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DETERMINATION OF VARIATION IN MORPHOLOGY AND LEAF BITTERNESS IN SPIDER PLANT *(GYNANDROPSIS GYNANDRA* (L.) BRIQ. ACROSS SIX AGRO-ECOLOGICAL ZONES IN KENYA

BY

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination or award of a degree. Where other people's work has been used, this has been properly acknowledged and referenced in according with the University of Nairobi's requirements

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DEDICATION

This thesis is dedicated to my daughters Thandi and Nahla, my parents Jamen Adeka and Rachel Adeka, and siblings for love and prayers throughout the study years.

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ABBREVIATIONS AND ACRONYMS

AEZs	Agro-ecological zones
CTs	Condensed tannins
FAO	Food and Agriculture Organization of the United Nations
GBIF	Global Biodiversity Information Facility
GPS	Global Positioning System
HCDA	Horticultural Crops Development Authority
HTs	Hydrolysable tannins
IFPRI	The International Food Policy Research Institute
IPGRI	International Plant Genetic Resources Institute
MOA	Ministry of Agriculture
MOH	Ministry of Health
MS	Microsoft
NRDs	Nutrition Related Diseases
RDA	Recommended Dietary Allowance
SI units	International System of Units
SPSS	Statistical Package for the Social Sciences
SSRs	Simple Sequence Repeats
TLVs	Traditional leafy vegetables
UN	United Nations
UPGMA	Unweighted Pair-Group Method using Averages
USD	United States American Dollar

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ABSTRACT

Gynandropsis gynandra (L.) Briq. also referred to as spider plant (English), is an important leafy vegetable in the diets of rural and urban communities in Kenya. Young leaves, stems and or flowers are consumed as vegetable relish and are reported to be rich in vitamins (A and C), minerals (calcium and iron) and other health promoting compounds. Spider plant is adapted to various ecological habitats and hence exhibits variation in morphology and leaf bitterness. This variation has not been studied systematically in Kenya while the bitter taste in some spider plant varieties hampers its wider consumption by certain community groups such as youth and children. The aim of this study was to evaluate variation in morphology and leaf bitterness in spider plant from six (6) agro-ecological zones and establish whether leaf bitterness is associated with morphological traits. Purposive sampling method was used to sample spider plants that were used for morphological characterization in 2017. A total number of seventeen (17) sites within the six (6) agro-ecological zones (AEZs) in Kenya namely, the upper and lower highlands, upper and lower midlands, inland and coastal lowlands were sampled. Morphological characterization was based on seventeen (17) qualitative (observational and sensory) and nine (9) quantitative traits identified by IPGRI. Leaves of the mature plants were subjected to organoleptic testing to evaluate the variation in leaf bitterness. Qualitative data was analyzed using descriptive and inferential statistics such as percentages, while the quantitative traits were subjected to statistical measures of means. Pearson correlation analysis was performed to find out the relationships between level of leaf bitterness and qualitative traits; colour of main stem, stem pubescence, colour of leaf blade and leaf waxiness. Results showed that there was morphological variation in all the traits studied, eight (8) of which recorded significant differences. There was also variation in leaf bitterness, with the bitterest plants scoring 4.2 in the lower midlands and 4.0 in coastal lowlands while the least bitter ones scoring 1.0 in the upper highlands. The colour of the leaf blade was the only morphological trait associated with leaf bitterness. Cluster analysis based on the level of leaf bitterness divided the *Gynandropsis gynandra* specimens into two (2) major groups and eight subgroups. The study concluded that agro-ecology variation (mostly associated with variation in temperature and moisture levels) had a significant effect on the morphology and level of bitterness of spider plant.

CHAPTER 1: INTRODUCTION

1.1 Background information

Kenya is endowed with a rich plant biodiversity due to a wide range of agro-ecology variation (Muchena and Gachene, 1988). According to Muchena and Gachene (1988), the land rises from sea level at the coast to approximately 5,199 m a.s.l. on Mount Kenya leading to a complex terrain which results into different parts of the country experiencing variation in temperature and precipitation. Kenya has both highlands and lowlands which influence distribution of plant species and varieties depending on their environmental requirements (Maundu *et al.*, 1999). Maroyi (2017) states that a rich plant diversity provides diverse ecosystem goods and services for both human and animals, which include; provisioning, regulating, supporting and cultural services. Food, animal fodder, medicines and timber are some of the products provided by plants (Kokwaro, 1993; Chweya and Mnzava, 1997; Maundu *et al.*, 1999; Maroyi, 2017). Gahukar (2014) reports that for centuries, plants have been used by local communities for their survival during difficult times such as drought, crop failure, erratic rainfall, floods, human disease epidemics among others. Altieri (2004) and Gahukar (2014) also report that local plants, crop species and varieties which include wild crop relatives, make a vulnerable genetic pool for supporting food security under climate change and conservation of agricultural biodiversity. This plant diversity is threatened by industrialization of agricultural techniques and simplified systems of land tenure which enhance food insecurity (Corinto, 2014).

Kahane (2013) predicts that by the year 2050, agriculture will need to meet the food and nutrition requirements of the world's nine billion people in the adverse of climate change. Kahane (2013) further reports that diversification using valuable under-utilized crops is key in meeting these nutritional needs. According to a food security report by KARI (2012), cultivation of orphaned-drought tolerant crops has been identified as a key driver to curbing food insecurity in arid and semi-arid areas in Kenya. In recognition of this need to promote such traditional foods, United Nations declared the year 2010 as the International Year of Biodiversity to celebrate plant and animal diversity of wild and horticultural biodiversity in which traditional vegetables are embedded (Abukutsa, 2010).

Over 1,000 species are used in Africa as leafy vegetables most of which are under-utilized (Pichop *et al.,* 2016). It is estimated that about 200 indigenous plant species are consumed as leafy vegetables in Kenya with only a handful fully domesticated, a few more semi-domesticated and a majority still regarded as wild (Maundu *et al.*, 1999). In Africa, traditional leafy vegetables (TLVs) are defined as food plants whose leaves, stems and flowers are used or considered as vegetables by rural and urban communities through food habits and tradition (Weinberger and Pichop, 2009; Maundu *et al.*, 1999) and are native to the region or were introduced long time ago (Hoeven *et al.*, 2013). They are also used as condiments when served with a starchy staple food such as *ugali* (stiff porridge) (Schippers, 2000; K'opondo *et al.*, 2005). Local communities have a well-developed knowledge on selection of palatable types (using morphological characters), cultivation, post-harvest technologies and food recipes (Maundu *et al.*, 1999). Maundu *et al.* (1999) and Abukutsa (2010) further report that traditional vegetables are preferred to exotic vegetables as they are said to have better organoleptic qualities, higher nutritional value, more medicinal benefits and are easier to cultivate. According to Capuno *et al*. (2015), TLVs play a critical role in food security and income generation. They are also adaptable in tropical environment, stable in marginal environments and resilient to stresses thus provide local communities with coping strategies to combat climate change (Bala *et al.,* 2010, Abukutsa, 2010). In this regard, Bharucha and Pretty (2010) consider them as 'crops of the future'. They are more nutritious than exotic vegetables such as cabbages and tomatoes, hence have been identified as source of micronutrients which can combat micronutrient deficiencies in Kenya (Sreeramulu, 1982; Hoeven *et al.,* 2013; Kutsukutsa *et al.,* 2014; Sogbohossou *et al.*, 2018). They are used to diversify diets of common local meals especially for those who do not have access to markets (Maundu *et al.*, 1999; Hoeven, 2013). Maundu *et al.* (1999) added that apart from food, they are also used as medicinal foods (nutraceuticals) and for food fortification of other meals such as soups and porridges by pastoral communities.

Ngugi *et al.* (2007) reports that the demand for traditional leafy vegetables has been on the rise over the past ten years especially in urban centres due to awareness created by several institutions on their nutritional and medicinal value and hence have a significant role in horticulture. Vegetables such as amaranth, spider plant, cowpea, Jew's mallow and pumpkin leaves have penetrated informal markets and high-value segments of markets such as supermarkets and high-end grocery stores through support to supply chain development (Ngugi *et al.,* 2007). The value of these vegetables in the domestic market rose from 4.3% in 2011 to 5% in 2013 (Wasonga *et al.,* 2015).

In Kenya, traditional vegetables have diverse local landraces due to variation in ecology (Bharucha and Pretty, 2010). Kenya is reported to have a wide agro-ecological range which has resulted in variation (types, varieties and forms) of plant species, and spider plant is no exception (Maundu *et al.,* 1999; Schippers, 2000). According to Govindaraj *et al.* (2015), a wide variation ensures that populations and species persist over evolutionary time as environment changes. On the other hand, reduced genetic variability leads to extinction or disappearance of species in their habitats (Bharucha and Pretty, 2010). Chweya and Mnzava (1997) affirmed that a plant's morphology and nutritional value varied with environment, ecotype and soil fertility among others. Genetic diversity in traditional vegetables is thus important for future breeding, providing options for the breeders to develop new varieties and hybrids (Chadha and Oluoch, 2003; Govindaraj *et al.,* 2015). Preliminary genetic diversity assessment within a plant species may be done by considering morphological traits such as flower and stem colour, and plant growth habits among others (Govindaraj *et al.,* 2015).

Spider plant is listed as one of the important traditional African leafy vegetables used in the preparation of vegetable relish in Kenyan households and other African countries (Maundu *et al.,* 2009). Its market demand is also on the rise (Omondi *et al.,* 2016). *Gynadropsis gynandra* is referred to as spider plant, spider flower (English) or 'saga' (Luhya, trade name) in Kenya (Maundu *et al.,* 1999). Spider plant is used both as a food and medicine in most cultures (Chweya and Mnzava, 1997). Reports indicate that it was originally used by the Nilotic speaking communities living around the Nile basin, served as an important vegetable to the chiefs (Maundu *et al.,* 2009). It is also used by other communities such as the Luhya, Kisii and the Mijikenda as a food relish and for its perceived medicinal value (Maundu *et al.,* 1999). In these communities it serves as a key vegetable during relish-gap periods hence plays an important role in household food security during lean times (Smith and Eyzaguirre 2007). In Kenya, spider plant has for a long time been picked from the wild (Maundu *et al.,* 2009) but with time it has been semi-domesticated in home gardens and commercialized to cater for its increasing demand and popularity in urban areas (Sogbohossou *et al.,* 2018). It is majorly produced in areas such as Kisii, Migori, Siaya, Kericho, Kiambu and peri-urban areas in

Nairobi such as Kiserian (Abukutsa, 2010). *Gynandropsis gynandra* is morphologically variable in its range (Schippers, 2000). Morphological variation has been recorded in the colours of stems, ranging from green to purple, and petals, from white to purple. The vegetable is said to be bitter and the bitterness varies (Schippers, 2000). Bitter taste inhibits the wider consumption of spider plant with some groups of people regarding it as unpalatable, though some appreciate bitterness as it is perceived to be of medicinal value (Schippers, 2000). The local communities gauge bitterness and texture of spider plant by the colour of the stems and petioles whereby they select purple-stemmed types because they are said to be less bitter than the green types (Schippers, 2000).

Nutritional analysis show that spider plant is rich in micronutrients such as calcium, magnesium, iron, zinc, vitamin A, C and E, hence suitable for combating hidden hunger and the management of lifestyle diseases (Wasonga *et al.*, 2015). Sowunmi *et al.* (2015) reports that spider plant is also rich in phytochemicals known to have strong anti-oxidant activity with the ability to scavenge free radicals providing scientific evidence for its use in traditional medicine in various African communities. An infusion of the leaves is used to treat anaemia and as an eyewash (Chweya and Mnzava, 1997). The vegetable has been a source of income for women in rural areas who sell it in the local markets (Schippers, 2000). Research shows that spider plant contributes 15-40% of the total income of small-scale farmers in Kenya with the price of fresh leaves selling at 0.40-0.50 USD/Kg when in plenty during wet season and sells for twice this value in the dry season (Sogbohossou *et al.*, 2018). Chweya and Mnzava (1997) state that spider plant is adapted to a wide agro-ecological range; hence existence of various ecotypes (Schippers, 2000). Muasya *et al.* (2009) also reported that several farmer landraces or varieties have been documented but have not been classified. Though past scientific research has identified a limited number of varieties of spider plant, no systematic evaluation of this variation has not been done using agro-ecological zonation as a criterion. Variation is important for selection of desirable traits for breeding and promotion for consumption.

1.2 Problem statement

Spider plant is a traditional leafy vegetable used for preparation of vegetable dishes by some communities in Kenya such as the Luhya, Kisii, Luo, Mijikenda (Maundu *et al*., 1999). Indigenous knowledge reports of various communities indicate that it is a highly nutritious vegetable, sometimes termed as a ‘medicinal food’ or ‘nutraceutical’ with the ability to replenish blood in recuperating individuals such as lactating mothers (Schippers, 2000). It is also rich in fibre enabling it to be easily dried and stored for use during lean periods enhancing household food security (Hassan *et al.,* 2007). Spider plant uses the C4 photosynthesis pathway which enhances its ability to thrive in semi-arid areas and hence a promising vegetable for propagation and promotion in drylands to enhance food security and income (Raju and Rani, 2016). It is widespread in its distribution and highly varied in morphology and leaf bitterness as reported in various reports (Schippers, 2000).

