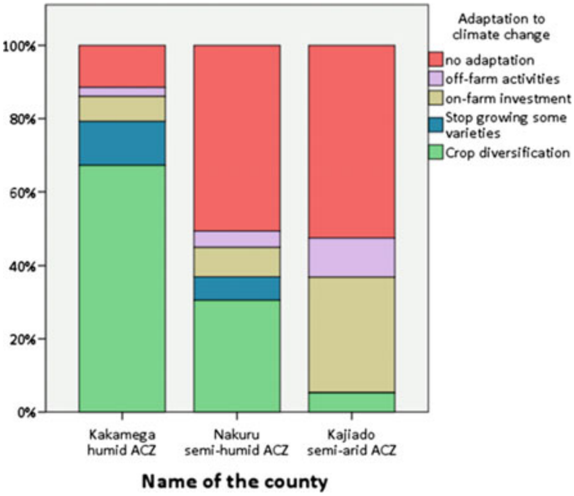

Fig. 6 Adaptation to climate change (n = 588). *Source* Data from HORTINLEA household panel survey 2014

Table 3 Adoption rate of farm-level adaptation strategies in AIV production

	Adoption rate			
	Kakamega	Nakuru	Kajiado	3 counties
Water management	*8%*	*3%*	*31%*	*10%*
Rainwater harvesting	6 (7%)	1 (1%)	27 (87%)	34 (18%)
Watering cans, buckets	25 (28%)	4 (6%)	14 (45%)	43 (23%)
Drip irrigation with bottles	5 (6%)	0	7 (23%)	12 (6%)
Drip irrigation with pipes	0	1 (1%)	5 (16%)	6 (3%)
Sprinkler	0	6 (9%)	2 (6%)	8 (4%)
Water pans	9 (10%)	1 (1%)	3 (10%)	13 (7%)
Land management	*21%*	*14%*	*9%*	*17%*
Agroforestry	11 (12%)	31 (46%)	1 (3%)	43 (23%)
Terraces	51 (57%)	10 (15%)	6 (19%)	67 (35%)
Raised seedbeds/double digging	7 (8%)	2 (3%)	7 (23%)	16 (8%)
Trash line	19 (21%)	0	0	19 (10%)
Retention ditch	6 (7%)	6 (9%)	0	12 (6%)
Soil fertility management	*40%*	*37%*	*30%*	*37%*
Crop residue mulching	45 (50%)	34 (50%)	15 (48%)	94 (50%)
Composting	62 (69%)	29 (43%)	9 (29%)	100 (53%)
Cover cropping	38 (42%)	3 (4%)	3 (10%)	44 (23%)
Advanced fertilising[a]	8 (9%)	1 (1%)	1 (3%)	10 (5%)
Ash	52 (58%)	29 (43%)	4 (13%)	85 (45%)
Manure	10 (11%)	56 (82%)	24 (77%)	90 (48%)
Crop management	*39%*	*42%*	*19%*	*37%*
Special seed varieties	19 (21%)	21 (31%)	0	40 (21%)

(continued)

Table 3 (continued)

	Adoption rate			
	Kakamega	Nakuru	Kajiado	3 counties
Integrated pest management	30 (33%)	11 (16%)	0	41 (22%)
Organic remedies	10 (11%)	11 (16%)	23 (74%)	44 (23%)
Mixed cropping/intercropping	47 (52%)	43 (63%)	7 (23%)	97 (51%)
Crop rotation	71 (79%)	56 (82%)	0	127 (67%)

[a] Micro-dosing, "deep" fertiliser, phosphate, Bokashi, effective microorganisms (EM)
Source Own compilation

practices have medium adoption rates. Organic remedies to build resistance to pests and diseases in Kajiado as well as crop rotation and mixed cropping/intercropping of AIVs with other species in Nakuru and Kakamega are widely practiced.

3.4 Adaptation Gap

Although various climate-smart AIV production technologies are practised in all three ACZs, only a few are widespread. Adaptation is linked to challenges in institutions and infrastructure, capacities, technologies, and finance. During FGDs, farmers provided more than 270 suggestions on how to close this adaptation gap. 25% of the solutions are improved funding for water systems and inputs along the value chain. Another 24% of solutions are providing extension services. Improvements to weak and non-systematic support in market integration (20%) and access to local water systems (15%) are also suggested. Only 15% of the solutions concern technology gaps, most frequently the lack of certified seeds, appropriate small-scale dryer and freezer systems, and effective pest management practices.

