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Email for Correspondence:

cbas-sdp@ug.edu.gh

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Morphological and Molecular Characterization of Frafra Potato (*Solenostemon rotundifolius*) Accessions in Ghana

Godson Nyawudzo[1], Jacqueline Naalamle Amissah[1*], Francis Kusi[2] and Kwadwo Ofori[1]

[1]Department of Crop Science, University of Ghana, Legon

[2]CSIR-Savanna Agricultural Research Institute, Manga Research Station, UER-Ghana

***Corresponding author:** Jacqueline Naalamle Amissah; jnamissah@ug.edu.gh

ABSTRACT

Frafra potato [*Solenostemon rotundifolius* (Poir. J. K. Morton] is a minor tuber crop that has the potential to address food and nutrition security issues in the wake of climate change. The crop contains higher levels of iron compared to other tuber crops like cassava, yam and sweet potato. In addition, it is adapted to marginal soils and drought conditions. Unfortunately, it is becoming extinct as the focus has been on a few declining but widely cultivated crop species. In this study, fifteen microsatellites (SSR) primers were used to characterize 57 accessions collected from the Northern, Upper West and Upper East Regions of Ghana. These accessions were subsequently characterized using 15 qualitative and 15 quantitative morphological descriptors. Both morphological and molecular analyses grouped the accessions into two clusters. Accessions UE004, UE008 and QA99067 were found to be very promising and can be multiplied for farmers or used as parents in a hybridization programme for improvement of the crop.

Keywords: Accessions, characterization, simple sequence repeats, minor tuber, indigenous crop, food security.

Introduction

Frafra potato (*Solenostemon rotundifolius*) is a minor underutilized tuber crop with resilience to climate change and global warming. It originates from East and Central Africa and is currently grown in parts of Asia and Africa. In Ghana it is traditionally grown in the Northern, Upper East and Upper West regions (Sugri *et al.,* 2013) where it is seen as an important food security crop. The local name of the crop varies depending on the geographic location. It is referred to as 'Frafra' potato (Persa) in Ghana, 'Hausa' potato in Nigeria, 'Sudan' potato in Sudan, 'Zulu' potato in South Africa and 'Chinese' potato in parts of India (PROTA, 2004).

S. rotundifolius is a dicotyledonous root crop belonging to the mint family Lamiaceae or Labiatae and a subfamily Neteptoideae (Agyeno *et al.,* 2014), and has 2n = 62 chromosomes (PROTA, 2004). The leaves of Frafra potato have a characteristic, minty aromatic smell which is said to be the result of volatile oils present in the sacs of the leaves (Enyiukwu *et al.,* 2014). Its leaves are slightly thick and distinctively veined or thick with invisible veins (Nkansah, 2004). The leaves are arranged in a simple opposite fashion and are either mostly pigmented along the edge or the entire leaf, or scattered on the leaf surface. It has a succulent stem that is branched and either erect or decumbent. Its flowers come in hues of purple/pink (pale violet, bluish purple, white or pinkish) and are small, hermaphroditic and zygomorphous in nature. The flowers are borne on a distal inflorescence with thin false spikes that are approximately 15cm long (Enyiukwu *et al.,* 2014; Sugri *et al.,* 2013). The pedicel of the crop is about 1-2 mm long and has a campanulate calyx about 1-3 mm long (PROTA, 2004).

As a food crop, it is rich in all the nutritional elements expected in a staple crop. According to Nkansah (2004), the composition of a 100 g portion of the raw tuber of Frafra potato contains approximately 75.6 g of water, 394 kJ of energy, 1.4 g of protein, 0.2 g fat, 21.9 g of carbohydrate, 1.1 g of fibre, 17 mg of Ca, 6.0 mg of Fe, 0.05 mg of thiamine, 1.0 mg of niacin, and 1 mg of ascorbic acid. The iron content of Frafra potato tubers is six times (6.0 mg/100 g) that of Irish potato (0.78 mg/ 100 g) and contains high amounts of reducing sugars (26 mg) in its tubers compared to other tuberous staples (Anbuselvi and Balamurugan, 2013a; Enyiukwu *et al.*, 2014; Kwarteng *et al.*, 2018). Its leaves also contain significant amounts of potassium (0.9 mg), phosphorus (24 mg) and 0.8 mg of sodium (Anbuselvi and Balamurugan, 2013b). It is known to have medicinal benefit due to the presence of a variety of secondary metabolites such as tannins, terpenoids, saponins, steroids, alkaloids and anthocyanins (Anbuselvi and Priya, 2013; Kwarteng *et al.*, 2018). The leaves of the crop are used in the treatment of dysentery, stomach pain, nausea, vomiting, diarrhoea, mouth and throat infections and as a purgative, a carminative and an anthelmintic (Anbuselvi and Priya, 2013; Archana *et al.*, 2015).

Despite these attributes, the availability of Frafra potato (FP) is impeded by a number of production constraints such as small tuber sizes, low yielding varieties, high postharvest losses, pests and diseases (Sugri *et al.*, 2013). Of these, small tuber sizes constitute the major constraint identified by Sugri *et al.* (2013) and hence the need for its improvement.

In order to address these production constraints, there is the need to identify promising Frafra potato accessions for use in crop improvement and cultivation. Characterization is the description of plant germplasm for identification and differentiation (de Vicente *et al.*, 2005) using physical, agronomic or morphological characteristics and molecular markers such as microsatellites to identify variation in plant species. Microsatellites, or simple sequence repeats (SSR) are repeated sequences of nucleotides distributed throughout the genome that occur mainly in non-coding regions (Ellegren, 2004). SSR markers have the advantage of being low-cost and highly polymorphic, making them an ideal tool for determining genetic diversity among different cultivars. It aids in the development of adequate information for species that are already existing and need improvement or are underutilized and require improvement (Bioversity International, 2007).

The aim of this study was to determine the variability and relatedness among Frafra potato accessions, and to identify potential accessions for cultivation and improvement.

Materials and Methods

Planting materials and DNA extraction

Fifty-seven (57) accessions of Frafra potato tubers from the Northern (15 accessions), Upper East (24 accessions) and Upper West (18 accessions) regions were obtained from the Savannah Agricultural Research Institute (SARI-CSIR) and the Plant Genetic Resource Research Institute (PGRRI) Bunso, Ghana. The tubers were planted out in the Department of Crop Science, University of Ghana. Leaf samples were collected and DNA extracted for molecular characterization using the Cetyl trimethylammonium bromide (CTAB) procedure (Winnepenninckx, 1998).

Experimental design, field layout and cultural practices

Field evaluations were carried out from September 2016 through March 2017 at the University of Ghana farms in the Coastal Savannah Zone of Ghana. The area has a mean annual rainfall of ~ 800 mm with a range of 500 mm to 1270 mm per annum. The field experiment was laid out in a randomized complete block design with three replications. Each experimental entry was represented by three mounds per replication, making a total of 171 mounds for the experiment. Mounds measured 1m x 1.5 m and were spaced 50 cm apart. Ten (10) sprouted tubers were transplanted onto the field at a planting distance of 20 cm apart per plot. Weeding was manually carried out as and when needed. To protect against insect pests, the field was sprayed with a systemic insecticide, Akape® 20SC (200 g/Litre imidacloprid) at a rate of 1ml per 2.2 litres of water two weeks after sowing and subsequently sprayed with Attack® (475 g/Litre pirimiphos-methyl +

25 g/Litre permethrin EC) at 2.5 ml per litre of water at six weeks after sowing.

Morphological characteristics assessed

Morphological characterization was carried out using 15 qualitative and 15 quantitative descriptors, developed from descriptors used by Opoku-Agyemang *et al.* (2007) and Nanema *et al.* (2009). Table. 1 shows the descriptors used and their measurements. All qualitative characters were described using five randomly selected plants from each accession. Data on the five plants were collected using a scoring system, where the presence or the absence of a character is scored as 1, 2 or 3 depending on the number of variants observed in the accession. Where two different colours were involved, Mansell's colour chart was employed. Both continuous and discontinuous quantitative variables were scored.

Molecular characterization

Polymerase chain reaction (PCR) was performed using 15 oligonucleotide primers developed by Hua *et al.* (2018). Ten (10) µL reaction: 4 ng genomic DNA, 1×PCR Gold Buffer (Applied Biosystems, Carlsbad, California, USA), 2.5 mM $MgCl_2$ (Applied Biosystems, Carlsbad, California, USA), 0.25 mM dNTPs, 5% dimethyl sulfide (DMSO; Fisher Scientific, Pittsburgh, Pennsylvania, USA), 0.4 U AmpliTaq Gold Polymerase (Applied Biosystems), 0.25 µM primer pair (both forward and reverse) and sterile water. The Qiaxcel Advanced Electrophoresis system was used with an internal alignment marker 15/600bp and an internal size marker 25-500bp.

Data analysis

The data collected using these descriptors were subjected to univariate and multivariate analysis in R software version 3.3.3, GENSTAT 2012, and XLSTATS version 2017. The univariate analysis was done using results of the quantitative traits while the qualitative traits were tested using descriptive statistics. Multivariate analysis was also performed on both qualitative and quantitative traits using principal component analysis. Correlation in phenotypic traits was assessed using the quantitative traits. Cluster analysis was used to determine relatedness among the accessions.

Results

Variation in qualitative morphological traits

Variation in basal stem colouration was observed among the accessions, with 47% showing stem colourations while the remaining 53% did not show any basal stem colouration (Figure 1). Colouration of the first node was observed in 38 % of the accessions (Figure 2). The rest of the accessions had the normal green colouration of the first node.

Thirty-five of the accessions were short (15-29 cm), while the remainder were taller (> 20 cm) (Figure 3).

Diversity in leaf pigmentation was observed among the accessions, pigmentation along half the edge of the leaf towards the narrow upper region of the leaf, pigmentation on the leaf surfaces, pigmentation along the entire edge of the leaf and no pigmentation on the leaves (Figure 4). The last group was the most common. Foliage colour among the accessions also varied, with some accessions having light green (19.3%), green foliage (73.3%) and a mixture of green and light green foliage colouration (7.4%) (Figure 5).

Two major variants were observed in leaf waffleness (Figure 6). One variant with small and slightly thick leaves measuring about 4.5 cm in length was observed in 68 % of the accessions, and the remaining accessions had broad, thick leaves approximately 8 cm in length. Also, two types of leaf arrangements , dense and very dense, were observed (Figure 7).

There were two variants among the accessions regarding the type of inflorescence they produce: pale violet (51%) or bluish white (31.5%) (Figure 8). Ten of the accessions (17.5%) did not flower. Two tuber skin texture variants were present among the accessions (Figure 9). Thirty-six (36) accessions had smooth skin tubers, while the others (21) were rough skin. Diversity was observed also in the shapes of the tubers, in the form of three tuber shapes: oblong, ovoid and long (Figure 10).

Three tuber skin colours were observed in the collection studied (Figure 11). The most common was the brownish skin colour. Some accessions showed blackish skin and others had whitish skin. Variations observed in tuber size showed 44 accessions representing 77.2% of all the accessions studied had small tuber sizes, 10 accessions representing 17.5% showed medium tuber sizes and 3 of the accessions representing 5.3% had big tuber sizes. Figure 12 shows the distribution of tuber size among the accessions studied.

Table 1: Qualitative Descriptors used to characterize *S. rotundifolius* accessions

Trait	Description	Measurement
Basal colour of the stem	Variation in the colour of basal stem	1. Coloured 2. Not coloured
Colour of first node	Variation in the colour of the first node of some of the accessions	1. Coloured 2. Not coloured
Presence of pigmentation on leaves	The leaves of some accessions are coloured at different parts of the foliage.	1. Presence of pigmentation on top of the edge of leaves 2. Pigmentation on all leaves 3. Pigmentation on both edges of the leaf 4. No pigmentation on leaves
Foliage colour	Colour of the whole foliage in different shades of green	1. Light green 2. Dark green
Leaf waffleness	The leaves of various accessions are different in thickness and smoothness	1. Small sized and slightly thick and distinctively veined leaf about 4.5cm in length 2. Broad and very thick leaf of about 8cm in length with invisible veins
Leaf density	Arrangement of leaves and number of leaves on the stem	1. Dense 2. Highly dense
Flowering	Has the accession flowered or not	1. Flowered 2. No flowering
Type of flower	Different flower colouration in the accessions that flowered	1. Blue-pale 2. Purple 3. No flowering
Tuber texture	Variations in the tuber texture	1. Smooth 2. Rough
Tuber shape	Shape of harvested tubers	1. Oblong 2. Ovoid 3. Both 1 and 2
Tuber Skin colour	Colour of harvested tubers	1. Brownish 2. Blackish 3. Whitish
Presence of lateral tubers	Other tuber apart from the oblong, and Ovoid	1. Present 2. Absent
Tuber size	Size of harvested tubers	1. Small tubers (< 10 g) 2. Medium (> 10 g < 20 g) 3. Big (> 20 g)

Fig. 1: Diversity in basal stem colour
(a= Coloured basal stem, b= Green Basal stem)

Fig. 2: Diversity in Colour of First node
(a= Coloured node, b= Normal green node colour)

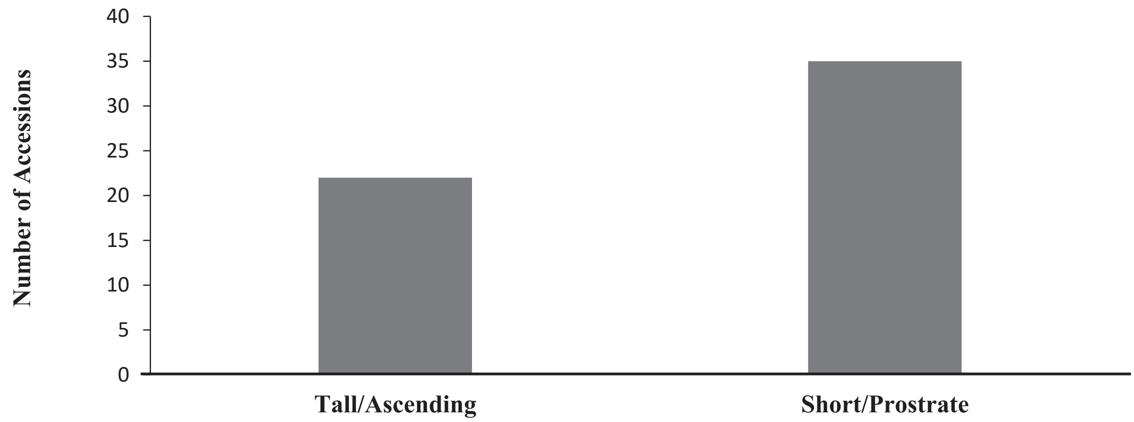

Fig. 3: Diversity in height and growth form among accessions

Fig. 4: Diversity in pigmentation on leaves
(a=Presence of pigmentation on half of the edge of leaf, b= Presence of pigmentation on Leaf (PPL) surface, c= PPL on entire edge of the leaf, d= No pigmentation on leaf)

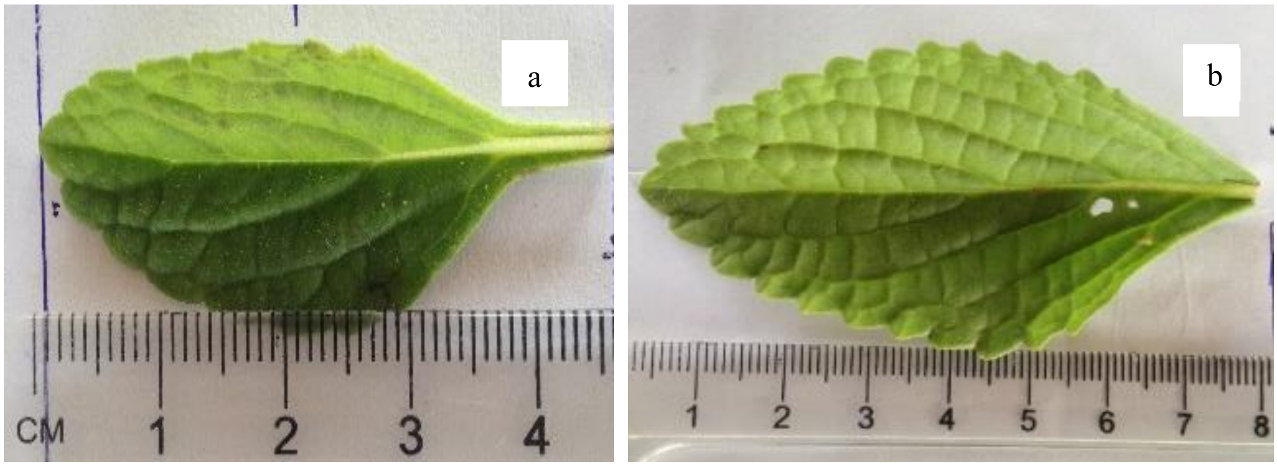

Fig. 6: Diversity in leaf waffleness
(a= Small sized and slightly thick leaf about 4.5 cm in length, b= Broad and very thick leaf of about 8 cm in length)

Fig. 7: Diversity in leaf density
(a= Dense, b= Highly dense)

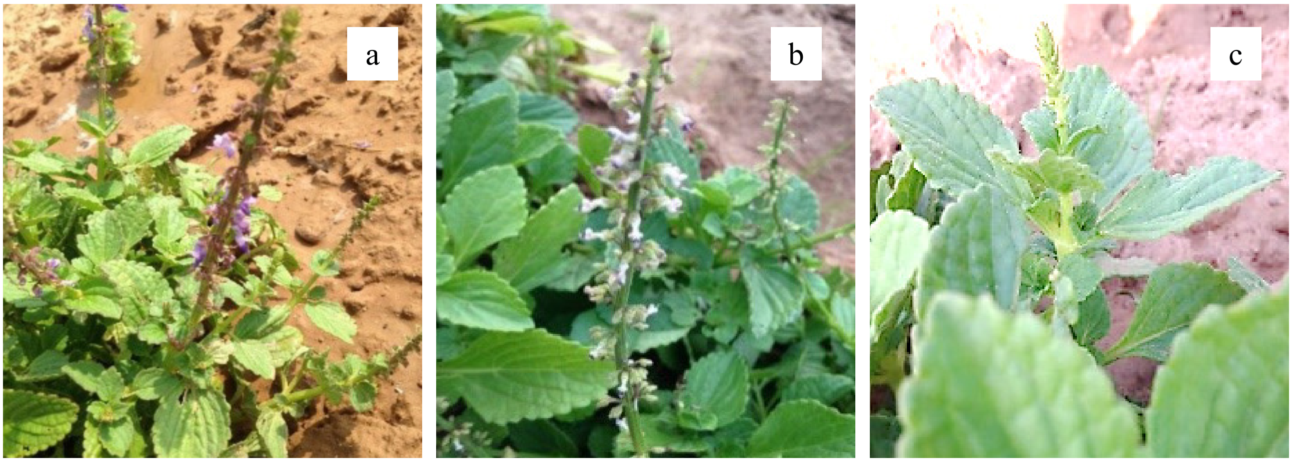

Fig. 8: Diversity in type of flower
(a= Pale violet, b= Bluish white, c= No flowering)

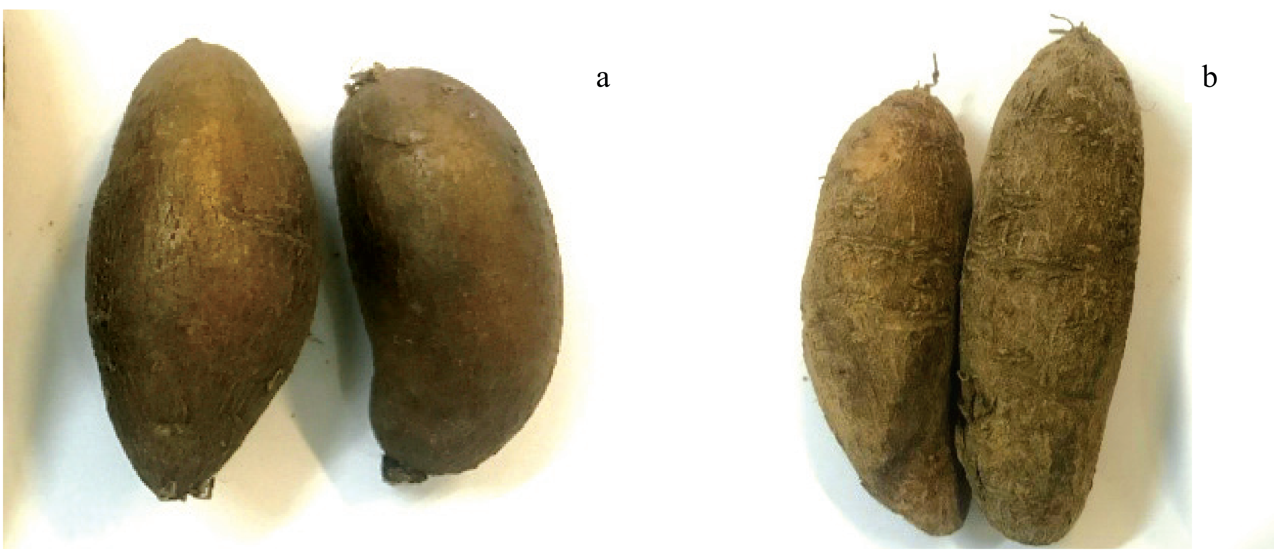

Fig. 9: Diversity in tuber skin texture
(a= Smooth Tuber Skin Texture (TTE), b= Rough TTE)

Fig. 10: Diversity in tuber shape
(a= Oblong Tuber Shape (TS), b= Ovoid TS, c = Long TS)

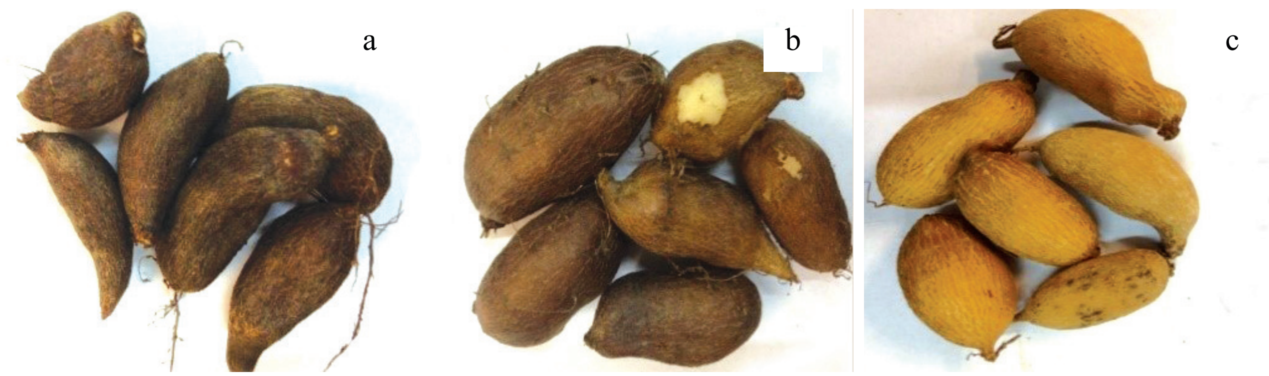

Fig. 11: Diversity in tuber skin colour
(a= Blackish tuber skin colour, b= Brownish tuber skin colour, c= Whitish tuber skin colour)

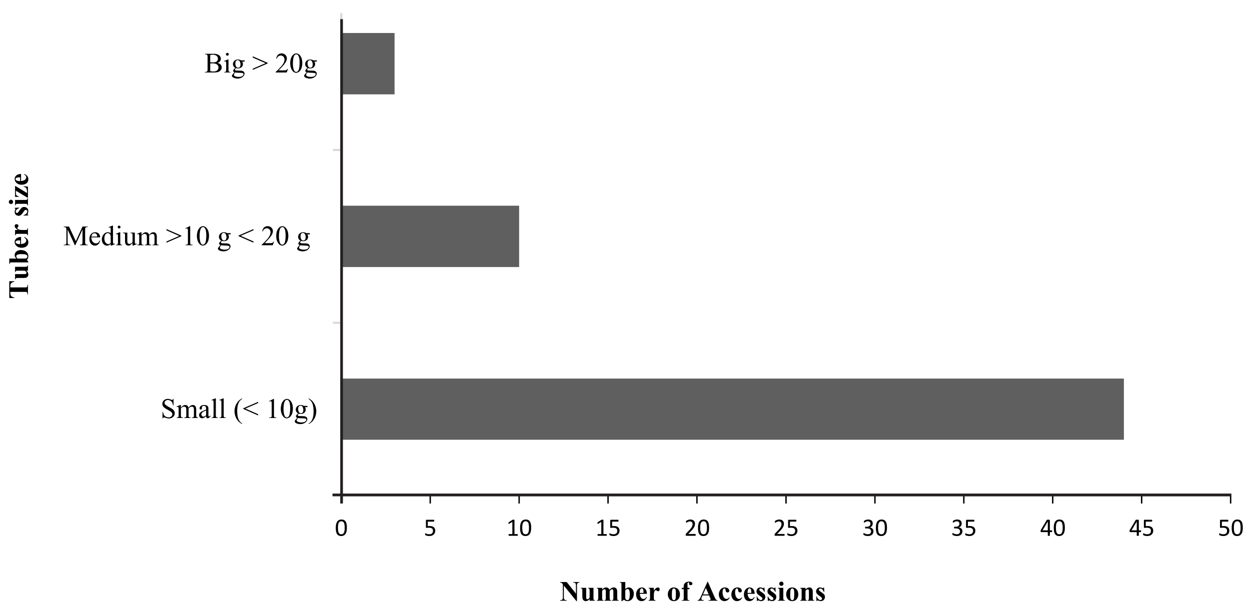

Fig. 12: Variation in tuber size among accessions

Relatedness of accessions based on qualitative traits

The sequential agglomerative hierarchical and nested (SAHN) cluster analysis using the Unweighted Pair Group Method on all qualitative descriptors grouped the accessions into three clusters (Figure 13). At a dissimilarity index of 86%, the first cluster included 10 accessions, the second cluster 36 accessions and the third cluster 11 accessions.

Associations among quantitative morphological traits

Days to flowering correlated negatively with leaf area, number of internodes, and the total number of tubers per plant, but this was not significant (Table 2). Days to flowering however correlated positively with all other descriptors. Days to maturity correlated negatively with plant height, length of the principal stem, number of internodes, and average weight of tubers, but correlated positively and significantly with Leaf area (r = 0.32, P < 0.05) and positively with the other descriptors. Plant height correlated positively with leaf area and weight of total tubers per plant, positively and significantly with Length of the principal stem ($r = 0.98$, $P < 0.001$) and number of internodes ($r = 0.71$, $P < 0.001$), but negatively with the remaining descriptors. Leaf area had a negative correlation with days to flowering, a positive significant correlation with the total number of tubers per plant ($r = 0.30$, $P < 0.05$), and positive correlation with leaf area and weight of total tubers per plant.

Length of principal stem showed high positive and significant correlation with only number of internodes ($r = 0.74$, $P < 0.001$) and correlated positively with the weight of total tubers per plant. The number of internodes showed a positive correlation with the total number of tubers per plant, the weight of total tubers per plant, and the average weight of tubers.

The total number of tubers per plant showed a high positive correlation with the weight of total tubers per plant ($r = 0.74$, $P < 0.01$), but correlates negatively with average weight of tubers. The weight of total tubers per plant showed positive significant correlation with average weight of tubers.

Relatedness of accessions based on quantitative traits

The SAHN cluster analysis of the quantitative descriptors grouped the accessions into four clusters (Figure 14). At a dissimilarity index of 65 %, the first cluster included 18 accessions, the second 19 accessions, the third 18 accessions and the fourth two accessions (UE004 and QA99067).

Relative contribution of quantitative traits to diversity in accessions

The relative contribution of each quantitative morphological trait to the total variability observed among the Frafra potato accessions studied is shown in Table 3. The sum of the first five principal components accounted for about 75 % of the total quantitative variation observed among the accessions.

The first principal component accounted for about 24 % of the total quantitative variation, with NST, NBT, TTP, WTP and DBT as the key traits of importance. The traits HE, LPS and NIN were the key ones accounting for 19 % of the variability in the second principal component observed. The third principal component (14 %) had the diameter of small tubers (DST), the average weight of tubers (AWT) and diameter of medium tubers (DMT) showing the greatest influence.

Figure 15 shows a biplot using the first and the second principal components. Principal component one separated the accessions into two major groups of 25 and 32 showing that the accessions within a group are closely related than accessions separated into the other group. Principal component two divided the accessions into two major groups of 26 and 31 as well. The plotting of both PC1 and PC2 grouped the accessions into four groups with closely related accessions clustering in one group and diverse accessions forming other groups.

Relatedness of accessions based on combined quantitative and qualitative traits

The SAHN cluster analysis using the combination of quantitative and qualitative descriptors grouped the accessions into three clusters (Figure 16). At a 95 % dissimilarity index, cluster one included 23 accessions, cluster two 32 accessions and the third, tow accessions two accessions.

Relatedness of accessions based on SSR results

The results of the SAHN cluster analysis using the 15 simple sequence repeat markers is shown in the dendogram in Figure 17. The accessions were grouped into ten main clusters, namely cluster 1 to cluster 10. The majority of accessions were grouped in cluster 1 (25 accessions). Cluster 2 had two accessions which are UE018 and UW015, cluster 3, 11 accessions, cluster 4 seven accessions, clusters 5, 8, 9 and 10 had one accession each: UE005, UW022, WHITE and QA99016 respectively. Meanwhile, cluster 6 had six accessions and cluster 7 had two accessions (UE014B and QA99067) clustering as one group.

Genetic parameter summary

Primers Sr021 and Sr034 showed the highest allele frequency of 0.82 and 0.83 respectively (Table 4). On average, all the primers showed 0.54 allele frequency. Primer Sr020 showed the highest allele number, while on average, all the primers showed 5 alleles. While the diversity of the genes among the accessions was 0.57, primer Sr020 showed the highest diversity of 0.78. On average, all the primers showed 0.58 heterozygosity. Primers Sr023, Sr024, Sr037, Sr039 and Sr045 showed the highest heterozygosity of 1 or 100 %. The most polymorphic primer was Sr020 while the least polymorphic was Sr034. All the primers showed 0.52 polymorphism information content, on the average.

Table 2: Correlation coefficient (*r*) among quantitative descriptors

	DFL	DMA	HE	LA	LPS	NIN	TTP	WTP
DMA	0.16 ns							
HE	0.11 ns	0.12*						
LA	-0.01 ns	0.32*	0.16 ns					
LPS	0.15 ns	-0.12 ns	0.98***	0.16 ns				
NIN	-0.002 ns	-0.19 ns	0.71***	0.24 ns	0.74***			
TTP	-0.01 ns	0.20 ns	-0.05 ns	0.29*	-0.03 ns	0.01 ns		
WTP	0.13 ns	0.24 ns	0.01 ns	0.22 ns	0.01 ns	-0.01 ns	0.74***	
AWT	0.04 ns	-0.01 ns	-0.06 ns	0.20 ns	-0.05 ns	0.02 ns	-0.01 ns	0.41**

*P< 0.05, **P<0.01, ***P<0.001, ns, not significant. Days to flowering (DFL), Days to maturity (DMA), Height (HE), Leaf area (LA), Length of principal stem (LPS), Number of internodes (NIN), Total number of tubers per plant (TTP), Weight of total tubers per plant (WTP), Average weight of tubers (AWT)

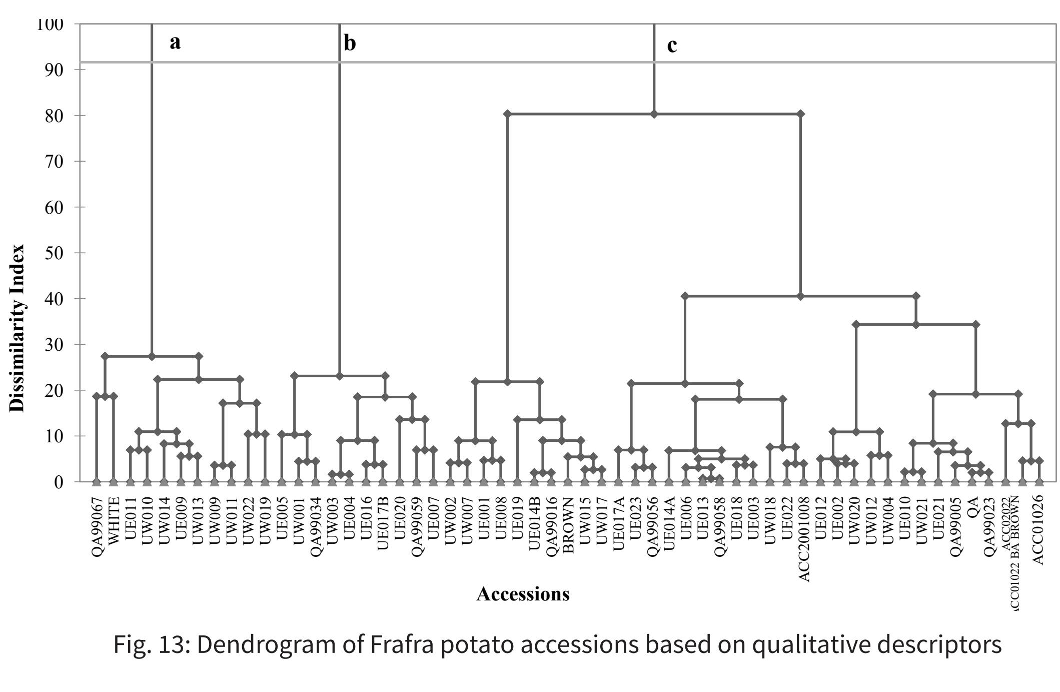

Fig. 13: Dendrogram of Frafra potato accessions based on qualitative descriptors

Table 3: Principal component analysis of quantitative morphological traits

	Principal component axes (Loadings)				
Trait	PC1	PC2	PC3	PC4	PC5
DFL	0.228	0.058	-0.035	**0.690**	-0.133
HE	-0.319	**0.881**	-0.134	-0.044	-0.051
LPS	-0.311	**0.894**	-0.130	-0.037	-0.060
NIN	-0.247	**0.831**	-0.039	-0.050	-0.070
LA	0.331	0.436	0.188	-0.074	**0.672**
DMA	0.390	-0.034	-0.045	0.368	**0.686**
NST	**0.806**	0.235	-0.422	-0.010	-0.065
NMT	0.122	-0.353	-0.333	**-0.645**	0.109
NBT	**0.503**	-0.021	0.465	-0.212	-0.131
TTP	**0.818**	0.227	-0.438	-0.036	-0.059
WTP	**0.857**	0.255	-0.041	-0.175	-0.161
DST	0.358	0.213	**0.628**	-0.237	0.025
DMT	0.030	0.105	**0.668**	0.470	-0.085
DBT	**-0.713**	0.055	0.098	-0.350	0.271
AWT	0.349	0.115	**0.675**	-0.344	-0.098
Variation (%)	**24.359**	**18.867**	**13.861**	**10.894**	**7.360**
Cumulative variation (%)	**24.359**	**43.226**	**57.088**	**67.982**	**75.341**

Note: **DFL** = Days to flowering, **HE** = Height, **LPS** = Length of principal stem, **NIN** = Number of internodes, **LA** = Leaf area, **DMA** = Days to maturity, **NST** = Number of small tubers, **NMT** = Number of medium tubers**, NBT** = Number of big tubers, **TTP** = Total number tubers per plant, **WTP** = Weight of total tubers per plant, **AWT =** Average weight of tubers, **DST** = Diameter of small tubers, **DMT** = Diameter of medium tubers, **DBT** = Diameter of big tubers, **V** = Percentage variability, and **CV** = Cumulative variability

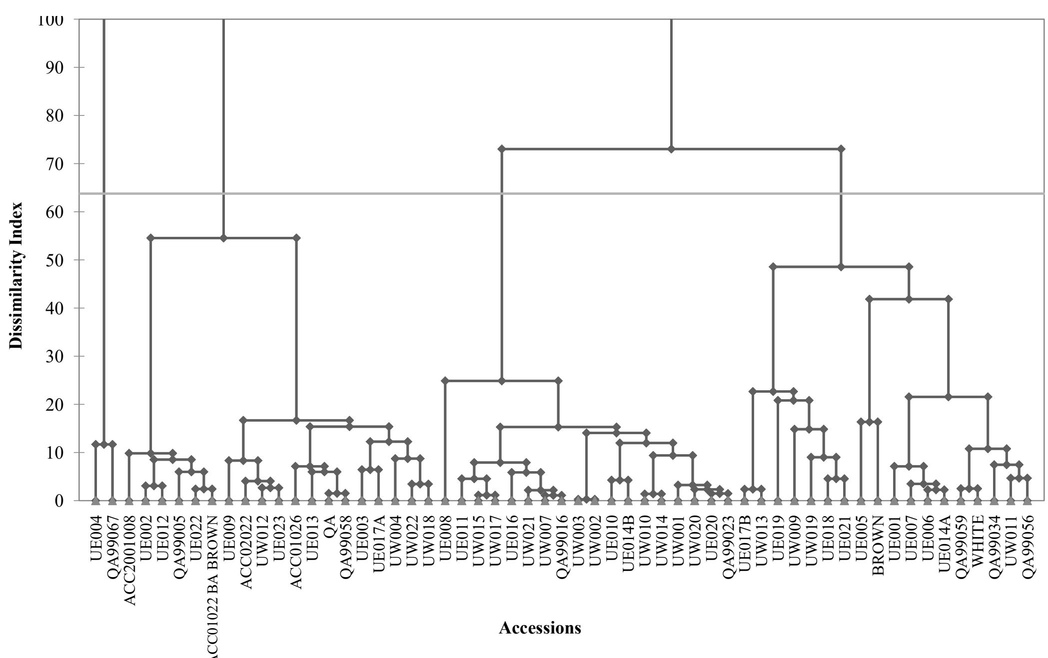

Fig. 14: Dendrogram of Frafra potato accessions based on quantitative descriptors

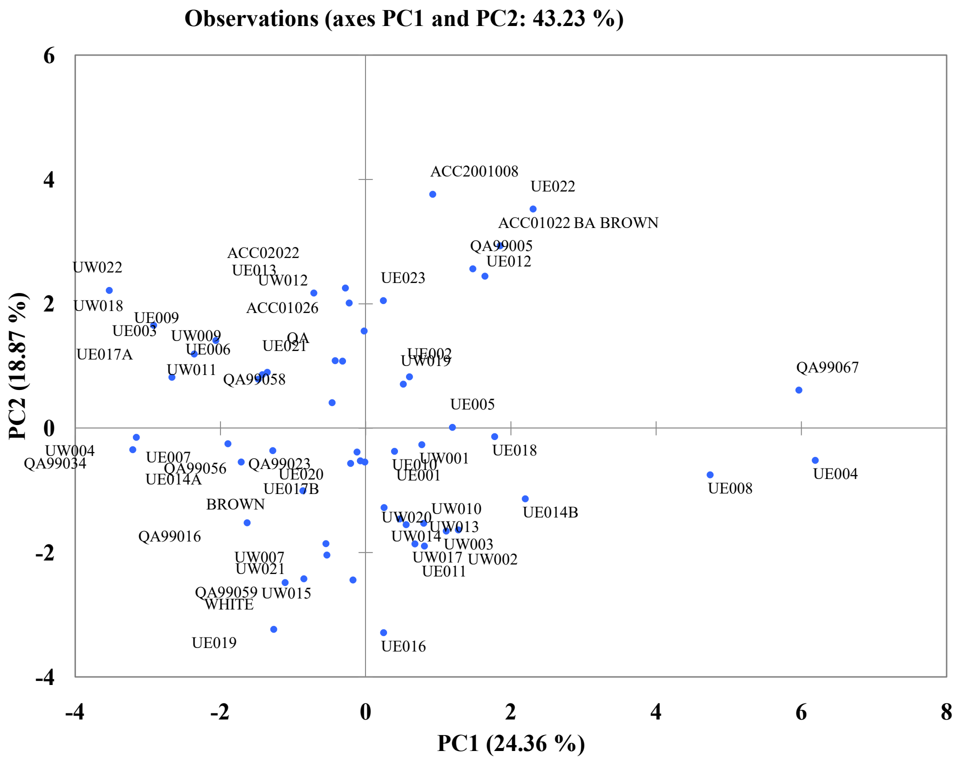

Fig. 15: Interspecific differences in Frafra potato accessions as given by PC1 and PC2.