Consumption of spider plant in Kenya is hampered by the bitter taste in leafy aerial parts leading to loses in gross revenue of Kshs 173,831.1 per week (Irungu *et al.,* 2007) as well as consequence of suffering nutritional related diseases (NRDs) due to lack of micronutrients (Mathooko and Imungi, 1994). Systematic evaluation of morphological variation of spider plant has not been done which links varieties to different ecological zones. There is limited data on leaf bitterness of spider plant which will enable selection of preferable types by breeders and consumers. This study therefore set out to evaluate variation in morphology and leaf bitterness in *Gynandropsis gynandra* in Kenya. Morphological traits such as colour of main stem, leaf waxiness, stem pubescence and colour of leaf blade were correlated to levels of bitterness of the plants in order to identify traits that may act as indicators of plant bitterness. Evaluation based on agro-ecological zonation was also evaluated to show whether it affected morphology and level of leaf bitterness in spider plant.

1.3 Research Questions

1. Are there variations in morphological characters and level of leaf bitterness in *Gynandropsis gynandra* across six agro-ecological zones?

2. Are there any significant relationships or correlation between level of leaf bitterness and specific morphological characters such as colour of leaf blade, colour of main stem, stem pubescence and leaf waxiness?

3. Are the variations in spider plant morphology and leaf bitterness associated with the agro-ecological zonation of Kenya?

1.4 Objectives

Main objective

To establish morphological variations and bitterness levels of *Gynandropsis gynandra* species and to determine whether they are affected by agro-ecological conditions in Kenya.

Specific objectives

1. To evaluate morphological variation within *Gynandropsis gynandra* species from six agro-ecological zones in Kenya.
2. To determine levels of bitterness in *Gynandropsis gynandra* vegetable from six agro-ecological zones.
3. To determine whether there is a relationship between levels of bitterness and morphological characters.

1.5 Justification

Kenya is currently facing adverse food insecurity due to over reliance on exotic crops which are vulnerable to climate change and micronutrient deficiency such as vitamin A, iron, iodine and zinc (KARI, 2012). These nutritional related diseases (NRDs) can be overcome through consumption of indigenous vegetables such as spider plant which are rich sources of micronutrients (Abukutsa, 2010). More so indigenous vegetables such as spider plant are a source of income, generating an estimated value of USD 6000 per month in sales (Weinberger and Pichop, 2009). Spider plant is consumed in Kenya majorly by communities from coast, western Kenya and parts of the Rift Valley because they are accustomed to its taste and its richness in important nutraceuticals that help regain health or build body strength among other uses (Maundu *et al.,* 2009). Spider plant has a wide distribution hence exhibits variation in morphology, nutrient content levels and levels of bitterness (Chweya and Eyzaguirre 1999). The bitterness is appreciated by some cultural groups as it is believed to be medicinal though some community groups, youths and children regard it as unpalatable (Maundu *et al.,* 1999; Kutsukutsa *et al.*, 2014). Some varieties are reported to be extremely bitter thus not consumed at all despite the high nutritional value (Kutsukutsa *et al.,* 2014). It is expected that this study will provide baseline data for producers, consumers, traders and researchers and will lead to well informed strategies to enhance production, food security, income and better health especially in drought prone areas. Enhancing food security is one of the Big Four (4) Agenda in Kenya's administration which can be achieved through use of traditional vegetables such as spider plant.

1.6 Hypotheses

1. Spider plant varies in morphology and leaf bitterness across six (6) agro-ecological zones in Kenya.

2. Leaf bitterness has a significant relationship with morphological characters; leaf waxiness, leaf blade colour, colour of the main stem and stem pubescence.

1.7 Scope and Limitations of study

This study focusses on evaluation of variation in spider plant's morphology and leaf bitterness based on agro-ecological zonation. The objectives of this study will be achieved through sampling mature spider plants only (with flowers and fruits), using purposive sampling method during dry season when seeds are mature for collection. Purposive sampling will be used to collect data thus the sample may not be an adequate representation of the actual population. Spider plant samples will be subjected to organoleptic tests using human participants to measure variation in leaf bitterness thus the results given are based on participants' perception and interpretation. The study therefore recommends further research to be conducted to collect more samples in order to make adequate generalization of the population.

CHAPTER 2: LITERATURE REVIEW

2.1 Botanical aspects of *Gynandropsis gynandra*

2.1.1 Taxonomy

Gynandropsis gynandra (L.) Briq. (Spider plant), synonym *Cleome gynandra* L., belongs to the genus *Gynandropsis* in the botanical family Cleomaceae of the order Brassicales (GBIF Secretariat, 2019). Cleomaceae family consists of herbaceous plants rarely shrubs and contains 17 genera and about 150 species which grow in warm and temperate regions (Klitgard and Baracat, 2009). This genus, which was previously placed in the family Capparaceae, order Capparales (Kiebre *et al.*, 2015), consists of herbaceous plants with well-developed C4 photosynthesis an adaptation mechanism that enables it survive hot environments (Raju and Rani, 2016). *G. gynandra* has an African and Indian region of diversity and is represented with more than 2600 geo-referenced occurrences at the Global Biodiversity Information Facility (GBIF), in which most of them are in Africa (Tien-hor *et al.*, 2018).

2.1.2 Morphology and distribution

Gynandropsis gynandra is widespread in the tropics as a weed and it is native to Africa, South America, Asia and Middle East (Chweya and Mnzava, 1997). It is an erect annual herb with multiple branches (Sowunmni *et al.*, 2015) which grows up to 1.5 m in height depending with prevailing environmental conditions (Elffers *et al.*, 1964; Agnew, 2013; Chweya and Mnzava, 1997; Wenyika *et al.*, 2015). The stem colouration varies from green to purple, sticky and may be hairy or not (Elffers *et al.*, 1964). The leaves are alternate, petiolate and digitatey palmate (Onyango *et al.*, 2013). Each leaf has 3-7 leaflets, with five being the most common and rarely 3-4 (Elffers *et al.*, 1964). The leaflet shape varies from oval to obovate to elliptic, 2-10 cm long and 2-4 cm wide (Wenyika *et al.*, 2015). The margins are either fine toothed or rounded (Agnew, 2013). The petioles are 3-23 cm long and often hairy (Chweya and Mnzava, 1997; Achigan-Dako, 2010; Wenyika *et al.*, 2015). The inflorescence is open and showy up to 30 cm in length, 1.25 cm in diameter and has four (4) sepals, six (6) stamens with long purple filaments arising from receptacle with an inflorescence formula of $K_4C_4A_6G$ (Chweya and Mnzava, 1997). The sepals are ovate to lanceolate measuring up to 8 mm in length and are glandular (Chweya and

Mnzava, 1997). The petals are white, pale pink or lilac in colour (Elffers *et al.,* 1964; Agnew, 2013). The flower is reported to be polygamodioecious with functional staminate short gynoecium and hermaphroditic medium and long gynoecium (Raju and Rani, 2016). The fruit is a long-stalked dry spindle shaped silique measuring up to 12 cm long and 10 mm wide (Chweya and Mnzava, 1997). The siliques are green, turning yellow when ripe and dehisce easily when dry to release seeds. The seeds are small, 1-1.5 mm in diameter suborbicular, rough and dark brown or greyish to black in colour (Elffers *et al.,* 1964; Onyango *et al.*, 2013).

2.1.3 Life cycle and growth of spider plant

Gynandropsis gynandra has a short life cycle of 3-4 months with seeds germinating within 4-5 days and may flower within six (6) weeks after planting while fruit development and maturation may take three (3) to four (4) months (Chweya and Mnzava, 1997; Sogbohossou *et al.*, 2018). Sogbohossou *et al.* (2018) describes spider plant as both self and cross pollinated with the latter facilitated by honey bees, thrips and butterflies. Spider plant is both self-compatible and facultative autogamous with allogamy occurring occasionally a trait that permits fruit set whether pollinators are available or not and offers flexibility in breeding methods that can be applied to improve spider plant (Sogbohossou *et al.,* 2018).

2.1.4 Ecological adaptations of Spider plant

Reports indicate that spider plant is adapted to a wide range of environmental conditions from sea level to 2700 m a.s.l. and has the ability to withstand both low and high temperatures (18-25°C). Raju and Rani (2016); Onyango *et al.* (2013) and Wasonga (2015) noted from recent studies that spider plant like fellow plants in the family Cleomaceae, uses NAD-malic enzyme type C4 photosynthesis which causes changes in leaf biochemistry, cell biology and development. This enables spider plant to use 3-fold less water, allowing it to grow in conditions of drought, high temperature, and carbon dioxide limitation (Raju and Rani, 2016). It is thus a suitable plant for restoring degraded lands and arid areas as it is resilient to climate (Raju and Rani, 2016). It requires high light intensity hence cannot tolerate shady conditions (Chweya and Mnzava, 1997; Schippers, 2000). Water stress induces early flowering leading to low leaf production and early maturity of the plant (Chweya and Mnzava, 1997). The plant thrives in soils rich in high organic matter, the reason why it thrives as a weed in animal shelters rich in manure (Chweya and Mnzava, 1997). Onyango *et al.* (2013) reports that it is a self-seeding herb of cultivated land and other disturbed areas, requiring little attention. It is also a common weed of cultivation and dry bushland (Agnew, 2013). It grows on soils that are deep, well drained and pH range of 5.5-7.0, sandy loam to clay loams (Chweya and Mnzava, 1997).

2. 2 Traditional uses of spider plant in Kenya

Spider plant is referred to as spider flower, spider plant, cats' whiskers or African cabbage in English (Chweya and Mnzava, 1997). Local communities in Kenya refer to spider plant as saga (trade name, Luhya), thageti (Kikuyu), chinsaga (Kisii), akeyo (Luo), mwangani (Giriama, Chonyi, Kambe, Swahili), changani (Duruma), echaboi (Teso), tsisaka (Luhya), kisakiat (Tugen), isagek (Kipsigis), mwianzo (Kamba) (Maundu, 1999). According to Kwekwe (personal communication, December 6, 2017), the Duruma of coastal Kenya further recognize two types of spider plants based on the colour of leaves; *changani cheruhe* (light green leaves) and *changani chiru* (dark green leaves).

The young leafy stems and flowers are reported to be used as vegetable cooked as a relish in Kenya especially in western and coastal region communities such as Kisii, Luhya, Luo, Teso, Nandi, Kipsigis and Mijikenda but it's not consumed by communities in Central Kenya (Chweya and Mnzava, 1997; Maundu *et al.*, 1999). Traditional vegetables are mainly used in the preparation of relishes that supplement and add flavour to diets which include starchy staples (K'opondo *et al.*, 2009) and in this regard, spider plant is cooked and served alongside staple stiff porridge (ugali) (Maundu *et al.*, 1999). It is a vegetable that was served to important visitors such as chiefs among the Teso (Maundu *et al.*, 2009) and also it was mandatory for pregnant and lactating women and also circumcised boys to consume it to replenish lost blood among communities in western Kenya (Maundu *et al.*, 1999; Schippers 2000; Bosire, 2014). Bosire (2014) analysis validates this information that spider plant stimulates the restoration of blood after delivery by increasing the number of red blood cells and the corpuscular hemoglobin concentration. In fact, it stimulates the synthesis of iron biomarkers such as transferrin and ferritin (Bosire, 2014). Many communities regard it as a medicinal meal believed to improve eyesight due to high levels of vitamin A (Schippers, 2000). It is said to reduce dizzy spells in pregnant women and ease childbirth (Schippers, 2000). In Nigeria, dried spider plant leaf is ground and mashed together in a child’s weaning food to enhance the dish’ nutritional value (Hassan *et al.,* 2007).

Spider plant is reported to be a bitter vegetable by consumers and various cooking techniques are applied to reduce the bitter taste (Chweya and Mnzava, 1997; Maundu *et al.,* 1999; Kutsukutsa *et al.,* 2014). Maundu *et al.* (2009) noted that spider plant is referred to as *bilolo* (Lingala) which means bitter due to its bitter taste. Some communities in Kenya and West Africa appreciate the bitter taste as it is said to be appetizing and also ‘medicine for the stomach’ (Schippers, 2000). Bitter spider plant leaves can also be mixed with less bitter vegetables such as amaranth, spinach and Ethiopian kale, left overnight then marinated in milk to improve overall taste of the cooked nutritious and is served with *ugali* (stiff porridge) (Abukutsa (2010). According to Maundu (2011), coastal communities cook extreme bitter types of spider plant in coconut milk to make it more palatable and can also mix it with less bitter vegetables such as amaranth, tsalakushe (*Asystasia gangetica*) or muzungwi (*Moringa oleifera*) to tone down its bitter taste.

The leaves of spider plant are rich in fibre content hence are easily dried and stored for use during dry seasons when the plant is in short supply Chweya and Mnzava (1997). Fresh leaves can also be blanched then moulded to small balls which are later sun dried (Maundu *et al.,* 1999).