4 Discussion

4.1 Perceptions of Climate Variability and Change

This research supports the climatological evidence of continuously increasing temperatures, with most farmers (85%) confirming this trend. In fact, between 1960 and 2003 Kenya has experienced an average annual temperature increase of 1 °C (Met Office 2011; GoK 2012). In the semi-arid zone, temperature increases are most pronounced and during discussions farmers unequivocally stressed a sharp temperature increase.

Insignificant historical rainfall trends in terms of total annual amount do not match the change perceived by a majority of farmers (67%), with the exception of the declining trend in the semi-arid ACZ. Given the differences in rainfall perceptions even within a small region, it is suggested that rainfall patterns and changes are very site-specific. In one village of Kakamega, farmers highlighted the increased occurrence of hailstorms, while the neighbouring village did not suffer from hailstorms at all. County averages and monthly averages do not have sufficient resolution to reflect farmers' assertions about rainfall changes. Recent studies in Kenya and Ghana also showed that farmers perceive temperature increases and rainfall decreases even though climatological evidence do not show declining rainfall trends (Bryan et al. 2013; Amadou et al. 2015). The authors argue that rain-fed dependent farmers associate climate change with the variability of rainfall, its irregular onset and cessation, changing intensities and dry spells, which do not necessarily influence the annual or monthly total amount. Similarly, Arku (2013) and Nzeadibe et al. (2012) argue that farmers' perceptions of climate change reflect the fact that rainfall is the most important constraining factor in rain-fed farmers' decisions about cropping patterns. The findings of this research suggest that farmers' perceptions of changes in rainfall reflect a change in rainfall patterns, particularly shifts in onset and distribution, rather than changes in annual amounts.

4.2 AIV Sensitivities in Dry and Wet Seasons

A key determinant of AIV vigour is a reliable rainfall pattern, which has become a constraint in all ACZs. A lack of rainfall and extreme heat cause wilting, attract pests, and reduce yields. However, more frequent and extreme precipitation events result in high moisture conditions, causing favourable environments for diseases, destroying fields, and leaching nutrients. Overall, sensitivities are least pronounced in rainy compared to dry conditions. The farmers call jute mallow, slenderleaves, pumpkin leaves, cowpea and amaranth "*survivor plants*", showing a wide tolerance to temperature and precipitation extremes, and being least affected by pests and diseases. The majority of farmers state that the most popular African nightshade (32% of market share within the AIV market) (Irungu et al. 2011) and spiderplant are more sensitive to dry spells than other AIV species. Due to a range of agronomic advantages, AIVs are very popular among smallholders. AIVs perform well under harsh climatic conditions, are not susceptible to pests and diseases, and have a very short growing period of 3–4 weeks (Abukutsa-Onyango 2010; Biovision 2015; Prota4u 2015). Studies emphasise AIV drought tolerance and their resistance to pests and diseases compared to exotic vegetables (Muhanji et al. 2011; Luoh et al. 2014).

4.3 Adaptation Strategies

Soil fertility (using manure, ash, composting, and mulching) and crop management practices (rotation and mixed cropping) are the most widespread. They can be carried out fairly autonomously, as they depend only on the individual smallholder's decisions. Complex interventions in water and land management, however, require joint planning efforts and more financial support. According to Chesterman and Neely (2015), rainwater harvesting methods are widely promoted, though unlike the semi-arid Kajiado, farmers in Nakuru and Kakamega have never been exposed to this technology. To speed up adaptation in water management, better coordination and additional support would be needed. The findings indicate that farmers consider most sustainable agricultural practices as effective adaptation strategies, even though extension services have not promoted them explicitly as adaptation strategies. Within the scope of this study it was not possible to further assess the impact of all adaptation strategies used.