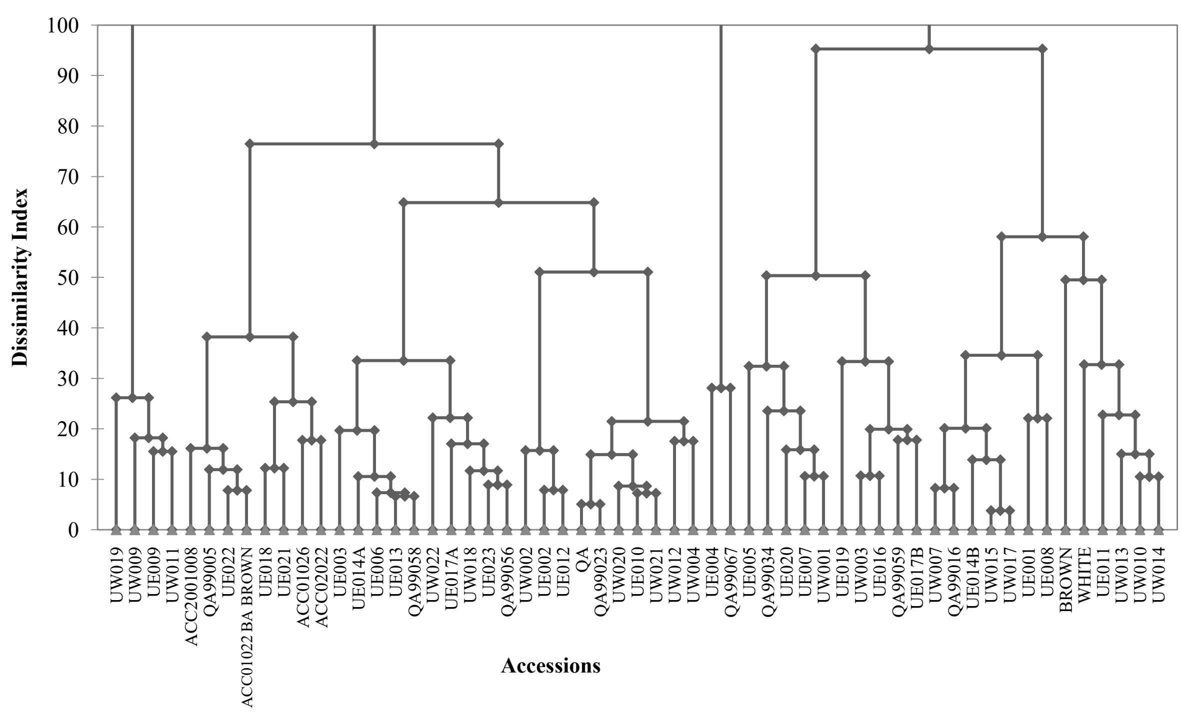

Fig. 16: Dendrogram of Frafra potato accessions based on qualitative and quantitative descriptors

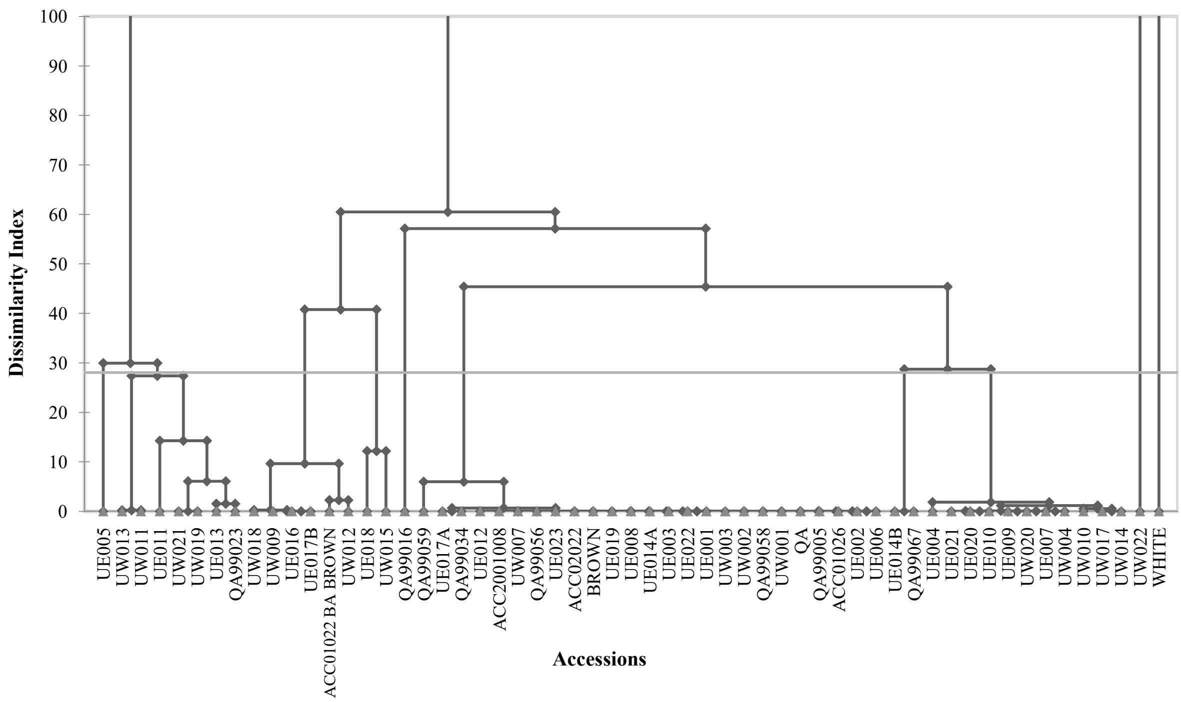

Fig. 17: Dendrogram of Frafra potato accessions based on SSR allelic data for fifteen primer

Discussion

The qualitative morphological traits showed an extensive diversity among the accessions studied. Colouration in Lamiaceae is reported to be due to the presence of anthocyanins which are mainly cyanidin saccharides and tannins (Opoku-Agyemang *et al.*, 2007). Nanema *et al.* (2009) observed similar variants in a diversity study using 155 Frafra potato accessions. The presence of pigmentation on the first node was observed in majority of the accessions used in the study. This observation was contrary to Opoku-Agyemang *et al.* (2007) who found pigmentation on the first node in a few of the same accessions in a previous study. The different results between the two studies could be attributed to differential expression of the anthocyanin gene or genotype-by-environment interactions resulting from the different study environments.

The presence of anthocyanins was also expressed in a form of pigmentation on the leaves of the accessions with the majority of the accessions not showing pigmentation, just as reported by Agyeno *et al.* (2014). Foliage colouration is a very important trait which conservationists and plant breeders cannot afford to neglect, as it could be linked to chlorophyll content (Liu *et al.*, 2014), an important trait indicating a plant's photosynthetic ability, which has a direct influence on crop yield. Nanema *et al.* (2009) and Opoku- Agyemang *et al.* (2007) observed similar traits at 53 % and 55 % respectively for the green foliage colour, indicating that the commonest, which could be the wild type foliage colour of the crop, is green.

Leaf waffleness and shape is an important trait in plants because it relates positively to chloroplast and stomata content (Kirhorekumar *et al.,* 2006). Nkansah (2004) reported two kinds of leaf forms and shape; these are predominantly slightly thick and distinctively veined or very thick with invisible veins. The current study observed that the majority of the accessions showed slightly thick and distinctively veined leaf types. This is an important trait that needs consideration for the breeding of Frafra potato since leaf waffleness and size influences carbon dioxide intercept and water use efficiency for growth and yield (Edison *et al*., 2006). Two kinds of leaf arrangement were observed. Most of the accessions had erect stems with dense simple opposite leaf arrangements, which agrees with a report by PROTA (2004). The rest of the accessions showed prostrating stems with very dense leaf arrangement. Leaf arrangement is known to influence light intercept and as a result affect photosynthetic action for growth and yield (Falster and Westoby, 2003). Flowering was variable among the accessions studied. Most of the accessions showed pale violet flowering which agreed with the literature (Taparga, 2001; PROTA, 2004).

Tuber characteristics are major traits used in the characterization of tuber crops for production and breeding purposes. Three main tuber skin colours were observed among the accessions; these were blackish, brownish and whitish, which correspond to nagra, rubra and alba as reported by NRI (1987). The majority of the accessions showed brownish tuber skin colour and this trait divided them into three morphotypes. Tanzubil *et al*. (2005) reported three main morphotypes using the above observed tuber skin colours. Prematilake (2005) and Jayakody *et al*. (2005), concluded that there were two morphotypes of Frafra potato in Asia based on the tuber skin colours seen in the current research. This is a good breeding trait for beauty and consumer acceptability. Based on tuber characteristics such as skin texture and shape, the accessions were characterized into two morphotypes. Tuber texture is reported to be advantageous for tuber storability (Cornelius, 1998). Two main shapes of Frafra potato tubers which are oblong and ovoid have been reported (Nkansah, 2004). The majority of the accessions produced oblong tubers. However, a long tuber shape was found mixed among the oblong and ovoid tuber shapes.

Tuber size distribution obtained was similar to that reported by Opoku-Agyemang *et al*. (2007). As this stands out as the major constraint of consumer acceptability of the crop (Sugri *et al*., 2013), accessions with big tubers in this study could be the starting material for developing tubers for consumer acceptability.

The quantitative data showed that flowering was observed at a minimum of 52 days and a maximum of 92 days after planting. Days to maturity was observed at a minimum of 92 days and a maximum of 136 days. Ouédraogo *et al*. (2007) reported longer days to maturity, between 120 and 180 days, compared to the current study. Meanwhile, Tarpaga (2001) observed similar days to maturity of 106 days. The mean diameter of the biggest and the smallest tubers was 26.14 mm and 11.09 mm respectively. The mean diameter of medium-sized tubers was 17.10 mm, ranging from 11.45 mm to 20.55 mm, and this was variable among the accession. Earlier research by Nanema *et al*. (2009) observed similar tuber diameter ranges (small = 10.30 mm, medium ones = 18.80 mm, big tubers = 28.50 mm). The low level of variability in the tuber size of *Solenostemon rotundifolius* observed in a previous study by Abraham and Radhakrishnan (2005) corroborates findings of the current study. The height of the plant and length of the principal stem both recorded 35 cm. The shortest plant was 15 cm and the tallest 35 cm. NRI (1987) reported height ranges of 20 cm to 30 cm. The result is similar to the reported height range for the crop. Meanwhile, Nkansah (2004) reported a height range of 40 cm to 60 cm. The variation observed could relate to the time of planting and the availability of resources (water and nutrient) since the crop is photosensitive. The accessions had a minimum of 5 internodes and a maximum of 13. The maximum and minimum leaf area observed was 87.5 cm^2 and 164 cm^2 respectively, although a larger leaf area is desirable for maximum light interception for photosynthesis (Charles-Edwards, 1982).

The minimum and the maximum number of tubers per plant observed was 17 and 126 respectively. Earlier research reported a similar number of tubers per plant of 100 to 150 tubers (Tarpaga, 2001). Weight of tubers per plant was very variable [minimum (13.7 g) and maximum (323.8 g)]. Such high variability is indicative of wide variation in the yield of the accessions studied. Earlier research by Tarpaga (2001) reported a lower number of tubers per plant (32 – 65 tubers), (16 – 36 tubers) and weight of tubers per plant (54 – 126 g) and (9 – 20 g) respectively. Meanwhile, Ouedraogo *et al*. (2007)

observed the tubers per plant ranging between 100-150 tubers. The average weight of tubers was given as 18.4 g minimum and 76 g maximum among the accessions. This shows a high level of variability in tuber yield of the crop.

Plant height correlated positively and significantly with days to maturity, implying that increases in plant height lengthen the days to maturity. Nanema *et al*. (2009) observed a similar correlation between height and days to maturity. Leaf area correlates positively with days to maturity, indicating the variation of these traits in the same direction. Length of the principal stem had a strong positive correlation with height, so it could be inferred that the length of the principal stem is the key determinant of the height of the accessions studied. Positive significant correlation was observed between number of internodes, leaf area and length of principal stem. A positive significant correlation was seen between the number of tubers per plant and leaf area, implying that leaf area affects the number of tubers per plant in the same direction. Nanema *et al*. (2009) had similar results. Weight of total tubers correlated positively with the number of tubers per plant, indicating that weight of tubers per plant increases as the number of tubers increases or decreases. Nanema *et al*. (2009) observed correlations between the weight of tubers per plant and number of tubers per plant. Total weight of tubers per plant correlated positively with the other descriptors analyzed for correlation. Total weight of tubers per plant also had a positive significant correlation with the average weight of tubers per plant.

The first principal component which represented about 24.36 % of the total variation seen in the accessions using quantitative descriptors had the number of big tubers, number of small tubers, total number of tubers per plants and the total weight of tubers correlating strongly with the first principal component. This implies that the first principal component increases or is dominated by these descriptors. The second principal component (18.87 %) increases with increasing height, length of principal stem and number of internodes. The third principal component increases with increasing diameters of small and medium size tubers, and the average weight of tubers. The fourth principal component increases with increasing days to flowering and decreasing number of medium tubers. The fifth principal component increases with increasing leaf area and days to maturity. UE004, UE008 and QA99067 recorded high values for PC1 and UW002, UW018, UE009, UE003 and UE017A recorded high values for PC2 based on the PCA plot.

Dendrogram analysis of the quantitative data classified the accessions into three morphotypes at a dissimilarity index of 65 %. Clusters one and two are closely related to each other and cluster three consisted of only two accessions thus corroborating the tree plot from the qualitative data. A tree plot generated from the combination of both quantitative and qualitative descriptors distinguished the accessions into three clusters at a 95 % dissimilarity index. Cluster three which consists of UE004 and QA99067, though it is bifolius and dissimilar from all the accessions, is later seen to show similarity with cluster 2. Hence the tree plot derived from the combined qualitative and quantitative data suggests the existence of three morphotypes, which could later be narrowed to two and subsequently a single population. It is therefore not wrong to assume that the collected accessions could be showing phenotypic differences that they acquired as a result of mutations at certain points to aid adaptation to the varying environments in which they are grown.

Molecular data were used to generate a dendrogram. The percentage similarity observed among the accessions ranges from 30 % to 100 %. There were 10 clusters at a 30 % dissimilarity index which was further distinguished into three clusters at a 60 % dissimilarity index. At a 95 % dissimilarity coefficient, the SSR results characterized the accessions into two clusters. The second cluster at 95 % consisted of only two accessions which were different from all the other accessions studied. These two accessions are WHITE and UW002 which were standing alone until a 95 % dissimilarity coefficient. These two accessions were the only ones that had white tuber skin colour, a possible indication that the difference observed in the molecular results, or the clustering of both of these accessions in one group, is due to an alteration in the genome, specifically the genes that code for tuber skin colour. These could be due to a nonsense mutation caused by extreme temperatures which converted the codon for tuber skin colour into a stop codon. Consequently, these two accessions do not translate the amino acid for tuber skin colour, leading to a situation known as albinism (white tuber skin colour), which might explain the similarity in the genome. The results from the molecular data indicate that the accessions studied could be derivatives of a single population and any visible difference could be attributed to a response to the environment and/or mutations.

Conclusion

The study revealed that considerable morphological variability exists within the 57 Frafra potato accessions studied. Morphological descriptors characterized the accessions into three morphotypes. Based on these quantitative descriptors, UE004, UE008 and QA99067 are the suggested promising accessions to be considered for improvement in tuber size and yield. The molecular characterization using SSR marker analysis consisting of fifteen primer pairs revealed diversity in the genome of the 57 Frafra potato accessions. The SSR results revealed 58 % heterozygosity among the accessions studied. The results of the molecular study showed relatedness in the genome of the accessions and hence placed the accessions into two groups which were further merged into a single group. Hence the molecular results suggest that the accessions came from a single population.

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Physicochemical and Sensory Characteristics of Bread Made from Wheat-Frafra Potato (*Solenostemon rotundifolius*) Composite Flour

Crossby Osei Tutu[1], Joris Gerald Niilante Amissah[1]*, Jacqueline Naalamle Amissah[2] and Firibu Kwesi Saalia[3]

[1]Department of Family and Consumer Sciences, University of Ghana
[2]Department of Crop Science, University of Ghana
[3]Department of Food Process Engineering, University of Ghana
***Corresponding author:** Joris Gerald Niilante Amissah; jgnamissah@ug.edu.gh

ABSTRACT

Climate change threatens food security globally. This has made it necessary to explore the potential of indigenous climate-smart crops on the verge of extinction to ensure food security. This research studied the performance of Frafra potato flour (FPF) in bread production. The study was a one factor design in which wheat flour (WF) was substituted with FPF at 5%, 10%, 15% and 20% levels of incorporation. Proximate composition of WF, FPF and FPF-WF composite samples were analyzed. Composite bread made from the formulations was analyzed for sensory characteristics, instrumental texture and tri-stimulus colour (L-value). Moisture, protein, fibre and ash content of the composite flour increased with increasing FPF while carbohydrate content decreased ($p \leq 0.05$). Composite bread samples were harder than the control (100% WF) when the FPF content exceeded 5%. Tristimulus L value reduced, relative to the control, as FPF increased in composite bread samples, with 20% FPF recording the lowest L value ($p \leq 0.05$). Sensory analysis of the bread samples showed that bread with 5% and 10% FPF had overall acceptability, aroma, flavour and mouth feel scores that were comparable with bread made from 100% WF ($p \leq 0.05$). Results indicate that WF can be partially substituted with FPF to produce nutritious bread, with higher protein, fibre and ash content. Frafra potato can help address food and nutrition insecurity by increasing the use of this underutilized nutritious crop while providing food processors with a partial substitute for wheat flour in baking applications.

Keywords: Frafra potato, bread, flour, climate-smart, food security

Introduction

Frafra potato (*Solenostemon rotundifolius*) is also known by common names such as Sudan potato, Madagascar potato, Livingstone potato, Hausa potato, Salaga potato, Kaffrr potato, Country potato and Coleus potato (Abbiw, 1990). It is grown in Ghana, Nigeria, Mali and Burkina Faso. It is an important food crop in Northern Ghana, where it is mainly cultivated (Tortoe *et al.*, 2018; Akanlu *et al.*, 2005; Quainoo and Bayorbor, 2002; Tetteh and Guo, 1997). Frafra potato ranks highest in protein and some micronutrients among the tuber crops in Ghana (Quainoo and Bayorbor, 2002; Tetteh and Guo, 1997). It also serves as a good source of dietary fibre and minerals which contribute significantly towards good health (Sugri *et al.*, 2013; Akanlu *et al.*, 2005). It has been reported that the crop, with its relatively high nutritional properties, could serve as a good supplement to wheat flour in the bakery industry (Ofori *et al.*, 2009).

Research into Frafra potato has become crucial because this staple food crop in northern Ghana is now on the verge of extinction due to over dependence on its close substitutes (sweet potato and yam). With the general growing concern for improving food security, agriculture and dietary diversity (FAO, 2015), globalization is opening up new markets and creating avenues for fair trade and business. A global growing interest in organic and healthy food products has also created enormous potential which can be explored through the use of lesser known crops or indigenous food resources.

Wheat is important due to its unique characteristics that make it most suitable for pastry applications. However, the crop is imported by most developing countries and so takes a significant toll on the already deplorable economic situation in these countries. Substituting wheat flour with local food resource alternatives such as yam flour and sweet potato flour in baked foods, such as composite bread, where weaker flour is desired, has shown great potential for the utilization prospects of tuber flour, which would empower local farmers and enhance their livelihoods (Gratitude Project, 2014; Komlaga *et al.*, 2012). These improvements are aimed at reducing gluten and calories, enhancing dietary fiber content and improving the quality of baked products. Studies have shown diverse success levels with different ratios of substituted flour, and it has been established that partial substitution of wheat flour is possible (Gratitude Project, 2014; Aprianita *et al.*, 2013; Komlaga *et al.*, 2012).

Though opportunities to maximize the utilization of Frafra potato are available, there are barriers hindering the promotion and full utilization of the crop. Challenges such as limited knowledge of the nutritional and economic benefits of the crop, limited research into potential food applications, inadequate documentation of research findings and dissemination of information, discourage further investigations (Akanlu *et al.*, 2005; Tetteh and Guo, 1997). To address these barriers to utilization, this research focused on the production of new food products to widen the scope of the application of Frafra potato in food systems. The use of Frafra potato (a nutritious indigenous crop) has been investigated in some food processing applications, but not in bread making. Confirming the potential of Frafra potato flour as a partial substitute for wheat flour in bread making will improve its utilization and enhance its economic importance.

Methods

Source of Raw Materials

Four sacks (approximately 50 Kg each) of Frafra potatoes were purchased from Wa, Upper-West region, Ghana. Hard wheat flour was obtained from a local market in Accra, Ghana.

Flour Preparation

Frafra potato tubers were washed and blanched in hot water at 95 °C for 5 minutes to minimize microbial load. They were sliced into 2-3 cm strips. The strips were blanched in hot water at 95 °C for 2 minutes to prevent browning. They were oven dried at 60 °C for 12 hours. The dried strips were milled with a hammermill (containing a vertical rotating shaft on which hammers are mounted; the hammers are free to swing on the ends) and sieved (212 µm, US Standard Mesh No. 70) to obtain Frafra potato flour. Hard wheat flour (WF) was substituted with Frafra potato flour (FPF) at 5%, 10%, 15% and 20% levels of incorporation. The moisture content of WF and FPF was 13.54 % and 7.99 % respectively. The formulations were designated as F0, F5, F10, F15, and F20 flour samples respectively.

Colour Analysis of Flour

The colour of the flour blends was determined using a Hunter Lab Colour Analyzer (CR310 Chroma meter, Konica Minolta, Tokyo, Japan 76981007) to obtain the L^* (lightness), a^* (redness) and b^* (yellowness) values. Total colour change was calculated using $\Delta E^* = [\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}]^{1/2}$.

Proximate Composition

Proximate composition of the flour blends was determined according to AOAC methods (AOAC, 2005). Carbohydrate content was determined as the difference between 100% and the sum of the moisture, crude fat, protein and crude ash content.

pH

Ten percent (10%) suspension of each flour blend was prepared and the pH determined using a pH meter (Mettler Toledo model: SC220).

Water and Oil Absorption Capacity

Water absorption capacity was determined using the AACC method 56-20 (AACC, 2000) with modifications. Ten grams of flour (from each formulation) was mixed with 100 ml distilled water or oil in a weighed 200 ml centrifuge tube. The mixtures were agitated on a vortex mixer for two minutes, allowed to stand at 30.7 °C for 30 minutes, and then centrifuged at 500 x g for 20 minutes. The clear supernatant was poured out and discarded. The adhering drops of water were removed, the tube was weighed and the weight of water/oil absorbed by one gram of flour was calculated and expressed as water absorption capacity.

Brabender Viscoamylograph Studies

Pasting properties of the flour blends were determined using the Brabender Viscoamylograph. Forty grams of flour was weighed and then mixed with 200 mL distilled water in a canister. The canister was fitted into a Brabender (Viscograph – E, Brabender GmbH & Co. KG. 803301, 803301E000-02, Germany). The suspension was heated till the temperature of the resulting paste reached 92 °C, then left at this temperature for 15 minutes, cooled to 50 °C and held for 15 minutes at 50 °C. The heating and cooling were done at 3.0 °C per minute. Parameters such as peak viscosity (PV), peak temperature (PT) and pasting temperature (PT) were expressed in terms of Brabender Units (BU).

Bread Preparation

Main ingredients used were flour (hard wheat and Frafra potato), whole milk, margarine, water and yeast. The composite flour formulations (F5, F10, F15, and F20) were used. Flour and yeast were measured into a mixing bowl. They were mixed gently by hand, then water was measured and added to the mixture. The ingredients were combined with a dough scraper until they formed together. The dough formed was placed on a bench and kneaded for 2 minutes, after which it was hand-shaped into a ball and allowed to rest for 2 minutes (this was repeated 4 times). It was then divided into hundred gram (100 g) pieces. The pieces of dough were hand-shaped into balls and proofed. Bread was baked at 180 °C for 30 minutes, cooled to 25 °C after baking and stored in plastic bags.

Baking Loss

Baking loss was determined using the change in weight of composite dough before and after baking. This was expressed as percent weight loss.

Colour Analysis of Bread Crumb

The colour of the bread was determined using a Hunter Lab Colour Analyzer (CR310 Chroma meter, Konica Minolta, Tokyo, Japan 76981007) to obtain the L^* (lightness), a^* (redness) and b^* (yellowness) values. Total colour change was calculated using $\Delta E^* = [\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}]^{1/2}$.

Volume of Bread

Volume of composite bread samples was determined using a BVM Volume Meter (Model 6610, SE-12653 Hägersten, Sweden).

Texture of Bread

Texture analysis of the Crumb was performed on three slices taken from the centre of each loaf using a TA.XT2 Texture Analyzer (Stable Macro System, UK). The bread Crumb samples (20 x 20 x 20 mm) from the centre of each slice were compressed two times using a pre-set speed of 1.5 ms^{-1}, a contact force of 5 g, a distance of 8 mm and a data acquisition rate of 100 pps. The parameters assessed include hardness, cohesiveness and gumminess.

Sensory Evaluation

A panel made up of 60 judges was used to assess the sensory attributes of the bread samples. Parameters such as flavour, mouth feel, aroma, crust colour, difference and general acceptance were assessed. The test consisted of a 10 cm scale, ranging from "dislike very much" to "like very much", for each parameter (Blay, 2012). The bread formulations were designated as B0, B5, B10, B15, and B20, and used for the sensory assessment.

Data Analysis

A Completely Randomised Design was used to study the effects of the different levels of FPF incorporation on the product properties. One-way Analysis of Variance (ANOVA) and where necessary, the Least Significance Difference (LSD) was used to determine the differences between levels of supplementation of WF with FPF on product characteristics. A Randomised Complete Block Design (where assessors were the blocks and flour supplementation levels were the treatment) was used in the sensory evaluation and the results analysed using two-way ANOVA without replication.

Results and Discussion

Proximate composition of the samples is shown in Table 1. The moisture content of the flour samples ranged from 7.99% for WF to 13.54% for FPF. The protein content of flour samples ranged from 8.72% to 12.62%. Significant differences ($p < 0.05$) existed in the protein content among the flour samples, with the highest and lowest values being WF and FPF respectively. The ash content of the flour samples ranged from 0.69% to 6.42%, with FPF having the highest and WF having the lowest values. Significant differences ($p < 0.05$) existed in the proximate composition of the flours. The carbohydrate content ranged from 71.71 to 76.65%. Significant differences ($p < 0.05$) existed in the carbohydrate content of the flours with the highest and lowest values being WF and FPF respectively. The differences in flour proximate composition, is a result of the combination of two flours (WF and FPF) with different composition, at different levels of incorporation. This is very useful as it allows for the use of composite flours made with climate-smart local food resources to promote varied diets and address food security challenges in underdeveloped communities (Tortoe *et al.*, 2018; Baah *et al.*, 2005).

pH values of the flour samples ranged from 4.95 - 6.38, with FPF (100%) and WF (100%) having the highest and lowest values respectively. No significant difference ($p > 0.05$) existed amongst composite flour samples. The proximate composition, especially the protein and fat content of the flours and the flour ratios used, contributed to the changes in pH. Ageing can significantly reduce the pH of wheat flour and this positively affects baking taste (Jahed *et al.*, 2007). Since WF is imported into Ghana, it is evident that WF in the local markets has significantly aged. This explains why WF had the lowest pH. Low pH levels in the flours means improved baking taste and overall sensory appeal.

Table 1: Proximate composition of the flour samples

FWF	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Carbohydrates (%)
0%	13.54 ± 0.14^a	0.44 ± 0.04^a	12.62 ± 0.02^a	0.69 ± 0.07^e	72.71 ± 0.21^c
5%	13.48 ± 0.16^a	0.45 ± 0.03^a	11.53 ± 0.03^b	1.37 ± 0.09^d	73.17 ± 0.54^b
10%	13.20 ± 0.09^a	0.46 ± 0.04^a	10.88 ± 0.08^c	2.82 ± 0.01^c	72.64 ± 0.33^c
15%	12.77 ± 0.36^b	0.48 ± 0.07^a	10.23 ± 0.11^d	3.41 ± 0.18^b	73.11 ± 0.52^b
20%	12.61 ± 0.15^b	0.48 ± 0.09^a	9.67 ± 0.06^e	3.47 ± 0.34^b	73.77 ± 0.43^b
100%	7.99 ± 0.28^c	0.22 ± 0.02^a	8.72 ± 0.13^f	6.42 ± 0.29^a	76.65 ± 0.61^a

0%, 5%, 10%, 15%, 20%, and 100% are Frafra potato flour percentages in composite flour formulations. Values are means and standard deviations of triplicates

Means in same column with different superscripts are significantly different ($p \leq 0.05$)

The values were reported as % dry matter, except for moisture content values.

Water absorption capacities of the flour samples ranged from 0.81g to 4.46g of water absorbed per 1 g of flour, with FPF and WF having the highest and lowest values respectively (Table 2). Oil absorption capacities of the flour samples ranged from 118.88% to 150.62%, with FPF and WF having the highest and lowest values respectively (Table 2). Significant differences ($p < 0.05$) existed between water and oil absorption capacities of composite flour and WF samples. Flavour, aroma and texture are important sensory characteristics of flour products and major factors affecting sensory perception and consumer acceptance of flour products (Ohimain, 2014; Jacob and Leelavathi, 2007). These sensory characteristics are influenced by the water and oil absorption capacity of the flour used for the products (Pomeranz, 1998). Products made with flour with higher oil absorption capacity are likely to have good flavour and aroma which are imparted by the relatively high fat absorbed into the product (Popov-Raljić *et al.*, 2013; Olliver *et al.*, 2003). Water absorption on the other hand tends to influence the volume of the product (Pasha *et al.*, 2011).