Spider plant is used by various communities in local treatment preparations to cure various ailments (Kokwaro, 1993). The leaves are used for treating headaches by rubbing them on head (Schippers, 2000). Pounded leaves are topically applied on boils to prevent development of pus while boiled leaf infusion is drunk to treat anaemia (Chweya and Mnzava, 1997). Spider plant is also used to treat ear, stomach aches, malaria and stabilize blood pressure (Achigan-Dako, 2010). Phenolic compounds (condensed tannins) present in the plant make the plant bitter thus protect the plant against pests hence a powerful anti-feedant and repellant property (Chweya and Mnzava 1997; Lwande, 1999; Kutsukutsa *et al.,* 2014). The leaves are mixed with coriander and grass mulch to control thrips in snap beans. Methanol extracts and volatile emissions of aerial parts of *Gynandropsis gynandra* have been shown to have strong acaricidal effects on spider mites and livestock ticks (Sogbohossou *et al.,* 2018). Spider plant is used as forage plant by cattle, goats, camels and game animals (Chweya and Mnzava, 1997).

2.3 Nutritional value of *Gynandropsis gynandra* as a vegetable

Spider plant is used in most tropical diets as a leafy vegetable (Efflers *et al.,* 1964; Maundu *et al.,* 1999) and is reported to be more nutritious than the exotic vegetables (see table 2.1) (Chweya and Eyzaguirre, 1999). It is an important nutraceutical rich in crude protein (3.1-7.7%), Beta carotene (6.7-18.9 mg), ascorbic acid (127-484 mg) calcium (213-434 mg), magnesium (86 mg), iron content (1-11mg) and fibre capable of alleviating micronutrient deficiencies, (Chweya and Mnzava, 1997; Voster *et al.*, 2002; WHO, 2005; Achigan-Dako, 2010; Schönfeldt *et al.*, 2011; Kutsukutsa *et al.,* 2015). This makes spider plant a good source of vitamin A and Iron which provides 50–75% RDA for children (Van Jaarsveld *et al.*, 2014). Spider plant is also rich in therapeutic phenolic compounds which are useful antioxidants (therapeutic) and the anti-oxidant capacity of spider plant is more pronounced than that of vitamins (Sowunmi *et al.*, 2015). These compounds enable spider plant to manage a number of life style diseases, such as hypertension and other cardiovascular diseases, diabetes, cancer and rheumatism, boost immunity as well as retard ageing (Kutsukutsa *et al.,* 2014; Sogbohossou *et al.,* 2018).

Table 2.1: Nutritional value of spider plant compared to the white cabbage (IPGRI, 2004)

Nutrients	**Spider plant**	**White cabbage**
Water (g)	86.6	91.4
Iron (mg)	6.0	0.7
Protein (g)	4.8	1.7
Calories (kJ)	34	26
Carbohydrates (g)	5.2	6.0
Fibre (g)	1.4	1.2
Ascorbic acid (mg)	13	54
Calcium (mg)	288	47
Phosphorous (mg)	111	40
B-carotene (mcg)	10,452	100

2.4 Bitter taste of *Gynandropsis gynandra* aerials parts

According to Mayes *et al.* (2012), consumption of traditional leafy vegetables is faced by various setbacks as they contain anti-nutritional factors, unpalatable tastes, and unpleasant texture among others. Various reports show that spider plant is among TLVs that has a bitter taste in its flavor profiles which help protect the plant against pests and browsers (Mathooko and Imungi, 1994; Chweya and Mnzava, 1997; Maundu *et al.,* 1999; Muthoni *et al.,* 2010; Kutsukutsa *et al.,* 2014). This has impeded its consumption by several population groups (Hoeven, 2013). According to Kutsukutsa *et al.* (2014) and Palermo *et al.* (2014), the bitter taste of spider plant is caused by accumulation of condensed tannins which are phenolic compounds in the plant. The two (2) commonly occurring tannins are hydrolysable tannins (HTs) and condensed tannins (CTs) (Naumann *et al.,* 2017). Naumann *et al.* (2017) states that CTs also referred to as proanthocyanidins are synthesized via phenylpropanoid pathway. Several research studies have shown considerable variation in concentrations of condensed tannins within plant species due to various reasons (Schweitzer *et al.,* 2008; Kutsukutsa *et al.,* 2014; Franziska, 2016). Franziska, 2016 noted variation (two-fold) in concentration of condensed tannins on 31 genotypes of *Populus tremuloides* of the same age. The level of condensed tannins also varied due to the age of the plant genotypes where the concentration increased up to five (5) years then remained constant (Franziska, 2016). Other causes of variation of production of CTs were abiotic factors such as nutrients, light and temperature; for instance, increase in light and carbon dioxide levels enhanced CT synthesis while addition of nitrogen and temperature decreased their synthesis (Franziska, 2016). Biotic factors such as competition with grasses, fungal infection and damage by herbivores induced synthesis of condensed tannins while leaf fall decreased the CT production (Franziska, 2016). Yet other factors which contribute to CT concentration in plants as much as four-fold include; ontogenetic stages i.e. juvenile and mature, tissue types and phenotypic plasticity in response to the environment (Schweitzer *et al*., 2008). Schweitzer *et al.* (2008) also found out that the astringent properties of condensed tannins reduced the palatability of plant tissues for both vertebrates and arthropod herbivores, and also reduce the nutritive value of plant tissues by binding proteins and other molecules into indigestible tannin complexes in the gut.

It is reported that the bitter taste of *Gynandropsis gynandra* is as a result of precipitatory reaction between condensed tannins and glycoproteins in the saliva (Kutsukutsa *et al.,* 2014; Naumann, 2017). Various crop improvement techniques have been used to decrease the level of condensed tannins, resulting in reduced leaf bitterness and also through selection of less bitter or non-bitter types (Achigan-Dako, 2010; Kutsukutsa *et al.,* 2014). In Kenya, local women boil the vegetable for a long time with several changes of water, a process that reduces the bitterness through migration of condensed tannins into the cooking water (Palermo *et al.,* 2014). However, sometimes, boiling and changing of water leads to loss of nutrients (Maundu *et al.,* 1999). Kutsukutsa *et al.* (2014) reported an 81% loss of vitamin C within the first 15 minutes of boiling in water. Significant leaching of nutrients also takes place when water is drained and thrown away (Mathooko and Imungi, 1994).

2.5 Past research studies on spider plant characterization

Characterization provides description or traits to accessions or plant germplasm according to Govindaraj *et al.* (2015). These traits are heritable and range from agronomical or morphological features to molecular markers (Omondi *et al.,* 2016). Information is useful for providing data for breeding programmes and selecting best varieties for utilization (Achigan-Dako, 2010). Morphological characterization is based on use of markers that are visual traits such as flower colour, seed shape, colouration, and growth habits among others (Saad and Idris, 2001). Govindaraj *et al.* (2015) ascertained that characters can be measured, compared and described to evaluate variation or differences. Diagnostic or key characters evaluated can be either quantitative or qualitative characters (Govindaraj *et al.,* 2015). Qualitative traits are those traits that are encoded by one gene or small number of genes and the traits do not change in response to the environment e.g. flower colour while quantitative traits are phenotypic traits that are affected by the environment and are controlled by many genes e.g. plant height (Pollak, 2001; Govindaraj *et al.,* 2015).

A number of past research studies have characterized *Gynandropsis gynandra* based on different criteria. Kutsukutsa *et al.* (2014) demonstrated that there was distinct genetic variation in five (5) *Gynandropsis gynandra* genotypes tested for levels of bitterness and genetic variability on levels of condensed tannins. He identified two (2) genotypes with low levels of condensed tannins thus less bitter hence were recommended for direct use because they required less amount of cooking time and therefore thermo-labile vitamins were preserved Kutsukutsa *et al.* (2014). This variation was explained as a result of evolutionary history in terms of pathogen or pest pressure in areas of origin of these genotypes (Kutsukutsa *et al.,* 2014). Such evolutionary adaptations are controlled by genes thus inherited and can be amended by breeding (Kutsukutsa *et al.*, 2014).

On the other hand, Chweya and Mnzava (1997) noted significant variation in vitamin C, phosphorous, protein and ash contents in two (2) plant types of *Gynandropsis gynandra* based on colour of the main stem and petiole; green stem/green petiole and purple stem/green petiole types. He found out that purple-stemmed types had high vitamin C content, phosphorous and protein compared to green-stemmed types (Chweya and Mnzava (1997). K'opondo *et al.* (2009) study showed significant variation in important agronomic traits such as plant height, growth habit, number of leaflets per leaf, petiole length and fruit width in accessions from western Kenya. Ayiecho and Omondi (1992) found out there was significant variation in dry leaf yield which could be improved by selection for number of leaves between different populations of spider plant, combined with late flowering. Wasonga *et al.* (2015) found out a high level of dissimilarity among accessions from Kenya and South Africa with major variation occurring in stem colour, and pubescence of the stem, petiole and leaves, petiole colour, leaf shape and number of leaflets per leaf. In his study, only erect and semi-erect growth habits were observed. Masuka's *et al.* (2012) study established that Kenyan morphotypes were relatively smaller in size and produced a lot of fruits compared to Zimbabwean morph-types. Recently, Tien-hor *et al.* (2018) reported that there was morphological variation in characters such as plant height, fruit length, leaf size, colour of the flower and maturity. He also concluded that there was phenomenal variation between African accessions and Asian accessions, in which African accessions were much taller, less uniform, experienced late flowering and late seed maturation (Tien-hor *et al.*, 2018). Lately, Sogbohossou *et al.,* 2019 study demonstrated that the level of carotenoids and tocopherols in spider plant leaves varied significantly across accessions and were linked to geographical origin and morphological variation. In this case, accessions from West Africa were short with small leaves but with higher levels of tocopherol and low carotenoids while those from East and Southern Africa were rich in carotenoids and low in tocopherol content (Sogbohossou *et al*., 2019).

2.6 Use of morphological traits in spider plant selection

Schippers (2000) reported that Kenyan local communities select palatable spider plant types, based on colour of the stem or petiole. Green types are selected because they are reported to be tenderer and less bitter (Schippers 2000). Moreover, green-stemmed types are said to regenerate better than purple-stemmed ones (Schippers, 2000). Govindaraj *et al.* (2015) noted that breeders tend to select plant types which display resistance to pests and diseases.

A study carried out by Kiebre *et al.* (2015) in Bukina Faso revealed that farmers used agro-morphological characters such as the color of the stem, leaves and the vegetative cycle of the plant to select suitable local varieties. He noted that farmers preferred spider plants with traits such as those with green stem colour, tallness, a higher number of primary branches and longer vegetative cycle (Kiebre *et al.*, 2015).

2.7 Agro-ecological zones in Kenya

According to FAO (1996), an agro-ecological zone is a land resource mapping unit defined by climate, soils and landform. Specific zones have specific range of potentials and constraints for land use (FAO, 1996). Therefore, agro-ecological zones are influenced by elevation, altitude and temperature, seasonality and rainfall levels including distribution during growing season (FAO, 1996). Africa's AEZ classification is therefore based on three (3) criteria; major climate zone (subtropics or tropics), moisture zones (water availability) and highland/lowland (warm or cool based on altitude) (Claessens, 2014). Kenya is thus divided into seven (7) agro-ecological zones (FAO, 2010) as shown in Table 2.2.

Table 2.2: Classification of agro-ecological zones based on rainfall, temp, humidity and altitude (FAO, 1996)

Agro-ecological zones	Humidity	Average rainfall (mm)	Altitude (m)	Temperature (°C)
Afro-alpine highlands	Humid	>2000	>3050	<10 *(Cold to very cold)*
Upper highlands	Sub-humid	1000	1980-2450	10-14 *(Very cool)*
Lower highlands	Semi-humid	950-1500	1840-2450	14-18 *(Cool to fairy cool)*
Upper midlands	Semi-humid to semi-arid	500-1000	1500-2450	18-20 *(Warm temperate)*
Lower midlands	Semi-arid	300-600	1000-1500	20-22 *(Fairly warm)*
Inland lowlands	Very arid	200-400	500-1050	24-30 *(Fairly hot to very hot)*
Coastal lowlands	Semi-arid	200-400	0-400	24-30 *(Fairly hot to very hot)*

The zones are Kenyan highlands which are further divided into afro alpine, upper highlands, lower highlands and upper midland zone (Muchena and Gachene, 1988); lower midlands, inner lowlands and coastal lowlands (FAO, 1996). The Kenyan highlands refer to areas lying above 1500 m a.s.l (Muchena and Gachene, 1988). Based on the climate and altitude, the Kenyan highlands can be divided into four (4) main agro-climatic zones; afro alpine, upper highlands, lower highlands and upper midland zones (Muchena and Gachene, 1988).

The tropical alpine or afro alpine (zone 1), lies above 3050 m a.s.l. and is confined to mountain tops and their immediate surroundings such as around Mt Elgon and Mount Kenya (Muchena and Gachene, 1988). The temperatures here make the zone unsuitable for growth of trees and crops. This zone experiences high precipitation and is the source of some of the largest rivers in the country (FAO, 1996).

The upper highlands (zone 2) are found in areas with elevations of 2450-3050 m with minimum rainfall of 1000 mm which is suitable for frost resistant crops (Muchena and Gachene, 1988). It occurs as a forest or open grassland and is found in areas such as Meru, Nyeri and some parts of Rift Valley (Mau), Aberdares (Kericho), Kitale and Webuye (around Mt Elgon) (FAO, 1996).