Low sensitivities during the rainy season make AIV production very easy and lead to oversupply and limited market potential. Amaranths, for example, are hardly purchased in the rainy season in rural areas, as they grow abundantly in home gardens or are collected freely outside the homestead. In the dry season, the opposite is the case, giving amaranths high market potential. A study in Tanzania therefore concludes that AIVs are an attractive commercial crop exclusively to be promoted in the dry season (Weinberger and Msuya 2004). The high market potential with scarce supply and higher prices in the dry season is coupled with higher sensitivities, and therefore requires improved adaptation packages for dry season AIV value chains. Commercialisation needs to consider the danger of biodiversity losses, as commercial production concentrates on only a few marketable species (nightshade varieties and spiderplant). The trade-offs of commercial production for on-farm AIV diversity have been already reported for farms around Nairobi (Irungu et al. 2011).

4.4 Adaptation Gap

Apart from the availability of improved certified vegetable seed and post-harvest technologies, adaptation gaps are linked to knowledge, funding, and institutional support. A number of CSA practices, recognized in the Kenya Climate Change Action Plan (2013–2017), are relevant for AIV production: drought-tolerant crops, water harvesting, drip irrigation, integrated soil fertility and pest management, and agroforestry (GoK 2012). These practices are not explicitly promoted in Kenya's agricultural strategy and not yet reflected in the agricultural sector budget. Funding for climate-smart adaptation is provided by a small number of stakeholders, including three relevant ministries—agriculture, environment, water and irrigation—research institutes, and NGOs. The technical document of the Kenya Climate-Smart Agriculture Programme 2015–2030 (Chesterman and Neely 2015) provides a good basis for developing funding opportunities for adaptation, but specific measures for AIVs are not included.

5 Conclusion and Future Research

Climate change is expected to have a significant impact on food security in Kenya. As nutrient-dense food, AIVs play an important role in fighting hidden hunger. While tropical vegetables require very specific water and temperature ranges, there is still little evidence of climate change having an impact on vegetable production. Farmers' understanding of climate change is highly associated with changes in rainfall. Farmers are mainly concerned with changes in rainfall distribution, which includes intensity, onset and cessation of rainfall, with significant differences between agro-climatic zones ranging from more and longer rains, to less or more unpredictable rainfall. Historical rainfall trends show little significant change in total amount, but differ considerably across the zones. It is recommended to analyse regional-scale historical trends more profoundly by analysing daily data and testing various parameters, such as increased variability, delayed onset and increased intensity of rainfall in order to confirm farmers' perceptions from the climatological perspective.

Many AIV species tolerate a wide spectrum of climate variability and are therefore considered insensitive to climatic variations. This is particularly true for the rainy season, while in the dry season, some AIVs are more affected by the consequences of climate variability, as some AIVs suffer from pests and diseases and water stress, particularly the marketable nightshade and spiderplant species. It is suggested to conduct market research on the potential of the so-called survivor plants, which are common on farms, but have a low market share (jute mallow, Indian spinach, local amaranth, pumpkin leaves, and slenderleaves). They play an important role in the mixed cropping system as they contribute to protection against pests and diseases.

Farmers' adaptation practices, such as crop diversification, crop rotation, simple irrigation with watering cans, tend to be of an incremental character. The same applies to a number of sustainable soil fertility management practices, as they are promoted by local extension services. These results underline the need for climate-smart strategies beyond autonomous adaptation, as the latter is not sufficient to increase resilience and productivity and to reduce trade-offs in smallholder AIV production. Only few farmers are able to invest in water and land management and are integrated well enough into social networks to be able to participate in commercial AIV value chains. The adaptation gaps include lack of funding, extension services, market integration, water resources, certified seed and post-harvest technologies. One potential adaptation pathway to promote AIV value chains is suggested by promoting a mixture of commercial AIV species in the dry season. This pathway would comprise a package of adaptation strategies starting from quality seed, efficient water use technologies, integrated pest management, and market empowerment. In this study, the climate-smartness of farm-level adaptation strategies wasn't assessed. In order to measure the impacts and trade-offs of adaptation, it is suggested to evaluate adaptation pathways against climate-smart criteria as proposed by the World Bank and CIAT (2015). Since AIV value chains are not yet considered in climate change adaptation policies, it is suggested to continue with a mix of qualitative and quantitative research, and to include farmers, extension services and policy makers in a participatory research process to jointly assess the costs and benefits of climate-smart adaptation pathways. Policy makers and practitioners being aware of the costs and benefits of AIV value chain adaptation will also contribute to developing socially inclusive policies and practices for fair and ecologically sustainable AIV value chains.

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