Table 2: Percent water and oil absorption capacity of flour samples

Frafra potato/wheat flour	Water (%)	Oil (%)
0%	81.85 ± 0.03	118.88 ± 0.02
5%	97.55 ± 0.04	120.58 ± 0.02
10%	101.50 ± 0.07	129.49 ± 0.05
15%	112.48 ± 0.05	133.62± 0.03
20%	115.02 ± 0.02	133.98 ± 0.02
100%	445.85 ± 0.05	150.62 ± 0.01

0%, 5%, 10%, 15%, 20%, and 100% are Frafra potato flour percentages in composite flour formulations.
Values are means and standard deviations of triplicates

Table 3: Pasting properties of flour samples

Flour	P_{Time} (min)	P_{Temp} (°C)	PV	BD	SB	FV
0%	5.25 ± 0.10^{d}	64.0 ± 1.01^{c}	348.0 ± 0.72^{a}	123.2 ± 0.48^{a}	186.3 ± 0.1^{a}	434.1 ± 0.4^{a}
5%	5.35 ± 0.27^{c}	64.1 ± 0.92^{c}	354.0 ± 1.03^{b}	117.9 ± 1.02^{b}	178.3 ± 1.05 ^{b}	410.4 ± 1.4^{b}
10%	5.40 ± 0.91^{c}	65.7 ± 1.03^{b}	310.0 ± 1.04^{c}	120.0 ± 0.71^{c}	160.4 ± 1.5 ^{c}	345.7 ± 1.1^{c}
15%	5.50 ± 1.02^{bc}	66.1 ± 0.81^{b}	274.3 ± 1.04^{d}	105.8 ± 0.82^{d}	137.1 ± 1.2 ^{d}	300.9 ± 1.6^{d}
20%	6.05 ± 3.71^{b}	66.5 ± 0.41^{b}	239.0 ± 1.08^{e}	91.7 ± 1.05^{e}	125 ± 0.9 ^{e}	267 ± 1.4^{e}
100%	14.40 ± 0.10^{a}	93.2 ± 0.71^{a}	28.7 ± 0.50^{f}	0 ± 0.01^{f}	18 ± 1.0 ^{f}	49.6 ± 1.1^{f}

Values are means of triplicate determinations. Means in the same columns with different superscripts differ significantly ($p \leq 0.05$). $P_{Temp.}$ = Pasting temperature; P_{Time} = Pasting time (min); PV = Peak Viscosity; FV = Final Viscosity; BD = Break Down; SB = Set Back

Pasting properties of the flour samples showed significantly different ($p \leq 0.05$) peak viscosity values, with WF having the highest peak viscosity score (348.0 BU) and FPF having the lowest peak viscosity score (28.7 BU). FPF had the lowest peak and break down viscosity (Table 3). Factors that might have contributed to the lower viscosities in this study include the components such as protein, which interfere with the pasting process, and the lower amount of amylose and starch or the activity of amylose in the composite flour (Aprianita *et al.,* 2013). Another factor is the effect of storage time. Disulphide-bond formation in protein networks, which increases during starch aging as a result of increased storage time, could lower the pasting viscosity of starch. The low setback value of these composite flour samples shows their low retrogradation tendency, which is important for foods that require cold storage or freezing. Low breakdown viscosity of these samples, as compared with that of wheat flour, reflects the stability of these materials toward heat and mechanical processing. This property is crucial for food production that involves heat and mechanical treatment in bread making (Tortoe *et al.,* 2018; Aprianita *et al.,* 2013).

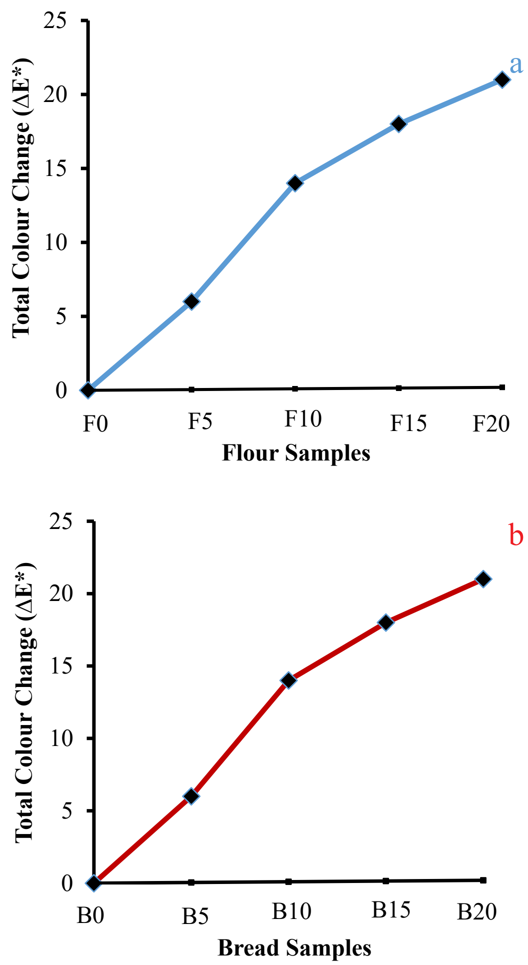

Fig. 1: Effect of Frafra potato flour incorporation on the colour of (a) Flour and (b) Bread Samples.

F0, F5, F10, F15, F20 are flour and B0, B5, B10, B15, B20 composite bread samples with 0%, 5%, 10%, 15%, and 20% Frafra potato flour, respectively.

Total colour change (ΔE*) of flour samples ranged from 6.72 - 21.89, with 5% Frafra potato-wheat composite flour and 20% Frafra potato-wheat composite flour having the lowest and highest values respectively (Figure 1a). Significant differences ($p < 0.05$) existed between the colour of flours and bread samples. Total colour change (ΔE*) of bread samples ranged from 6.58 - 23.30, with 5% Frafra potato-wheat composite bread and 20% Frafra potato-wheat composite bread having the lowest and highest values respectively (Figure 1b). The effect of colour change increased with increasing levels of FPF substitution in the samples. Significant differences ($p < 0.05$) existed between flour and bread samples. Hence it can be deduced that increased addition of FPF made the samples turn darker relative to the control. There were relatively higher b* values in the composite bread samples compared with their respective flour formulations. This may be due to the introduction of fat (margarine) in making the bread. The brand of margarine used has a bright yellowish colour which may have contributed to the higher b* values recorded.

Percent weight loss of bread samples after baking ranged between 8.34% to 20.35% with 20% Frafra potato-wheat composite bread and WF bread having the lowest and highest values respectively (Table 4). Significant differences ($p < 0.05$) existed between the weights of the bread samples after baking. Higher water absorption capacity of FPF indicates the tendency for a relatively high water retention capacity of composite flour dough even after baking. It is not surprising that composite bread samples were relatively heavier than the control. Weight is an important quality of bread, especially in Ghana where consumers associate bread quality with weight (Tortoe *et al.*, 2018)

The volume of bread samples ranged between 357.60cm^3 to 447.31cm^3 with 20% Frafra potato-wheat composite bread and wheat bread having the lowest and highest values respectively (Table 4). Significant differences ($p < 0.05$) existed between bread samples. Since fermentation is involved in bread making, there was an obvious loss in bread volume as levels of FPF substitution increased. This is due in part to poor CO_2 production in composite dough, but largely the result of inadequate gluten-activity in composite dough. Thus, Frafra potato flour is ideal for baked foods which do not require proofing or rising such as unleavened bread, cake and cookies (Aprianita *et al.*, 2013).

Table 4: Percent weight loss and volume of bread samples

Bread sample	% weight loss	Volume (cm^3)
B0	20.35 ± 0.19^a	447.31 ± 1.19^a
B5	16.10 ± 0.09^b	424.65 ± 0.82^b
B10	15.12 ± 0.05^c	402.30 ± 0.25^c
B15	9.27 ± 0.24^d	379.95 ± 0.94^d
B20	8.34 ± 0.51^e	357.60 ± 1.51^e

B0, B5, B10, B15, B20, are composite bread samples with 0%, 5%, 10%, 15%, and 20% Frafra potato flour respectively. Values are means and standard deviations of triplicates. Means with different superscripts are significantly different ($p \leq 0.05$)

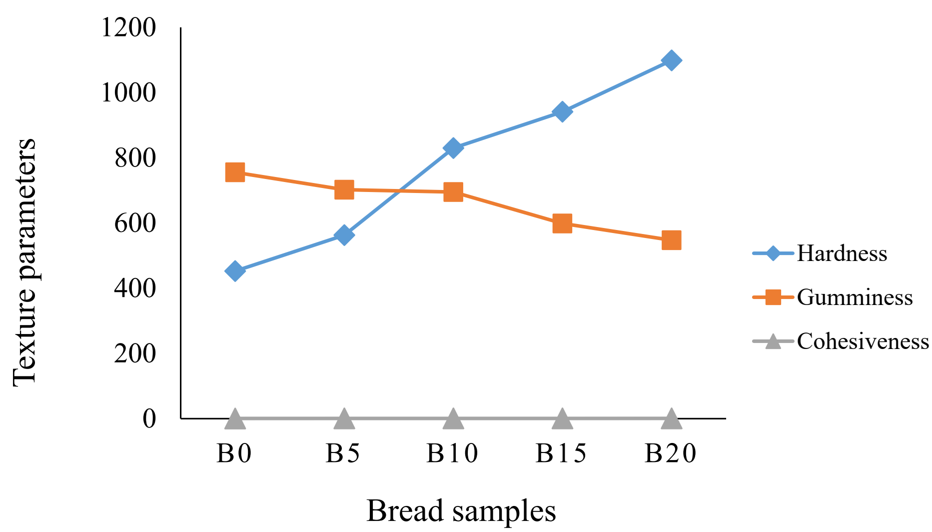

Fig. 2: Texture of bread samples

B0, B5, B10, B15, B20, are composite bread samples with 0%, 5%, 10%, 15%, and 20% Frafra potato flour respectively.
Values for hardness and gumminess in the text are multiplied by 100 and 1,000 respectively.

Texture analysis of bread samples showed that peak force (hardness) of composite bread samples ranged from 5.52N - 10.77N, with 20% Frafra potato-wheat composite bread and wheat bread having the highest and lowest values respectively. Significant differences ($p < 0.05$) existed between bread samples. Gumminess values ranged between 0.603 to 0.744, with wheat and 20% Frafra potato-wheat composite bread having the highest and lowest values. No significant differences ($p < 0.05$) existed between the bread samples for the texture parameters gumminess and cohesiveness. As seen in Figure 2, composite bread samples became harder, relative to the control, as FPF increased. Nonetheless, the highest peak force (10.77 N) recorded, indicating peak hardness of bread from composite flour with 20% FPF, was within the reported range of instrumental texture of bread (Mandala *et al.,* 2006). This is an indication that composite bread samples are still likely to appeal to consumers even though they were relatively harder than the control. Hardness in composite bread can be attributed to the reduced activity of gluten. Also, the water absorption capacity of the flour plays a significant role in textural hardness since it gives an estimate of the volume occupied by starch granules after swelling in excess water, which in turn is an index for gelatinization or hardness (Mandala *et al.,* 2006).

Table 5: Sensory evaluation of bread samples

Attribute	(Control) F0	F5	F10	F15	F20	SSE
Overall acceptability	8.23^{a}	8.26^{a}	8.05^{a}	6.46^{b}	5.99^{b}	1.393
Colour	8.08^{a}	8.02^{a}	7.23^{b}	6.15^{c}	5.23^{d}	1.165
Aroma	7.77^{a}	8.08^{a}	7.78^{a}	6.77^{b}	6.30^{b}	0.991
Flavour	8.15^{a}	8.31^{a}	8.23^{a}	6.83^{b}	6.45^{b}	1.709
Mouth feel	8.85^{a}	8.54^{a}	8.30^{a}	5.54^{b}	5.28^{b}	1.147
Aftertaste	8.54^{a}	8.69^{a}	7.38^{b}	6.15^{b}	5.84^{c}	1.113

10 ≤ Like Extremely; 5 ≤ Neither Like nor Dislike; 0 ≤ Dislike Extremely; SSE: Sum of Squared Error. F0, F5, F10, F15, and F20 represent bread with 0%, 5%, 10%, 15% and 20% respectively of FPF in the bread. Means in the same row with different superscripts are significantly different ($p \leq 0.05$).

Sensory scores ranged from 5.23 - 8.85, which is an indication of different levels of likeness. Significant differences ($p < 0.05$) existed for the sensory attributes studied (Table 5). Panellists' preference for overall acceptability was comparable for wheat bread (100%), 5% and 10% Frafra potato bread followed by 15% and 20% Frafra potato bread (Table 5). For colour, significant differences existed between bread samples, but there was no significant difference ($p > 0.05$) between 5% Frafra potato bread and wheat bread, which were the most preferred, with 20% Frafra potato bread being the least preferred. No significant difference ($p > 0.05$) was observed between wheat bread and 5% - 10% Frafra potato bread in terms of aroma, flavour and mouth feel (Table 5). For aftertaste, significant differences existed between bread samples, but there was no significant difference ($p > 0.05$) between 5% Frafra potato bread and wheat bread. Frafra potato bread (5%) was comparable to 100% wheat bread for all the sensory attributes evaluated (Table 5). Frafra potato bread 10% had overall acceptability, aroma, flavour and mouthfeel that was comparable with 100% wheat bread and 5% Frafra potato bread, but had lower values for colour and aftertaste. The lower liking scores for composite bread samples with increasing addition of FPF (15-20%) may be due to the rather strong unfamiliar aroma of FPF which was not properly masked by the mixture of ingredients used to make the composite bread. Overall, panellists preferred composite bread samples made from composite flour with 5% and 10% Frafra potato flour more than the control (Table 5). This finding suggests that substituting bread formulations with 5% - 10% FPF would produce composite bread that will be preferred over WF bread.

Table 6: Correlation between Overall Acceptability and other Sensory Attributes of Bread Samples

Correlation Between	Correlation Coefficient (R)
Overall acceptability and Colour	0.98765
Overall acceptability and Aroma	0.95321
Overall acceptability and Flavour	0.83474
Overall acceptability and Mouth feel	0.96304
Overall acceptability and Aftertaste	0.72882

Regression analysis of the data obtained showed that overall acceptability correlated strongly with colour, aroma, flavour, mouth feel and aftertaste for the bread samples (Table 6). This implies that overall acceptability of the bread was influenced strongly by these sensory attributes. Thus, in developing bread from composite flour, attributes of colour, aroma, flavour, aftertaste and mouth feel should be taken into consideration.

Conclusion

Substituting WF with FPF positively affected the pH, percentage water and oil absorption capacity and negatively affected tristimulus colour and pasting property of the composite flour formulations. Frafra potato-wheat composite flours which had lower pasting property, but higher water and oil absorption capacity, gave harder and darker bread with lower overall acceptability, whereas composite flours with higher pasting property gave bread with higher overall acceptability. The study has shown that the overall acceptability of bread produced using 5% to 10% Frafra potato-wheat composite flour was comparable to bread made from 100% wheat flour. Thus, further optimization of bread formulation and processing conditions may promote the use of Frafra potato in the production of Frafra potato-wheat composite bread with attributes comparable to already existing ones.

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Soil management for resource-constrained urban agriculture: An ABCD approach in Cape Town

David. W. Olivier
Global Change Institute, University of the Witwatersrand, South Africa.
david.olivier@wits.ac.za

ABSTRACT

Maintaining soil health is essential for urban agriculture, as space in urban centres is limited. This challenge is exacerbated by resource limitations when urban agriculture is used for promoting sustainable livelihoods. This study assessed the appropriateness of the Asset-Based Community Development (ABCD) model for addressing soil management issues of economically marginalised urban farmers. The study is structured as a case-study, using purposive selection of exemplary cases of urban agriculture in Cape Town and in-depth interviews with key informants. The findings indicate that good practice for soil management in this area includes agro-ecological methods drawing on locally sourced biodegradable waste products. Key aspects of the methods applied in this case include: digging a trench bed one meter wide; using organic waste to refill the bed as well as to compost; mulching; zero-tillage; intercropping and crop rotation. These methods are taught by four local non-governmental organisations. The present study demonstrates the usefulness of the ABCD approach for analysing urban agriculture studies, and in so doing contributes to a limited body of literature on this subject. While the case study methodology results in findings that are not statistically representative of the broader population, the lessons learned from this study may be usefully interpreted for other contexts, provided that such an application is informed by an adequate understanding of the local context to which it may be applied.

Keywords: Cape Town, urban agriculture, soil fertility, resource-poor farmers, asset-based community development, soil health

Introduction

Accessing land of sufficient size and soil quality is a characteristic challenge for urban farmers, as plots in urban areas tend to be far smaller, and far more valuable than in rural areas (Opitz *et al.*, 2016). The mainstream agro-industrial model of rural agriculture seeks to maximise economic efficiency through economies of scale, as well as through conformity with the agro-industrial regimes, of which important features are petrochemical-based inputs, loans, tax-breaks and subsidies (Wiskerke and van der Ploeg, 2002). Urban farming, however, tends to be unable to compete on these terms, not only because of the limited scales of production, relating to limited land size and value, but also because of a lack of formal systems to support it (Opitz *et al.*, 2016).

Scholarly research tends to portray urban agriculture in the northern hemisphere as contributing to social cohesion, and in the Global South as facilitating food security (Battersby and Marshak, 2013). However, socio-economically marginalised urban farmers in Africa derive the least food-security and economic benefits from urban farming (Frayne *et al.*, 2016); thus, it appears unlikely that urban agriculture can empower people without it being supported by an institution, whether a governmental or non-profit organisation (NPO) (Olivier, 2019). In Cape Town, public support for urban agriculture tends to be modelled on the extension service models rolled out for rural agro-industrial agriculture (City of Cape Town, 2007). Nevertheless, an alternative model is presented by which NPOs train urban farmers in agro-ecological farming, which strives to harness natural goods and services through mimicking the natural processes that promote soil health, namely using organic matter for inputs, mulching and zero-tillage. Based on a central tenet of providing low-income individuals with access to healthy food at no financial cost, the NPOs in question provide the basic inputs for start-up, and ongoing extension support. Nevertheless, reflecting principles of sustainable development, these NPOs aim to reduce their beneficiaries' dependency on these services over time by encouraging urban farmers to prioritise the sourcing of freely available organic waste in their surroundings. It is possible for farmers using this model to require no additional financial inputs after start-up (Olivier, 2018).

The principles of reduced dependency and prioritising the use of local resources coincides with the Asset-Based Community Development (ABCD) framework. ABCD is a conceptual framework that bases community development on locally-sourced assets, rather than grants or donations from outside the community (Martin *et al*., 2004). Examples of such assets include the passions or skills of individuals; vacant or underutilised plots; waste materials; natural bodies of water; climate; and local networks and relationships. By basing development on local assets, the ABCD strives to address the problem of dependency that external support tends to create and which undermines the sustainability of the development process (Mathie and Cunningham, 2002). Nevertheless, some intervention is necessary to overcome some of the key causal factors constraining people from accessing the resources around them, or from developing their own capabilities (Kretzmann and McKnight, 2005). Such is seen in case studies on ABCD urban agriculture projects, as happens in Cagayan de Oro in the southern Philippines, where local government and universities initiated the process (Holmer and Mercado, 2007). In Cape Town, NGOs have played this role (Olivier, 2018).

Considering the longevity of urban agriculture in Cape Town (Eberhard, 1989), it is reasonable to assume that some lessons may be drawn for good practice in soil management. The problem this paper seeks to address is, what lessons on soil management may be drawn from Cape Town's case for promoting urban agriculture that seeks to benefit economically marginalised people? In this paper, this question will be addressed primarily through relating to the farmers' own perspectives on this issue. To this end, the paper begins with a description of the context for the case study, as well as the qualitative research methods that were used. The findings are related thereafter, which provide a breadth of description of aspects of soil management, as well as qualitative depth within each aspect. The discussion compares the farmers' responses on these issues to the leading perspectives in the scholarly literature, and the synthesis of these perspectives is reported as concluding insights, lessons learned and how these lessons should be interpreted for application in the broader context of urban agriculture for community development.

Methods

Geography of the area

The Cape Flats lies on the southern portion of a sandy plain between the Table Mountain range along the southwest coast and the hills of Durbanville to the northeast, in the City of Cape Town Municipality, South Africa (Brodie, 2015). Notwithstanding that a portion of this land currently called Browns Farm has been used for horticulture since colonial times (Battersby-Lennard and Haysom, 2012), the Cape Flats in general, and the lowest-income residential areas within it, have the poorest soil quality in the municipality (Geyer *et al*., 2011). The highly alkaline soil (96% sand) (Fermont *et al*., 1998) is further depleted by the excessive illegal dumping and burying of general and construction waste from the intensive construction of high-density housing and informal settlements, which have all but eliminated natural ecosystems from the area (Geyer *et al*., 2011). Nevertheless, the climate is conducive to year-round horticulture, as is the presence of groundwater (Adelana *et al*., 2010).

Socio-economic characteristics of the population

The Cape Flats consists primarily of informal dwellings, government-subsidised housing estates and low-income residential areas (Brodie 2015; Adelana *et al*., 2010). The area has an unemployment rate of 29%, and is infamous for high levels of gangsterism and crime, alcohol and drug abuse, theft and domestic violence (Chetty, 2015). As a residential area constructed by apartheid, it continues to receive suboptimal service delivery and utilise poor-quality infrastructure (Adelana *et al.*, 2010; Brodie, 2015). Many of those living on the Cape Flats have strong familial connections with the Eastern Cape province of South Africa, to which they travel, particularly for major holidays, and to which they send provisions for the family members who remain there (Battersby, 2011).

Challenges to empirical research in an informal context

This study selected a case-study design, using primarily in-depth face-to-face interviews and focus groups, supplemented with field notes and grey literature. A case study method of this nature was chosen as the most appropriate for this study because of the complexities of how urban agriculture is structured in Cape Town. The empirical research had to be designed from scratch, using exploratory research techniques and relying on data saturation to ensure representivity.

Designing the empirical research commenced with delineating the population frame, as there was no list of urban farmers in Cape Town at the time the research was conducted. The researcher chose to assume that the vast majority of urban farmers would be affiliated with an NPO or with extension support from the City of Cape Town, as desktop research had established that rural agricultural methods are not successful in the area. Partial lists of NPOs practicing urban agriculture existed, such as procurement notices by the City of Cape Town for the delivery of implements and agricultural inputs, published online; the attendance register for the City of Cape Town Urban Agriculture Summit; the membership database belonging to one major NPO in the city; and the Republic of South Africa Registered NPOs in the Western Cape database (hereinafter, 'Registered NPO database'). No additional lists were forthcoming. The researcher then synthesised the lists of all of the NPOs affiliated with urban agriculture, and cross-referenced this synthesis with the Registered NPO database. This created the first comprehensive list of registered NPOs affiliated with urban agriculture. As the vast majority of the names obtained came from private lists and were provided to the researcher on the proviso that they were not to be published, the complete list is not publically available.

The newly formed list of registered NPOs involved in urban agriculture in the Western Cape held the names of 134 NPOs. Thereafter followed a whittling-down process, whereby the NPOs on the list were looked up online or phoned, to establish how much urban agriculture featured in their programmes. By these means, it was established that the overwhelming majority only had a horticulture plot on their premises (as a recreational activity or to supplement the meals they prepared). Only four actually *promoted* urban agriculture in Cape Town by training urban farmers and providing ongoing extension support to those whom they trained. The researcher assumed that no individual affiliated with an NPO would be practicing urban agriculture without having had training and extension support from at least one of these four core NPOs.

The four NPOs training and supporting urban agriculture in Cape Town at the time of research were Inity, the Sozo Foundation, Soil for Life and Abalimi. The researcher then arranged visits to these NPOs to meet a key informant, such as a director or manager. The interviews with these key informants laid the foundation for this empirical research, as they provided a broad understanding of how these NPOs operated and how they won the support of these individuals, as gatekeepers to the considerably sizeable population of urban farmers affiliated with their organisation (namely 6563 individuals).

Sampling

The population frame of 6563 urban farmers was treated as a whole, rather than designating which farmers were affiliated to which NPO. This was possible because by that time, it had been established that all of the NPOs taught the same agro-ecological methods.

Traditional simple random sampling from the population frame proved impossible because of the number of unmapped roads and lack of road names in the study area. Thus, snowball sampling was utilised, beginning with attending urban farmers' meetings and sitting at the NPOs' 'garden centres' requesting interviews from customers (Patton, 2002). During these interviews, the researcher requested referrals to other urban farmers from interviewees and from NGO representatives. The researcher employed the services of a local guide, who was himself an urban farmer, who helped to navigate the area, overcome language difficulties and introduce the researcher to potential interviewees. The only exclusion criterion was that the farmers could not be children (under 18 years of age), for ethical reasons. Otherwise, all willing urban farmers actively farming at the time of being interviewed were included.

Data were gathered until data saturation, indicating sampling sufficiency, namely: no new discussion themes emerged; no new information was forthcoming on existing themes; and the socio-demographic trends of the sample reflected those of the broader population. Using data saturation is a standard practice for indicating sampling sufficiency in qualitative research (Patton, 2002).

At the point of data saturation, the interviewer had selected 59 urban farmers. Of these, 74% were over the age of 40; 60% were female; and 85% were of Xhosa ethnicity. Although no population profile of urban farmers in Cape Town exists, this distribution of characteristics appears representative of the population frame, according to existing research (Tembo and Louw, 2013).

Data gathering, capturing and coding

Interviews with the urban farmers took place from March to August 2014. Individual, face-to-face interviews were conducted with 34 of the urban farmers, and the remainder consisted of four focus groups: two mixed-gender groups, one all-male group and one all-female group. All interviews and focus groups were voice recorded and transcribed.

Transcriptions from the interviews were made in Microsoft Word format. The "code and retrieve" method was adopted (Willis, 2007) to code and group data according to themes on soil management, as reflected in the subsections of the following Results section.

Results

Origins of soil management methods

Of the four NPOs in this study, Abalimi had the longest history in Cape Town, beginning in 1982 when it was established by the then Catholic Welfare Bureau. Soil for Life, established in 2003, was the second oldest. The directors of both of these NPOs gained their agro-ecological expertise independently. Abalimi's methods originate from training that two of the founding members received in horticulture and biodynamic farming in America and England, respectively. Soil for Life's methods originate from the training that a founding member received in permaculture. Over time, both of the NPOs adapted these methods into a curriculum for individuals with low levels of formal education, low literacy and constrained resources. The other two NPOs in this study, Inity and the Sozo Foundation, were trained by Abalimi and Soil for Life, respectively, and copy their methods exactly. Thus, the methods that are taught by all four of the NPOs in this study are so similar that the descriptions reported in this section are generalisable to all four of the NPOs.

The NPOs' 'garden centres'

One of the most important characteristics shared by each of the NPOs in this study is that they all had at least one 'garden centre' located within the neighbourhood they focus on for recruiting, training and supporting urban farmers. Abalimi, Soil for Life and the Sozo Foundation had two garden centres each. Every garden centre had some basic characteristics: a demonstration plot, where vegetables are grown all year-round using the methods that the NPO teaches; a seedling nursery; a drop-in consultation service for free advice; and storage for tools and inputs. In terms of support for the membership base, the garden centres were invaluable as they operate as a social 'hub', where local urban farmers can purchase inputs at subsidised rates; see a successful application of the methods they were taught, in context; and receive advice from a professional, local urban farmer who was employed by the NPO to run the garden centre.

An overview of the training method

Although the focus of the present study is on soil management, it is necessary to provide an overview of the training methods used by the NPOs in question in order to provide some context for the results that follow. Furthermore, the focus of the training methods is primarily on promoting soil health, as reflected in Soil for Life's name. To generate interest in their urban agriculture training course, these NPOs either canvas door-to-door within neighbourhoods or conduct a promotional presentation at a community event. Alternatively, urban farmers may approach an 'official' at one of the garden centres, where they may sign up for training. The NPOs group the applicants according to their proximity to each other, as one of the efforts to ensure sustainability includes mutual support between neighbourhood urban farmers after the completion of training.

The training course typically takes place one day per week for the duration of seven weeks (Soil for Life 2017). An NPO-authorised trainer conducts the training on the properties of the applicants. Each training episode includes the practical application of the lesson, and the rest of the group are expected to implement what they learned, on their own properties, before the next training session. Each training session is hosted on a different trainee's property, so that by the end of the training course, each trainee should have received hands-on training and advice on their own property at least once.

Following the completion of the course, every trainee would have an established vegetable garden and a seedling nursery. Follow-up extension support includes training on how to harvest and store seeds and how to transplant the seedlings for the next season's crop. The expectation is that over time, the group members will support each other, thereby reducing demand on extension support. To encourage such mutual support, the NPOs donate the tools that were used for training to the group, with the expectation that the group share them among their members. A group member who needs expert advice may drop-in at the nearest NPO garden centre.

Land size and characteristics

Land is a highly limited resource, according to the urban farmers. Therefore, most simply use the small tract of land around their domicile, and are called "home gardeners" or "home farmers". Such farmers are taught to prepare a plot $2m^2$ in size, but with experience and enthusiasm, they may expand their cultivated area throughout the small property.

Some of the urban farmers managed to obtain land through agreements with state departments or local organisations. Many, however, found the process too complicated, slow and frustrating, and simply gave up. Thus, it was common for the urban farmers to draw up an informal arrangement for the use of land belonging to a faith-based organisation, civil society organisation, crèche, local school or clinic. Usually, in such cases, the agreement is to donate a portion of the harvest for the meals prepared by the organisation for their beneficiaries. Unsanctioned occupation of land for cultivation appears rare, most probably because of the risks associated with the loss of the investment made in fertilizing and working the land, as well as the loss of the growing crops, following eviction. Nevertheless, at least one of the current formal groups began by illegally occupying power line servitude land, but received formal permission to continue cultivating that land, as well as donations in kind, from the City of Cape Town municipality.

Tools, implements and infrastructure

The vast majority of urban farmers require only the most basic implements, due to the small size of the plot they cultivate. Thus, the NPOs, following the training course, make a once-off donation of spades, garden forks and wheelbarrows to the group.

The NPOs teach urban farmers to utilise the waste materials readily available in the neighbourhood due to littering and illegal dumping: for example, scrap timber, tyres and cool drink bottles were typically used for landscaping, bordering and terracing. Cultivation groups are eligible to receive such infrastructure as shipping containers for on-site storage, the installation of perimeter fencing, well point or borehole drilling and electric water pumps from the City of Cape Town. One group also had agricultural tunnels on their property.

Trench-bedding, sheet mulching and container-planting

The soil quality encountered in the areas of the Cape Flats in which these NPOs operate is characteristically too depleted and polluted to be serviceable through the application of fertilizers. In order to prepare their soil for cultivation, the urban farmers typically have to remove quantities of rubbish and building rubble from the soil. They are also required to dig considerable volumes of organic matter into the almost pure sand to give the soil structure and to improve its water retention.

The predominant method of soil preparation is trench-bedding. This labour-intensive practice is common due to the vast majority of urban farmers being 'home-gardeners', and therefore operating at small scale.

The trench-bedding method that is taught by these NPOs is as follows: A trench is dug with an area of 1.0m x 2.0m and a depth of 0.5m. Trench-beds may be longer than 2.0m, but they may not be broader, according to these NGOs' methods, as at no point should one ever stand on the bed. Thus, being narrow, they allow for the urban farmer to work the bed from either side. The sand that is dug from the trench is separated into a pile of topsoil and subsoil. The trench sides and bottom are lined with corrugated cardboard to reduce rapid water drainage into the surrounding sand. A mat of sticks is then cast into the trench to prevent water-logging and to encourage aeration of the soil, and some bones and cans may be thrown in to provide the slow release of calcium and iron into the soil, respectively. Upon this is placed a layer of newspaper sheets, in order to prevent the re-filled soil from filling the air gaps created by the sticks. Three layers then follow, with each layer made up of: a handbreadth of dry straw-like material, a handbreadth of wet organic waste, and a third of the subsoil. Each time such a layer is completed, it is irrigated. Once all three layers containing the subsoil are complete, the topsoil, mixed with compost, is spread over the top. The finished bed stands a little higher than ground level, making it necessary to border it using any freely available material from the surroundings, such as timber, stones or sand-filled soft drink bottles. The trench-bed is finished with a layer of mulch, and may be planted in immediately.

Those without any garden are encouraged to plant in containers, while those who farm tracts of land too large for trench-bedding are taught to sheet-mulch. Container planting, trench-bedding and sheet mulching all utilise the same principles of laying woody material at the bottom, layering alternately with dry and wet organic waste, and soil, and finishing with compost-enriched topsoil and a mulch layer. Container planting utilises the trench-bed method within a container, and sheet mulching utilises the method on the soil surface.

Mulching and zero-tillage

The trench-bed method is designed to keep the soil aerated, making tillage unnecessary. The introduction of sticks and straw to the layers introduces trapped air to the soil, and thereafter the activity of organisms within the soil, such as earthworms or moles, continues to aerate the soil. Tillage is actually discouraged, as it is believed to release nitrogen from the soil and disturb the colonies of microorganisms that contribute to soil health.

Mulching also encourages soil health, the NPOs believe. Key contributions mulching makes to soil health include reduced leaching of the soil from weather extremes; reduced compacting of the soil from rainfall; suppression of weed growth; and reduced evaporation from the soil. Urban farmers are encouraged to use any material that is available to mulch the soil. Typical mulches included straw and grass clippings, leaves and newspapers. Nevertheless, some urban farmers believed that the mulch layer harbours pests such as snails and caterpillars, and were reluctant to utilise it.

Fertilizers

All of the NPOs in this study were strongly against petro-chemical inputs, which include industrial fertilizers. Some of the key arguments espoused were that the sandy soil required organic matter, not chemicals, to preserve moisture and improve soil structure; that the misapplication of petrochemical fertilizers could have detrimental effects on groundwater, the ecology and public health; and that the core principles of self-reliance, re-use and recycling of waste materials, and the reduction of input-costs preclude dependence on petrochemical suppliers or donations of these products. The urban farmers readily echoed this stance, as these arguments were included in the lessons.

During their training, urban farmers are taught to make their own compost using biodegradable wastes from their kitchen or garden, or by collecting them from their neighbourhood. The NPO representatives described urban farmers obtaining wastes from green grocers in their area, or from the grass clippings from municipal maintenance activities. One urban farmer described travelling to the beach by train to collect kelp for her compost heap. The use of kitchen waste was however not as pervasive as may be supposed. An NPO representative explained that urban farmers would generally cook such waste up to feed to their dogs.

Manure was negligible among home gardeners, as few kept animals that generated appropriate manure for horticulture. One urban farmer who kept goats used their manure to fertilize his cultivated plot, but such practice was the exception. Any manure that is available is collected by the NPOs from stables and cattle stalls further afield, in addition to the vast quantities of compostable waste from landscaping companies.

Other means to fertilize crops include a fertilizing 'tea' using organic wastes, which the NPOs teach urban farmers to make, as well as 'earthworm tea', which is a by-product of an earthworm farm and is claimed to be highly nutritious for plants. Very few of the urban farmers had earthworm farms, although these were in operation at the garden centres, but a fair number had tubs of 'tea', in which green matter could be seen brewing.

Intercropping and crop rotation

Intercropping and crop rotation are taught as methods of soil management. The impetus behind this practice, according to the training courses, is to balance the extraction of nutrients from the soil. Thus, planted in alternate rows are root vegetables, leafy greens, fruiting plants and legumes. With each season, the rows are rotated so that the nutrient-demanding fruiting plants of the new season are planted in the area where the legumes replenished the soil's nitrogen the season before, and the root vegetables, which do not benefit from too rich a soil, are planted in the soil that has been depleted over two seasons.

Discussion

In the post-industrial world, limitations of the urban setting, such as limited space, poor soil quality on marginal land, and the lack of economies of scale force urban farmers to maximise the variety and volume of their output all year-round without compromising the fertility of their relatively small tract of land (Opitz *et al*., 2016). Urban farmers in Cape Town face similar challenges, as shown by the results, making it necessary for them to learn soil management techniques that are highly specialised to this context.