Lower highlands (zone 3) occurs in elevation of 1840-2450 m with annual rainfall of 950-1500 mm which has a key role in agricultural production (Muchena and Gachene, 1988)). It is rich in tree diversity which are shorter than those in upper highlands (FAO, 1996). It is confined to areas in Central Rift Valley (Nandi, Bomet, Kitale, Eldoret, Nakuru) and a small section of the Coast. Other parts include vast parts of Nyanza, Western and Central Kenya (FAO, 1996).

Upper midlands (zone 4) lies between 1500-2450 m a.s.l. and receives 500-1000 mm of rainfall (Muchena and Gachene, 1988). This zone is found in Naivasha, Laikipia, Machakos, vast parts of Southern Coast area and Central Kenya (FAO, 1996).

Lower midlands (Zone 5) is much drier than zone 4 and receives annual rainfall of 300-600 mm (FAO, 1996). The zone is found in areas such as Baringo, Makueni (lower), Turkana and large parts of Northern Kenya (FAO, 1996).

Inland lowlands (zone 6) is the driest part of the country and is considered as semi-desert which receives annual rainfall of 200-400 mm and very unreliable (FAO, 1996). The zone is found in Mandera, Turkana, Marsabit and Wajir regions (FAO, 1996). Coastal lowlands (zone 7) is found in coastal Kenya where it lies next to the Indian Ocean. It is very hot and humid (Claessens, 2014).

2.8 Organoleptic testing

For a long time, organoleptic tests or sensory tests have been done to determine the quality of food and its acceptability (Carbonell-Barrachina, 2007). These sensory tests are based on colour, odour, texture and taste which are important factors in making food choices (Hoeven, 2013). According to Vindras-Fouillet *et al.* (2014), sensory properties are usually measured through sensory methods (descriptive analyses) as instrumental techniques are still limited to predict human perception. The tests are also used to delineate differences between varieties of plants or crops (Muthoni *et al.*, 2010). Organoleptic tests for plant varieties are done at 50% flowering stage (Muthoni *et al.,* 2010). Certain procedures or protocols are followed when conducting organoleptic tests on vegetable types, they include;

1. Labelling of types or varieties of food samples using codes to prevent bias.
2. Familiarizing the participants with the techniques and concepts of sensory analysis and providing the necessary background information.
3. Explaining to the participants the procedure of testing and how to score on the sheet.
4. Providing snacks such as a sandwich with margarine to participants to eat an hour before the sensory evaluation takes place to prevent potential hunger from influencing the rating of different food types.
5. Presentation of food samples simultaneously which requires that the whole set of samples to be tested is available at the same time. It is advised not to exceed six (6) samples per session of testing
6. Serving food samples randomly to each panelist.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study site

The study site was in six (6) agro-ecological zones as illustrated in figure 3.1, where *Gynandropsis gynandra* was found growing. These agro-ecological zones were; upper and lower highlands, upper and lower midlands, inland and coastal lowlands. The specific regions in the agro-ecological zones visited are indicated in table 3.1. These regions were Baringo, Bungoma, Elgeyo Marakwet, Garissa, Homabay, Kakamega, Kericho, Kilifi, Kisii, Kitui, Makueni, Nakuru, Taita, Trans Nzoia, Uasin Gishu, West Pokot and Nyeri.

Table 3.1: Collection sites for *Gynandropsis gynandra* in various agro-ecological zones in Kenya

Accessions	**Area**	**Lat/Long**	**Elevation (m)**	**Soils**	**Temp (°C)**	**Annual Rainfall (mm)**	**Humidity (%)**	**AEZ**
BAR 1807B	Baringo	N00.46544 E036.01440	1012	Clay soil	21.9	684	56	IL
BAR 1807A	Baringo	N00.46777 E036.01886	1013	Loam soil	21.9	684	56	IL
BGM 2107A	Bungoma	N00.76367 E034.72483	1713	Loam soil	21.1	1628	62	UM
BGM 2107C	Bungoma	N00.61241 E034.61735	1506	Loam soil	21.1	1628	62	UM
ELG/1907B	Elgeyo Marakwet	N00.46728 E035.60924	1247	Rocky soil	14-24	400-1400	70	UM
ELG/1907C	Elgeyo Marakwet	N00.46728 E035.60924	1253	Rocky loam soil	14-24	400-1400	70	UM
ELG/1907A	Elgeyo Marakwet	N00.46728 E035.60924	1247	Rocky soil	14-24	400-1400	70	UM
GA-01	Garissa	S00 28.292 E039 38.193	1035	Clay	29.3	362	35	IL
HBY 2307A	Homabay	S00.54397 E034.28947	1155	Black cotton soil	22.5	1226	65	LM
HBY 2307B	Homabay	S00.54397 E034.28947	1155	Black cotton soil	22.5	1226	65	LM
KK 2207	Kakamega	N00.23009	1568	Loam	20.4	1971	64	UM

Accessions	Area	Lat/Long	Elevation (m)	Soils	Temp (°C)	Annual Rainfall (mm)	Humidity (%)	AEZ
		E034.83690		soil				
KRC 2507B	Kericho	S00.31112 E035.28067	2063	Rocky soil	18.1	1735	69	LH
KRC 2507A	Kericho	S00.58607 E035.19402	1948	Loam	18.1	1735	69	LH
KF-11	Kilifi	S03 32.364 E039 31.812	282	Sandy loam	26	1063	56	CL
KF-05A	Kilifi	S03.2654 E40.01466	50	Sandy clay	26	1063	56	CL
KF-01	Kilifi	S03 03.239 E040 08.197	10	Clay	26	1063	56	CL
KF-05	Kilifi	S03.2653 E40.01468	50	Sandy clay	26	1063	56	CL
KF-09	Kilifi	S03 33.609 E039 30.362	236	Sand	26	1063	56	CL
KF-07	Kilifi	S03 35.569 E039 51.324	29	Clay	26	1063	56	CL
KIS/2407A	Kisii	S00.88754 E034.79023	1787	Loam	19.6	1922	67	UM
K1-01	Kitui	S 01 12.774 E037 50.763	1240	Alluvial sandy	21.4	1068	35	LM
K1-02	Kitui	S01 12.775 E037 50.772	1240	Clay with little sand	21.4	1068	35	LM
KW-02	Kwale	S04.29055 E039.56532	20	Clay rich in organic matter from goats	23.5	1118	47	CL
MK-01	Makueni	S02 33.747 E03800.610	920	Clay	21.5	834	29	LM
MK-02	Makueni	S02 33.246 E038 00.390	925	Clay	21.5	834	29	LM

Accessions	Area	Lat/Long	Elevation (m)	Soils	Temp (°C)	Annual Rainfall (mm)	Humidity (%)	AEZ
NKR 1807	Nakuru	N00.01964 E036.22417	2016	Loam	17.5	895	69	UH
KIS/2407B	Kisii	S01.00975 E034.88179	1756	Black cotton	19.6	1922	67	UH
TT-01	Taita	S03 28.678 E038 22.791	864	Sand	23	754	35	UM
TT-02	Taita	S03 28.678 E038 22.791	867	Sand	23	754	35	UM
TT-00	Taita	S03 47.263 E039 22.842	188	Sandy clay	25	650	36	LM
TNZ 2107B	Trans Nzoia	N00.89914 E034.97070	1791	Loam	18.3	1097	76	UM
UAG 1907C	Uasin Gishu	N00.62237 E035.43269	2252	Clay	16.8	995	73	LH
UAG 1907A	Uasin Gishu	N00.62237 E035.43269	2252	Clay	16.8	995	73	LH
UAG 1907B	Uasin Gishu	N00.62237 E035.43269	2252	Clay	16.8	995	73	LH
WPK 2007A	West Pokot	N00.01309 E035.20480	1722	Black cotton soil	23.6	623	90	LM
WPK 2007D	West Pokot	N00.01309 E035.20480	1722	Black cotton soil	23.6	623	90	LM
WPK 2007E	Kapenguri a	N01.23054 E035.11934	2016	Black cotton soil	16.9	1140	76	LH
NYR 2107C	Nyeri	S00.33867 E036.85818	2016	Loam soil	17.1	1004	73	UH
NYR2107B	Nyeri	S00.33867 E036.85818	2016	Loam soil	17.1	1004	73	UH
NYR2107A	Nyeri	S00.33867 E036.85818	2016	Loam soil	17.1	1004	73	UH

UH (Upper Highland), UM (Upper Midland), LH (Lower Highland), LM (Lower Midland), IL (Inland Lowland), CL (Coastal Lowland)

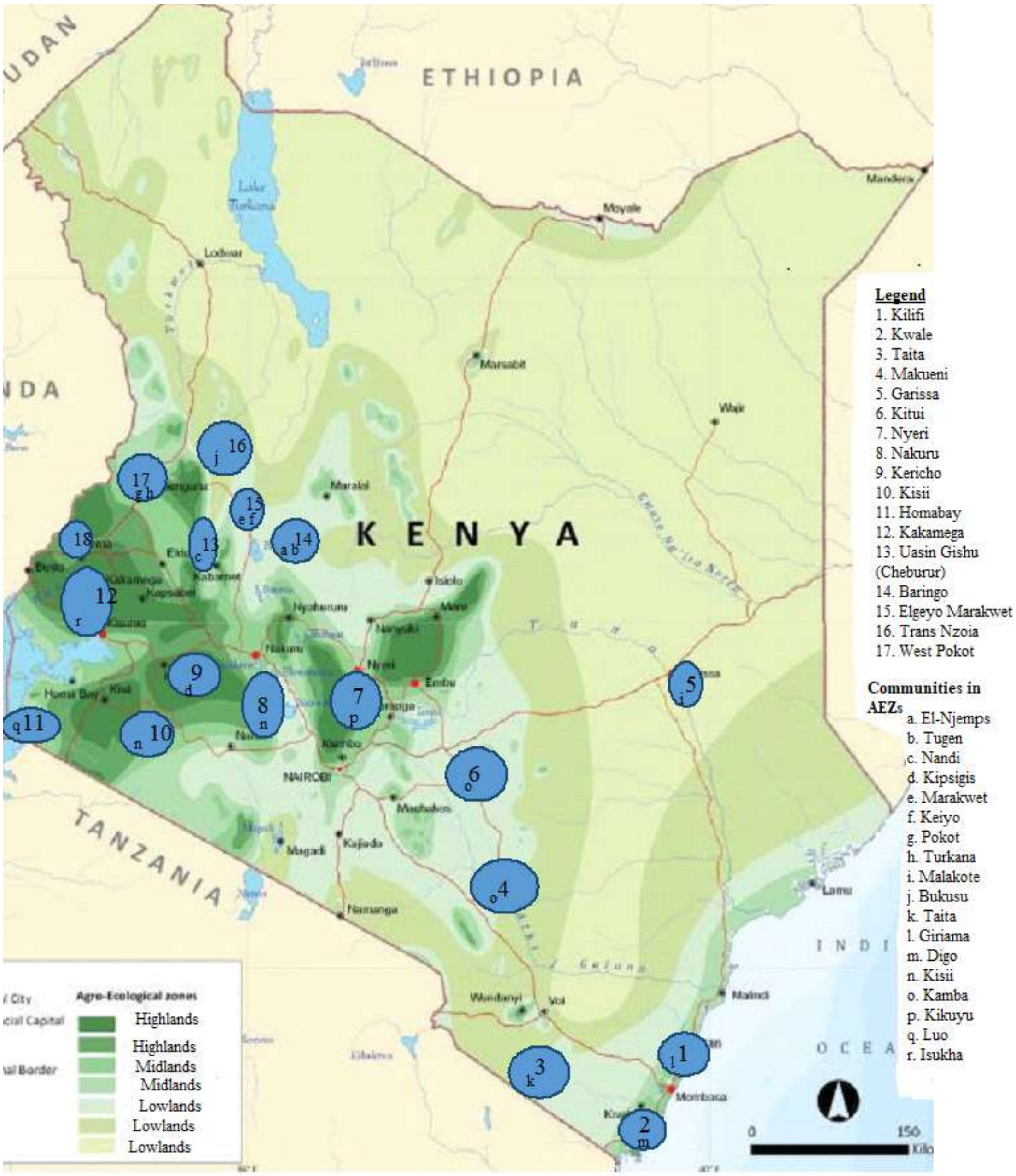

Figure 3.1: Map of Kenya showing the collection sites National Environment Management Authority, 2010 (https://www.researchgate.net/figure/Agro-ecological-zones-in-Kenya-National-Environment-Management-Authority-2010-112)

3.2 Field work preparation

The objectives for this study were to be fulfilled by carrying out two studies;

- Morphological characterization of *Gynandropsis gynandra* to evaluate variation
- Organoleptic tests to determine variation in bitterness in spider plant's leafy stems

A field data collection itinerary was organized to collect data on morphological variation of *Gynandropsis gynandra* across six (6) agro-ecological zones. The collection was done in two (2) field trips during the dry season in June 2017 when spider plant was mature with flowers and fruits and also seeds. The sites of collection were selected because they represented specific agro-ecological zones and were also accessible.