Poverty is the result of constrained *access* to resources, not necessarily the absence of resources (Mathie and Cunningham, 2002). Thus, some intervention is necessary to catalyse the development process as well as to steward it, to protect it from the environmental limitations that created the conditions in the first place (Kretzmann and McKnight, 2005). The results indicate that the NPOs promoting urban agriculture in Cape Town draw on a range of local asset bases to do so. The initial recruitment of trainees draws on assets such as passion or enthusiasm for soil health, which all of the farmers shared and which are aspects of human capital.

Social capital also presented important assets: in particular, the creation of supportive networks (Kretzmann and McKnight, 2005; Mathie and Cunningham, 2002). The NPOs initiated these by encouraging applicants to bring friends, family and neighbours to the training courses. The formation of neighbourhood groups who share tools also indicates harnessing social capital. The networks that were built through which urban farmers sourced material, or gained access to land, are a further example of the use of social capital-related asset bases. The location of garden centres within the target neighbourhood also sustained supportive networks between urban farmers and the NPOs, and these became a social hub where urban farmers from the neighbourhood could meet, chat, share experiences and receive moral support.

Physical and natural capital are extensively used by the urban farmers in this study to promote soil health. Assets relating to these included using waste materials to build up soil health through composting, mulching or building basic infrastructure. By these means, natural goods and services were harnessed, such as natural predation of pests, microbial activity that promotes soil health and nitrogen fixing by legumes.

Financial capital is perceived as scarce on the Cape Flats, which is why an urban agriculture model is promoted that requires no financial inputs by urban farmers. Furthermore, the NPOs managed to obtain much of their resources from actors that were happy to get rid of materials such as manure from stables, or landscaping companies' refuse.

ABCD appears well suited to urban agriculture in resource-constrained contexts. It is surprising therefore that so few studies record this concept being deliberately applied, or fail to analyse such cases using this framework. The use of this framework by the present study may contribute to similar studies on resource-constrained farming in other contexts. Thus, although the case study method makes it impossible to generalise the findings to other contexts, it provides lessons that may be usefully interpreted for informing empirical research in other contexts, or for implementing urban agriculture projects with comparable methods and objectives.

Conclusion

Considering the challenges relating to soil management for urban farmers in Cape Town, it is notable that over six thousand urban farmers exist. The longevity of this practice in Cape Town (over 30 years) indicates the sustainability of the model in question. Key to its sustainability is the utilisation of freely available asset bases, in line with the ABCD approach.

What is interesting in these cases is that the four NPOs were central players in the development process, but the entire programme was directed at increasing the urban farmer's independence from extension support and external inputs through their utilisation of freely available waste materials from their surroundings. Thus, with the exception of some donated hand-tools, soil management was theoretically possible without any financial expense.

This study originated to answer the question: What lessons on soil management may be drawn from Cape Town's case for promoting urban agriculture that seeks to benefit economically marginalised people? Some of the key lessons are:

Any such project requires the identification of local asset bases that may be freely or cheaply available, in order to minimise the use of external material assistance. Such asset bases are not limited to material inputs, but also draw on existing relationships and networks that may sustain the project.

Investment in human capital through training is necessary, and any urban agriculture course would ideally be tailored to the socio-economic and cultural context of the target group, as well as to the ecological context of the area.

A catalyst is necessary to initiate and facilitate the development process. This can be an external actor such as an NGO, but the role of the actor remains to transfer ownership and sustainability of the development process to the target group over time.

The present study helps to address a gap in the literature by analysing a good practice case of soil management for urban agriculture. Furthermore, the present study not only contributes towards understanding why urban agriculture may be working in Cape Town, and which lessons may be applied to improve urban agriculture elsewhere, but also communicates the complexities of conducting data gathering in similar informal contexts, and how some major challenges may be overcome.

This research could contribute to improving an already exemplary policy environment for urban agriculture in Cape Town through providing policy-makers and development planners with a clearer idea of what works, and why it works. Such an understanding could increase effective and sustainable soil management practices for urban agriculture in Cape Town, ultimately contributing to sustainable livelihoods on the Cape Flats.

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Climate change: Its implications on urban and peri-urban agriculture in Dar es Salaam city, Tanzania

Asnath Alberto Malekela[1]*and Agnes Nyomora[2]

[1]Department of Education, The Mwalimu Nyerere Memorial Academy, Dar es Salaam. Tanzania.
[2]Botany Department, University of Dar es Salaam, Tanzania.
***Corresponding author:** Asnath Alberto Malekela; asnathmalekela@yahoo.com

ABSTRACT

Climate change is one of the challenges facing the world today. This study examined the impact of climate change on urban and peri-urban agriculture. Secondary data were collected through a literature survey and primary data were collected using structured and in-depth interviews, observations and focus group discussions. A total of 201 respondents who engaged in urban and peri-urban agriculture (UPA) in Dar es Salaam city were interviewed. The findings revealed that urban and peri-urban agriculture make a positive contribution to food security as 84% of the respondents claimed to engage in UPA for food and income. It was also observed that urban and peri-urban agriculture was affected by climate change, leading to drying of crops (41%), crop pests and diseases (28%), decrease in crop yields (13%), loss of soil fertility (8%), animal diseases (43%), drying of pasture lands (41%) and death of livestock (16%). It is evident that urban and peri-urban agriculture is severely affected by climate change. The study recommends that new farming systems such as vertical farming with the use of limited water resources should be adopted for better output.

Keywords: Climate change, climate variability, temperature, rainfall, urban and peri-urban agriculture, food security

Introduction

Climate change is one of the challenges facing the globe. Development efforts are threatened by climate change owing to its adverse impacts on various sectors including agriculture, health, the environment and infrastructure, especially in the least developed countries (IPCC, 2007; UNFCCC, 2007). Sub-Saharan Africa (SSA) is the region most vulnerable to the impact of climate change on agricultural production due to dependence on unpredictable rainfall which lowers production (IPCC, 2007; Cooper, 2002). The Tanzanian agricultural sector is key to economic development; several studies report that about 75% of the country's population works in the sector. However, its productivity is very low compared to other countries in Sub-Saharan Africa. Some of the major reasons for the low productivity is the dependence on unpredictable rainfall, poor seed and fertilizers, as well as low productivity of indigenous animal breeds (Baseka, 2016; Mbilinyi *et al.*, 2013). In urban areas, vulnerability to climate change and variability is greatly influenced by the extent and quality of infrastructure, public services, economic conditions and institutional parameters (Satterthwaite *et al.*, 2007, Roberts *et al.*, 2011).

Around the world, food is produced within cities and areas immediately surrounding them, a practice which has become known as urban and peri-urban agriculture (UPA). Involvement in UPA is a result of fast urban growth in most cities caused in part by rural-urban migration. The activity encompasses some broad acre farmlands, diminutive community gardens, domicile gardens, fruit trees along wayside reserves and greenhouses (Pearson, 2007). In the past, agriculture was seen as a rural phenomenon, but currently it is an activity that is expanding rapidly to urban areas. Dramatic population increase in urban areas has been a reason for the extension of this originally rural phenomenon to cities as a way of coping with food insecurity (Baseka, 2016). Urban and peri-urban agriculture perform an essential function in providing varieties of food stuffs to the urban dwellers, along with ecological services in urban and peri-urban areas by greening the cities (Oyedipe, 2009; Mlozi *et al*., 2014). Farming in and around the cities contributes positively to food security, i.e. food availability, accessibility, stability and utilization, leading to sustainable livelihood among the city dwellers.

The impact of climate change in cities ranges from sea level rise to floods, droughts and damage of infrastructures, with enormous effects on urban and peri-urban agriculture, i.e. crop production and animal husbandly (Rosenzweig *et al*., 2011; Grimm *et al*., 2008). According to IPCC (2001), there has been an unprecedented warming trend throughout the 20th century. The current average universal surface temperature of 15°C is nearly 0.6°C higher than it was in the past 100 years, and most of such increase has been due to human activities.

Agriculture has been identified as the second most vulnerable sector to the impacts of climate change, preceded only by the water sector (NAPA, 2006). Climate change-induced warmer temperatures, more extreme rainfall and more prevalent drought and flooding pose significant challenges for UPA in Dar es Salaam (Mlozi *et al*., 2014). The total annual rainfall in Dar es Salaam city has decreased from about 1430.9mm in 1986 to 782.9mm in 2016, and the temperature has been increasing steadily from an average monthly minimum temperature of 20.7^{0}C in 1986 to the current 23.2^{0}C (TMA, 2017). These changes and variability in climate negatively affect the urban and peri-urban agriculture, which is very important for the people of Dar es Salaam. This sector ranks as Dar es Salaam's second largest employer and provides the city with a large quantity of food, e.g. 354,657 tons in 2004 (Ricci, 2012).

Most studies of climate change impacts on agriculture have focused on rural agriculture; very few recent studies have investigated the impact of climate change on urban and peri-urban agriculture. This study therefore intended to fill this gap in the body of knowledge.

Methods and Materials

The study was conducted in Dar es Salaam city in Tanzania. This area was selected because with about 5.5 million people (POD, 2017), Dar es Salaam is the most populous city in Tanzania and has the largest number of urban farmers. A total of 201 respondents from ten wards who engaged in urban and peri-urban agriculture were selected through stratified random sampling. The studied wards were Toangoma, Chamazi, Chanika, Kivule, Ukonga, Kipunguni B, Mbezi, Kisarawe II, Mabwepande and Mbweni.

Primary data were gathered by means of questionnaires, structured interviews and focus group discussions with agriculturalists and the local authorities in the study area. In addition, direct observations were conducted in the study area to identify different crops cultivated and livestock raised. Secondary data were collected through a literature survey. The study unit consisted of 201 urban and peri-urban farmers and 5 focus group discussions (FGDs) were conducted.

Results and Discussion

Profile of the respondents

The ages of the urban and peri-urban farmers in the study area ranged from 18 to 61+ years, averaging between 41 to 60 years (Table 1).

Table 1: Distribution of respondents by age and sex (%)

Age (Years)	Gender	
	Male	Female
18-30	61.5	38.5
31-40	44.4	55.6
41-60	43.9	56.1
Over 61	55.6	44.4
Mean	**45.8**	**54.2**

Urban and peri-urban agriculture in the study area

Urban and peri-urban agriculture involves both crop cultivation and animal keeping. In the study area, 61.7% of the respondents were engaged in crop cultivation only, mostly vegetables; 21.9% reported being involved in livestock keeping only; while 16.4% engaged in both livestock keeping and crop cultivation (Table 2).

Table 2: Agricultural activities performed in the study area

Activity	Frequency	Percentage
Crop cultivation only	124	61.7
Livestock keeping only	44	21.9
Both crop cultivation and livestock keeping	33	16.4
Total	**201**	**100**

Crops produced in the study area

Among the crops produced were vegetables. 76.1% of the respondents mentioned producing leafy vegetables including sweet potato leaves, amaranth, pumpkin leaves, okras and Chinese cabbage and 23.9% mentioned producing fruits. Other crops such as maize, cassava, tomatoes, carrots and potatoes were grown to an insignificant extent (Figure 1). Leafy vegetable production dominated in the study area because most of the crop growers had pieces of land which were too small to grow other crops such as cassava, fruits and rice which require large pieces of land. However, in the peri-urban areas some farmers had large pieces of land and thus it was possible for them to grow crops other than vegetables. Also, vegetables are perishable and therefore should be grown near to the market so that consumers can get them while they are fresh. These findings are in line with those of Mhache (2015) who also observed that common crops farmed in Dar es Salaam city were leafy vegetables.

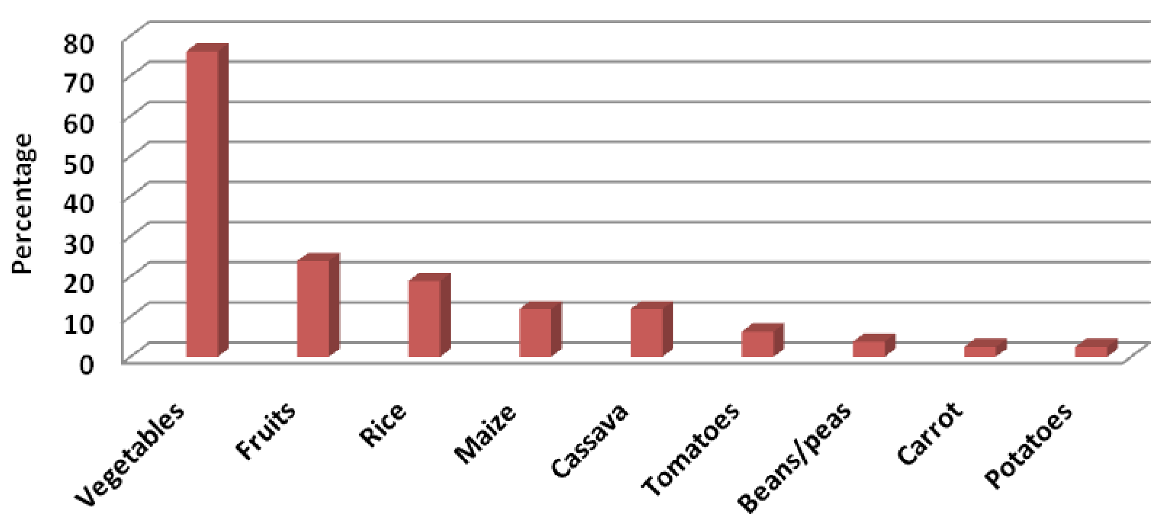


Fig. 1: Crops farmed in the study area

Livestock kept in the study area

About 33.3% of the respondents in the study area kept dairy cattle, followed by 16.7% who kept layers. Other livestock kept comprised goats, broilers, local fowls, pigs, ducks and beef cattle (Figure 2). The majority keep dairy cattle in enclosed places (zero grazing). The Von Thunen Theory suggests that due to the perishability of dairy cattle products, specifically milk, and the need to consume them while fresh, dairy cattle should be kept near the customers (Rodrigue, 2013). The low percentages for beef cattle in the city can be attributed to city regulations (Animal by-laws of 1982 of the Local Government Act, no. 8 section 80 of CAP 378) which stipulate direct zero grazing for all livestock, and the shortage of grazing land.

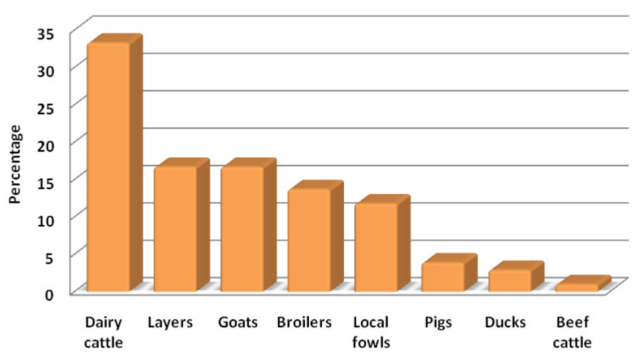


Fig. 2: Livestock kept in the study area

Contribution of urban and peri-urban agriculture to food security in the study area

The practice of urban and peri-urban agriculture has contributed positively to the four pillars of food security, i.e. food accessibility, availability, stability and utilization. A cross-tabulation was done to investigate the relationship between the highest level of education attained by the household head and participation in crop production in urban and peri-urban area. The results showed that 84% engaged in crop production for purposes of home consumption and generating income (Table 3). The results showed a significant positive relationship between reasons for crop production and education level of the farmers, at X^2=19.64; P Value =0.02.

Table 3: Cross-tabulation between education status and reasons for crop production.

Education Level	**Reasons for Crop Production (%)**			
	To get food	To get income	Lack of other job	Both income and food
No formal education	25.0	00.0	00.0	75.0
Primary education	03.5	03.5	05.3	87.7
Secondary education	06.7	00.0	20.0	73.3
Tertiary education	08.7	13.0	00.0	78.3
Mean	**05.6**	**04.4**	**05.6**	**84.4**

X^2=19.64; P Value=0.02

People's perception of climate change in the study area

Climate change has been considered as the most serious environmental threat facing the world today. However, the extent of knowledge on climate change and variability is not similar among communities. In the study area, our findings showed that the majority of urban and peri-urban farmers (98%) perceived climate change and variability while only 2% claimed they had not perceived any climatic changes. The finding implies that from the farmers' point of view, climate change is a reality in Dar es Salaam city. The extent of variation between farmers on the perception and awareness of climate change in the study area was due mainly to differences in households' socio-economic characteristics. These findings support the general perception that climate change is felt more by the poor people, who rely greatly on the natural resource base for their livelihoods, than by those who are economically well off (Melilo *et al.*, 2014; Crimmins *et al.*, 2016). Many other studies have documented similar observations in different parts of Tanzania including Kangalawe *et al.* (2009), Mlozi *et al.* (2014), and Mwamfupe (2014) in Kasulu, Dar es Salaam and Rufiji districts respectively.

Local indicators of climate change in the study area

The earth's climate is changing as various climatic elements such as temperatures and rainfall patterns are changing and more extreme climate events like heavy rainstorms, rising sea water levels and melting snow are already being recorded. In the current study, people perceived climate change in various ways including increased temperatures, shift in the rain season, decrease in rainfall, flooding, reduced rainfall duration and drought (Figure 3).

Temperatures

Temperature is a crucial environmental factor that directly influences growth and development of plants and animals. In this study 45.9% of the respondents mentioned increased temperatures as an indicator of the changing climate in their areas (Figure 3). This was also evidenced from the data obtained from Tanzania Meteorological Agency (TMA) (1986-2016) which showed that there have been variations in average minimum and maximum temperature over the past 30 years. While in 1986 the average annual minimum temperature was 20.7°C, this had increased to 23.2°C by 2016. The trend line shows that the average annual minimum temperature in Dar es Salaam city is increasing at the rate of 0.064 each year, R^2=0.804 (Figure 4).

Also, the average annual maximum temperature in the study area has increased, from an average maximum temperature of 31°C in 1986, to 31.3°C in 2016. The trend line shows that the average annual maximum temperature in the study area is increasing at the rate of 0.046 each year, R^2=0.465 (Figure 5). These findings are in line with those observed by Mwamfupe (2014) in Rufiji district where the majority mentioned increased temperatures as an indicator of climate change in their areas. However, it has been reported that mean global temperature has increased by 0.76°C since the 1850s owing to the emission of greenhouse gases (GHGs) provoked by industrial revolution during the second phase, and has been predicted to rise by 1.8–4.0°C between 1990 and 2100 (IPCC, 2007).

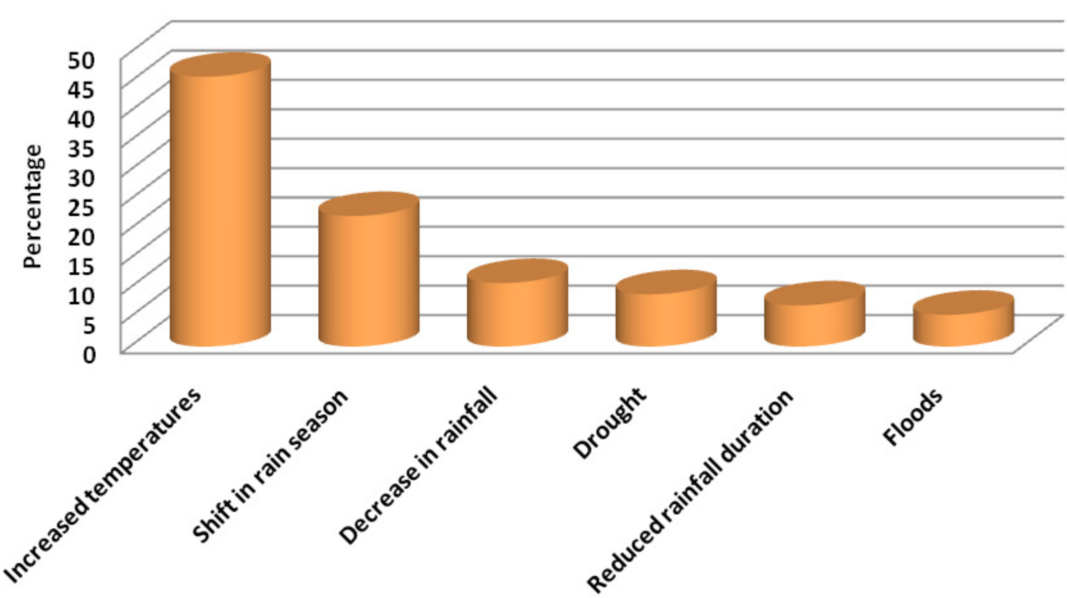


Fig. 3: Local indicators of climate change in the study area (%).

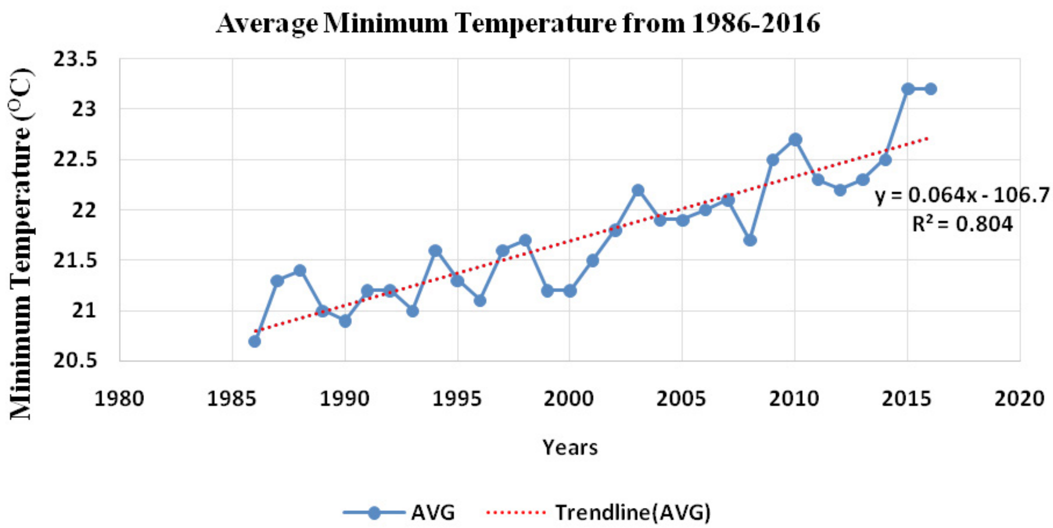


Fig. 4: Average annual minimum temperature (°C) from 1986-2016 in Dar es Salaam city
Source: Tanzania Meteorological Agency

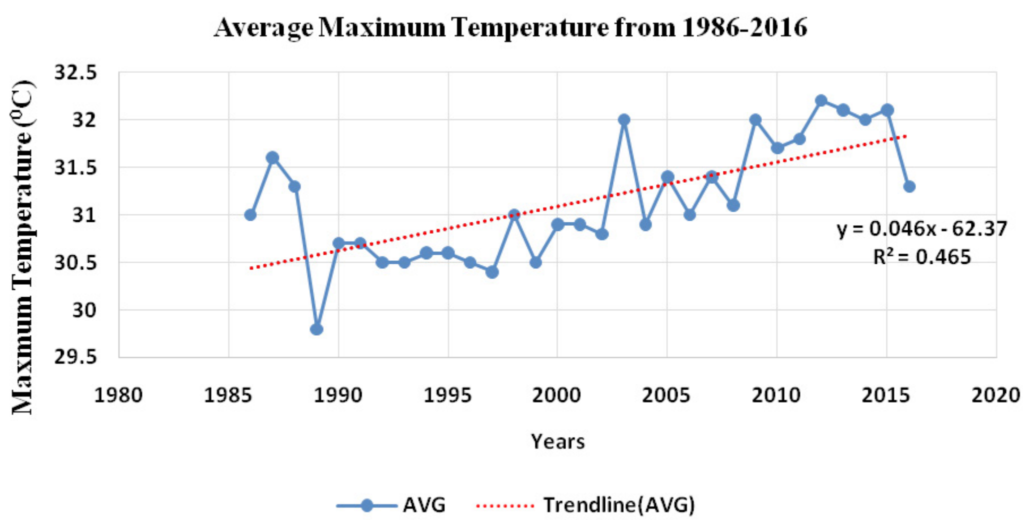


Fig. 5: Average Maximum temperature (°C) from 1986-2016 in Dar es Salam city
Source: Tanzania Meteorological Agency

Shift in rain season

The findings from the study area revealed that about 22.2% of respondents reported experiencing erratic and delayed start of rainfall as an indicator of climate change in their areas (Figure 3). They recalled that there used to be a clear cut bimodal rainfall, with a short rain season from November to December followed by heavy rainfall from March to May. But in recent years there has been a considerable shift in rainfall patterns, so that sometimes the rains start early but at other times they start late compared to the previous years. One respondent in the study area had this to say:

"The climate has changed as evidenced by the changed seasons of rainfall. Sometimes rains come early and sometimes late. Sometimes we experience normal rainfall pattern sometimes not. In the previous years the rainfall seasons was fixed but currently the climate has changed thereby affecting our farming practices"

Decrease in rainfall totals

Decrease in rainfall was one of the climate change indicators mentioned by 10.8% of the respondents (Figure 3). This is because rainfall is the most important source of water for crop production as well as livestock keeping. The climatic data from Tanzania Meteorological Agency (TMA) for the years 1986-2016 showed that there had been a decrease in rainfall over the past 30 years. While the annual rainfall in 1986 was 1430.9mm, this had dropped to 782.9mm in 2016. The trend line shows that the average annual rainfall in Dar es Salaam city is decreasing at the rate of -9.703 each year R^2=0.115 (Figure 6). Also, the annual average relative humidity in the study area has been changing; while the average annual relative humidity in 1986 was 82%, it had dropped to 81% in 2016 (Figure 7).

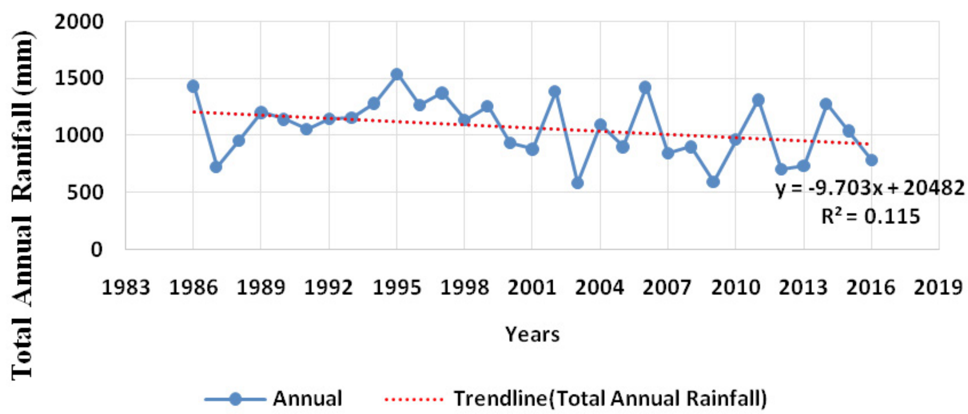


Fig. 6: Total annual rainfall (mm) from 1986-2016 in Dar es salaam city
Source: Tanzania Meteorological Agency

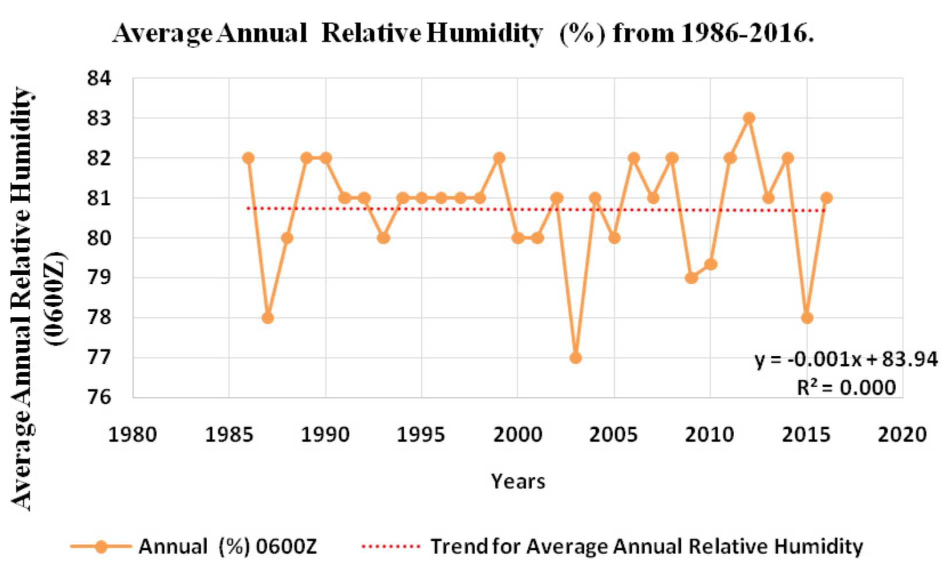


Fig. 7: Average Annual Humidity (0600Z) from 1986-2016 in Dar es Salaam city
Source: Tanzania Meteorological Agency

Drought

Drought is an environmental stress which is characterized by periods of limited or no soil moisture during the growing season. In this study, it was revealed that drought was reported to be among the climate change indicators (Figure 3). Drought resulted from increased temperatures and decrease in rainfall as well as increased water use. The Dar es Salaam Water and Sewerage Corporation (DAWASCO) estimates that the daily water demand in the city is at least 450,000 m^3, but the maximum daily production is just 300,000 m^3 (Smiley, 2016). These results concur with those of Jacob *et al.* (2000) in Dar es Salaam city which revealed that water was a scarce commodity during the dry season, as the public water-supply system can hardly keep up with the requirements of the population which is said to be increasing by 5.6% per year (URT, 2012). Access to a reliable source of water, which varied tremendously between wards, determines the potential of the agricultural enterprise. Where there is no water supply to irrigate, farmers cultivate and produce only under rain fed conditions, which are not predictable.

Drying of crops

An increase in temperature adversely affects crops as excessive heat is a limiting factor of production. In the current study, 41% of the farmers reported that their crops were adversely affected by average temperature changes and drought (Table 4). The farmers also reported that they were experiencing delays in the start of rainfall, thus leading to poor germination of seeds, specifically of rice seeds. These findings indicate that changes in climatic conditions affect the production of crops. This tallies well with what was found by Kasimba (2012) in Zimbabwe, that an increase in temperature poses a threat to the growth of crops as they end up drying.

Crop pests and diseases

In the study area, 28% of the farmers reported that there has been an increase in pests such as aphids and leaf chewing larvae as a result of climate change (Table 4 and figure 8). Several major crop pests and diseases were identified during the questionnaire survey. Several other studies have reported that climate change has led to the prevalence of crop pests and diseases which put agricultural systems at risk. Crop diseases such as anthracnose most often affect tomatoes, cucumbers, melons and beans. Other vegetables are affected by bacterial leaf spot, club root, downy mildew, late blight, mosaic virus, and powdery mildew which are often spread through an insect vector.

Fig. 8a: Okras and Amaranth plants attacked by Aphid pests in Mpiji river valley-Mbezi.

Fig. 8b: Okras and Amaranth plants attacked by Leaf chewing larvae in Mabwepande.

Decrease in Crop Yields

In the study area 23% of the farmers reported that there has been a decrease in crop yields due to increased temperatures, water scarcity and shift in rainfall duration (Table 4). Rainfall has become unpredictable in the study area; this has affected farmers' plans for their activities. Also, lack of capacity for farmers to make proper plans on what to produce, when and how to produce, has led to crop failure and thus decrease in crop yields. This conception is also shared by farmers in the Niger Delta of Nigeria as observed by Nzeadibe *et al.* (2011). This confirms that the majority of farmers associate climate change with crop failure. Similar results were also observed by Kikoyo (2013) whose study in Uganda revealed that climate change and variability led to a decrease in crop yields. In the current study, the farmers reported a decrease in crop yields compared to the previous years when the farmers obtained larger yields because the temperature was moderate and there was stable rainfall.

Table 4: Farmers' perception of the impact of climate change and variability on crop production.

Response	Percentage
Drying of crops	41
Crop pests and diseases	28
Decrease in crop yields	23
Loss of soil fertility	8
Total	**100**

Loss of soil fertility

In the study area, 8% of the crop growers reported a decrease in soil fertility in their areas due to excessive rainfall and resultant floods, or a decrease in rainfall which can result in drought, thus affecting the soil quality. Similar results were also reported by Nutall (2007) who observed that climate change negatively affects the functioning of agricultural soils making them unproductive. It is evident from the results that climatic elements, specifically temperature and rainfall, impact for soil fertility. During this study, it was reported that when there is excessive rainfall, it affects the soil quality.

Impact of climate change on livestock keeping in the study area

In developing nations, livestock keeping plays a major role in the agricultural sector in particular, and economic development in general. It has been reported that there is an expanding demand for foods of animal origin (FAO, 2009). The impact of climate change on agricultural production is not limited to crops, but also affects livestock keeping. Heat agony suffered by animals will decrease the pace of animal feed intake and affect their regular growth (Rowlinson, 2008).

Animal diseases

Variations in temperature and rainfall are the most major climatic variables distressing livestock and leading to disease outbreaks. In the study area 43% of the respondents reported that climate change had led to increased animal diseases. Increased temperatures make livestock such as dairy cattle susceptible to diseases such as bluetongue (bovine anaemia, calf diphtherias), blackleg and anthrax. Also, poultry is affected by diseases such as bacteria (salmonella), mycoplasma, viruses (new castle disease, influenza, infectious bronchitis, infectious laryngotracheitis, avian encephalomyelitis, egg drop syndrome) and parasites. These animal diseases lead to loss of livestock, 16% of the respondents in the study area mentioned that their livestock were dying due to climate change (Table 5).

Drying of pasture lands

Scarcity of good pasture is a major problem for the livestock keepers. Due to climate change and variability, the green nature of the ground fades, leaving it bare or with dry grasses which are not suitable for grazing. In the study area, 41% mentioned that drying of pasture lands was one of the impacts of climate change they felt (Table 5). The increased temperatures and decrease in rainfall have dried up various areas where they used to get grasses for feeding their livestock, leading to reduced livestock outputs. Also, the expansion of agriculture has reduced the grazing land as the farmers' shift to those areas which have water for irrigating their fields, thus diminishing the grazing land.

Table 5: Farmer's perception of the Impact of Climate Change and Variability on Livestock keeping.

Response	Percentage
Animal diseases	43
Dying of livestock	16
Drying of pasture lands	41
Total	**100**

Climate change was reported to affect farmers negatively, but lack of land for farming was also reported to affect farming activities. In areas close to the city, urban agriculture occupies small areas compared to peri-urban areas where bigger parcels of land can be accessed and used for agricultural activities. In the study area most of farmers had small parcels, with 61.3% having an area ranging between 0.2-0.1 hectare and only 0.4% having more than 4.05 hectares (Figure 9). Thus, most farmers in urban settings have smaller plots for farming and most of these plots are either rented or open spaces owned by the government. The same was observed in Kenya by Ogendi *et al.* (2014) who also revealed that people involved in UPA normally use small farm sizes because most areas are built up, as opposed to rural areas where large farm sizes can be found. Studies by Mhache (2015) also revealed that about 50% of the crop growers in Dar es Salaam city had small farm sizes ranging from 0.1-0.5 hectare.

Furthermore, Geographic Information Systems (GIS) analysis using land sat images used to map the spatial and temporal land cover changes over the years (1981-2016) showed that there was a significant change in agricultural land due to urban sprawl. Available data show that in 1981 the agricultural land in Dar es Salaam city was 65,960 hectares, and in 2016 it shrank to 51, 287 hectares. On the other hand, built up area had expanded from 13,939 hectares in 1981 to 45, 467 hectares in 2016 (Figure 10).

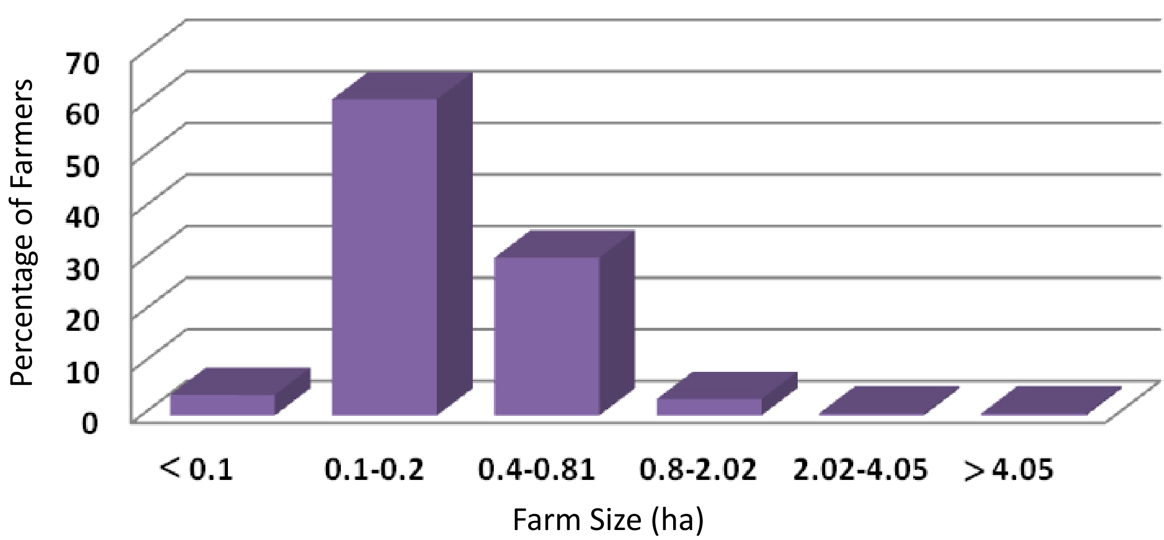
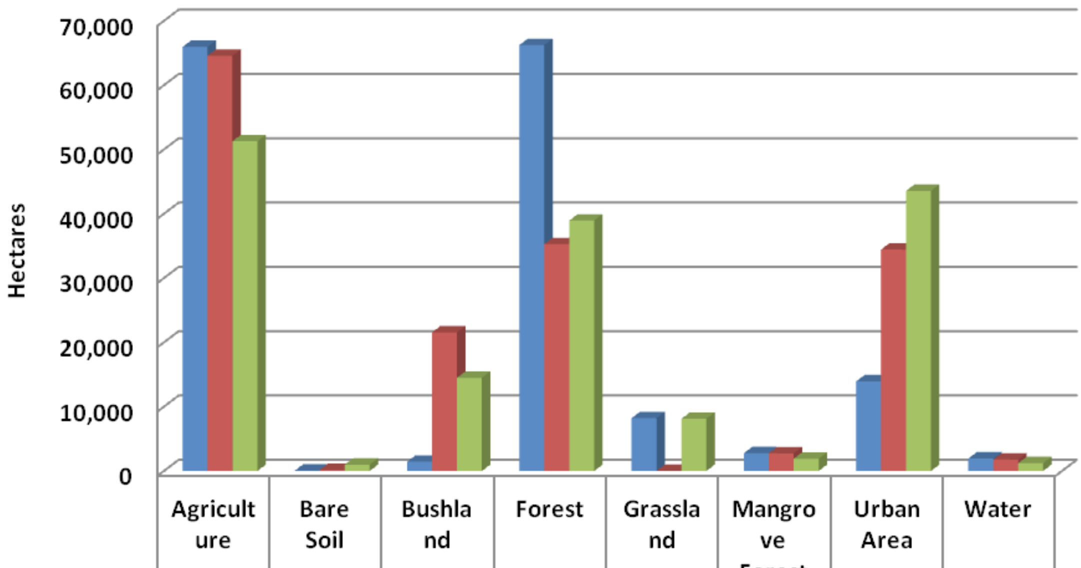


Fig. 9: Farm sizes for crop production in the study area (%)



	Agriculture	Bare Soil	Bushland	Forest	Grassland	Mangrove Forest	Urban Area	Water
Year:1981	65,960	63	1,446	66,245	8,223	2,764	13,939	1951
Year:2000	64,571	176	21,560	35,273	13	2,747	34,445	1781
Year:2016	51,287	989	14,503	38,953	8,129	1,920	43,567	1217

Fig. 10: Dar es Salaam Land cover types from 1981-2016

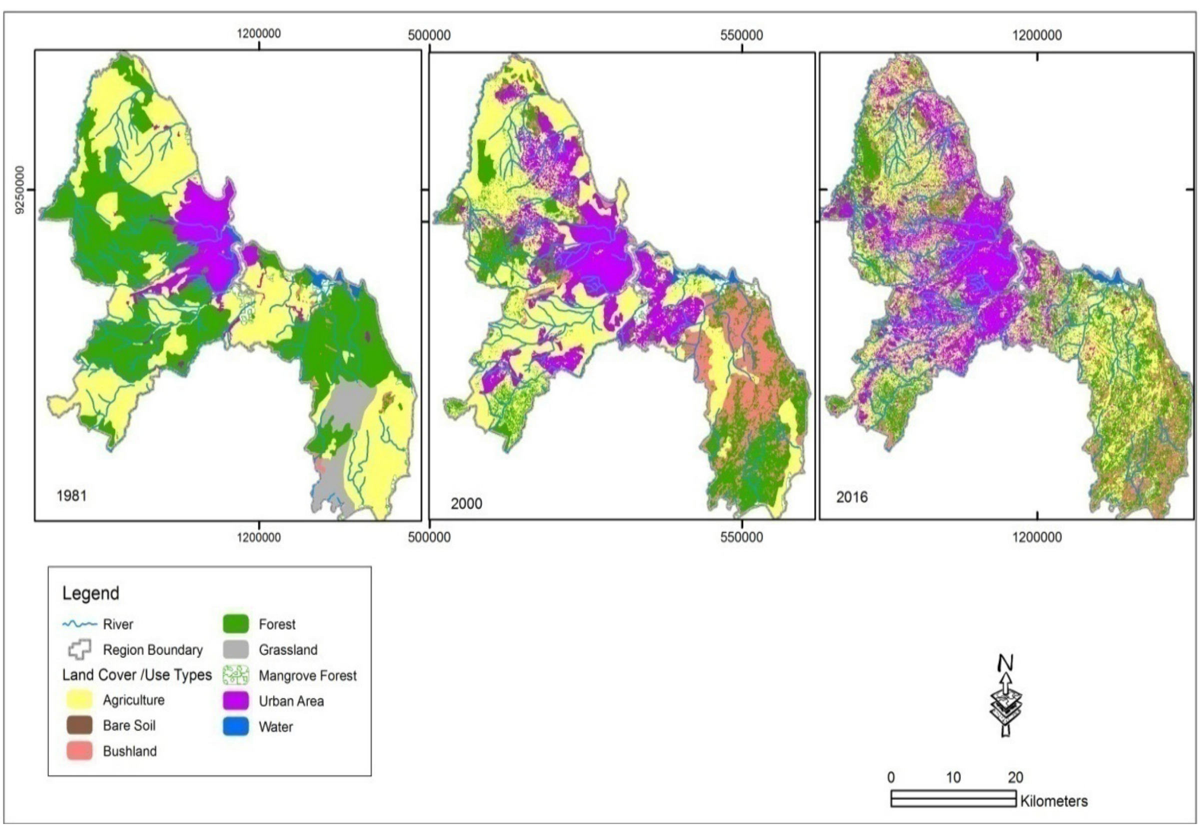


Fig. 11: Land cover/use types in the study area in 1981, 2000 and 2016.

In 1981 most parts of Dar es Salaam city were covered by agricultural lands and forests, and only small parts were built up, specifically in the city centre. In 2000, agricultural land continued to diminish as built land expanded and by 2016, most parts of Dar es Salaam city had changed into built settlements, thus substantially diminishing agricultural lands (Figure 11).

Conclusion

Based on the findings, it is evident that crop production and livestock keeping in urban and peri-urban areas of Dar es Salaam city were highly affected by increasing temperatures, decrease in rainfall totals, drought, shift in rain season and floods, leading to increased crop pests and diseases, drying of crops, decrease in crop yields and loss of soil fertility, as reported by the farmers and evidenced in the agricultural fields. Also, climate change had negative impacts on animal husbandry, leading to dying of livestock, drying of pasture lands and animal diseases. We recommend the adoption of vertical farming systems which use limited water resources while giving large amount of yields, instead of depending on unpredictable rainfall.

Acknowledgments

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The Impact of Rainfall and Temperature on Food and Nutrition Security in Bongo District, Ghana: The Voices of the People

Patience Atitsogbey[1]*, Richard Stephen Ansong[1], Christina Antwiwaa Nti[2] and Matilda Steiner-Asiedu[1]

[1]Department of Nutrition and Food Science, University of Ghana, Legon
[2]Department of Family and Consumer Sciences, University of Ghana, Legon
***Corresponding author:** Patience Atitsogbey; atitsopat@gmail.com

ABSTRACT

The Upper East region of Ghana is known to be particularly vulnerable to climate change and its associated impacts such as decreased rainfall, drought and food insecurity. These adverse impacts are skewed towards the poor, women and children. This study examined the awareness and knowledge of farmers, agriculture extension officers and meteorological officers on climate change and its impact on food and nutrition security within the Bongo district of the Upper East region. Four (4) focus group discussions and thirteen (13) key informant interviews were conducted in four (4) farming communities (Anaafobiisi, Bogrigo, Gorigo and Gowrie). Data were collected on awareness of climate change, coping strategies, effect of climate change on food crop production and consumption patterns within households. The data were then transcribed and analysed using Nvivo 10 software based on identified thematic areas. The findings indicated that poor rainfall pattern affected food crop production, resulting in poor household food consumption patterns. Although the level of awareness of the causes of climate change was low among the participants, they had a fair idea about climate variations across the district. High levels of misconception regarding causes of climate change were also reported. Effective education and sustainable strategies are needed to mitigate the effect of climate change on agriculture in order to improve food and nutrition security at the household level.

Keywords: Climate change, household food security, focus group discussion, Upper East Region, Bongo District

Introduction

Globally, droughts, extreme temperature events and floods have witnessed significant changes since the twentieth century. These extreme weather events have affected food crop production and food systems, thereby threatening food security, especially in developing nations (Lesk *et al.*, 2016). In developing countries like Ghana, food crops such as maize, rice, soybeans, sorghum and other smaller grains are very sensitive to extreme temperature during their flowering stages. For instance, maize has 3-5 days of anthesis while the rest have 7 or more. Hence, elevated temperature with longer duration may affect the fertility of the crops at their flowering stage, which could result in low yields (Singh *et al.*, 2015).

Agriculture is the major livelihood across West Africa, and it is also the most vulnerable to climate change because it depends solely on rainfall (Roudier *et al.*, 2011). Reduced rainfall leads to drought which has a detrimental impact on water security, resulting in the failure of crops to thrive (Field *et al.*, 2012). On the other hand, extreme rainfall events have a negative impact on food security through flooding of farmlands (WFP, 2012a). In Senegal, farmers perceived climate change factors such as rainfall and wind as the most destructive causes of poor livestock production and decreased crop yields (Mertz *et al.*, 2009).

Currently Ghana is experiencing the impact of extreme weather conditions (GAWU, 2012), and in the Upper East region of Ghana in particular where 95.2% of the people are farmers, livelihoods have been disrupted, so that achieving food security in the region is a herculean task (Aniah *et al.*, 2016; Fagariba *et al.*, 2018). In 2012, the World Food Programme documented that Bongo District was the most food insecure in the Upper East region, with 20% of households being food insecure (WFP, 2012b). This study therefore investigated the awareness and knowledge of people living in Bongo District regarding climate change and its possible effect on food and nutrition security among households in the district, with a view to informing educational campaigns, advocacy for change and policies to mitigate the effects of climate change.

Methodology

Research design, population and setting

A cross-sectional design by Neuman (2003) that employed a descriptive qualitative approach for data collection was used. Key informants' interviews and focus group discussions were conducted. Each focus group was made up of participants, who were food crop farmers and had lived within the Bongo district for more than ten years at the time of the research.

The study was conducted at Anaafobiisi, Bogrigo, Gorigo and Gowrie. The district is 15km away from Bolgatanga, the regional capital. Bongo District shares borders with the Bolgatanga Municipality to the south; Kassena-Nankana West and East districts to the west; and Burkina Faso to the north and east. The district has a land area of 459.5 kilometer square and a total population of 84,545, with females forming about 53.3% (Ghana Statistical Service, 2010). The majority of the populace (90%) are into animal rearing and food crop production. The Frafra and the Bossi are the two dominant ethnic groups.

The climate is characterized by one rainy season from May/June to September/October (an average of 70 rain days a year). The annual rainfall is between 600 mm and 1,400 mm. The rainfall is erratic and is followed by an extended dry season from November to May characterized by cold dry and dusty harmattan winds. Temperature ranges from 12°C at night during the dry season to over 40°C during the daytime. The flora is that of Guinea Savannah. Streams and rivers dry up during the dry season and the trees and grasses wither. Figure 1 shows the map of the study area.

Data collection

Key Informant Interviews: Thirteen key informant interviews were conducted, eight (8) with farmers, two from each of the four communities, with the help of community leaders. Other participants were four agricultural extension officers who oversaw the study communities and the meteorological officer in charge of the district. Discussions were held using open-ended questions and audiotaped with respondents' permission using a digital voice recorder. Each interview lasted for one-hour. The interviews focused on information on level of awareness and knowledge of climate change in the area, its effect on food crop production, and hence, on household food security.

Focus Group Discussions: Four focus group discussions were held, one in each community. Community leaders helped in identifying participants who consented to take part in the discussions. The discussions were held separately for men and women due to cultural contextual factors that might otherwise not allow women to speak freely without intimidation. Each group was made up of 10 participants aged 30-60 years and the sessions were led by a moderator and an assistant competent in the indigenous languages and English. Another assistant took notes and recorded non-verbal communication. The discussions were audiotaped using a digital voice recorder and each lasted for an hour and half. Questions from the interview guide focused on the level of awareness and knowledge of climate change in the area; the impact of climate change on food crop production; changes in food consumption patterns; and coping strategies employed to mitigate the negative impact of climate change during food shortage periods.

Data analyses

The audio recordings of both key informant interviews and focus group discussions were transcribed verbatim. The transcripts were then reviewed by another independent person who coded and analysed them using Nvivo™ 10 software. Thematic content analysis as described by Guest, *et al.,* (2012) was adopted for the interpretation of the qualitative data.

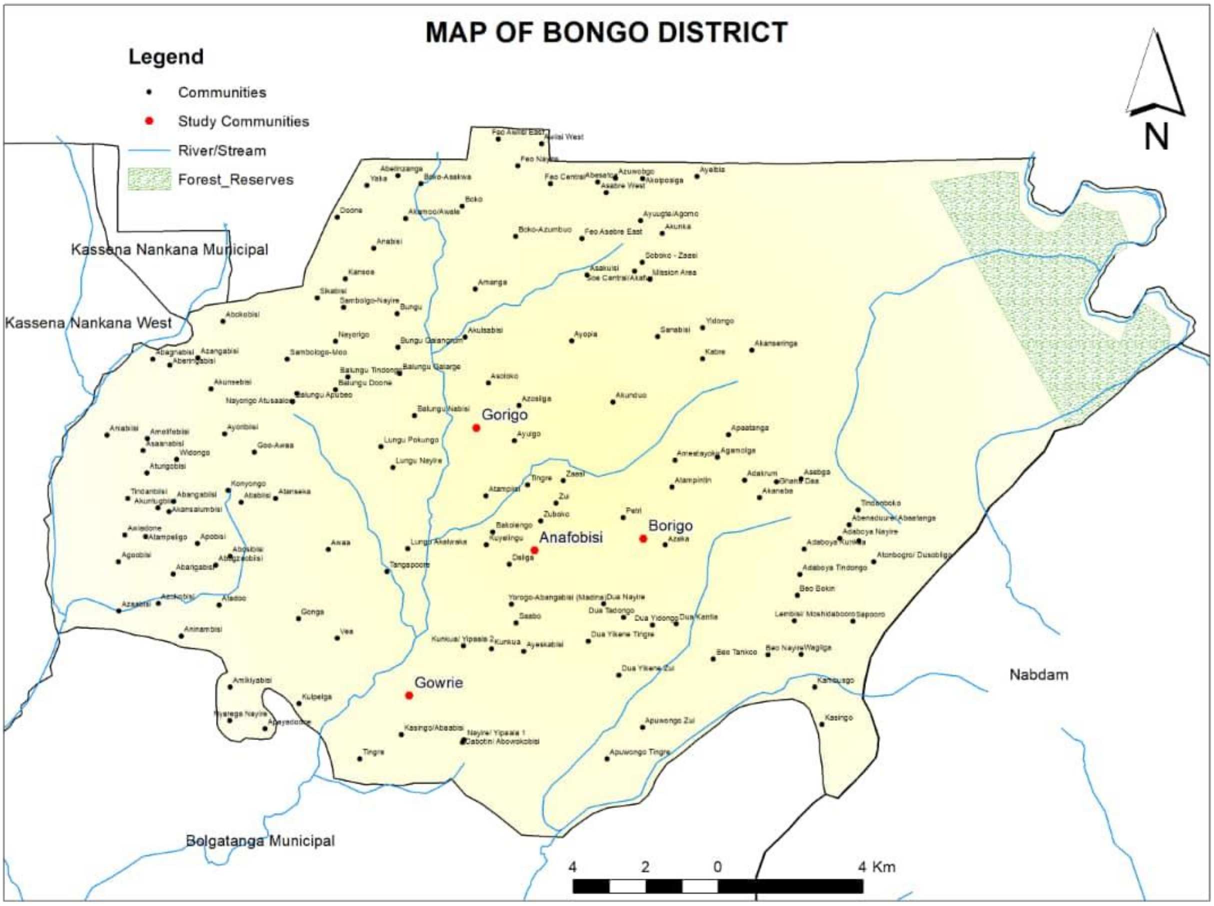

Fig. 1: Map of the study area (study sites were within valley, Zorko and Central zones)
Source: Bantiu Cabral (District Nutrition Officer, Ghana Health Service, Bongo)

Results

Three broad themes identified were: awareness and knowledge of climate change, impact of climate change on food production, and coping strategies employed to mitigate the impact of climate change on households.

Awareness and knowledge of climate change:

Findings from the study revealed that there was a low level of awareness and knowledge of climate change among the farmers. The following were some of the views expressed by the respondents when they were asked what they knew about climate change, using rainfall and temperature as a proxy:

"It is the changes that occur in the moon. Sometimes the moon is dark; other times it is bright" (Male respondent, Anaafobiisi).

"Me I don't know but people have been saying when our crops are dying then the climate has changed" (Female respondent, Bogrigo).

"Hmmm, I know the climate has to do with the weather but I don't know if I can say climate change is the change in the weather" (Male Agric extension officer, Bongo).

"Truly I don't know what climate change is. I only know that the weather is not the same. The sunshine has increased; we have less rain now (Male respondent, farmer, Gowrie).

I think climate change is when the harmattan is very strong and we can't even talk for fear that our lips will crack……." (a 52 year old female respondent, Gurigo).

"It is all about the irregular rainfall pattern in our community" (Female respondent, Gurigo).

However, some of the technical officers were abreast with what climate change is when asked the same question.

"………it is rainfall, temperatures, humidity and so forth. Climate change of an area therefore is the variation or the change in those things that I already mentioned and how it has changed over the period of 30 years" (Male respondent, meteorological officer, Bolga).

The study further explored respondents' knowledge of how the climate has been changing in their respective communities. Findings showed that there was a high level of awareness of various changes that were occurring in the four communities. Respondents identified irregular rainfall, high temperatures, too much heat, the drying up of rivers, and many more. But the change that was reported most was delayed /reduced rainfall. The statements below put into perspective the views of the participants when they were asked how the climate in their community was changing:

"Now we keep shifting the sowing time because you don't know when the rain will come; it delays and stops early too" (Male respondent, Gurigo).

"The time I was a child I never experienced much heat as it is now. Now there is too much heat but little rainfall" (Female respondent, Gowrie).

"……formerly planting starts in April, and by June we use to harvest the early millet and by October the late millet and most of the crops are then harvested too, but because of the change in the rainfall pattern nowadays, we plant late. When you plant late the rains stop early and most of the crops do not mature well resulting in low yield. And consequently lead to food insecurity" (Male Agric extension officer, Bogrigo).

"Of late it looks like we have late starting of rainfalls, compared to former years if I could recall, 10-15 years ago, the rains set in earlier say March or April thereabout, but now it starts around June or even July and is decreasing. Temperatures are also warmer now compared to former times. Around this time, we should be experiencing very cold weather now but it's warmer than it used to be" (Male meteorological officer, Bolga).

However, many of the respondents were not able to mention what the actual cause of climate change is as they attributed it to various things including non-observance of taboos, divine retribution for their many sins and disrespectful youth, among others. These were some of the answers given when respondents were asked what they thought was causing climate change in their community.

"Now our daughters don't get married before they become pregnant. They end up giving birth in the shrines. Since the shrines are responsible for giving us rain and keeping the climate normal, they have changed the climate so that when the sun burns us and we don't get rainfall we will change for the better" (Female respondent, Gurigo).

"We commit too much sin, people kill each for money and others have sex in the bush. A lot of us say we are Christians now so we won't send our sacrifice to the shrine. Why won't the gods punish us by changing the climate?" (Male respondent, Gowrie).

"Climate change is caused by human behavior which has made God angry. Some years ago it was a taboo to have sex in an open space. But now people often do it outside. This has made God to punish us by changing the climate" (Male respondent, Anaafobiisi).

"We were told it is global warming but we don't also know what is causing the global warming" (Male Agric extension officer, Bogrigo).

"It is caused by the way we do farming these days. We cut down many trees, that is why the climate is changing" (female respondent, Gowrie).

"Bush burning, obsolete vehicles, electronic equipment that we use now disturbs the ozone layer causing the climate to change" (Male Agric extension officer, Bongo).

Impact of climate change on food crop production

The findings indicated that most participants were affected by the changing climate that resulted in low yield of food crops, and this they attributed to poor weather patterns. Hence, there is a general reduction in interest in farming. Participants further stated that the returns from farming are not worth investing energy, money and time for several months. The farmers' concerns were corroborated by the technical agriculture officers. These were the views they expressed when they were asked how the changing climate had affected their farming activities and the food crops grown in their community over the past five years:

"Our yields have reduced. The land does not yield anymore. We don't harvest much so we cannot even sell any for money or buy other things including fertilizer. A lot of people go hungry now including my household" (Female respondent, Gurigo).

"I even want to stop farming but if I stop my children and I will go hungry. We harvest so little now due to bad weather and we don't have money to buy fertilizer too" (Male respondent, Bogrigo).

"When I was young we did farming with joy because you would harvest plenty and nobody would go hungry till another farming season. Now I am 62 years when you farm you get just a little so how can I seriously farm?" (Male respondent, Anaafobisii).

"Ten years ago when I planted maize and millet on the small land around this my house, I harvested plenty for food, so that we could sell those we grew on the bigger land outside my house, but now even the big farm is not yielding much, let alone the land around my house. It is not only me; everybody in this community is experiencing poor harvest" (Male respondent, Gurigo).

"It is affecting food production negatively now. People in this community used to have abundant food, especially the cereals, but now, by December most houses have to start buying food from the market or starve most of the time" (Male Agric extension officer, Bongo).

On the effect of rainfall and temperature, it emerged that low or delayed rainfall and high temperature were the climate variables contributing to poor harvest. Below were some perspectives reported.

"The dry season has become longer than before. We used to record rainfall in March but now we do not get rains early" (Female respondent, Gowrie).

"Formally the rains come in March but now the rains start in May, even June, sometimes September or October. When the rains come in June, by October the rains stop. So those crops that need long period to grow, have little rains so they die" (Male Agric extension officer, Bongo).

"Because of very high temperature, when I even fetch water and pour it on my vegetables and maize they still die" (Male respondent, Anaafobiisi).

All the respondents stated that the crops most affected by climate change are the cereals and the legumes. This was what they said when asked: which food crops are the most affected by climate change in this community?

"Almost all the crops, but the cereals and the legumes are the most affected. With the legumes if there is no rain around the fruiting time, the crops do not perform well. Millet too will have small size grains" (Male Agric extension officer, Bongo).

"Groundnuts, beans and millet are the ones most affected" (Female respondent, Gowrie).

On the effect of rainfall and temperature on the food crops grown in the various communities, it was mentioned that erratic rainfall in Bongo District was the cause of crop failure. Participants overwhelmingly acknowledged that poor rainfall patterns and high temperature contribute to crop failure, leading to low yields. Illustrated below are some of their views in response to the question: how have the rainfall patterns and temperature affected your food crop production?

"Rainfall is very irregular in our community. This time, we do not get the rain early as it used to be. Our crops are always failing us because they do not get water" (Female respondent, Gurigo).

"The soil living organisms are dead because of high temperature. Because of this, we don't get better yield" (Male respondent, Gowrie).

"Because of high temperature, I stopped doing vegetable farming. The sun just burns all the vegetables I grow. Life has become very difficult because of this high temperature" (Male respondent, Bogrigo).

The food crops grown in the four communities were millet, sorghum, rice, maize, sweet potatoes, beans, Bambara beans and groundnuts. Vegetables such as okro, kenaf, *aleefu* (*Amaranthus spinosus)* and *ayoyo* (Chorchorus), tomatoes, onions and pepper are also cultivated. Below were some of the responses from the participants when they were asked: which of the food crops were mainly affected by the changes in the weather pattern in this community?

"Rice, millet, and beans are the most affected because they need regular rainfall to do well" (Male respondent, Bogrigo).

"Early millet, sorghum, rice, beans, Bambara beans and groundnuts are the crops that are affected by these changes in the weather" (Female respondent, Gurigo).

The data revealed that the phrase most used with regard to the effect of climate change on household, food consumption was, "not having enough food to eat". The majority of the participants indicated that they do not get enough food to eat in their households due to low yields. Below are some responses to the question: in what ways has the changing climate affected the type of food people eat and the way they ate in previous years?

"Sometimes I don't eat in the morning myself but I give food to my children to eat and go to school. The harvest is mostly poor and we don't get enough. Now when you cultivate rice it doesn't yield well" (Female respondent, Anaafobiisi).

"I don't cook plenty because I don't get good yield from the crops I grow. I don't eat plenty like I used to eat. What I do is that, I do not eat in the afternoon" (Female respondent, Gurigo).

"We don't get enough food to eat. Because the yield is not high we cannot eat three times a day because we don't get enough food" (Male respondent, Anaafobiisi).

"It is not easy for my household to eat well because of the poor harvest these days. We buy from the market to support what is available. We just don't have enough to eat" (Female respondent, Bogrigo).

"Yields are affected and because yields are affected, the little that they harvest does not take them anywhere. A lot of the households' finish what they harvest in October by December" (Male Agric extension officer, Bongo).

Coping strategies employed to mitigate the impact of climate change on households

Our data showed that various coping strategies were employed in the communities to reduce the impact of climate change on families and households. Respondents indicated that some of them reduced the size of their meals and skipped meals, while others migrated to towns and cities for greener pastures. Below were some views expressed in response to the question: What do you do when there is poor harvest or inadequate food for the household?

"Some people do not eat in the mornings and afternoons, they only eat in the evenings" (Female respondent, Gowrie).

"……… we do not eat full bowls of sagituliga (touzafi) again. The women reduce the portions so that everybody can get some to eat." (Male respondent, Gurigo).

"There is also seasonal migration to some part of the northern region. Northern region harvests their crops later than us, so some people migrate to the Northern region to do harvesting and some of them migrate to Brong Ahafo and Kumasi for menial jobs" (Male Agric extension officer, Bongo).

"We travel to places like Kumasi or Accra to work for money; we carry loads for people during the dry season so that we can earn money and use it to buy more food to supplement the little that we harvest" (Female respondent, Anaafobiisi).

"In my house the grown-ups eat once a day when we don't have enough food, but the children eat in the morning and in the evening" (Female respondent, Gurigo).

"We ask for support from family members so that we can purchase foodstuffs when the harvest is poor, or if you have animals you sell them so you can buy food." (Male respondent, Bogrigo).

"For my family we cultivate more beans and Bambara beans which are very good. Normally we eat more of the beans and the Bambara beans during food shortage. When you eat it you drink a lot of water and you do not get hungry soon afterwards" (Male respondent, Bogrigo).

Food preservation has been one strategy used to prepare for the lean season. The common methods used were drying, storing dried crops in traditional barns, putting crops in sacks and treating them with chemicals. The following were some of the responses given by participants when asked how they preserved their food crops to prevent shortage of food in their households:

"I dry what I harvest and put it in barns. If I have money, then I buy the treated sacks and put them inside." (Male respondent, Gowrie).

"We boil the leaves of neem trees in water and sprinkle the water on the beans, millet or maize to preserve it" (Male respondent, Bogrigo).

"I dry my food crops and put the groundnuts in a pot. As for the millet, after drying I heap it on a mat in the storeroom or sometimes in the barn" (Female respondent, Anafobiisi).

"They have these traditional barns which are locally made (built) with clay and sticks. They put the crops there after drying and fetch a little at a time for the women when they need it, especially the millet and the corn. Some of them use these traditional pots for storage of the cereals and the legumes; some just store them in sacks after drying them" (Male Agric extension officer, Bongo).

"Some use botanical preservation. Botanical preservation is the one that they use the leaves of trees, the succulent ones, especially neem tree leaves mix it with the food they want to store. It is done to cereals and legumes" (Male Agric extension officer, Gowrie)

Discussion

Generally, awareness and knowledge of changes in the weather variables were high among key informants and focus group discussion participants. Participants mentioned, among others, delayed and decreased rainfall patterns, hotter days experienced, drought and stronger winds. Although participants could not quantify their observations, their assertions are consistent with the findings of Rasul *et al.* (2011) who reported an increase in temperatures from 0.7°C in the 20th century to 1.0°C in the 21st, making it the warmest century ever; the result is havoc and abnormalities in the climate system globally. Similarly, in Uganda, delayed rainfall and inconsistent timing of rain have made it difficult for farmers to forecast the best period to sow (Okonya *et al.*, 2013), and this situation is taking its toll on food crop production and availability.

Rainfall data collected between 1960 and 2006 revealed a mean decline of 2.3mm (GPJ, 2013). Furthermore, trend analysis of 30 years of data on rainfall and temperature (1986-2015) collected from the Ghana Meteorological Department (2016) indicates a decrease in rainfall of approximately 9.0mm at the rate of 0.3mm/year and an approximation of minimum temperature changes over the same period showed a marginal increase of 1.2°C at the rate of 0.04°C in the Bongo district (Atitsogbey *et al.*, 2018). Etwire *et al.* (2013) reported that Northern Ghana was the most susceptible to the erratic weather pattern caused by extreme weather events than the other regions of the country due to its drier and poorer nature, and these conditions affect the majority of people involved in subsistence agriculture (Etwire *et al.*, 2013). These observations corroborate those made by participants about decreased rainfall and increased temperatures over the years.

Although knowledge and awareness of the climate change events were high among the participants, there were misconceptions about what climate change is and what causes the changes in climate. These misconceptions are embedded in cultural contextual factors such as divine retribution and the engagement of young females in premarital sex in the fields. These beliefs are in sync with others reported in a study by the Asia Foundation (2014), where 46% of the respondents believe that climate change is the work of God, while 31% believe that it is caused by the action of human beings. In particular, rural households with inadequate access to weather reports are most likely to misconstrue the alterations in weather patterns, especially extreme atmospheric conditions, as the results of non-observance of sacraments and cultural practices (Nyanga *et al.,* 2011). Clearly, within the African context superstition continues to influence perceptions of the causes of climate change and may partly explain the sentiments observed.

With respect to coping strategies to ensure food and nutrition security, participants reduced meal size, skipped meals, migrated to bigger towns and cities to do menial jobs and depended on relatives elsewhere. These assertions are comparable to those made in a study by the United Nations Standing Committee on Nutrition which reported that droughts and weather associated threats consistently push households to adopt to some deleterious coping mechanisms, such as decreasing the quality and quantity of meals, decreasing health and education expenditures in order to acquire food and selling vital personal assets. These adverse coping strategies could lead to a rise in malnutrition, especially among women and children (UNSCN, 2010). Another coping strategy used by families during food scarcity situations is women reducing their own food intake so as to be able to feed their children and men (Quaye, 2008). Thus, during extreme weather variability, calorie consumption and dietary diversity are compromised, leading to stunting, poor health and loss of revenue (WFP, 2012a; Porter *et al.,* 2014).

Atitsogbey *et al.* (2018) documented that 97.2% of the households in the Bongo district were food insecure. The impact of extreme weather conditions on food security and the debilitating coping strategies has been reported also by other studies elsewhere (Ayanwuyi *et al.*, 2010; Manandhar *et al.*, 2011; Ali *et al.*, 2017; Osbahr *et al.*, 2011; Mongi *et al.*, 2010). The situation calls for efforts from all stakeholders to target the causes of climate change and its adverse effects on food crop production in the district if zero hunger (SDG2) is to be achieved in Ghana.

Conclusion

Unstable rainfall and temperature variations are negatively impacting food and nutrition security in the Bongo district of the Upper East Region of Ghana. The farmers are aware of climate change but are helpless to deal with it. There is therefore the need to get all stakeholders to work in unison to mitigate the effects of climate change through education with an approach that considers the entire food system (all the processes involved in food production and consumption) using modern technology.

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Loss of Indigenous Crop Species: Implications for Crop Diversity and Food Security in Ghana

Jacqueline Naalamle Amissah
Department of Crop Science, Legon, Accra, Ghana
jnamissah@ug.edu.gh

ABSTRACT

The overdependence on a relatively small number of crop species for food supply and security has compromised crop diversity and led to the loss of several crop genetic resources. This has lasting implications for biodiversity conservation and the ability to feed the ever-increasing world population. Indigenous crop species (ICS) such as Bambara groundnut (*Vigna subterranea*), African Yam Bean (*Sphenostylis stenocarpa*), Kersting's groundnut (*Macrotyloma geocarpum*), Asaman ntorewa (*Solanum torvum*) and Bokoboko (*Talinum triangulare*), have the potential of meeting Ghana's food needs and addressing issues of nutrition security, poverty and health. ICS do not only serve as a repository of genetic diversity, but also some are micronutrient rich and have the added advantage of being better adapted to prevailing environmental conditions. The aim of the study was to gather indigenous knowledge on crop species that are no longer cultivated and the reasons for non-cultivation, with the aim of identifying those with potential to address food security challenges in Ghana. This study tapped into the indigenous knowledge existing within farming communities across five of the six agro-ecological zones in Ghana. Surveys were conducted in 41 farming communities across Ghana (Upper East, Northern, Ashanti, Eastern, Volta, Western and Central Regions). Data were obtained through 41 focus group discussions followed by face-to-face questionnaire interviews with 600 individuals (427 males and 173 females). A combined total of 40 species and varieties of crops were recorded as currently cultivated in the study areas, with a further over 50 species/varieties reported to have previously been cultivated. Change in rainfall patterns, infertile soils, deforestation, pests and diseases, and the high cost of cultivation were some of the reasons given for not growing the indigenous crop species. We profile the indigenous crop species with the potential to withstand climatic extremes and contribute to food security, and discuss the implications of the loss of such crop species and/or varieties for agro-biodiversity and food security.