A *Gynandropsis gynandra* characterization protocol was prepared using IPGRI descriptors (Chweya and Mnzava, 1997) while SI units were used to document morphological characterization. The selected descriptors represented a recognized set of characters important for characterization.

Digital photographs were also taken using a camera (Samsung model SM-A720F) for all the accessions collected at different sites to demonstrate variation. A GPS (model Garmin eTrex 30x) was used to mark sites and plants in which characterization was done and the seeds collected. Altitude, latitude and longitude were marked on the GPS. Other data collected included local names of the spider plant, description of the habitat and whether the plant was used as vegetable or not.

Mature healthy and dry seeds from spider plants evaluated were collected and placed in paper envelopes then sealed and labelled. The seeds were collected from siliques (fruits) which were collected from upper positions of the plant because immature seeds are found at the bottom of the plant.

3.3 Experimental design and data collection

Purposive sampling was used to sample mature spider plants growing i.e. those with flowers and mature healthy fruits. Purposive sampling is a type of non-probability sampling in which choice of samples is based on one's judgment and they fit particular characters or profile (Tongco, 2007). In this case the plant samples chosen had to be spider plants which were mature with fully mature seeds for collection either in the wild or farms. Farmers at the sites where spider plant was characterized were asked whether they consumed spider plant or not and this was recorded in the datasheet.

3.4 Data collection

Both qualitative and quantitative data were collected in the field to evaluate variation.

3.4.1 Morphological characterization (Qualitative characters)

Qualitative data collected were both observational and sensory data as shown in table 3. Observational qualitative traits evaluated were 15 and they included; growth habit, colour of the main stem, stem pubescence, colour of leaf blade, shape of terminal leaflet blade, leaf pubescence, upper surface leaf venation, petiole colour, petal colour (open), colour of immature fruits, colour of mature fruits, presence of folds on fruit, surface texture of fruits, shape of nearly mature or mature fruits and colour of mature healthy seeds. Other two (2) qualitative characters evaluated were sensory in nature and they were leaf bitterness (raw) and leaf waxiness.

Table 3.2 Descriptor codes for qualitative traits of spider plant accessions

S/no.	Characters	Descriptors and codes
1	Growth habit	Erect (1), semi prostrate (2), prostrate (3), spreading (4), mixture (5)
2	Colour of the main stem	Green (1), green tinged purple (2), purple tinged green (3), light purple (4), purple (5), dark purple (6), mixed (7)
3	Stem pubescence	Sparsely hairy (1), hairy (2), very hairy (3), wooly (4)
4	Colour of leaf blade	Light green (1), green (2), dark green (3)
5	Shape of terminal leaflet blade	Elliptic (1), Elliptic towards obovate (2), majority obovate, few elliptic (3), majority elliptic, few obovate (4), obovate (5), lanceolate (6)

S/no	Characters	Descriptors and codes
6	Leaf pubescence	Glabrous (1), sparsely hairy (2), hairy (3)
7	Upper surface leaf venation	Not depressed (1), slightly depressed (2), depressed (3), deeply depressed (4)
8	Petiole colour	Green (1), green tinged purple (2), light purple (3), purple (4), dark purple (5), mixed (6)
9	Petal colour	White (1), cream (2), light purple (3), white tinged purple (4)
10	Colour of immature fruits	Green (1), glossy green (2), dark green (3), green turning yellow (4), purplish green (5), purple (6)
11	Colour of mature fruits	Yellow green (1), yellow (2), deep yellow (3), grey (4), brown (5)
12	Shape of nearly mature or mature fruits	Round (1), spindle (2), wide spindle shaped (3)
13	Surface texture of the fruit	Slightly scabrid (1), scabrid (2)
14	Presence of folds on fruit	No folds (1), few folds (2), many folds (3), mixed (4)
15	Colour of mature healthy seeds	Grey (1), greyish black (2), light brown (3), brown (4), black (5)
16	Raw leaf bitterness	Not bitter (1), mild (2), bitter (3), very bitter (4), extremely bitter (5)
17	Leaf waxiness	Not waxy (1), fairly waxy (2), waxy (3), very waxy (4)

3.4.2 Morphological characterization (Quantitative characters)

Quantitative characters evaluated were nine (9) and they were plant height, stem circumference, number of branches, terminal leaflet length, terminal leaf width, number of terminal leaflets, petiole length, fruit length and fruit width. In all measurements done, three (3) plants from the same accession were measured and the average taken to represent the characters in the accession. Plant height was measured using a centimeter rule from the base of the plant to the tip of the main stem. Some spider plants had a main stem which was tilted hence it was measured when lifted and this was indicated in the results. Stem circumference was measured at the middle of the stem using a string which was calibrated on a cm rule. Terminal leaflet length was measured using a cm rule and the basal leaves were selected and measured from pulvinus to the tip of the leaves. Leaf width was measured in mm at the middle of the leaf. Leaf petiole was measured in cm from pulvinus to the end of the petiole where it attaches to the stem. Fruit length was measured in cm from the tip of the fruit stalk to the tip of fruit while fruit width was measured in the middle of the fruit in mm. All data collected on paper sheets were entered into MS Excel sheet, including photograph number for each spider plant accession.

3.5 Seed propagation of spider plant accessions

A pre-germination test was first conducted in a laboratory to ensure that spider plant seeds were viable. In order to determine variation in leaf bitterness, 56 accessions were planted in the field garden arranged in a randomized complete block design with three (3) replications. Organoleptic testing was carried out on harvested fresh raw leaves of *Gynandropsis gynandra* plants at 50% flowering stage to determine levels of bitterness.

Spider plant seeds were planted in December 2017 at the Nairobi Botanic Garden. Nairobi Botanic Garden is located in Nairobi, Kenya on latitude -1.274469 and long 36.813941 and falls under upper midland zone (Jaetzold and Schmidt, 1983). Nairobi has a bimodal distribution of rainfall with long rains starting early March to late May and short rains from October to December with an average rainfall of 1000 mm (Mburu, 1996). Mean annual temperatures are 13°C to 23°C (Jaetzold and Schmidt, 1983). The land had no shading as spider plant does not tolerate shaded condition as this hampers growth. Land was prepared by hand digging using a hoe and making plots or beds. Planting rows were made in each plot, and 10 seeding holes were made in each row. Inter row spacing was 30 cm and intra row spacing of 30 cm. Each accession was planted in each row with three (3) replicates. A single seed was placed in each hole measuring five (5) cm deep and covered with soil but not compacted. The garden was kept weed free by hand weeding. No fertilizer or pesticides were used in growing the spider plants. The experiment was conducted under rain-fed conditions though supplemental overhead irrigation was applied two times, at two weeks after planting and two weeks after flower initiation. The spider plant leaves were ready for harvesting at 50% flowering to conduct the organoleptic test.

3.6 Organoleptic characterization of leaf bitterness

After two (2) months, organoleptic test was carried out on raw leaves of 40 accessions using the ‘within participants’ design’ (Coulthard *et al.,* 2011). The ‘Within participants’ design’ is an experimental design in which all participants are exposed to the same treatment and in this case all participants tasted all leaf samples from all accessions. The design reduces errors associated with individual differences (Coulthard *et al.,* 2011). The protocol that was used for organoleptic testing was derived from Kutsukutsa *et al.* (2014) research on spider plant's bitterness. The raw leaves were tested for level of bitterness by chewing in the mouth.

Leaves from three (3) plants in each accession were randomly collected, put in a clean container and labelled. Only a handful of the leaves were collected. The three (3) selected plants were tagged for evaluation. A Panel of 10 people; five (5) men and five (5) women aged 20-55 years were selected based on history of consuming the vegetable. Each person collected the leaves from each accession, then cleaned it in water and tasted. The level of bitterness was recorded which ranged from 1-5, then the tester rinsed mouth and waited for five (5) minutes before tasting the next accession. The leaves bitterness levels were ranked as follows in Table 3.3.

Table 3.3 Range of leaf bitterness levels based on the perception of the ten selected tasters

	Taste description	**Value**
1.	Not bitter	1
2.	Mild	2
3.	Bitter	3
4.	Very bitter	4
5.	Extremely bitter	5

This was on a scale of 1 to 5 with 1 have the least while 5 had the highest bitterness levels. The Data was entered in an excel file; then mode and mean were conducted on the results of each accessions.

3.7 Data analysis

3.7.1 Analysis of qualitative data

Qualitative data collected was analyzed using descriptive and inferential statistics such as percentages (Chweya and Eyzaguirre, 1999) and chi-square test using SPSS (Statistical Package for Social Sciences) version 21 (Wasonga *et al.*, 2015).

Hierarchical clustering analysis based on relationship of levels of leaf bitterness among spider plant accessions was performed using SPSS Software version 21. UPGMA (unweighted pair-group method using averages) (Sneath and Sokal, 1973) was used which distributes the accessions into a reasonable number of groups. It calculates differences between clusters as the average of all the point-to-point distances between a point in one cluster and a point in the other. The clusters and relationships were displayed on a dendrogram. In cluster analysis, two (2) most similar accessions are clustered together in a group and similarities of this group calculated. The results were then depicted in a dendrogram which represent multivariate relationships among accessions (Hair *et al.*, 1995).

A chi-square test was used to test whether the variation was significant or strong enough in the sample which would allow the study to generalize that the relationship holds for a large population as well. An observed relationship was referred to as statistically significant when the p-value for a chi-square test was less than 0.05. A correlation analysis was done using Pearson correlation chi-square method (Ayiecho and Omondi, 1992) to find out whether there was a strong relationship between levels of bitterness (dependent variable) and colour of leaf blade, leaf waxiness, colour of the main stem and stem pubescence (predictors).

3.7.2 Analysis of quantitative data

Variability within each quantitative trait was estimated using measures of maximum and minimum means for each agro-ecological zone. Chi-square test using SPSS software was then used to estimate variables that were significantly different at $p<0.05$ (Sirkin, 2011).

CHAPTER 4: RESULTS

4.1 Morphological characterization of qualitative characteristics

Spider plant accessions studied showed variation in 15 qualitative characters; growth habit, colour of the main stem, stem pubescence, colour of leaf blade, shape of terminal leaflet blade, petal colour, upper surface leaf venation, colour of immature fruits, colour of mature fruits, shape of mature or nearly mature fruits, surface texture of the fruit, presence of folds on fruits, colour of mature healthy seed, raw leaf bitterness and leaf waxiness as shown in the photographs with magnification of 819x460px. Significant differences ($p< 0.05$) were noted for colour of leaf blade, presence of folds, shape of mature or nearly mature fruit, colour of immature fruit, colour of mature fruit and colour of mature healthy seed. However, growth habit, number of branches, colour of the main stem, leaf pubescence, petiole colour, petal colour, upper leaf surface venation, surface texture and leaf waxiness did not show significant differences. All the statistical information concerning the qualitative data appear in appendix 1.

4.1.1 Growth habit

Spider plant exhibited diverse growth characters which were erect, semi-prostrate, prostrate, spreading and some were a mixture as recorded in figure 4.1. Approximately half of the accessions had an erect growth habit (57.5%), 30% were spreading, 7.5% were prostrate and the least had semi-prostrate and mixed growth habits (2.5%) respectively (see figure 4.1 and plate 1). Mixed growth habit was a type with different growth habits occurring in one accession. Only one accession BAR 1807A had a mixed growth habit. Growth habit of spider plant accessions studied also varied across different agro-ecological zones. The stem and leaf forms are recorded in Appendix 2 and 3. Variation within agro-ecological zones is shown in figure 4.1. Accessions from coastal lowlands were erect and prostrate while those from lower midlands had majority of accessions with spreading habit while few were erect. Inland lowlands, upper highlands, lower highlands and upper midlands were greatly varied with three (3) variations each. Inland lowland accessions were spreading, erect and mixed growth habit while majority of accessions in lower highlands were erect while others were prostrate, spreading and of mixed growth habits. Accessions from upper midlands and upper highlands were majorly erect and few were prostrate and spreading.