Keywords: Deforestation, farmer perceptions, rainfall, soil infertility

Introduction

Agriculture plays a major role in sustaining the economies of African countries by providing jobs, income supporting industries and foreign exchange through exports. The agricultural sector contributes approximately 20-30% of the continent's GDP and is a source of livelihood for 60-70% of Africans (UNECA, 2009). According to FAO (2004), three–quarters of the world's food is generated from just 12 plant and five animal species. Even though Africa possesses a myriad of indigenous crop species, ensuring food security and maintaining economic growth is dependent on a few declining crop species that are widely cultivated. It is estimated that approximately 75% of the world's plant genetic diversity has been lost as farmers depend on high-yielding, genetically uniform varieties (Maxted *et al.*, 2007; FAO, 2004). The replacement of local varieties and landraces with improved high-yielding varieties seemed like a brilliant solution to the fight against food insecurity, but in the long term, this has compromised crop diversity and led to the extinction of several genetic resources. Many of the conventional crop species are not able to withstand the ongoing climatic changes and the associated fluctuations in temperature and rainfall, thus resulting in declining yields. The narrowing of the crop species' diversity poses a threat not only to food security, but also to nutritional security, exposing the already food insecure populations to crop failures and nutrition related risks associated with non-communicable diseases (Khoury *et al*., 2014).

In Ghana the effects of climatic change in terms of changes in the rainfall patterns are impacting negatively on the cultivation of staple foods such as rice and yams (Mabe *et al*., 2012; Ofori-Sarpong & Asante, 2004). Under the current and projected impact of climate change and in the wake of concerns about water availability for agriculture in developing countries, there is the need to look into the potential of indigenous crop species to contribute to food security. Several of these indigenous crop species are not only rich in nutrients, but are better adapted to poor soils, drought conditions and pests and diseases. Also, the diversity of diets resulting from a diverse crop base will result in better human nutrition with subsequent productivity benefits. Apart from the direct contribution as a food resource and their richness in micronutrients, the genetic potential available in indigenous crop species could be exploited to mitigate the declining agrobiodiversity and to address the food security challenges facing African nations. Unfortunately, these traditional crops are becoming extinct and are restricted only to the indigenous communities where the crop holds traditional importance and/or where the older generation still appreciates the nutritional and medicinal value of such crops.

Many of the neglected indigenous crop species have the potential to become foods of the future and would need to be integrated into existing agricultural research programmes to gain visibility and attract attention. To reinstate them as alternative food sources, there is the need to tap into indigenous knowledge that exists within farming communities. Knowledge of the production practices, changes in the characteristics of the production environment and utilization of these crops resides with the people in some of the communities. Most of the knowledge has never been documented and may be scattered among people in the farming communities.

The aim of the study was to gather indigenous knowledge on crop species that were previously cultivated in Ghana, but are no longer grown, and reasons why they are no longer cultivated. We also profile the indigenous crop species that have the potential to address food security challenges in Ghana in the face of climate change and discuss the implications of the loss of such crop species/varieties for agro-biodiversity.

Materials and Methods

The study site

The survey was carried out in 41 farming communities in twelve districts (Kassena-Nankana, Tamale, Gonja West, Ejura-Sekyeredumase, Upper Manya Krobo, Fanteakwa, Gomoa, Adaklu, Afadzato South, North Tongu, Nkwanta South and Wassa Amenfi East) within six regions spread across Ghana (Figure 1). The districts selected represent areas in Ghana where agriculture is the main economic activity of the people.

Data collection instrument and process

The data reported here were collected between March and September 2014 through direct observations of farm produce on farms and at markets, focus group discussions and face-to-face questionnaire interviews of individual farmers. GPS coordinates were taken to mark the location of each community visited (Table 1). Data required to develop the crop profile were collected during interactions with respondents in the focus group discussions and also from review of published works.

Fig. 1: Map of Ghana showing Locations where interactions were held.

Source of Map: Author's construct

Table 1: Location and Vegetation of Study Sites

Regions	Districts	Communities	GPS coordinates	Respondents /Community	Ecological Zones
Upper East	Kassena-Nankana	Nyangua	10°56’19.2” N; 001°04’05.4” W	20	Guinea/ Sahel Savanna (Upper East), Guinea savannah (Northern)
		Bonia	10°51’53.0” N; 001°07’29.4” W	22	
Northern	Tamale	Tibali	09°40’04.4” N; 000°50’39.6” W	20	
		Botingli	09°36’41.5” N; 000°47’17.8” W	9	
	Gonja West	Frafra Settlement	09°03’17.0” N; 000°47’49.3” W	15	
		Yipala	09°07’59.0” N; 001°50’39.1” W	10	
Ashanti	Ejura-Sekyeredu-mase	Kyekyebon,	07°09’28.0” N; 001°04’22.8” W	17	Forest/savanna Transition (Semi-deciduous forest - south eastern parts; Guinea Savanna - northern parts)
		Dome	07°17’15.2” N; 001°12’33.2” W	11	
		Kunja	07°17’32.7” N; 001°12’52.3” W	10	
		Balana	07°17’32.7” N; 001°12’52.3” W	11	
		Congo Nkwanta	07°20’35.0” N; 001°08’37.9” W	13	
		Nyamebekyre	07°15’17.5” N; 001°11’03.5” W	14	
		Asasebonso	07°13’19.8” N; 001°10’04.7” W	15	
Eastern	Upper Manya Krobo	Konkoney	06°24’01.0” N; 000°13’54.9” W	15	Semi-deciduous forest and derived Savanna zone
		Nyakumase	06°23’02.0” N; 000°14’24.8” W	15	
		Sekesua	06°17’51.0” N; 000°09’45.9” W	15	
	Fanteakwa	Miaso	06°33’07.2” N; 000°28’28.9” W	16	Wet-semi deciduous rain forest and savanna grassland (north of the district)
		Mianya	06°33’07.2” N; 000°28’28.9” W	15	
		Akwanserem	06°27’02.8” N; 000°26’55.1” W	24	
		Feyiase	06°30’29.7” N; 000°27’12.2” W	15	
Central	Gomoa	Gomoa – Enyeme	05°22’00.4” N; 000°41’00.5”W	15	Dry coastal savanna and moist semi-deciduous forest
		Gomoa – Oguaa	05°25’14.2” N; 000°48’45.9”W	10	
		Gomoa – Bewuadze	05°21’58.4” N; 000°40’38.0”W	15	
		Gomoa – Amanfi	05°22’00.4” N; 000°41’00.5” W	15	
		Gomoa – Kumasi	05°23’59.8” N; 000°47’53.8” W	15	
		Gomoa- Ayanful	05°28’44.2” N; 000°52’05.1” W	15	
Volta	North Tongu	Aveyime	06°02’16.2” N; 000°22’27.4” E	18	
		Dadome-Fakpoe	06°06’34.2” N; 000°26’23.7” E	15	Semi-deciduous forest (northern parts) and tropical rainforest (southern parts)
	Afadzato South	Tafi-Atome	06°54’22.1” N; 000° 22’51.8” E	15	
		Logba-Alakpeti	06°53’39.5” N; 000° 25’56.5” E	15	
	Adaklu	Adaklu-Waya/ Adaklu Anfoe	06°26’49.4” N; 000° 37’48.5”E	14	
	Nkwanta South	Adaklu Vodze	06°32’27.3’’ N; 000° 26’48.7” E	6	
		Abrɛwankor	08°20’54.4’’ N; 000° 30’08.8” E	23	

Regions	Districts	Communities	GPS coordinates	Respondents /Community	Ecological Zones
Western	Wasa Amenfi East	Wasa Nsuopun	05°51'41.8'' N; 001° 59'05.0" E	15	Semi-deciduous forest (Northern parts) / tropical rainforest (Southern parts)
		Wasa Abeneso	05°52'51.2'' N; 002° 01'50.9" E	15	
		Dikoto junction	05°47'32.0'' N; 002° 11'57.2" E	20	
		Wasa Saa	05°55'05.7'' N; 002° 01'00.5" E	15	
		Abesewa Gjaman	05°49'08.7" N; 002° 01'21.4" W	14	
		Appiah Nkwanta	05°46'27.6'' N; 001° 57'20.4" W	15	
		Kokoado	05°46'27.6'' N; 001° 57'20.5" W	10	

Sample Population and sampling technique

Participants of the focus group discussions were selected based on their knowledge and experience with farming activities in their communities. The respective district agricultural extension officers were very instrumental in identifying the farming communities. Communities were selected based on their history of involvement in crop production to ensure that the information obtained on crop species was a true reflection of what pertained in each district. In all, a total of 600 individuals, comprising 427 males and 173 females, were contacted. Fifty percent of the farmers who participated in the study were between the ages of 30-50 years, with 41% being above 50 years. In addition, a focus group discussion was held with six grain aggregators (2 males and 4 females) at the Aboabo Market in Tamale to get a sense of market trends for the crop species that were no longer being cultivated.

For each of the communities, 10-25 farmers participated in the focus group discussion conducted using a guided dialogue approach that was tape recorded. This was followed by random administration of individual face-to-face interviews using a structured questionnaire comprising open- and close-ended questions. The face-to-face interactions served to validate and build on the questions addressed during the focus group discussions. Field notes taken during each focus group discussion included non-verbal cues during the interviews and the main concerns of participants. Participants shared their views on why certain indigenous crop species are no longer cultivated and these were queried until full understanding was gained. The focus group discussions comprised questions such as: 1) what are the common crops currently cultivated? 2) what crop species were previously cultivated that are no longer under cultivation? and 3) why are these crop species no longer cultivated? Focus group discussions and interviews were conducted in the local language of the communities visited. Agricultural extension officers served as interpreters in communities where the research team could not speak the local language.

Data analysis

Transcripts from the focus group discussions were checked several times to ensure clarity of participants' accounts and corroborated with field notes. The questionnaires were coded and imported into SPSS 18.0. Data were analyzed using non-parametric statistics and summarized into averages, frequencies or percentages. Data required to develop the crop profile were collected during interactions with respondents in the focus group discussions and also from the review of published works.

Results

Crop species currently and previously cultivated

A combined total of 40 species and varieties of crops were recorded as currently cultivated in the study areas; in addition to these, over 50 species/varieties were reported to have been cultivated in the past but were no longer cultivated. A selection of the indigenous crop varieties at risk of disappearing is presented in Figure 2(a–f). Table 2 presents the list of crops cultivated by farmers in the study areas as well as those previously cultivated but no longer grown. These are categorized under cereals, legumes, vegetables, tree and plantation crops, roots and tubers. Eight crops were common to four or more of the study regions. These were: maize (*Zea mays*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), okra (*Abelmoschus esculentus*), garden eggs (*Solanum aethiopicum* and *Solanum melongena*), tomato (*Solanum lycopersicum*), pepper (*Capsicum* spp.) and cassava (*Manihot esculenta*).

Fig. 2: A selection of Indigenous Crop Species, a) Aerial yam (*Dioscorea bulbifera*); b) Neri (*Citrullus vulgaris*); c) Apatram (*Phaseolus vulgaris*) d) Yellow yam (*Dioscorea cayenensis*); e) Frafra potato (*Solenostemon rotundifolius*); f) Kersting's groundnut (*Macrotyloma geocarpum*)

Table 2: Currently and previously cultivated crop species per survey location

Region/District/ Communities	Crops Currently Grown	Crops No Longer Grown
Upper East/Kassena Nankana/ (Nyangua & Bonia)	Cereal(s): Millet (*Pennisetum glaucum)*, Rice (*Oryza sativa)* and Maize (*Zea mays*) Legume(s): Cowpea (*Vigna unguiculata*), soya beans (*Glycine max*), Bambara groundnut (*Vigna subterranea*), Groundnuts (*Arachis hypogaea*) Vegetable(s): Kenaf (*Hibiscus cannabinus*), okra (*Abelmoschus esculentus*), pumpkin (*Cucurbita maxima*), amaranths (*Amaranthus* spp.), garden eggs (*Solanum incanum*), onions (*Allium cepa*), cabbage (*Brassica oleracea* var. Capitata), green pepper (*Capsicum annum*), carrot (*Daucus carota*), tomatoes (*Lycopersicon esculentum*) Roots and Tuber(s): Frafra potatoes (*Solenostemo rotundifolius*) (black type), Sweet potato - yellow fleshed (*Ipomoea batatas*),	Cereal(s): Millet (*Pennisetum glaucum*) varieties [Banyio, Tangwamyise, Candabuna, Gamba, Sununimu &Wolo]; Rice (*Oryza sativa*) varieties [Kukula, Avadjuwa, Bengayiri, Kaliqua]; Sesame (*Sesamum indicum*) Legume(s): Groundnut (*Arachis hypogaea*) *varieties* [Solokopro – big and stout shelled variety & Sonogangolo – long shelled groundnut with 3-4 groundnuts per pod] Vegetable(s): Red Kenaf (*Hibiscus cannabinus*),
Northern/Tamale & Gonja West/ (Tibali, Botingli, Yipala & Frafra Settlement)	Cereal(s): Maize (*Zea mays*), Rice (*Oryza sativa)*, Sorghum (*Sorghum bicolor*), and Millet Legume(s): Bambara groundnuts (*Vigna subterranea*), Cowpea (*Vigna unguiculata*), Groundnuts (*Arachis hypogaea*), Soya vean (*Glycine max*), Pigeon pea (*Cajanus cajan*), Vegetable(s): Okra (*Abelmuoschus esculentus*), Pepper (*Capsicum annuum*), Tomato (*Lycopersicon esculentum*), Ayoyo/Jute Mallow (*Corchorus olitorius*) Roots and Tuber(s): Sweet potato (red, white and yellow fleshed) (*Ipomoea batatas*), Yam (*Dioscorea* spp.), Cassava (*Manihot esculenta*)	Cereal(s): Sesame (*Sesamum indicum*) Legume(s): Lanseya (*Canavalia* spp.), Simpee/Kersting's groundnut (*Macrotyloma geocarpum*) Vegetable(s): Nele/Neri (*Citrullus vulgaris*), Root and Tuber(s): Frafra potato (*Solenostemon rotundifolius*), Afaseɛ yam (*Dioscorea alata*) Nasa/ Tigernut (*Cyperus esculentus*)
Ashanti/ Ejura-Sekyeredumase/ (Kyekyebon, Dome, Kunja, Balana Congo Nkwanta , Asasebonso and Nyamebekyre)	Cereal(s): Maize (*Zea mays*), Rice (*Oryza sativa*). Legume(s): Cowpea (*Vigna unguiculata*), Soya bean (*Glycine max*), Groundnut (*Arachis hypogaea*), Beans (*Phaseolus vulgaris*), Root and Tuber(s): Yam (Pona/ Bayerɛ pa (*Dioscorea rotundata*), Water yam/Afaseɛ (*Dioscorea alata*), Cassava (*Manihot esculenta*), Cocoyam (*Colocasia esculenta*) Vegetable(s): Tomato (*Lycopersicon esculentum*), Garden eggs (*Solanum melongena*), Pepper (*Capsicum annuum*), Hibiscus/Sobolo (*Hibiscus* spp.)	Cereal(s): Sorghum/Atokuo (*Sorghum bicolor*), Pearl Millet/ Ayuo (*Pennisetum glaucum*), Legume(s): Apatram type of kidney bean (*Phaseolus vulgaris*); Adua, and Bambara groundnut (*Vigna subterranea*), red cowpea (*Vigna unguiculata*) Vegetable(s): Alefu (*Amaranthus* spp.); Akatoa/Egushi (Citrullus colocynthis) Tree and Plantation Crop(s); Oil palm (*Elaeis guineensis*), Plantain (*Musa paradisiaca*), Cocoa (*Theobroma cacao*), Cola (*Cola nitida*), Citrus (*Citrus* spp.), Coffee (*Coffea arabica*), Coconut (*Cocos nucifera*), Avocado pear (*Persea americana*), Cashew (Anacardium occidentale), Root and Tuber(s): Arial yam (*Dioscorea bulbifera*), Nkanfo/ Bitter yam (*Dioscorea dumetorum*), Sweet potato (red and white varieties) (*Ipomoea batatas*)

Table 2 cont.

Region/District/ Communities	Crops Currently Grown	Crops No Longer Grown
Western/ Wasa East/ (Wasa Nsuopun, Wasa Abeneso, Dikoto junction, Wasa Saa, Abesewa Gjaman, Appiah Nkwanta and Kokoado)	Cereal(s): Maize (*Zea mays*), Legume(s): Cowpea (*Vigna unguiculata*), Vegetable(s): Okra (*Abelmoschus esculentus*), Garden egg (*Solanum melongena*), Pepper (*Capsicum annuum*), Tomato (*Solanum pimpinellifolium*) Tree and Plantation Crop(s): Cocoa (*Theobroma cacao*), Oil palm (*Elaeis guineensis*), Plantain (*Musa paradisiaca*), Citrus (*Citrus* spp.) Pineapple (*Ananas comosus*) Root and Tuber(s): Cassava (*Manihot esculenta*), Cocoyam (*Colocasia esculenta*), Yam (*Dioscorea* spp.)	Cereal(s): Rice (Wasa MƆ), Legume(s): Groundnut (*Arachis hypogaea*), Vegetables(s): Onion (Asante fo gene), Tomato (Woso woso), Tree and Plantation Crop(s): Sugarcane (Saccharum *officinarum*), Coffee (*Coffee arabica*), Root and Tuber(s) Yam (AfaseƐ, Cocoa ase baiyirƐ (Dioscorea cayenensis)), Brobe (*Colocasia esculenta*), Nkanfo, Ntwibo, Nkankano, Sweet potato (*Ipomoea batatas*)
Volta/North and South Tongu, Afadjato South, Adaklu and Nkwanta South/ (Aveyime, Dadome-Fakpoe, Tafi-Atome, Logba-Alakpeti, Adaklu-Waya/Anfoe, Adaklu-Vodze, Abrɛwankor)	Vegetable(s): Chili pepper (*Capsicum frutescens*), okra (*Abelmoschus esculentus*), tomatoes (*Solanum lycopersicum* -wosowoso type), Garden eggs (*Solanum melongena*), KpaKpo Shito (*Capsicum annum*), Ginger (*Zingiber officinale*) Cereal(s): rice (*Oryza sativa*), maize (*Zea mays*), Root and Tuber(s): cassava (*Manihot esculenta*), Yam (*Dioscorea spp.*) Legume(s): groundnut (*Arachis hypogaea*), cowpea (*Vigna unguiculata*) Tree and Plantation Crop(s): Oil palm (*Elaeis guineensis*), Cocoa (T*heobroma cacao*) (minor), mango (*Mangifera indica*), Plantain (*Musa paradisiaca*), Banana (*Musa* spp.), Orange (*Citrus* spp.)	Cereal(s): Mansah Blue- type of rice with violet husk, white seed and sweet taste, Agbadzahlao-Brown rice with big rounded grains, high yielding, Ewebli- type of maize has good milling properties, long shelf-life, Legume(s): Bambara beans (*Vigna subterranea*), Lima beans (*Phaseolus lanatus*)–Kpokpo, Kulengɛ- type of beans with small coloured seeds, used in soups, Otini/Atiyi (Pigeon pea)-leaves are used in treating measles, Vegetable(s): Pepper [(*Capisicum annuum*)- Agoo (pungent smelling, hot pepper, round shaped, called Ojinma in twi) and Agootse (long shelf-life), Tree and Plantation Crop(s): Sugarcane (*Saccharum officinarum*), Asikpu - type of banana with short, thick fingers, Amaga (Dawadawa) Root and Tuber(s): Sweet potato (*Ipomea batatas* - white and red fleshed), Yam [(*Dioscorea* spp.)-Water yam (Avadjɛ); Yellow and purple varieties with purple vines and insides], Cassava (*Manihot esculenta*) -Ankrah, Grace, Fetorgbodzidi, Appoe- has a sweet taste and white under skin and Yesuvi variety, Avadjɛ - water yam with violet insides, Kelevu - type of yam with blue or yellow insides, Djantiba/Kasante - types of yam,
Eastern Upper Manya Krobo & Fanteakwa (Konkoney, Nyakumase, Sekesua, Miaso, Mianya, Akwanserem and Feyiase)	Legume(s): Asedua/Lima beans- *Phaseolus lunatus*), groundnut (*Arachis hypogaea*), cowpea (*Vigna unguiculata)*, Vegetable(s): Garden eggs(*Solanum melongena*), Pepper (*Capsicum annuum/Capsicum frutescens*), Okro (*Abelmoschus esculentus*), Cabbage (*Brassica oleracea* var. Capitata), Tree and Plantation Crop(s); Plantain (*Musa paradisiaca*), Cocoa (*Theobroma cacao*), Avocardo pear (*Persea americana*) Root and Tuber(s): Cassava (*Manihot esculenta*), cocoyam (*Xanthosoma sagittifolium*) (pink fleshed variety), Water Yam (*Dioscorea* spp.)., Yellow Yam (*Dioscorea cayenensis*)	Legume(s): Groundnut (*Arachis hypogaea)*. African yam bean (*Sphenostylis stenocarpa*), Lima beans/Akotrobo - *Phaseolus lunatus*, Vegetable(s): TongƆ/native type of Bell pepper - *Capsicum annuum*), Ginger (*Zingiber officinale*), Kpakpo shito/ Adibolo (*Capsicum chinense*), Egushi (*Citrullus lanatus*) Tree Crop(s): Oil palm (*Elaeis guineensis*), Coconut (*Cocos nucifera*) Root and Tuber(s): Brobe/Taro (*Colocasia esculenta*), cocoyam (white and yellow flesh type), Yellow yam (*Dioscorea cayenensis*), Bitter yam/Nkanfo (*Dioscorea dumetorum*), Kwakolekwa/AsƆ bayerɛ/Wild yam - *Dioscorea villosa*); cocoa ase bayerɛ (*Dioscorea prahelensis*), yellow yam (*Dioscorea cayenensis*) sweet potato (*Ipomoea batatas*), (*Dioscorea alata),* water yam (*Dioscorea rotundata*)

Table 2 cont.

Region/District/ Communities	Crops Currently Grown	Crops No Longer Grown
Central Gomoa (Gomoa- Enyeme, Gomoa- Oguaa, Gomoa-Kumasi, Gomoa- Amanfi, Gomoa- Bewuadze and Gomoa-Ayanful)	Cereal(s): Maize (*Zea mays*); Vegetable(s): Pepper (*Capsicum annuum/ Capsicum frutescens*), Onion (*Allium cepa*), Garden egg (*Solanum melongena*), Tomatoes (*Solanum lycopersicum*), Okro (*Abelmoschus esculentus*); Root and Tuber(s): Cassava (*Manihot esculenta*), cocoyam (*Colocasia esculenta*) -white and pink varieties; Tree and Plantation Crop(s): Cocoa (*Theobroma cacao*), Orange (*Citrus* spp.), Oil Palm (*Elaeis guineensis*), Rubber (*Hevea brasiliensis*)	Legume(s): Beans (*Phaseolus vulgaris*), red cowpea (*Vigna unguiculata*) Vegetable(s): Akinton /Zucchini/ Courgette (*Cucurbita pepo*), Shallot (*Allium cepa* var. aggregatum) Root and Tuber(s): Puk3 (*Dioscorea alata*) -type of water yam, Akatoa/ Egushie (*Citrullus colocynthis*), Obo aduonum (*Dioscorea rotundata*), Yellow Yam (*Dioscorea cayenensis*, Asorbayerɛ /Aerial yam (*Dioscorea bulbifera*), Sweet potato (*Ipomoea batatas*), Tree & Plantation Crop(s): Plantain (*Musa paradisiaca*), Cocoa (*Theobroma cacao*), coconut (*Cocos nucifera*), Sugarcane (*Saccharum officinarum*),

The natural vegetation (Guinea Savannah) in the Kassena Nankana, Tamale and West Gonja Districts made the area suitable for the production of cereals (millet - *Pennisetum glaucum*, sorghum - *Sorghum bicolor* and maize) and legumes (groundnuts). Vegetables in the Kassena Nankana, Tamale and West Gonja Districts were grown mainly by women. Farmers in the Ejura-Sekyeredumase area produced mainly cereals (maize) and root tubers (yam, *Dioscorea* spp.); while those in the Upper Manya Krobo & Fanteakwa Districts produced a wider array of crops, including maize, cassava and plantain. Farmers in the Gomoa District produced mainly maize, cassava, plantain, yam and pineapples. Farmers in the North Tongu District produced mainly cassava, maize, cowpea and pepper. Crops commonly grown in the Adaklu District were maize, cassava, sweet potato, groundnut and tomato. In Afadzato and Nkwanta South Districts farmers cultivated mainly tree crops such as cocoa (*Theobroma cacao*), coffee (*Coffea arabica*), oil palm (*Elaeis guineensis*), banana (*Musa* spp.) and plantain (*Musa paradisiaca*). In the Wasa Amenfi East District crops produced included cocoa, cassava, plantain, oil palm, rice (*Oryza* spp.) and maize.

Farmers' perceptions of reasons why certain crops are no longer cultivated

The reasons given for non-cultivation of various crop varieties and species are presented in Figure 3 (combined data from all sites) and Figures 4A-F (individual sites). Approximately 65% of the farmers interviewed across the study sites gave changes in rainfall patterns (22.9%), infertile soils (20.4%), production not being economically viable[1] (13.7%) and the loss of forest canopy resulting from bushfires and farming activities (7.7%), as reasons why certain crop species were no longer cultivated (Figure 3). While farmers in the northern savannah sites gave two main reasons "soil infertility" and "changes in rainfall" as the cause for non-cultivation of the crops, the reasons given in the southern areas were much more varied, but even within these areas "soil infertility", "production not being economically viable" and "changes in rainfall" scored highly. During the focus group discussion at Akwanserem in the Eastern Region, a farmer pointed out that because of the unpredictable rainfall patterns, taro *Colocasia esculenta*, normally found in marshy areas close to water sources, could no longer be cultivated because of the drying up of these water sources. Clearing of the forest canopies in Nyakumase in the Eastern Region has led to the disappearance of several yam *Dioscorea* spp. varieties as well as the yellow and white cocoyam *Colocasia esculenta* types. The "introduction of new and improved crop varieties" came up as a major reason (20.8%) for non-cultivation of indigenous crops in the Volta Region. The new and improved crop varieties have the advantage of ready markets, a sustainable seed system and extension support. A farmer from Tafi - Atome in the Volta Region had this to say in response to why indigenous crop varieties were no longer cultivated:

[1] Not economically viable is interpreted to mean low monetary gains considering the labour investments put into the production of the crop

"Extension officers promote the improved varieties over the indigenous crop varieties. There is limited extension support for farmers cultivating indigenous crops."

In the Western Region "pest and disease" problems came up strongly as one of the main reasons for the non-cultivation of indigenous crop species. The heavy rainfall in the area accounted for the high disease incidence reported, which in some communities resulted in general misconceptions. Farmers in Kokoado in the Western Region, for example, avoid eating taro *Colocasia esculenta* because of the misconception that anyone who ate the diseased leaves would be blind for 5 years. Birds and millipedes were the main pests which accounted for the non-cultivation of the local rice variety (Wasa mo) and tuber crops (cocoyam and yam varieties) respectively.

Infertile soil was identified as one of the major constraints to the cultivation of previously grown crop species and came up strongly in our interaction with farmers in the Kassena Nankana, Tamale and Gonja West Districts (39.6% of responses). Farmers in the Ejura-Sekyeredumase District identified the loss of forest canopy as a result of bushfires and farming activities (24.2%), and lack of economic viability (18.7%) as major reasons why some indigenous crop species were no longer cultivated. Interestingly, farmers in the Ejura-Sekyeredumase District linked the loss of forest canopy and bush burning to a loss in soil organic matter, resulting in soil infertility. Similar responses were given by farmers in the Upper Manya Krobo and Fanteakwa Districts. Apart from these, farmers also pointed out that because of the inadequate land available for farming (6.7%), they avoided the cultivation of crops with spreading forms (such as sweet potato and groundnut). Although not indicated specifically as a reason for the loss of indigenous crop species in the Wasa Amenfi East District, the youth in the district expressed the view that "galamsey" (illegal mining) activities provide a much better alternative to farming. A young man in Wasa-Nsuopun (Western Region) was quoted as saying:

"galamsey gives me a lot more money so why should I go into farming."

In the Wasa Amenfi East District (Western Region) "galamsey" operations are seen to have taken over farm lands. Large tracts of land dotted with open pits (showing the activities of illegal mining operations), are a common feature in the community. A crop like Wasa rice, previously widely cultivated as a main crop, is no longer grown in the district.

In response to the question, "whether any of the previously cultivated crop species have the ability to withstand high temperature and rainfall extremes?", 52.4% of the farmers identified crop species that could withstand low rainfall, 41.6% identified crops that could withstand continuous rainfall (i.e. potential flooding); while 6.0% identified those that could withstand high temperatures.

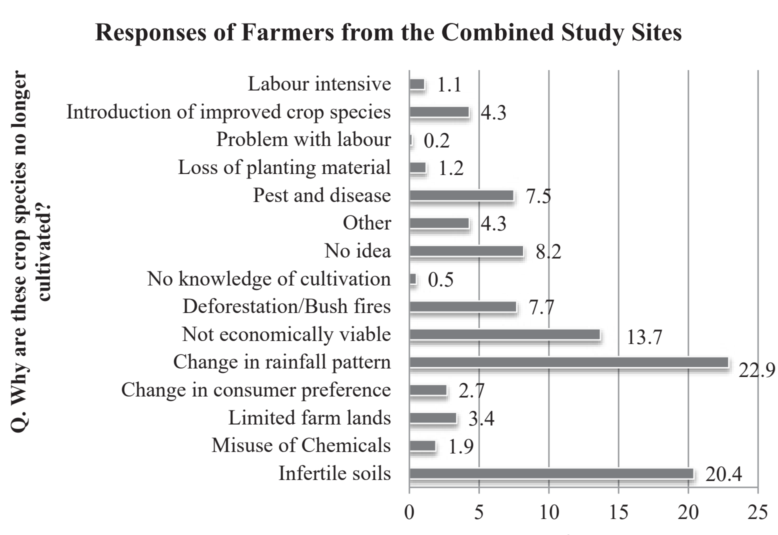
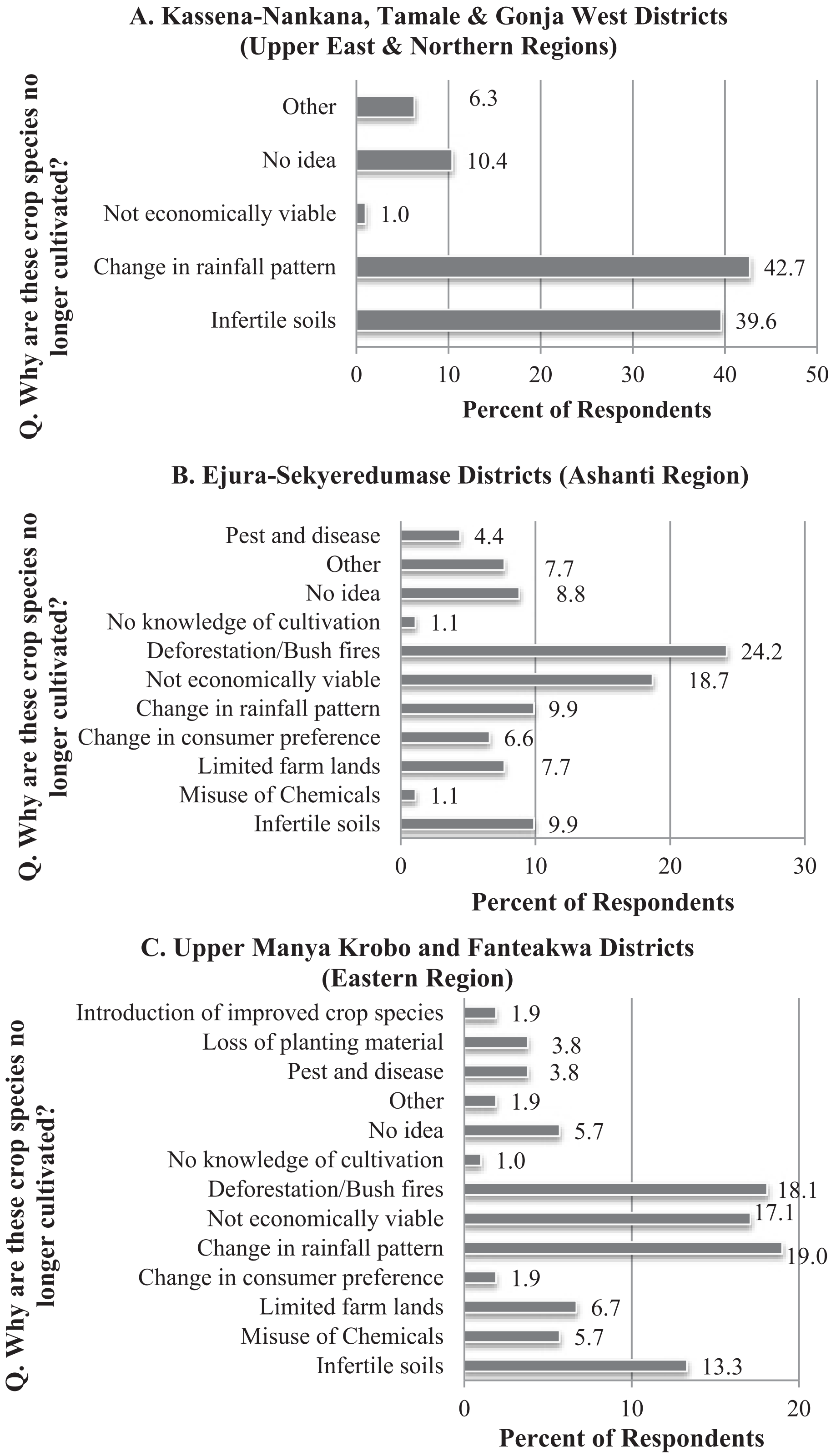


Fig. 3: Reasons given by farmers across all the study sites for non-cultivation of certain indigenous crop species


A. Kassena-Nankana, Tamale & Gonja West Districts (Upper East & Northern Regions)
Q. Why are these crop species no longer cultivated?
Other 6.3
No idea 10.4
Not economically viable 1.0
Change in rainfall pattern 42.7
Infertile soils 39.6
0 10 20 30 40 50
Percent of Respondents
B. Ejura-Sekyeredumase Districts (Ashanti Region)
Q. Why are these crop species no longer cultivated?
Pest and disease 4.4
Other 7.7
No idea 8.8
No knowledge of cultivation 1.1
Deforestation/Bush fires 24.2
Not economically viable 18.7
Change in rainfall pattern 9.9
Change in consumer preference 6.6
Limited farm lands 7.7
Misuse of Chemicals 1.1
Infertile soils 9.9
0 10 20 30
Percent of Respondents
C. Upper Manya Krobo and Fanteakwa Districts (Eastern Region)
Q. Why are these crop species no longer cultivated?
Introduction of improved crop species 1.9
Loss of planting material 3.8
Pest and disease 3.8
Other 1.9
No idea 5.7
No knowledge of cultivation 1.0
Deforestation/Bush fires 18.1
Not economically viable 17.1
Change in rainfall pattern 19.0
Change in consumer preference 1.9
Limited farm lands 6.7
Misuse of Chemicals 5.7
Infertile soils 13.3
0 10 20
Percent of Respondents

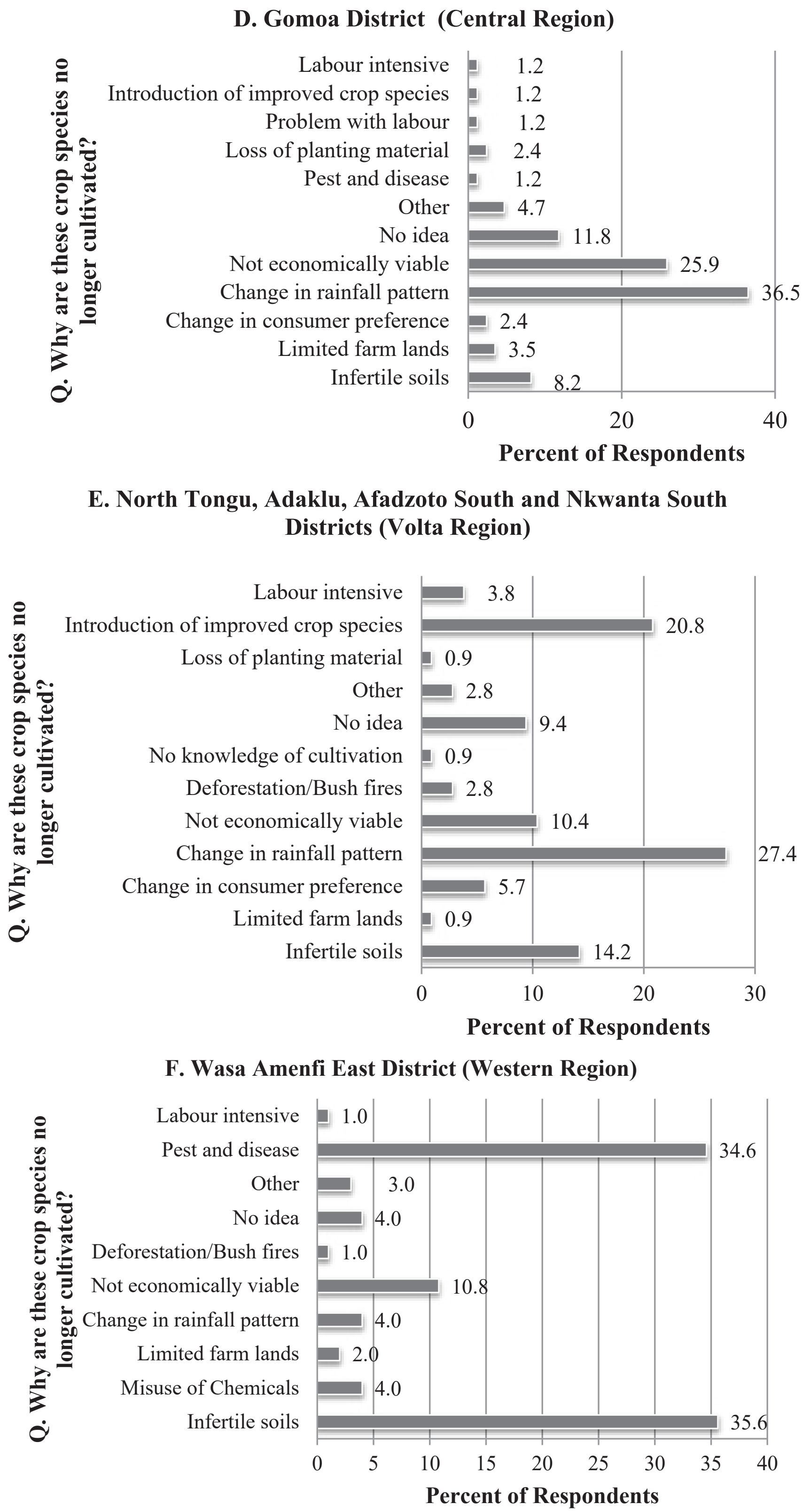


Fig. 4A-F: Response of farmers to non-cultivation of selected indigenous crop species in Ghana

Profile of crop species/varieties no longer cultivated

Crop species identified as 'previously cultivated' are profiled for their climatic and nutritional attributes in Tables 3A – D, grouped into roots and tubers, legumes, cereals and vegetables.

Table 3A: Indigenous Crop Species Profile – Roots and Tubers

Scientific /Common Name	Family	Plant Attributes
Colocasia esculenta (Brobe/Taro)	Araceae	• It loves waterlogged conditions. • It is an important source of digestible carbohydrates • The leaves are high in Vitamins A, C and B (Nip, 1997; More and Lawrence, 2003).
Xanthosoma sagittifolium (Mankeni/ Cocoyam)	Aracaeae	• It is an important source of carbohydrate. The edible parts are the corms which contain 15-39% carbohydrate and have a higher nutritional value compared to potato (FAO, 1994). • Cocoyam leaves have substantial levels of vitamins, dietary fiber and antioxidants (Lebot, 2009; Ekwe *et al*., 2009) • It thrives well in forest ecologies, under forest canopies and does not tolerate water logged areas
Solenostemon rotundifolius (Frafra potato/Peha/ Pessa/ Hausa Potato)	Labiatae	• A rich source of vitamin A and iron, is high in protein and resistant to several pests and diseases and thrives in unfertile soils. • It is suitable for feeding babies and also used as a de-wormer. • A small area can produce large amounts of food. • Serves as food security hunger food
Dioscorea rotundata (Fasikoye/ White yam/ Guinea yam)	Dioscoreaceae	• The root tubers are a good source of carbohydrate.
Dioscorea prahelensis (Cocoa ase bayerɛ/) *Dioscorea cayensis* (Yellow yam/Nkani)	Dioscoreaceae	• The tubers are a good source of carbohydrate.
Dioscorea rotundata [Obo aduonum (Twi)]	Dioscoreaceae	• The tubers are rich in carbohydrate. • One tuber will yield ~50 tubers hence its local name
Dioscorea bulbifera (Aerial yam)	Dioscoreaceae	• The tubers are a good source of carbohydrate.
Dioscorea dumetorum (Bitter yam /Forest yam/ Nkanfo)	Dioscoreaceae	• This type of yam has a bitter taste, hence the name bitter yam.
Ipomoea batatas [Sweet Potato (red and white fleshed varieties)]	Convolvulaceae	• The crop can adapt to poor soils but tubers are reduced in size. • It is a source of carbohydrate, dietary fibre, anti-oxidants and minerals (calcium, magnesium and potassium). The leaves are rich in vitamin C, Vitamin K and iron (Rudrappa, 2014).

Table 3B: Indigenous Crop Species Profile – Legumes

Scientific/ Common Name	Family	Plant Attributes
Vigna subterranea (Bambara groundnut)	Fabaceae	• It thrives well in unfertile, light soils (sandy soils) with pH 5-6.5. • The crop is drought tolerant and does not require much water for growth. • The seeds are high in protein (Azam-Ali *et al*., 2001)
Vigna unguiculata [Cowpea (Red & black types)]	Fabaceae	• Seeds are reported to contain 24% crude protein, 53% carbohydrate and 2% fat (FAO, 1994) • It is drought tolerant and adapted to a wide range of soils and soil pH
Cajanus cajan (Pigeon Pea)	Fabaceae .	• The seeds contain 21-28% protein (FAO, 1994) • The crop is drought tolerant as its roots are able to grow deep into the soil. • It is a nitrogen-fixing crop and can be used as green manure.
Macrotyloma geocarpum [Kersting's groundnut /Ground bean]	Fabaceae	• The bean seeds are high in protein, amino acids and carbohydrate (Dako and Vodouché, 2006). • Also, a good source of mineral salts such as iron, calcium, magnesium and phosphorus. • The crop is drought tolerant and can adapt to both biotic and abiotic stresses.
Sphenostylis stenocarpa (African Yam Bean)	Fabaceae	• It thrives deep well-drained, loose sandy and loamy soils. • The protein level is twice the protein in sweet potato, cassava and yam (Adewale and Dumet, 2009). It is also rich in calcium, magnesium, iron, potassium and phosphorus (Adewale and Dumet, 2009).
Phaseolus vulgaris (Kidney Beans/Apatram)	Fabaceae	• It does not tolerate heavy rainfall and grows best in well-drained soils. • The seeds are high in protein and carbohydrate. • The plant is also used as green manure due to its nitrogen fixing properties.
Phaseolus lunatus [Lima beans (Akotrobo)]	Fabaceae	• Used as a green manure crop. • The bean seeds are high in proteins, vitamin B and C and minerals including iron, magnesium, potassium and phosphorus (Courteau, 2014). • It prefers deep, well-drained soils.
Canavalia ensiformis (Jack Beans/Lanseya)	Fabaceae	• The crop is hardy, drought-resistant and immune to pests. • It is used as a cover crop as it produces phytochemicals which act as pesticides.

Table 3C: Indigenous Crop Species Profile – Cereals

Scientific/ Common names	Family	Plant Attributes
Sesamum indicum Sesame/Bungu	Pedaliaceae.	• The seed contains 50-60% oil and the oil extracted from sesame seeds contains antioxidants (*Ram et al*., 1990). • The seeds are high in iron, manganese, calcium, vitamin B1 and vitamin E (Fapohunda *et al*., 2012). • It has antioxidants and anticancer properties (Ram *et al*., 1990). • The seeds are effective in controlling cholesterol levels as it contains sesamin, which is proven to protect the liver from oxidative damage. • It also has a protein content of 35-50% (Ram *et al*., 1990). • It cannot withstand prolonged periods of heavy rains as well as prolonged drought.
Sorghum bicolor Guinea corn / Atokuo/Sorghum	Poaceae	• It is adapted to a wide range of soils. • Tolerates drought and can survive temporal waterlogged conditions. • It is gluten-free and an excellent source of protein and starch (Kulamarva *et al*., 2009)

Scientific/ Common names	Family	Plant Attributes
Pennisetum americanum Pearl Millet	Poaceae	• It is adapted to a wide range of soils and tolerates low pH and fertility. • Has moderate tolerance to drought but is not tolerant to flooding. • It contains a significant amount of minerals – iron and zinc, protein, fibre, essential amino acid and vitamins (Chauhan, 2018)
Digitaria exilis Fonio	Poaceae	• It is drought tolerant and fast maturing. • The husked grains contain 8% proteins. • It is also rich in carbohydrates and amino acids such as methionine, leucine, valine and cysteine (Alercia, 2013). • It has a low sugar content and low glycemic index which makes it suitable for diabetics (Alercia, 2013).

Table 3D: Indigenous Crop Species Profile – Vegetables

Scientific/ Common Name	Family	Plant Attributes
Lycopersicon pimpinellifolium [Wild tomato/Samai tomato (Ghost tomato)]	Solanaceae	• The soil must be kept moist until the seeds germinate. • The pulped fruits are used in skin therapy for people with oily skin, the roots are used in treating toothache and the skin of the fruit contains lycopene, which reduces the incidence of heart attacks. • Used as tomato especially in high rainfall areas
Hibiscus cannabinus (Kenaf, Red kenaf)	Malvaceae	• Is drought tolerant and tolerant of a wide range of soils.
Amaranthus spp. (Pigweed, Alefo)	Amaranthaceae	• The crop is tolerant of arid environments and is drought tolerant. • The crop is also adapted to a wide range of soils. • The leaves contain some amount of beta-carotene, vitamin E, vitamin C, folic acid calcium beta Cynin and oxalic acid (DAFF, 2010). • The fresh leaves contain higher quantities of both calcium and phosphorus compared to the leaves of cabbage (DAFF, 2010). • The seeds are high in calcium and riboflavin
Solanum torvum [Turkey Berry/ Thai eggplant/ Asaman notrewa]	Solanaceae	• It has medicinal properties (antibacterial, antifungal and anti-inflammatory properties) (Jaiswal, 2012). • It is resistant to soil-borne pests and diseases such as nematode infestations and bacterial wilt (Schippers, 2004). • The crop is adapted to swampy areas and tolerates flood. • Fruit and leaves used as cure for anemia
Trichosanthes cucumerina (Snake gourd/Ayoyo)	Cucurbitaceae	• It is adapted to a wide range of soils but prefers well drained soils.
Capsicum annuum (Bell pepper)	Solanaceae	• It is the most extensively cultivated. • The crop tolerates sandy, clayey and loamy soils as well as acidic soils.
Capsicum chinense (Meko hwaam/ Kpakpo shito)	Solanaceae	• The crop tolerates sandy, clayey and loamy soils as well as acidic soils. • Fragrant pepper
Citrullus vulgaris (Neri)	Cucurbitaceae	• The seeds are used in preparing stews and also have some amount of oil. The seeds are effective in lowering blood pressure.
Citrullus colocynthis (Bitter melon / Bitter apple/ Bitter gourd Akatoa/ Egushie)	Cucurbitaceae	• It does well in sandy loose soils. • Moderate tolerance to drought.
Cucurbita pepo (Pumpkin/Summer squash Akin-ton /Zucchini/ Courgette)	Cucurbitaceae	• The fruit is rich in amino acids, linoleic and oleic acids, Vitamins A and B, calcium, zinc, potassium, iron, magnesium and zinc (https://health-from-nature.net/Pumpkin.html).

Discussion

Bennett-Lartey and Oteng-Yeboah (2008), reported that although precise figures are not available to quantify genetic erosion in Ghana, reports of extensive land use and land use change provide enough evidence. The findings from the study show that several species and varieties of indigenous crops that were common in the past are no longer cultivated and that many of these could be on the verge of extinction. This obviously would constitute a significant loss of biodiversity and have major implications for food security. Bickel *et al.* (2000) define food security as access by all people at all times to enough food for an active, healthy life. Hollben (2004) expanded the definition of food security as having access to enough food, including the ready availability of nutritionally adequate, safe foods for active healthy life. WFP (2009) provides a more comprehensive definition of food security as "all people at all times have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". Indigenous crop species have been shown to possess high nutrient value and offer wider varieties to satisfy food preferences; hence they contribute to ensuring food security in its totality.

Kersting's groundnut (*Macrotyloma geocarpum*) is an example of a crop species with tremendous potential for use in sub-Saharan Africa. It is an annual herb belonging to the Fabaceae family. Like other legumes, it has the ability to improve soil fertility by fixing atmospheric nitrogen in the soil. Its protein, fat, carbohydrate and fibre content is comparable to that of cowpea (*Vigna unguiculata*). Bambara groundnut (*Vigna subterranea*) falls into the same category (Achigan and Vodouhè, 2006; Ofori *et al.*, 2001; Amoatey *et al.*, 2000). It is also relatively pest and disease free and tolerant to drought (Kumaga *et al.*, 2003). Another example is the African yam bean (*Sphenostylis stenocarpa*); it produces two main consumable products, the tuber underneath the ground and beans that grow in the pods above the ground. The beans are a good source of protein (21% by wt) and carbohydrates (61.6%), and compare well with soyabean in this regard; they have a higher amino acid content than pigeon pea, cowpea and Bambara groundnut (Baudoin and Mergeai, 2001; Uguru and Madukaife, 2001). Nwaoguikpe (2008) also reported the use of extracts of the African yam bean to improve the $Fe2+/Fe3+$ ratio of sickle cell blood. The roots (tuber) contain higher amounts of protein than sweet potato, yam and cassava.

The micronutrient richness of these indigenous crop species gives them the added advantage of addressing food security challenges. With time, however, these indigenous crops are gradually becoming extinct and restricted only to the indigenous communities where they hold traditional importance or where the older generation continue to be aware of their nutritional and medicinal value; thus, they face the risk of extinction.

Across all the study areas, climatic variability (changes in rainfall patterns) and climate influenced factors (deforestation, bushfires and infertile soils) came out as the main reasons for the non-cultivation of the extinction threatened indigenous crops (over 50% of respondents). The responses from the northern savannah sites support the Ghana Environmental Protection Agency's report of high deforestation rates in the savannah zone, where annual deforestation rate is estimated to be twice the national average (EPA 2000).

Infertile soil was identified as one of the major constraints to the cultivation of previously grown crop species and came up strongly during interaction with farmers in the Kassena Nankana, Tamale and Gonja West Districts (39.6% of responses). Low fertility of soils in the Northern Region has been identified in a number of agriculture related studies as the major constraint to crop production (e.g. RELC, 2005; Diao and Sarpong, 2007). Illegal mining activities ("galamsey") have contributed immensely to the poor state of agriculture lands (deep excavations, infertile soils and loss of vegetative cover). In the Wasa Amenfi East District (a major cocoa producing area in Ghana) farmers would rather sell their cocoa farms to "galamsey operators" for bulk money. Infertile soils have serious implications for crop biodiversity and crop yields which are directly linked to food security. As a result of low crop yields, farmers are unable to save seed for the next planting season, thus impacting on their ability to ensure food security or sustain livelihood sources to break the poverty cycle.

Traditionally, indigenous crop species in Northern Ghana are cultivated with the minor rains as farmers prepare their land for the major rains. However, with the introduction of tractors, farmers wait until the onset of the major rains to plough their land and as a result miss out on cultivation of the minor season crops. The minor season crops were viewed as hunger crops which provided food sources for the farmers until the major season crops were ready. Such crops were planted also in combination with other higher yielding varieties during the major season as insurance against unfavourable weather conditions resulting in crop losses and/or lower yield (Ofori-Sarpong and Asante, 2004).

Contrary to expectation, only a small number of farmers (2.7%) attributed the loss of indigenous crops directly to a change in consumer preference, but a significant proportion of the farmers (13.7%) linked the decline in cultivation of such crops to the lack of adequate economic incentive. A small proportion (1.1% of respondents) attributed the non-cultivation of indigenous crops to their cultivation being labor intensive, thus making the crops expensive to grow. Under the 'not economically viable label' farmers explained that as with crops currently grown, market queens exploited them by waiting to determine the value of their produce at the close of the market day, leaving them with no option but to sell at ridiculously low prices.

Across the study sites, 55.2% of the farmers indicated that some of the indigenous crops previously cultivated were still available, while 44.8% said they could not be found. Farmers' strategies to maintain crop diversity have been reported from several parts of Ghana. For example, Blay (2004) reports effective traditional production and management strategies used by farmers in southern Ghana to ensure availability and diversity of yams; while Kranjac-Berisavljevic and Gandaa (2004) report the cultivation of an average of five types of yam on every farmer's field in northern Ghana.

The farmers' attribution of loss of indigenous crop species to changing rainfall and soil infertility is supported by the linkages between agrodiversity and climatic variability reported by Sarpong and Asante (2004), and also the decreasing rainfall over most of Ghana reported by Owusu and Waylen (2009; 2012). Wherever the opportunity arose, collections of specimens of the vanishing indigenous crops were made during this study for further studies, including germination trials and analysis of nutrient values, with the ultimate aim of promoting the cultivation of such crops.

Conclusion

Modern agriculture systems have concentrated on the cultivation of a limited number of crop species and varieties, resulting in the narrowing of the crop diversity base. Over fifty crop species spanning cereals, legumes, vegetables, roots and tubers, tree and plantation crops are not cultivated in some areas. To achieve food and nutritional security, developing countries need to embrace and reinstate indigenous crop species that have the potential to withstand the impact of climate change.

The neglect of agriculture over the years has serious implications for food production in developing countries, as young people turn their attention to more profitable activities (illegal mining, road construction, migration to urban areas in search of opportunities). The younger generation expected to take over from their aging parents are not interested in farming, which poses a threat to the future of agriculture in Ghana. There is a need to rethink ways of making farming more attractive.

The main reasons given for the non-cultivation of indigenous crop species in the combined study sites were infertile soils, change in rainfall patterns and the high cost involved in production. The introduction and focus on improved varieties was identified as a major reason for non-cultivation of indigenous crop species in the Volta Region.

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Ethics approval and consent to participate

Individual informed consent was obtained from all participants of questionnaire interviews and permission was obtained in each community before taking pictures and audiotaping the focus group discussions.

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Trichotomous Analysis of Climate Change, Migration and Food Security in the Agro-Ecological Zones of Ghana

Azzika Yussif Tanko[1*], Delali Margaret Badasu[1], Samuel Nii Ardey Codjoe [2], Christina Antwiwaa Nti[3] and Joseph Awetori Yaro[4]

[1]Centre for Migration Studies, University of Ghana
[2]Regional Institute for Population Studies, University of Ghana,
[3]Department of Family and Consumer Sciences, University of Ghana
[4]Department of Geography and Resource Development, University of Ghana

***Corresponding author:** Azzika Yussif Tanko; azzika2002@yahoo.co.uk

ABSTRACT

Climate change, migration and food security are serious sustainable development challenges of global proportions. However, there is a dearth of research on the interrelationships among these three factors. This study examines the trichotomous relationship of climate change, migration and food security in the Coastal, Forest, Transition and Savannah agro-ecological zones of Ghana. The study adopted mixed research methods, using data from household surveys, focus group discussions (FGDs), in-depth interviews (II) and expert interviews. The Multidimensional Poverty Index (MPI) was used to construct the overall Food Security Index (FSI). The unit of analysis was the migrant household and a total of 567 households were surveyed. The study used bivariate analysis and probit logistic regression models for analysis. Three types of households were found, namely, migrant, climatic migrant and non-migrant. Migrant households have members who migrated from the household. The findings of the study indicate that overall, migrant households were more food secure compared to non-migrant ones. Furthermore, climatic migrant households are more food secure than non-climatic migrant ones. Other significant determinants of food security include age, sex, marital status, education, wealth and health status of the household head. The study concludes that when climate change impacts on food security, migration is adopted as an adaptation strategy in times of food shortages.

Keywords: Migration, climate change, food security, households, adaptation

Introduction

The Brundtland report, "Our Common Future" predicted as early as 1987, that given the unprecedented pressures on the global environment, the planet was bound to experience unimaginable altercations unless urgent concerted global giant steps were taken to halt the process. The Report further warned that the pressure on the environment, if allowed to continue, would threaten every living species on earth unless it is recognized and managed (Brundtland *et al.,* 1987). Thirty-three years later, in 2020, climate change, migration and food security have become the most serious global environmental and development challenges of all time (IOM, 2020; Shukla *et al.,* 2019; Pauly and Zeller, 2017; Black *et al.,* 2011c). The Sustainable Development Goals call for a concerted global effort to end poverty and hunger in all their shapes and forms (UNDP, 2015). The African Union Commission Agenda 2063 (AU, 2014) also calls for a prosperous Africa based on inclusive growth and sustainable development with environmentally sustainable and climate resilient economies. But all these aspirations cannot be realized without empirical evidence on the linkages between climate change, migration and food security.

Climate change is affecting human survival, livelihood and ultimately human development (Warner *et al.,* 2012; FAO, 2020). Climate change is manifested in the form of drought, flooding, erratic rainfall, windstorms and high temperatures (Tschakert *et al.,* 2010). In 2013 alone, over 320 million people were affected by extreme weather events caused by climate change, the highest in this century (Cannon, 2014). In addition, food security and food systems have been largely affected by climate change (FAO, 2019; FAO, 2020). In 2014 for instance, 795 million people were unable to afford 1,800 calories per day which is not even enough to support a medium level of activity for an adult (FAOSTAT, 2015). Poor regions such as sub-Saharan Africa would be greatly affected (Adger *et al.,* 2015; Antwi-Agyei, 2013). When food systems are affected, it poses food security threats which force people to construct their livelihood adaptations sometimes around migration (Black *et al.,* 2011b; Yaro *et al.,* 2015). It has been estimated that there are 272 million international migrants across the globe, most of them in search of sustainable livelihood options in major cities (IOM, 2020). Moreover, close to 740 million moved within their own countries as internal migrants, mostly to urban areas in search of jobs (IOM, 2010; IOM, 2020; UNDESA, 2013). Even though migration may impact positively on food security as a result of remittances sent from migrants to their households at their origin, it does have negative consequences under some conditions (Piguet *et al.,* 2011; Fussell *et al.,* 2014). This is because when the youth migrate, food production is left in the hands of the elderly (Gomez, 2013; Bawakyillenuo *et al.,* 2016; Yaro *et al.,*2015).

Some studies argue that climate change will lead to increased migration and ultimately affect food security (WMR, 2015; Brown *et al.,* 2015; Gitz, *et al.,* 2016). There is also a counter argument that migration as a result of climate change will improve food security in the long run because it is a major adaptation strategy during food shortages (Black *et al.,* 2011b; Fussell *et al.,* 2014; WMR, 2015). But given the implications of climate change for migration and food security, no one single method can comprehensively deal with the multidimensional complexities of the phenomena. Only a few studies have dealt with the trichotomous relationship of climate change, migration and food security at multivariate levels using mixed research methods (Rademacher-Schulz *et al.,* 2012; Warner *et al.,* 2012; Afifi *et al.,* 2014; Milan and Ruano, 2014).

In Ghana, studies that have dealt with climate change, migration and food security across all the agro-ecological zones are rare. This study focused on a trichotomous analysis of climate change, migration and food security in the coastal, rainforest, transition and savannah (CRTS) agro-ecological zones of Ghana. By this trichotomous approach, the research examined the linkages of climate change and migration, climate change and food security and migration and food security across all the ecological zones. It further throws light on the need to examine a contextual analysis of the relationship among climate change, migration and food security.

Conceptual Consideration

While many studies have examined the impact of climate change and food security, few have explicitly conceptualized climate change, migration and food security relationships (Black *et al.,* 2011a; Codjoe and Owusu, 2011; Fussell *et al.,* 2014). Black *et al.,* (2011a) identified environmental drivers of migration in their study while Fussell *et al.,* (2014) argued that both environmental factors and household characteristics are critical factors that influence migration. Adopting a livelihood approach, Codjoe and Owusu (2011) emphasized that households' characteristics, assets (human, social, financial, natural and physical capital) environmental drivers, public and traditional institutions and the larger socio-economic context influence migration during climate change and dwindling food security conditions. However, depending on the socio-economic context and public policies and institutional frameworks available, climate variability could also affect individuals and households (UNEP, 2011). Synthesizing from all these arguments, the conceptual framework underpinning this study is presented in Figure 1. The study areas can be categorized into four agro-ecological zones.. In these agro-ecological zones, key manifestations of climate change are likely to be rainfall and temperature. The impact of these climate change manifestations usually comes in the form of drought, flooding, erosion and sometimes, windstorms (Tschakert *et al.,* 2010; Jarawura, 2013).

When households feel the impact of climate change, they are likely to construct their livelihood adaptation strategies which may include migration. Others may also migrate, not because of the impact of climate change, but due to other push and pull factors. Historically, it has always been a livelihood strategy to migrate from the Savannah agro-ecological zone, to the Coastal, Forest and the Transition zones for economic reasons (Anarfi *et al.,* 2000; Kwankye *et al.,* 2009).

Households in the agro-ecological zones may be categorized broadly into migrant households and non-migrant households. Migrant households are those whose member(s) migrated from the household. Within such households, some likely migrated because of the impact of climate change while others may have done so for economic reasons (Kwankye *et al.,* 2009). A second level of categorization thus emerges where climatic and non-climatic migrant households are sub-sets within the migrant household.

On the other hand, some characteristics such as household assets could also influence who migrates and the type of migration, whether climatic or non-climatic. Resources/assets can also influence food security status of households and the type of adaptation strategy adopted (Black *et al.,* 2011b). The adaptation strategies and household assets could determine whether or not households could improve their food security conditions (Egyir *et al.,* 2015).

It must be noted that migration as an adaptation mechanism is not always a guarantee for improved livelihood; there can be consequences. The efficacy of migration as a livelihood strategy largely depends on the context and who migrates to where. Therefore, the relationships of climate change, migration and food security are neither simple nor uni-directional. As shown in Figure 1, such relationships are complex, sometimes recursive and even internally contradictory. Much of the linkages among climate change, migration and food security are contextual, varying with time and space and depending on whether the place in question is mostly a migrant-sending or a migrant-receiving community.

In Ghana, the impact of climate change is already being felt across the ecological zones through erratic rainfall, flooding, drought and desertification (Addo *et al.,* 2008; Yaro, 2010; Van der Geest, 2011; Teye and Owusu, 2015). It has been predicted that these conditions will probably lead to low crop yield, resulting in food insecurity (Hesselberg and Yaro, 2006; Rademacher-Schulz's *et al.,* 2012). Out-migration also has implications for food and water security in an increasing population. Migration also comes at a cost and only those who can afford the cost of migrating do so. When the youth and those who can afford the cost of migration move, food production is often left in the hands of the poor and the elderly. Consequently, migration as an adaptation to climate change can contribute to increased food insecurity conditions in an agrarian economy (Hjelm and Dasori, 2012).; UNDESA, 2013; GSS, 2014; Hunter and O'Neil, 2014).

Methodology

Study Areas and Locations

This study was conducted in June-July 2016 in the agro-ecological zones in Ghana across four districts.: the Mfantseman District in the Coastal agro-ecological zone, Amansie West District in the Rainforest agro-ecological zone, Techiman South Municipality in the Transition agro-ecological zone and Tolon District in the Savannah agro-ecological zone (Figure 2). Within each district, four communities were chosen for the study (Table 1).

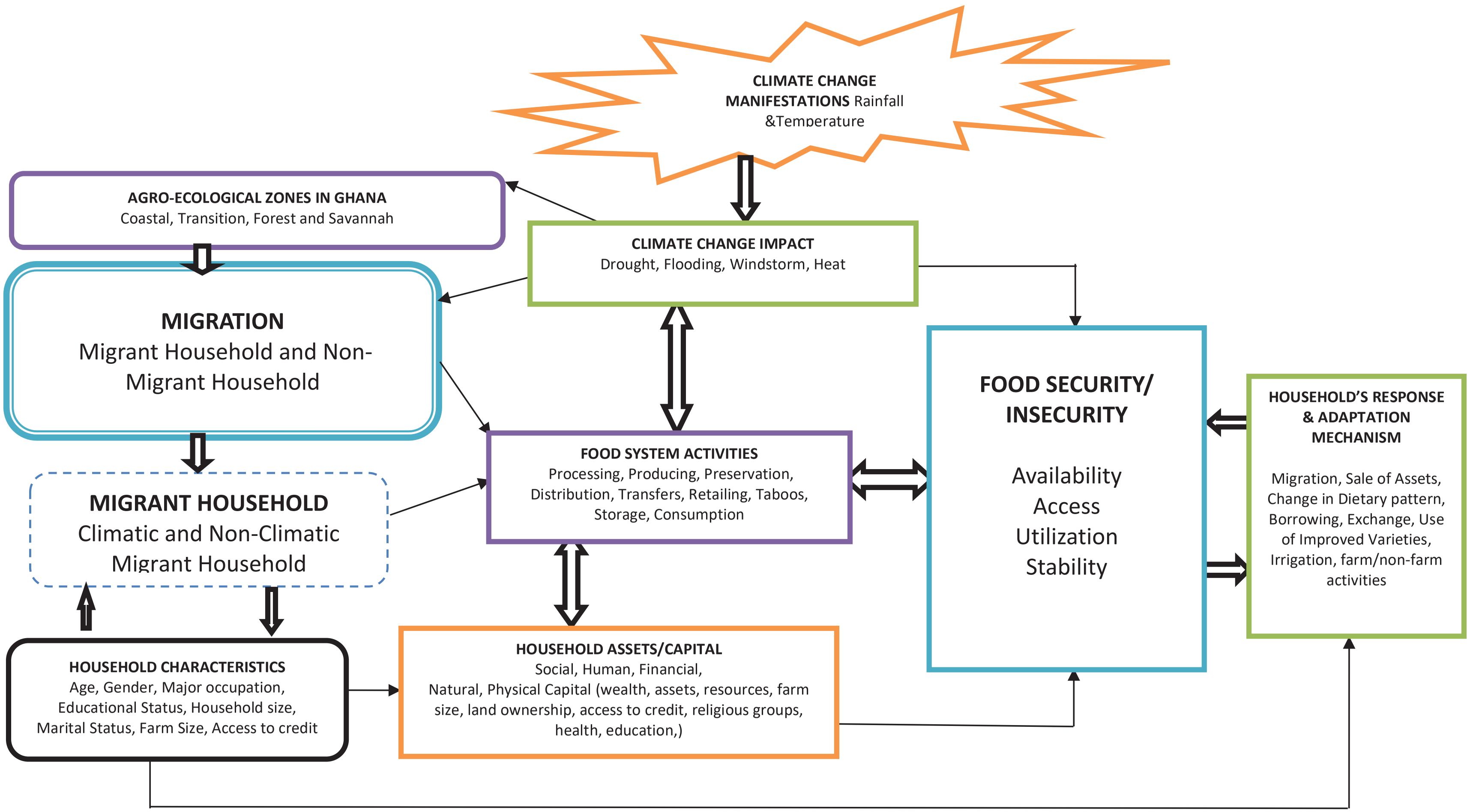

Fig. 1: Climate Change, Migration and Food Security Conceptual Framework

Source: Authors' own construct 2016

Table 1: Agro-ecological zones and communities of study

Agro-ecological zone/ Districts	Study communities of Study	Number of respondents
The Coastal agro-ecological zone (Mfantseman District),	Biriwa, Kormantse, Akobima and Dominase	141
Rain Forest ecological Zone (Amansie West District)	Manso Atwere, Manso Dominase, Manso Mosea-soe and Manso Kwahu	140
Transition ecological Zone (Techiman South Municipality)	Nkwaeso, Nsuta, Tadieso and Hansua.	140
Savannah ecological zone (Tolon District)	**Tunaayili, Koblimahgu, Tingoli, Kukuonayilli**	**146**
TOTAL	**16**	**567**

The major occupation of these communities is farming. However, some households, especially in the Coastal zone, engaged in fishing as their major occupation. The districts and communities chosen were largely representative of the various features of each ecological zone. The Coastal and the Forest zones benefit from bi-modal rainfall seasons, making them greener compared to some parts of the Transition zone and the entire Savannah zone which largely depends on a uni-modal rainfall season.