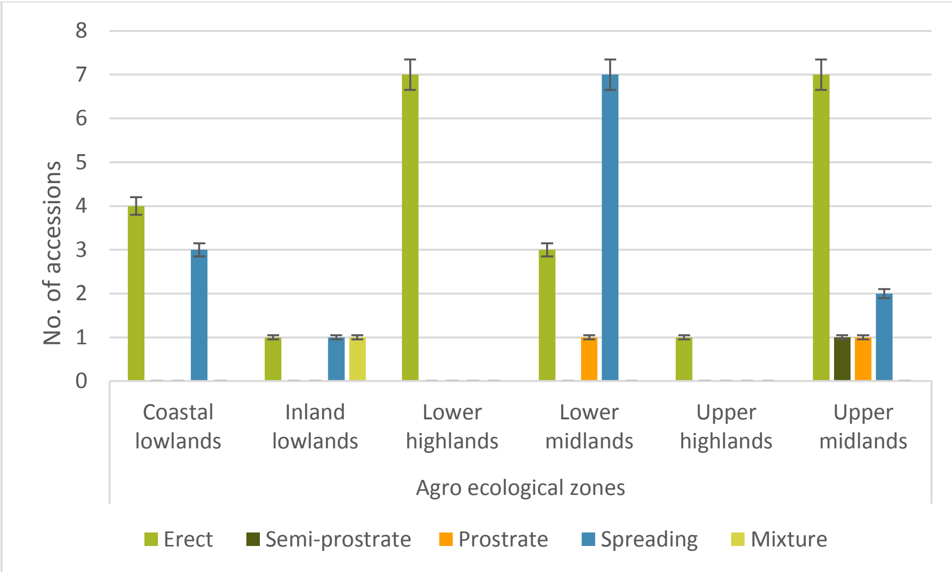

Figure 4.1: Variation in growth habit across six agro-ecological zones

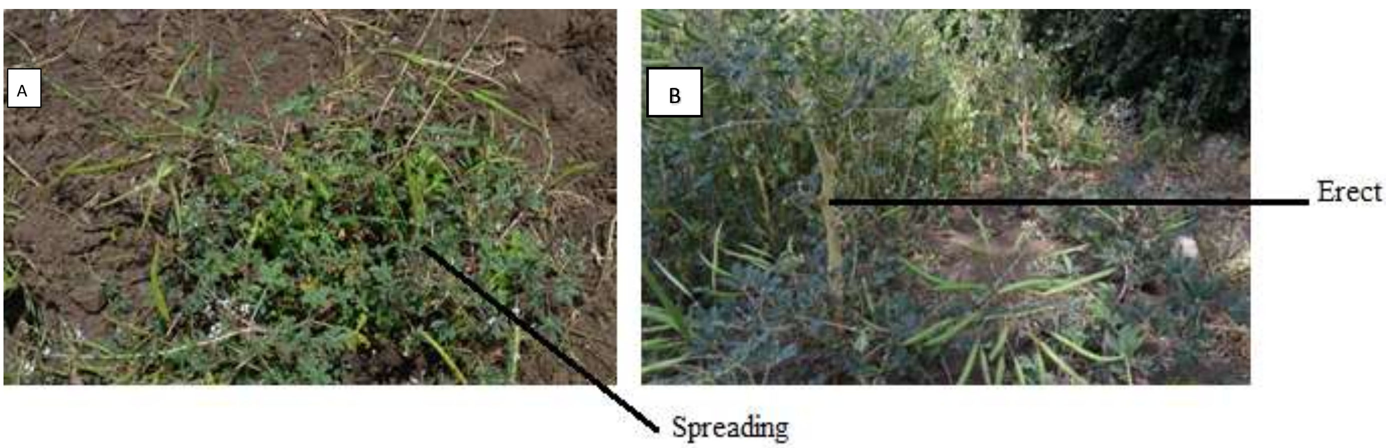

Plate 1: Growth habits of *Gynandropsis gynandra;* A-Spreading and B-erect

4.1.2 Colour of the main stem

Spider plant accessions varied in the colour of the main stem from purely green to dark purple as (see figure 4.2 and plate 2). Green coloured stems dominated the accessions with 25% being purely green and 25% being green with a tinge of purple. A total of 16 accessions were purple in colour but with varying intensity. Only 5% had dark purple stems while those with purple and pink stems were both 12.5% of the accessions. Some populations had their main stem with mixture of green and purple which made 5% of the accessions.

Colour of the main stem varied across six (6) agro-ecological zones as shown in figure 4.2. Accessions from coastal lowlands, lower midlands and upper midlands were highly varied with six (6) variations each. Those in inland lowlands, lower highlands and upper highlands were less varied with 3 variations each. Green was the dominant colour in all agro-ecological zones while dark purple and mixed coloured types were the least common.

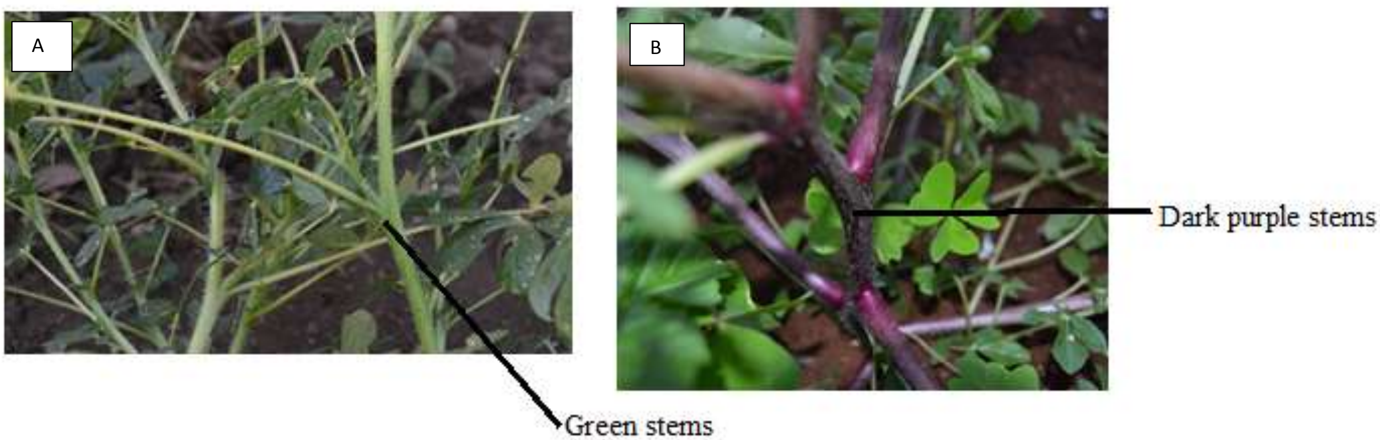

Plate 2: Colours of the main stem of *Gynandropsis gynandra; A*-Green and B-dark purple

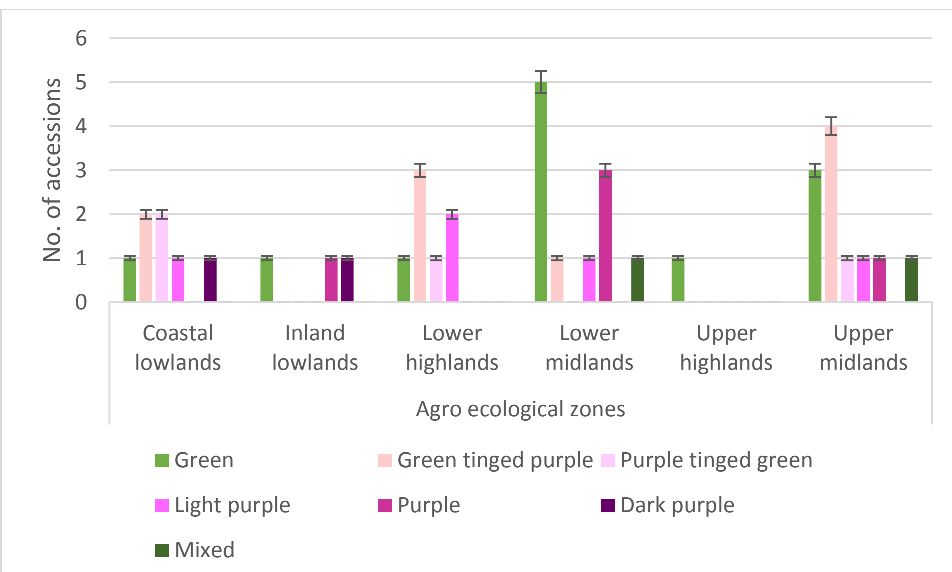

Figure 4.2*:* Colour variation of the main stem across six agro-ecological zones

4.1.3 Stem pubescence

Stem pubescence for spider plant accessions ranged from being sparsely hairy to wooly (densely hairy) (figure 4.3 and plate 3). No glabrous stems were observed. A total of 77.5% of the accessions were mainly sparsely hairy, 12.5% were hairy, 2.5% were very hairy and 7.5% were wooly. Stem pubescence varied in the six agro-ecological zones. Accessions in lower midlands had the highest variation followed by upper highlands, upper midlands, lower highlands and coastal lowlands. Those from inland lowlands exhibited the lowest variation. Sparsely hairy character was dominant in all agro-ecological zones while very hairy character was the least common (see figure 4.3).

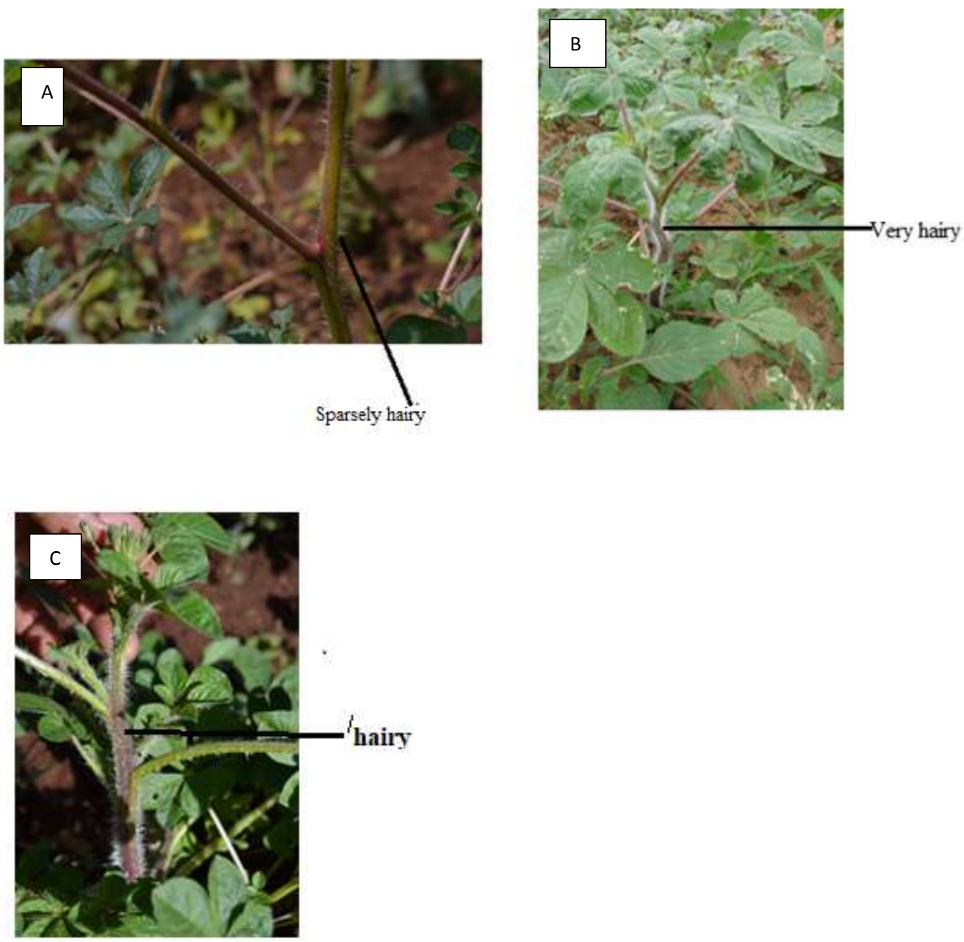

Plate 3: Stem pubescence of *Gynandropsis gynandra;* A-sparsely hairy, B-very hairy and C-hairy

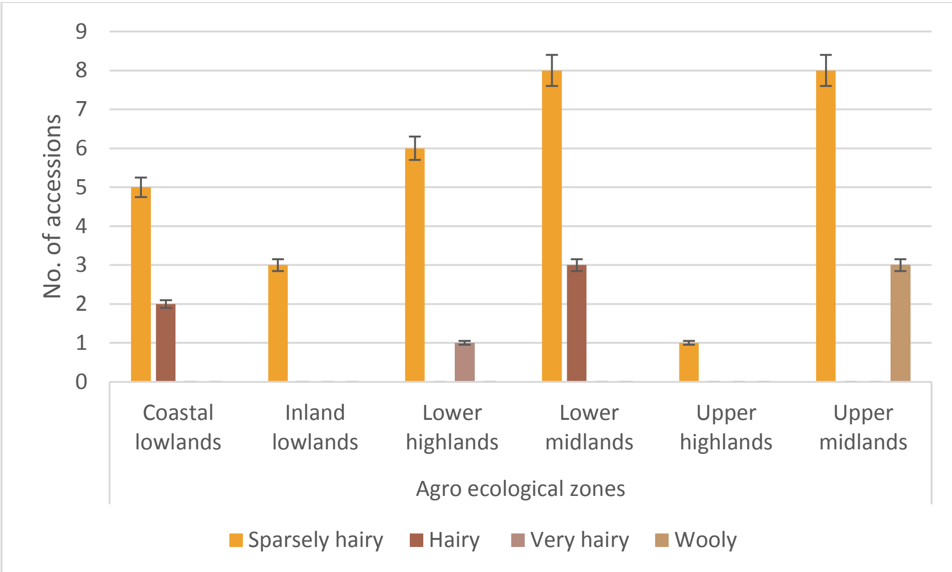

Figure 4.3: Variation in stem pubescence across six agro-ecological zones

4.1.4 Colour of leaf blade

Colour of leaf blade was reported to vary from light green, green to dark green. In total 42.5% of the accessions were green, 35% were dark green while 22.5% were light green in colour (see figure 4.4 and plate 4).