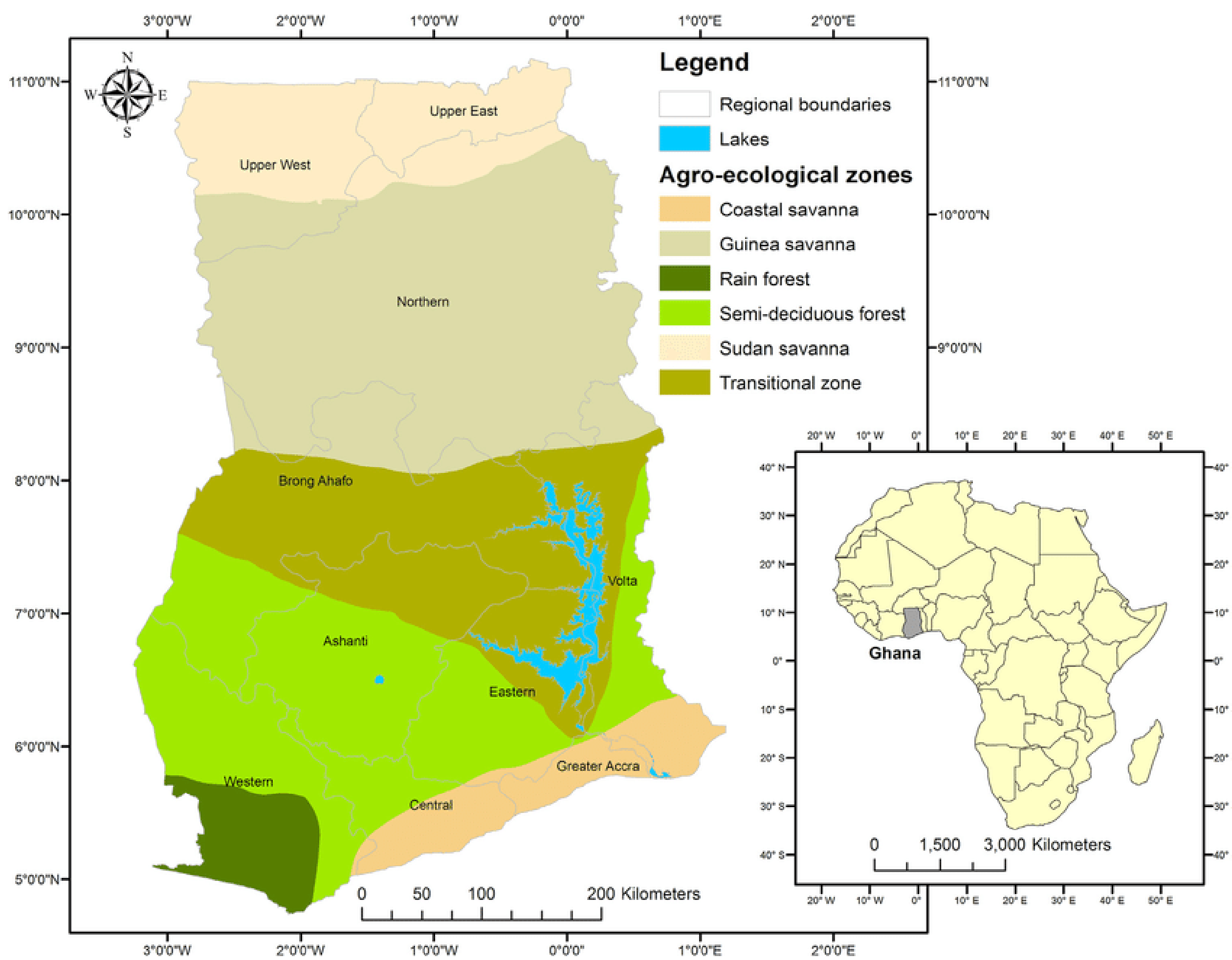

Fig. 2: Location of Agro-ecological zones

Source: Research Gate, https://www.researchgate.net/figure/307569254_fig6_Fig-A1-Map-showing-six-agro-ecological-zones-in-Ghana (accessed on 08.06.17)

The Study Design

This study adopted a mixed methods approach. To understand the triadic relationships of migration, climate change and food security, quantitative data alone was not enough to help make inferences and to understand how some household level decisions were undertaken for members to embark on migration. To assess the perceptions of households, it was important that qualitative data were collected and used to match evidence collected from quantitative data. Qualitative data were collected through key informant interviews (KII), In-depth Interviews (IDI) and Focus Group Discussions (FGDs) while the quantitative data were collected through household surveys. The mixed methods approach was considered more appropriate to holistically deal with the research objectives.

Overall, 567 household heads were interviewed. The focus of this study was farmer-based households and migrant households, but not the migrants themselves. But as at the time of the field work, no such comprehensive data existed across all the agro-ecological zones. Therefore, it became necessary to determine the sample size through mathematical *computation*. The study used a method for calculating sample size for large populations given by Fox *et al.,* (2009). The mathematical formula for computing the sample size was given as:

$$N = \frac{P(100\% - P)}{(SE)2}$$

Where
N= required sample size,
P= proportion of the population having the characteristic;
and SE is the standard error.

This method usually assumes a 50 percent proportion as the worst-case scenario in cases where one has no idea what the actual proportion should be. However, this study assumed a confidence level of 99 percent, a 5 percent margin of error and a response rate of 70%.

Therefore;
P= 70% (maximum heterogeneity of 70/30 split)

To be 99% confident that the confidence parameters included the true population, the confidence interval was divided by 2.56. to get the Standard Error (SE).
The standard error was therefore computed to be 5/2.56 = 1.95.

The true sample size of the study population was determined as follows:

Therefore $N = \frac{70\%\ (100\% - 70\%)}{(1.95)2}$, N=553

While a sample size of 553 was estimated, a total of 567 questionnaires were completed due to an improved response rate. This was nearly evenly distributed as 141 for the Coastal agro-ecological zone, 140 for the Forest Zone, 140 for the Transition zone and 146 for the Savannah agro-ecological zone. The slight increase in the number of questionnaires completed over the estimated sample confirms the 99 percent confidence level estimated, the 70 percent proportion assumed as the worst-case scenario and the 5 percent margin of error.

Data Collection and Analysis

Primary data were collected from household surveys, Key Informant Interviews and Focus Group Discussions. Key Informant Interviews were conducted with research institutions, government officials, agricultural extension service officers and older people in the communities who were above 60 years and had experienced or observed weather patterns regarding farming and other human activities over several decades. Secondary data were obtained from reviews of both published and unpublished literature from various sources which were based on observed meteorological data for the ecological zones from 1981 to 2011 (GoG, 2011). Quotes from respondents were also used to support evidence collected from the household surveys and Focus Group discussions. The quantitative data collected were coded and processed using CSPro while data analysis was carried out using STATA version 14. The Multidimension Poverty Index (MPI) (Alkire and Santos, 2010) was used to construct a Food Security Index (FSI).

The Multidimensional Food Security Index

Given that food security is multifaceted and a multidimensional phenomenon (FAO, 2014), the MPI was applied in the computation of the FSI for this study. The mathematical function for the estimation of the MPI is given below:

$$MPI = M0 = H * A$$

M0=*Adjusted multidimensional head count ration*
H= *the head count/percentage poor people (incidence)*
A= *the average percentage of dimensions in which poor people are deprived (intensity of people poverty).*

Using the MPI approach, the FSI was computed from a list of six food security indicators measuring the different dimensions of food security. These indicators were (1) condition of food shortages, (2) unbalanced diet, (3) did not eat (4) no money for food, (5) eat less food, and (6) loss of weight. These indicators were measured as often true, sometimes true and never true. The "often true" response means that the household often experiences that dimension of food security measurement and "never true" means that the household never experiences that dimension of food insecurity. The Food Security Index (FSI) was then taken as a cumulative sum of all the six indicators.

The six indicators of food security were then assigned individual weights which cumulatively sum up to 100. Given the potential value and varying effect of the indicators on food security, 'food shortages' and 'unbalanced diet' were given a weight of 10 each out of 100. The rest of the indicators (didn't eat, no money for food, eat less food and loss of weight) were each given a weight of 20, signifying their level of severity, value, depth, intensity and importance regarding household food security conditions.

The indicators such as 'food shortages', 'no money to buy food' and households inability to 'eat a balance diet' were measured by the following scales: 'often true', 'sometimes true' and 'never true'. The rest of the indicators were measured categorically with yes and no responses.

Variables of Interest for this study

The dependent variable for this study was food security. This was assessed as availability, access, utilization and stability across the ecological zones. To assess food security conditions of households, a Food Security Index (FSI) was constructed using the Multidimensional Poverty Index (MPI) approach.

The independent variables of interest for this study included climate change and migration. Households' perception of climate change such as rainfall and temperature were found to have an influence on food availability, access and utilization. Migrant households were labeled as one (1) while non-migrant households were measured as zero (0). Among the migrant households were also household members who had migrated for climate related reasons (climatic migrant household) and those who migrated for reasons other than climate (non-climatic migrant households). To determine the weight, true value, impact and direction of the independent variables on the dependent variables, it became necessary to control for some variables on the dependent variable (food security). Given that the primary unit of analysis in this study was the migrant household and the respondents were the household heads, the socio-economic characteristics of the household and household-heads were considered as determinants of the welfare and food security status of the households.

Results

Reasons for Migration in the Agro-ecological zones

For a household to qualify as a migrant household, a person from the household should have been staying outside of his/her original household in another geographical area for a minimum of six months. The focus of this study was the migrant household at the place of origin and not the migrants (absent or returned) themselves.

Various reasons accounted for migration across the agro-ecological zones (Figure 3). They are broadly categorized as climatic and non-climatic reasons. Climatic factors for migration included no dry season farming jobs (10%), low farm yield/poor harvest (19%) and degraded poor agriculture land for farming (10%) while those for non-climatic migration included job search (42%), joining relatives (6%), marriage related (6%) and education (4%). However, 3% of households could not tell the reasons why a household member migrated because such household members took the migration decision without informing the household head or giving any reason why they migrated. Almost 6 out of every 10 (58%) of the households reported that members migrated because of non-climatic reasons or gave economic reasons, compared to approximately 4 out of every 10 (39%) of the households whose members migrated because of climatic factors. While economic reasons dominate in migration in the ecological zones, climate change also accounts for a relatively large percentage of migration of household members.

The reasons for migration in the agro-ecological zones were further categorized into push and pull factors as related by Lee (1966). The pull factors included the search for job opportunities at the destination, desire to join relatives, marriage arrangements and educational opportunities at place of destination, while the push factors were largely related to climate-related reasons such as crop failure, poor harvest, poor/infertile degradable agriculture land for farming and lack of agriculture-related dry season jobs given that the communities are mostly farmers. A farmer noted:

"Now the weather has changed, the rains come late and end early. As such the yield is no more good compared to 10 years ago. So, when the dry season comes and you are not near a big dam, you cannot farm. In the past, the rain could fall for more than six months but this is no more the case today. The dry season now sets in so early. Due to shortage of rains and the failure of our crops two of my sons left the village two years ago and they are in Accra and Kumasi. I had no option than to let them go. Once in a while they send us money for food and sometimes clothing". (Alhassan Naparo, Tingoli, Tolon District, Savannah Agro-ecological zone.)

Migrant and Non-Migrant Households in the agro-ecological zones

Given the reasons for migration, households in the ecological zones could be categorized broadly into two: migrant households and non-migrant households. The migrant households were further categorized as climatic migrant households and non-climatic migrant households (Figure 4).

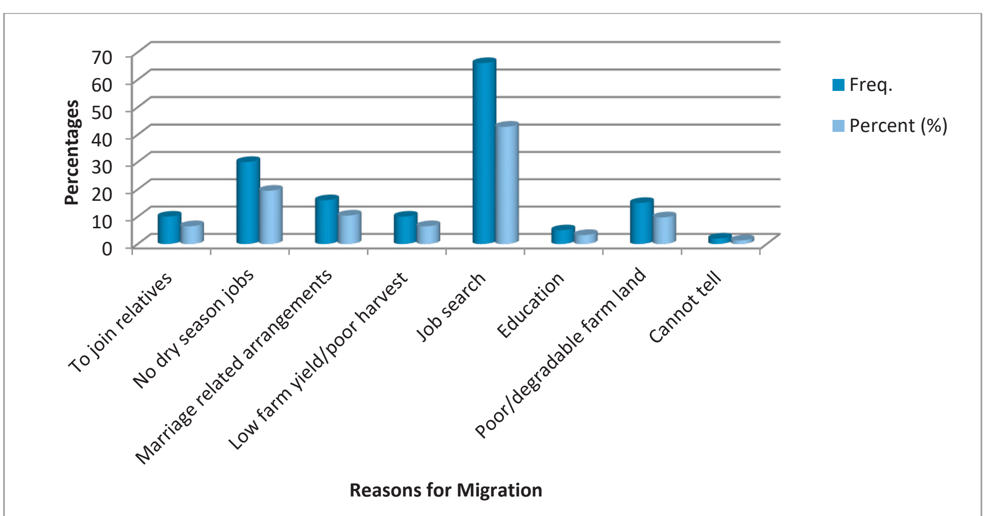

Fig. 3: Reasons for Migrations

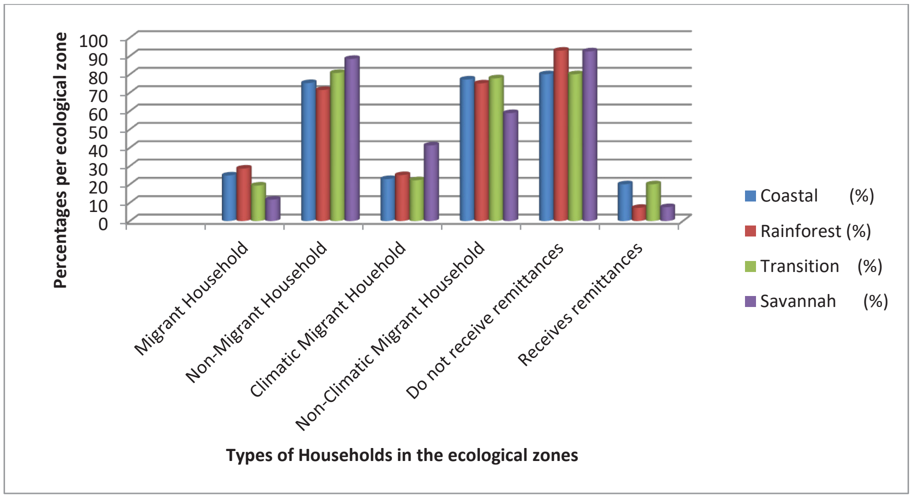

Fig. 4: Categories of Households in the agro-ecological zones

Overall Multidimensional Food Security Index

Given the indicators and assigned weights, the overall Food Security Index (FSI) was constructed (Table 4). If the MPI function by Alkire and Santos (2010), as M0=H*A is adapted to compute for the overall FSI, the results of the individual household head count (H) which show the depth of food insecurity indicated that most of the households were food insecure. The depth showed that about 73% of respondent households were food insecure.

Table 4: Overall Multidimensional Food Security Index (FSI)

Main results		N=526
Food Insecurity Index	Coef.	Std. Err
Food Insecurity Head Count (H)	0.7319	0.0193
Additional Headcount (A)	0.8467	0.0094
Adjusted Head Count (M0)	0.6197	0.0177

Note: Adjusted Multidimensional Headcount M0 = H*A

The additional headcount was computed to show the level of severity. It showed a much higher score, indicating that households are deprived in food insecurity for close to 85 percent of the indicators while the overall adjusted multidimensional head count (M0) which indicates the average intensity and share of household food insecurity deprivations experienced in depth and breadth stood at 62%.

Migrant and Non-Migrant Households and Food Security

The levels of food security among the households in the agro-ecological zones were estimated. Table 5 shows that food insecurity is more pronounced among non-migrant households (74.1%) compared to migrant households (69.7%).

Table 5: Results of food security, migrant and non-migrant households

Food Insecurity	Non-Migrant Households	Migrant Households	Total
Food Insecurity Head Count	0.741	0.697	0.732
Adjusted Head count (M0)	0.633	0.571	0.620
Pop share	0.793	0.207	1.000
Percentage Contribution of Households			
Food Insecurity Head Count	0.803	0.197	1.000
Adjusted Head count (M0)	0.809	0.191	1.000

The adjusted headcount (M0) also showed a similar pattern, with food insecurity within non-migrant households (63.3%) being higher than among migrant households (57.1%). It implies that migrant households are more food secure compared to non-migrant households. Regarding the contribution of households to food insecurity, there is a significant difference between non-migrant and migrant households. Non-migrant households contributed 80.3 percent to the overall food insecurity head count, while migrant households contributed 19.7

percent. The adjusted head count which shows the depth and breadth of the situation also indicated that compared to migrant households (19%), non-migrant households (81%) contributed more to the overall food insecurity deprivation.

Climate Change, Migration and Food Security relationships

In finding out the relationship of climate change, migration and food security, logistic regression analysis was used. The results showed that the logit regression model fits the data very well, as shown by the Chi-square at 1 percent level of significance (Table 6). The results of the logit model showed that climatic migrant households have reduced levels of food insecurity, compared with those who either do not migrate at all or do so for economic reasons or reasons other than climate change. This association underscores the argument that a trichotomous relationship among climate change, migration and food security can be observed.

Table 6: Probit logistic regression for Climate Change, Migration and Food Insecurity

Wald chi^2 (23) = 54.61, Prob > chi2 = 0.0002, Log pseudolikelihood = -272.21103 Pseudo R2 = 0.1032

Variables/Eco-zones	Overall	Coastal	Rainforest	Transition	Savannah
Migration: Non-Migrants (Ref)					
Non climatic migrant households	-0.117	-1.236**	-0.114	1.832**	1.427
	(0.307)	(0.622)	(0.606)	(0.887)	(1.195)
Climatic migrant households	-0.205	-1.399	-1.021	-0.880	0.262
	(0.431)	(1.026)	(0.992)	(1.152)	(0.993)
Remittances: Receive remittances (Ref)	0.548	1.274*	-0.133	1.834**	-0.560
Do not receive remittances	(0.361)	(0.769)	(0.878)	(0.926)	(0.865)
Age : <40(Ref)					
40 to 60	-0.952***	-0.263	-0.823	-3.045**	-0.709
	(0.313)	(0.691)	(0.647)	(1.312)	(0.561)
>60	-1.319***	0.928	-1.657	-6.919***	-0.459
	(0.416)	(0.930)	(1.152)	(1.872)	(0.771)
Sex: Female (Ref)	0.247	0.372	0.525	1.918	-15.64***
Male	(0.465)	(0.745)	(0.798)	(1.285)	(1.811)
Marital Status: Not in Union (Ref)	-0.0478	0.188	0.685	-0.0857	-15.38***
In Union	(0.477)	(0.815)	(0.771)	(1.494)	(1.133)
Household Size (mean)	0.0537	0.259*	-0.126	0.112	0.0936
	(0.0571)	(0.156)	(0.115)	(0.232)	(0.0956)
Education: No Formal Education (Ref)					
Basic Education	-1.012***	-1.485**	-1.894**	-1.700	-0.915
	(0.334)	(0.614)	(0.868)	(1.415)	(1.552)
Post-secondary Education	-0.683**	-1.101*	-1.818**	-1.687	0.343
	(0.298)	(0.621)	(0.757)	(1.455)	(0.785)
Agro-ecological Zones: Coastal (Ref)					
Rainforest	-0.0608				
	(0.374)				
Transition	-0.218				
	(0.339)				
Savannah	0.0692				
	(0.577)				

Table 6 cont.

Variables/Eco-zones	Overall	Coastal	Rainforest	Transition	Savannah
Occupation: Farming (Ref)	0.0048	-0.513	-0.112	0.520	-0.216
Others	(0.330)	(0.533)	(0.895)	(0.854)	(1.286)
Religion: Traditional/Other (Ref)	-0.0290	-0.210	-0.717	1.183	
Christian	(0.455)	(0.801)	(0.909)	(1.699)	
Islam	-0.364	-0.252	-2.716*	0.995	-
	(0.597)	(1.441)	(1.473)	(1.748)	
Wealth (Assets/Capital) Index: Higher (Ref)					
Lower	1.318***	-0.293	0.0943	3.526***	1.083**
	(0.349)	(0.648)	(0.951)	(1.119)	(0.536)
Middle	0.996***	-	-0.458	3.825***	1.363**
	(0.337)		(0.853)	(1.340)	(0.607)
Health Status: Less than average (Ref)					
Average	-0.331	-0.122	0.453	-0.736	-0.165
	(0.435)	(1.086)	(0.789)	(2.162)	(1.365)
Above average	-1.017**	-0.840	-0.324	-1.709	-1.001
	(0.437)	(0.895)	(0.728)	(2.182)	(1.358)
Household farmland Size	-0.0191	-0.199*	0.0001	-0.269**	-0.0449
	(0.0625)	(0.108)	(0.0115)	(0.122)	(0.0468)
Land Tenure/Ownership: Inherited or Purchased (Ref)					
Rented/Other types of ownership	-0.0188	-0.414	-0.850	0.407	-
	(0.296)	(0.624)	(0.720)	(0.841)	
Credit: Do not receive credit (Ref)	0.686	0.385	1.129	1.371	-
Receive credit	(0.424)	(0.645)	(1.015)	(1.595)	
Constant	1.821**	2.514*	4.313**	1.717	16.17***
	(0.854)	(1.482)	(1.783)	(2.458)	(1.862)
Observations	522	134	119	122	124
Wald chi² (23) = 54.61, Prob > chi2 =0.0002, Log pseudolikelihood = -272.21103				Pseudo R2 = 0.1032	

Note: Robust standard errors in parentheses, Margin of significance: (***, **, *). Coefficient is statistically significant at *** $p<0.01$, ** $p<0.05$, * $p<0.1$, reference categories/dummies: non-climatic migrant households, receive remittances, age<40, Female, Not in union, No formal education, Coastal, Farming, Traditional/others, Highest wealth category, Health status: less than average, Land: Inherited/purchase, Do not receive

Synthesis of the Relationship of Climate Change, Migration and Food Security

A synthesis of the relationships of climate change, migration and food security was drawn from participants through focus group discussions and key informant interviews (Figure 5.) Variation in climate in the form of increases in temperature and erratic rainfall affects farming through change in seasonality, poor crop yield and low agriculture production. Agriculture-related jobs are also lost when climate change affects the livelihoods of households. When climate change affects agricultural production, it leads to decline in food availability, and ultimately food insecurity conditions set in. Households, in an attempt to diversify their livelihood and to overcome food insecurity challenges, have some of their members embark on migration. Such migrations are supported by households in anticipation of remittances. Given that the communities under study are largely agrarian, it is possible that climatic factors are part of the larger economic reasons for migration. Some successful migrants remit their households, which helps to improve food and livelihood security conditions of their left-behind households.

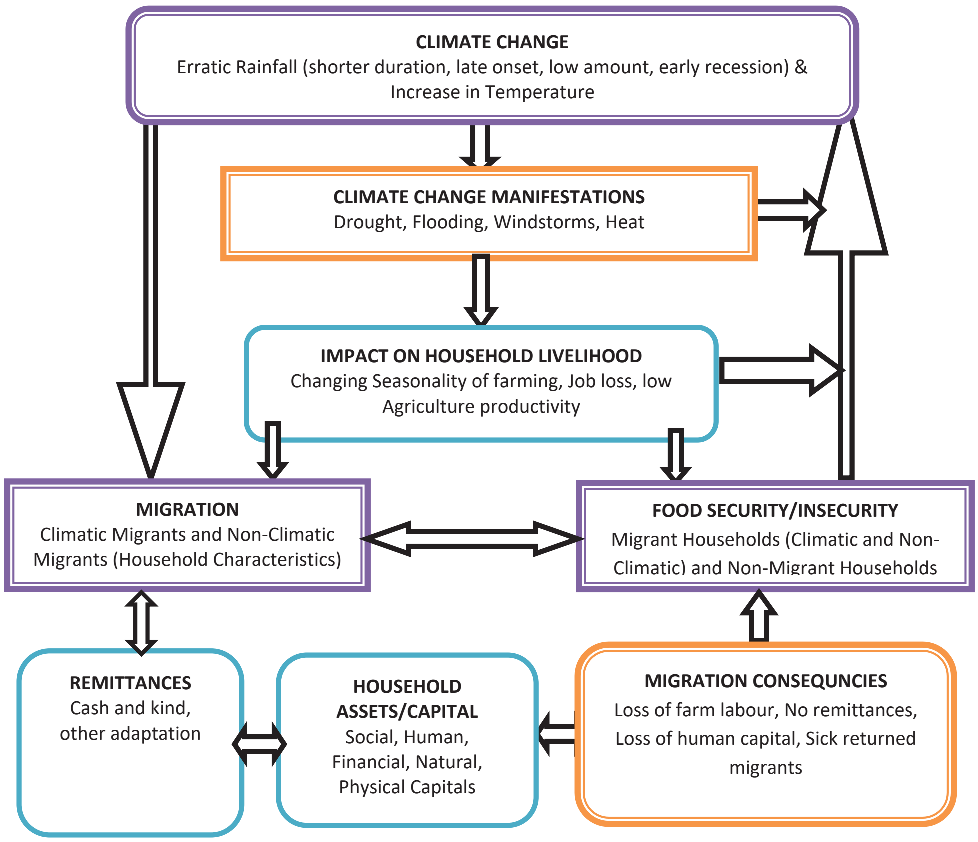

Fig. 5: Synthesis of the Relationship of Climate change, Migration and Food Security

Source: Authors construct (FGD/KII 2017)

On the other hand, migration of household members could also lead to loss of farm labour or present other consequences to the household such as unsuccessful return migrants or the return of sick migrants. As a result, migration does not always result in benefits to the household. Therefore, under some conditions, migration can have serious consequences for the household. Household accumulated resources can be depleted on a household member who migrated or returned with other burdens.

Discussion

Analysis of Trichotomous Relationships of Climate change, Migration and Food Security

The geographical location of individuals and households is a crucial influencing factor of their food security status and potential to migrate during climate change conditions (Brown *et al.* 2015). The results of the present study showed that location tends to play a critical role in influencing food security conditions of households across the agro-ecological zones under study. In the Coastal agro-ecological zone for instance, climatic migration tends to have a positive impact on food security. When household members migrate as a result of climate change it tends to improve the food security status of the household compared to non-climatic migration in other zones such as the Forest agro-ecological zone. But the Coastal agro-ecological zone recorded the highest rate of food insecurity. This is probably due to the influence of climate change on fishing which is the main occupation of inhabitants along the coast in addition to some farming (WHO, 2018; Teye and Owusu, 2015; AGRER, 2011). The onset of climate change in the form of high temperatures which affects fish catch is negatively affecting the main livelihood of the people. The result of the present study is consistent with those of previous studies which indicate that sea level rise, coastal erosion, flooding and rise in temperatures are eroding the gains and fish harvest of households in coastal communities (Addo, *et al.,* 2008; Stabinsky, 2014; Huq *et al.,* 2015; Pabi *et al.,* 2015). Fish catch and fish stock have been projected to further reduce if immediate steps are not taken to deal with the impact of climate change on marine life (FAO, 2008; Gitz, *et al.,* 2016). This implies that more coastal residents who are in the fishing and related sectors are likely to further migrate as a result of the impact of climate change on fishing in the coastal communities in the form of dwindling fish catch and the associated food insecurity conditions (AGRER 2011; Fisheries, 2014; WHO, 2018). Changing rainfall pattern was identified as a major change in the zone.

The Savannah agro-ecological zone recorded the second highest rate of food insecurity under climate change conditions. This evidence is consistent with the findings of previous studies which indicate that the Savannah zone, due to its relative historical deprivation, has high levels of poverty and food insecurity incidence (Awumbila and Ardayfio-Schandorf, 2008; Stanturf *et al.,* 2011; Rademacher-Shultz's, *et al.,* 2014; Van der Geest, 2011; Hjelm and Dasori, 2012; Yaro, 2013). The results further showed that climatic reasons for migration are associated with high food insecurity conditions in the Savannah agro-ecological zone. This result is also consistent with the findings of Awumbila and Ardayfio-Schandorf (2008), Van der Geest (2011) and Rademacher-Schulz's *et al.,* (2012), that when households are food stressed in the Savannah agro-ecological zones, they turn to migration as an adaptation strategy. Historically, migration has been a livelihood adaptation strategy among the people of the Savannah zone (Anarfi *et al.,* 2003; Kwankye *et al.,* 2009; Awumbila *et al.,* 2014).

In the Forest agro-ecological zone, non-climatic migration is having a greater impact on food security compared to climatic migration. This is because even though household members might have migrated, they are probably not remitting enough to lift their households out of food insecurity The household survey confirmed by focus group discussions that the Forest zone has been more attractive to migrants because of its greater economic opportunities, mostly in the informal sector in recent decades, that draw especially the youth from the northern Savannah agro-ecological zones. .

The Transition agro-ecological zone which shares some similarities with the Forest agro-ecological zone recorded the lowest food insecurity rate. In this zone, however, climatic migrant households tended to be more food secure, but compared to the Forest zone, the variation was insignificant. The Transition zone's better food security could probably be attributed to many factors including rich soil nutrients and abundant labour from the Savannah agro-ecological zones that serve farming communities in this zone (Van der Geest, 2011).

Also, given that households depend on agriculture, when crop yield is affected, farmers' source of wealth and income could also be affected. The weakening assets and resource base of the household without a corresponding increase in entitlement bundles can affect households' labour, trade, production and exchange-based entitlements. Entitlement failure under climate conditions can further expose farmers to other vulnerabilities and food insecurity conditions (Sen, 1981) depending on the household characteristics. When food insecurity conditions set in, households begin to reconstruct their livelihood adaptation strategies with migration as an option. This corroborates previous findings (Black *et al.,* 2011c; Black *et al.,* 2011b; WHO, 2018). However, being utility maximizing entities, the households undertake decisions that embrace the welfare and aspirations of other household members. The decisions about migration revolve around the household head. Given dwindling agriculture fortunes, households begin to devise different ways to discharge surplus labour in a beneficial way by supporting a household member to migrate. Prior to departure, potential migrants are supported financially and spiritually in order to arrive with luck for jobs at destination. This narrative conforms to the arguments of the New Economics of Labour Migration (NELM) theory that migration ultimately is a utility maximizing decision of entire households (Massey *et al.,* 1993) and not merely a wage-labour affair.

Climate change, migration and food security dynamics are also influenced by some household characteristics (Table 6). Households' (migrant, climatic migrant and non-migrant) characteristics that strongly influence food security status include age, sex, household size, marital status, education, access to credit, wealth and health status of the household head. The age of the household head is a good predictor of food security status of households under climate change conditions. Elderly household heads (>60 years) in the Transition zone tend to be more food secure compared to younger household heads (40 to 60 years). This could be due to the fact that the elders could be enjoying some comparative advantage over the youth by virtue of their experience and access, ownership and control of productive resources such as land.

Younger household heads (40 to 60 years) in the Savannah zone were more food secure compared to those below 40 years and those above 60 years. While this could be attributed to ownership of land by the youth in the Savannah zone, it could also mean that, given the labour intensive nature of farming in the Savannah zone, the youth are stronger and able to farm better than the elderly and those less than 40 years. Those in the 40-60 years category may also have more young adult and unmarried children who can be a source of labour, while the children of those below 40 years may not be able to contribute to farm labour and those of the farmers aged above 60 years may be mostly married and have their own families. Resources could also be playing a key role in determining the food security status of households in the Savannah zone because the youth probably are more able to diversify and sell their labour in order to mobilize more resources to engage in more food cultivation compared to the elderly and those below 40 years. The youth are also probably more likely to be exposed to new and modern methods of farming, given their high levels of propensity to migrate compared to the elderly.

Furthermore, in the Savannah agro-ecological zone, farming is more of a subsistence activity, mostly with the use of simple rudimentary tools such as cutlasses and hoes. Labour intensive but simple methods of farming are largely used, with less agriculture mechanization, unlike in the Forest and Coastal zones where relatively non-poor farmers are able to afford agriculture extensification and mechanization (Stanturf *et al.,* 2011; Codjoe and Bilsborrow, 2011).

Experience may be playing a critical role in determining household food security status in the Coastal and Forest agro-ecological zones, given that older household heads (<60 years) are more food secure. Probably, older household heads are more experienced in farming and also have more resources since the Forest zone is well endowed with the potential of good agriculture yield compared to the Savannah zones. Experience and money could be playing a significant role in farming, given that the elderly were more food secure in the Forest and Coastal zones. This evidence corroborates previous findings that resources, labour strength and quality of the households influence farming and food security status of households (Dasgupta and Baschieri, 2010).

The sex of the household head presented varying results on food security in times of climate change across the agro-ecological zones (Table 6). With regard to sex, male-headed households are more food secure in the Coastal, Forest and Transition zones compared to the Savannah agro-ecological zone. This could mean that the male-headed households have more control over means of production, especially in the Coastal zone where the majority of male-headed households are. In the Savannah agro-ecological zone, female-headed households are more food secure than male-headed households. This could be attributed to remittances where recipients are mostly women in the Savannah zone. Women were also likely to benefit more from social capital from other family members given the strong social networks and the role the social economy still plays in that zone compared to the monetized and relatively more urbanized communities with more weakening social ties in the Coastal, Forest and Transition zones. This evidence conforms to the literature (Darkwah *et al.,* 2016; Van der Geest, 2011). Darkwah *et al.,* (2016) further indicated that the patriarchal powers of the male are dwindling as women in the Savannah zone are empowered due to remittances.

The wealth (assets/capital) and health status of the household head and access to credit are strong predictors of household food security during climate change. The higher the head of the household's position in the 'wealth category', the lower the food insecurity status of the household. Household heads in the 'lowest wealth' category were more food insecure compared with household heads in the 'highest wealth' category. A similar relationship was observed between households in the 'middle wealth' category and household heads in the 'highest wealth' category. Household heads in the 'middle wealth' category were found to be less food secure compared with households in the 'higher wealth' category. The accumulation of assets and resources by the household head therefore serves as a good protector against food insecurity.

The impact of migration on household livelihood and food security conditions is neither always positive nor uni-directional, but complex and interrelated. Migration under some conditions does not improve household livelihood conditions, but rather exacerbates them, given further exposure to other vulnerabilities. Some houses receive remittances that help improve their livelihood conditions.

There are other households that do not receive remittances probably because a migrant household member is not successful. Unsuccessful migrants may also return with further burdens, such as ill-health which further depletes accumulated household assets and resources. Against this background, Sen (1981) argued that in the face of entitlement failure (social, financial, natural, physical), the likelihood of households falling into further deprivation is high.

The impact of migration on household livelihood and food insecurity conditions also depends on who migrated from which household and to where (Warner and Afifi, 2014; Afifi *et al.,* 2014; Black *et al.,* 2011a), The findings refute generally held notions that once migration occurs, remittances in cash and in kind should be expected. Arguably, it can be said that it takes a responsible and successful migrant to remit their households to enable them to improve their livelihood and food security status, *ceteris paribus*.

Apart from migration, households used other adaptation strategies to manage food insecurity conditions, such as skipping meals in times of food shortages. This adaptation mechanism was commonly used across all the agro-ecological zones.

Across the agro-ecological zones, non-farming activities played a critical role in improving household food insecurity conditions. In the Savannah agro-ecological zone for instance, households' non-farm activities included petty trading, 'mancheli' (blacksmithing), hunting, some occasional fishing, rearing of livestock (cattle, sheep, goats), poultry, charcoal production and sale of locally brewed drinks such as 'sobolo' and 'pito'. Some households also indicated that during the farming season (a period often characterized by food shortages just before harvest), they occasionally sell wage labour to neighboring farms and communities.

Conclusion

There is evidence that climate change manifests in increasing temperatures and erratic rainfall. This further leads to drought, flooding, increase in windstorms and rainstorms. The manifestations of climate change affect the seasonality of farming and agriculture production, especially in rain-fed agrarian economies. The impact is seen in poor crop yield, poor harvest, job losses and food insecurity. In order to adapt to food insecurity conditions, household members migrate in search of better jobs. Successful migrants remit their households, which probably helps to improve food security conditions.

Given the impact of climate change on livelihoods and agriculture production, livelihood diversification of households is an important consideration. Managing migration resulting from climate change entails strengthening farmers' capacity to improve on their adaptation mechanisms in both farm and non-farm activities. Given the prevalence of drought, especially in the Savannah agro-ecological zones and some parts of the Transition zones, it is recommended that irrigation facilities be provided for farmer-based communities. .

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