Colour of leaf blade varied across the agro-ecological zones (figure 4.4). Lower midlands had the highest variation while lower highlands had the least variation in colour of leaf blade. Coastal lowlands, inland lowlands, upper highlands and upper midlands had two (2) colour variations each. Green and dark green colours were dominant in the agro-ecological zones while light green colour was the least common and was only restricted to coastal lowlands and lower midlands.

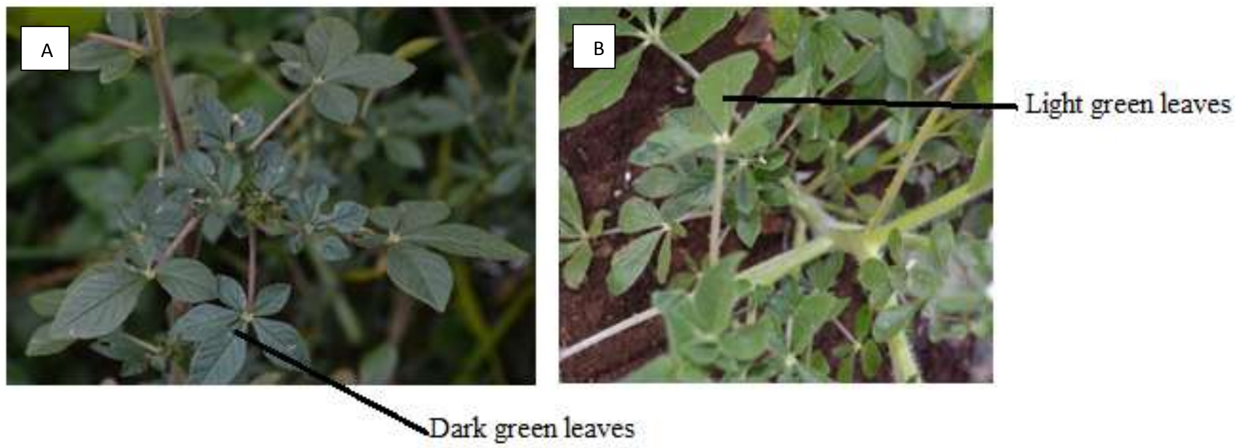

Plate 4: Colours of leaf blade of *Gynandropsis gynandra;* A-dark green leaves and B-light green leaves

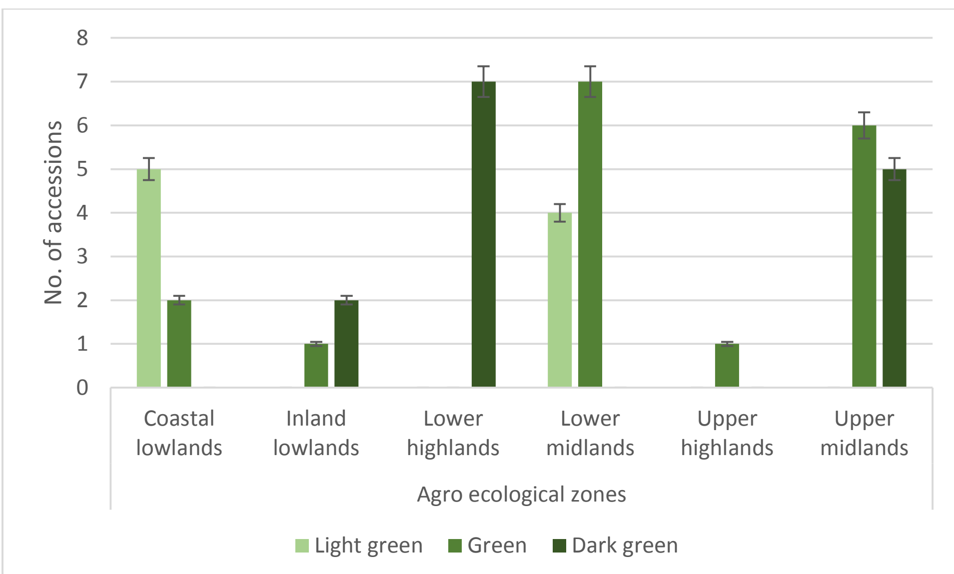

Figure 4.4: Colour variation of leaf blade across six agro-ecological zones

4.1.5 Shape of leaflet blade

Shape of leaflet blade varied as shown in figure 4.5. Majority of the accessions were elliptic (72.5%) while 12.5% of the accessions were obovate and 2.5% were lanceolate in shape. On the other hand, 7.5% of the accessions had an elliptic shape but tended towards being obovate while two (2) accessions had mixed shapes, one had two (2) leaflet shapes with majority being obovate and a few elliptic (2.5%), while the other accession had majority being elliptic and few obovate (see figure 4.5 and plate 5).

Shapes of leaflet blade varied in different zones as shown in figure 4.5. Accessions in lower midlands had the highest variation in shape of terminal leaflets followed by those in coastal lowlands and upper midlands. Those in upper highlands, lower highlands and inland lowlands had the least with no variation as they were all elliptic. Accessions in coastal lowlands were majorly obovate while those in lower midlands and upper midlands were majorly elliptic in shape of terminal leaflet. Lanceolate shape was only recorded in lower midlands.

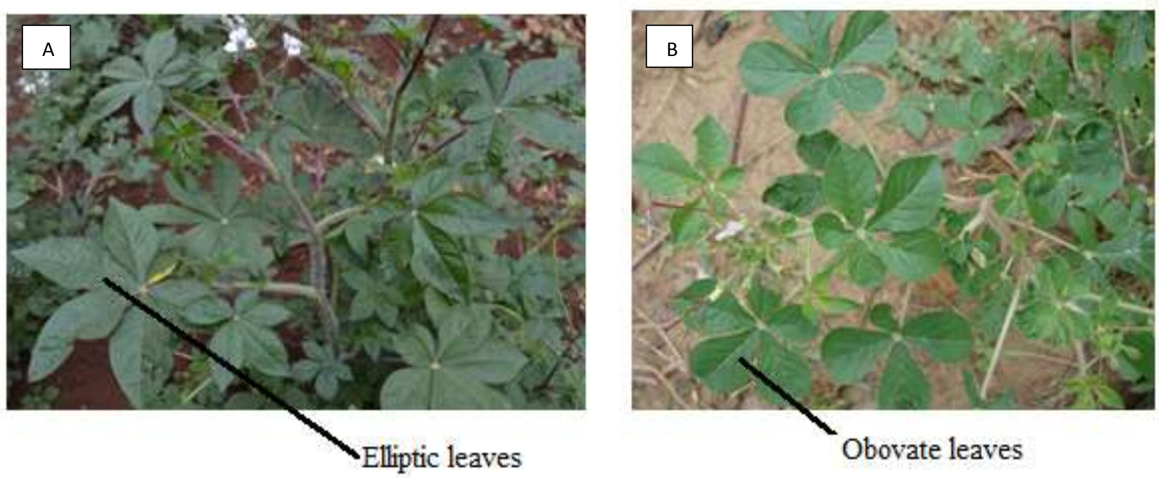

Plate 5: Shapes of leaflet blade of *Gynandropsis gynandra;* A-elliptic leaves and B-obovate leaves

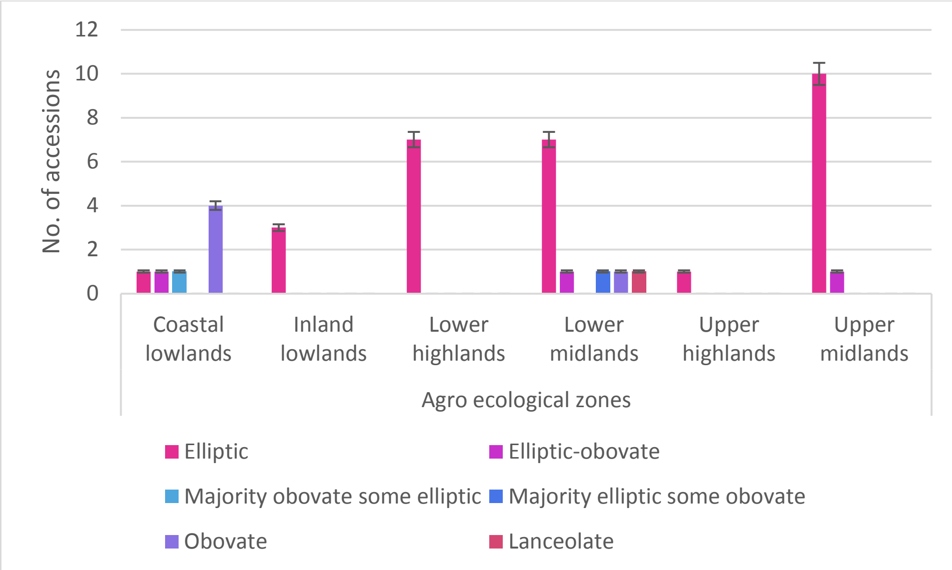

Figure 4.5: Variation in shape of terminal leaflets across six agro-ecological zones

4.1.6 Leaf pubescence

There were three (3) types of leaf pubescence across the agro-ecological zones; glabrous, sparsely hairy and hairy (see figure 4.6). A total of 57.5% of the accessions' leaf surface were glabrous, while 22.5% were hairy and 20% were sparsely hairy. Least variation in leaf pubescence was recorded in upper highlands while coastal lowlands, inland lowlands, lower highlands and upper midlands had the highest variation (see figure 4.6).

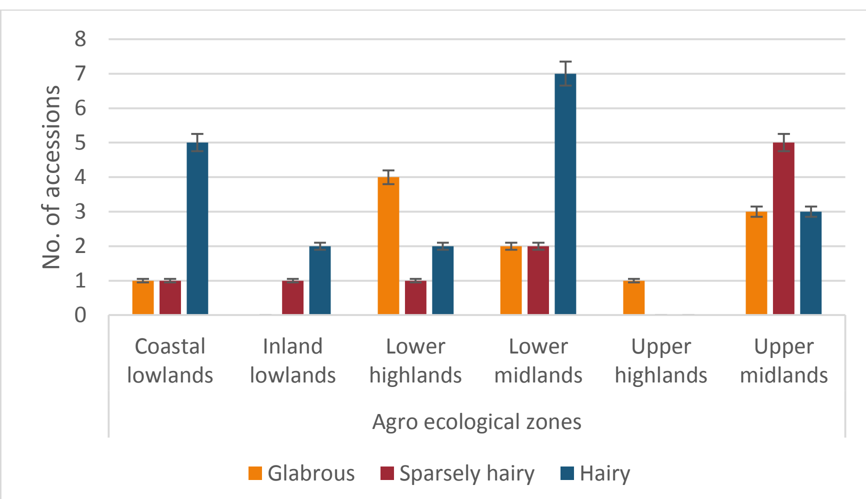

Figure 4.6: Variation in leaf pubescence across six agro-ecological zones

4.1.7 Petiole colour

A total of six (6) colourations of petiole were recorded across different agro-ecological zones. They were green, green tinged purple, pink, purple and dark purple. Approximately 42.5% of the accessions were entirely green, 17.5% were green tinged purple, 10% were light purple (pink), 20% were purple, 2.5% were dark purple while 10% were of mixed colours within the same accession as shown in figure 4.7. Accessions in lower highlands expressed the highest variation in petiole colour as recorded in figure 4.7. Lower highlands' accessions were green, pink, green tinged purple, purple and some populations with mixed colours. Those in the lower midlands were majorly green but also green tinged purple, pink and accessions with populations with mixed colours. Upper midlands types were majorly green but also green tinged purple, purple and purple in colour. Those in coastal lowlands and inland lowlands had three (3) colour variations each. Majority of the coastal lowlands' accessions were green but also green tinged purple. On the other hand, inland lowlands' accessions were dark purple, purple and green. Accessions in upper highlands were majorly green tinged purple and purple in colour.

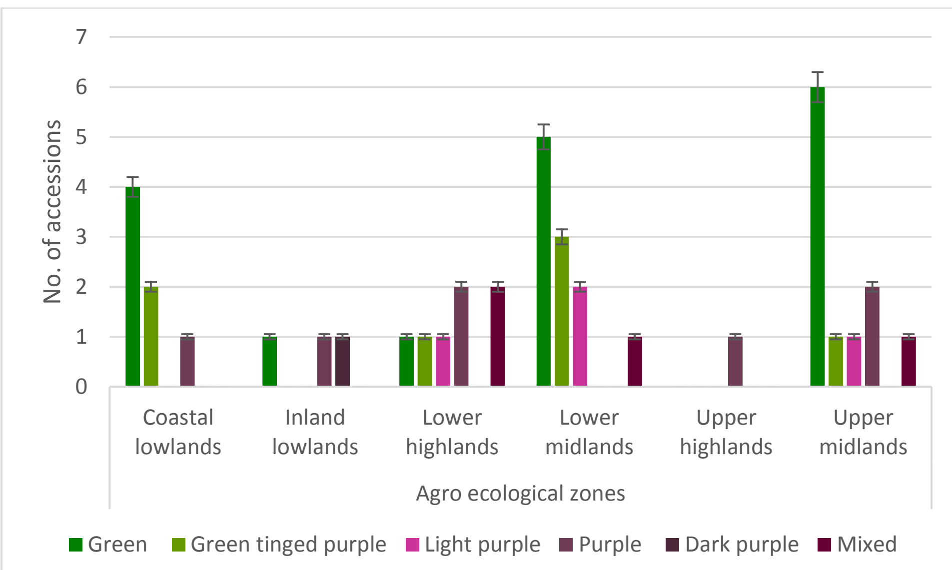

Figure 4.7: Variation in petiole colour across six agro-ecological zones

4.1.8 Upper surface leaf venation

Spider plant accessions across different agro-ecological zones had different depths of leaf venation (see figure 4.8). A total of 42.5% of the accessions upper surface leaf vein were depressed, 22.5% were deeply depressed, 25% were not depressed while 10% were slightly depressed.

Coastal lowlands, lower midlands, upper midlands had three (3) variations of leaf venation while those in inland lowlands, upper highlands and lower highlands had two (2) variations in leaf venations as shown in figure 4.8. Accessions from coastal lowlands were majorly slightly depressed but also depressed and not depressed. Majority of accessions from lower midlands were slightly depressed but also not depressed and deeply depressed. The upper midlands accessions were majorly deeply depressed and also not depressed and depressed. On the other hand, upper highlands were not depressed and slightly depressed while those from inland lowlands were majorly slightly depressed and also deeply depressed. Lower highlands' accessions were majorly slightly depressed and few were deeply depressed.

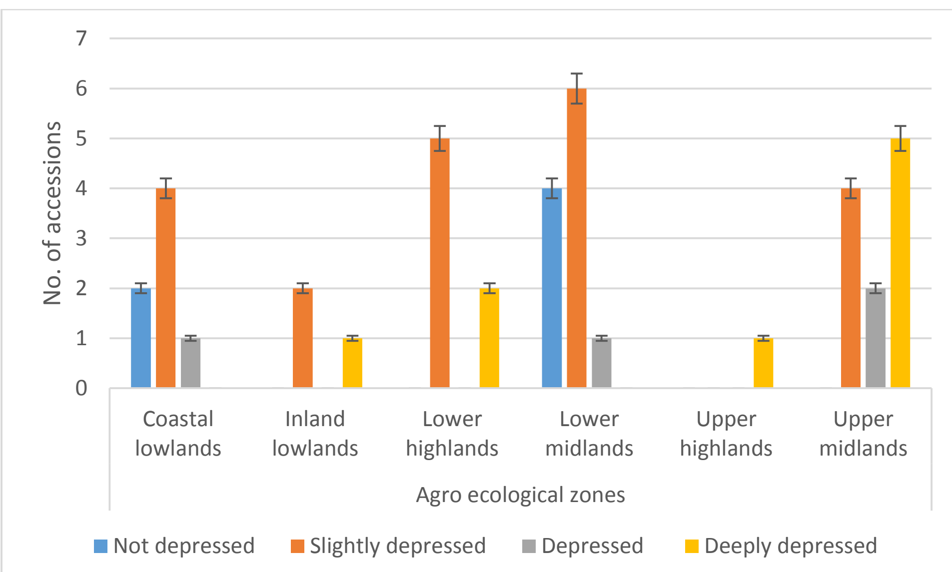

Figure 4.8: Variation in upper leaf surface venation across six agro-ecological zones

4.1.9 Petal colour

Petal colour displayed four (4) colour variations in which 50% of the accession's petal colour were white, 5% were cream, 15% were light purple and 30% were white tinged purple as shown in figure 4.9 and plate 6. Petal colour also varied in the agro-ecological zones as indicated in figure 10. Coastal and inland lowlands accessions had three (3) colour variations while lower highlands and upper midlands had two (2). Accessions from lower midlands were majorly white but also cream and pink coloured, while those from inland lowlands were pink, white and white tinged purple. Those in coastal lowlands were majorly white and pink and few cream coloured while lower highlands' accessions were white and white tinged purple. Accessions in upper highlands and upper midlands were white and white tinged purple in colour.

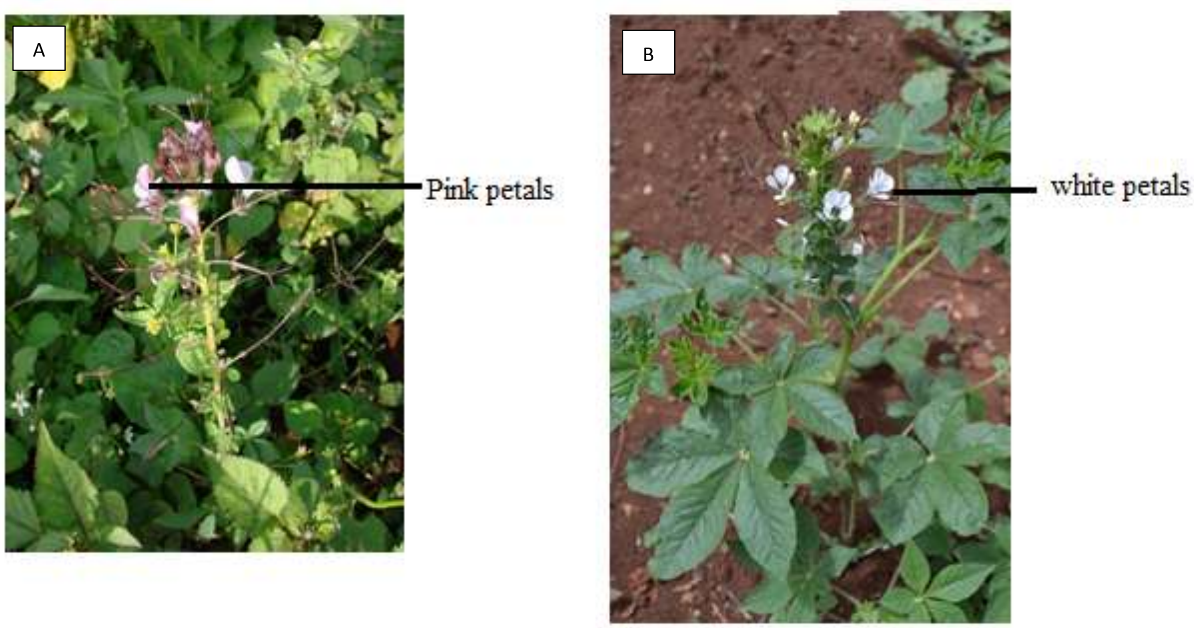

Plate 6: Petal colours of flowers of *Gynandropsis gynandra;* A-pink petals and B-white petals

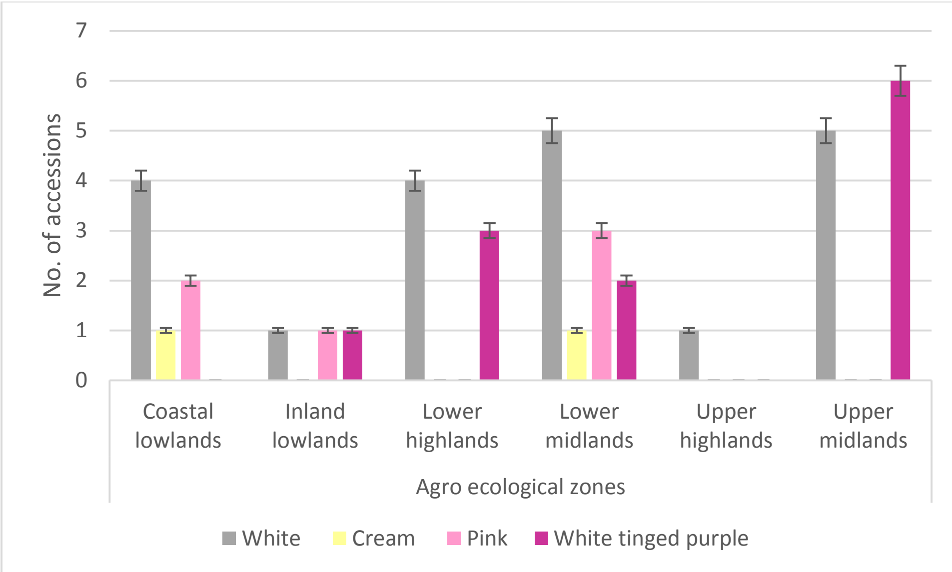

Figure 4.9: Variation in petal colour across six agro-ecological zones

4.1.10 Colour of immature fruit

Majority of the accessions were green in colour (90%), while 10% of the accessions had other colours which included glossy green (2.5%), darker green (2.5%), green turning yellow (2.5%) and purple or purplish green fruits (2.5%) as indicated in figure 4.10 and plate 7.

Colour of immature fruits was majorly green for all the agro-ecological zones, except for some few accessions within AEZ which had other colour variations as shown in figure 4.10. Coastal lowlands had an accession whose fruits were dark green while some in upper highlands glossy green fruits. Moreover, upper midlands had purple and green-turning-yellow coloured fruits. Accession ELG 1907A in the upper midlands had fruits which were all purple in colour.

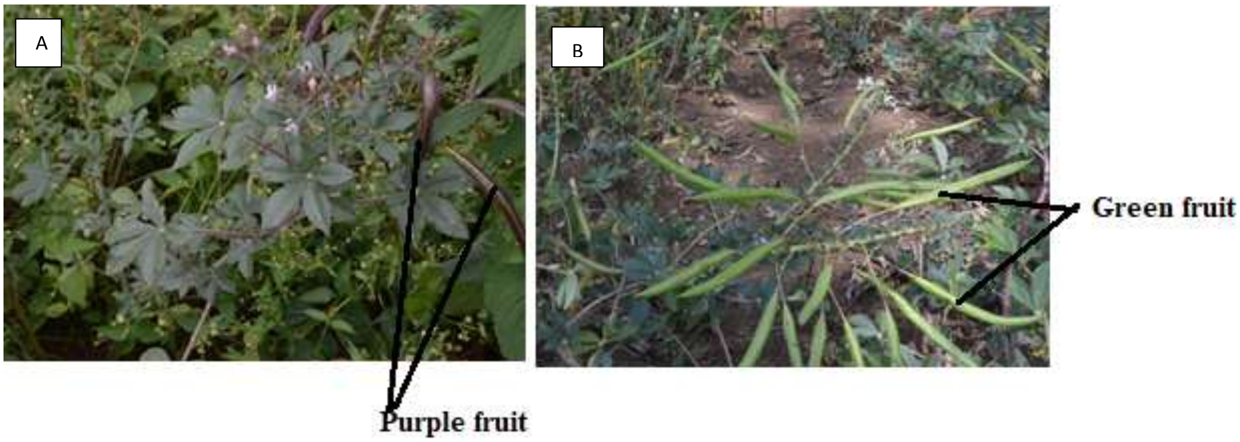

Plate 7: Colour of immature fruits of *Gynandropsis gynandra;* A-purple fruit and B-green fruit

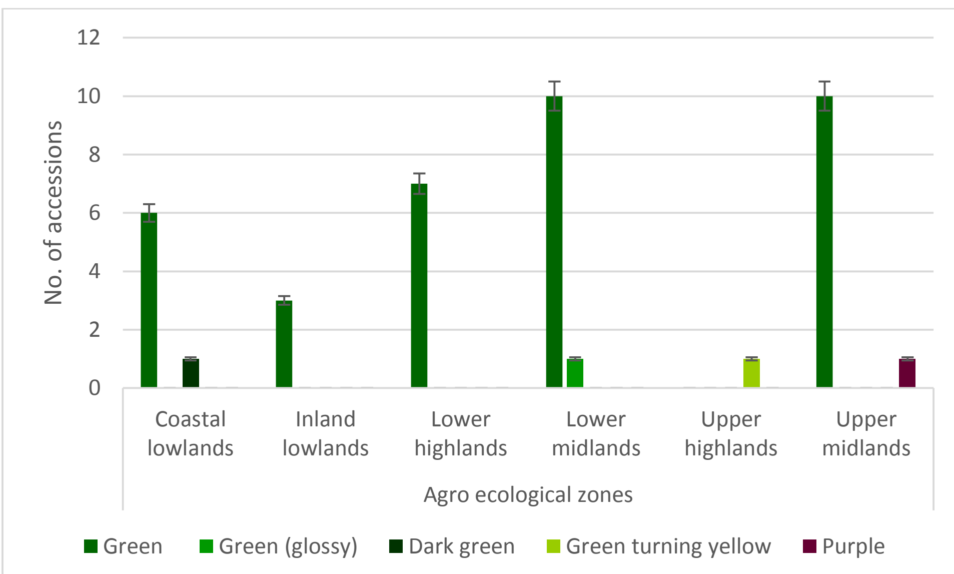

Figure 1: Colour variation in immature fruits across six agro-ecological zones

4.1.11 Colour of mature fruit

Majority of the accessions were yellow (90%) in colour, while 10% had other colour variations; yellow-green (2.5%), dark yellow (2.5%), grey (2.5%) and brown fruits (2.5%) as indicated in figure 4.11. There was no colour variation for mature fruits in most of the agro-ecological zones as noted in figure 4.11, which were all yellow except for upper midlands which were also yellowish-green, dark yellow, grey and brown. Lower midlands had also yellowish-green fruits. Accession NKR 1807 in upper highlands had brown fruits as recorded in appendix 5.

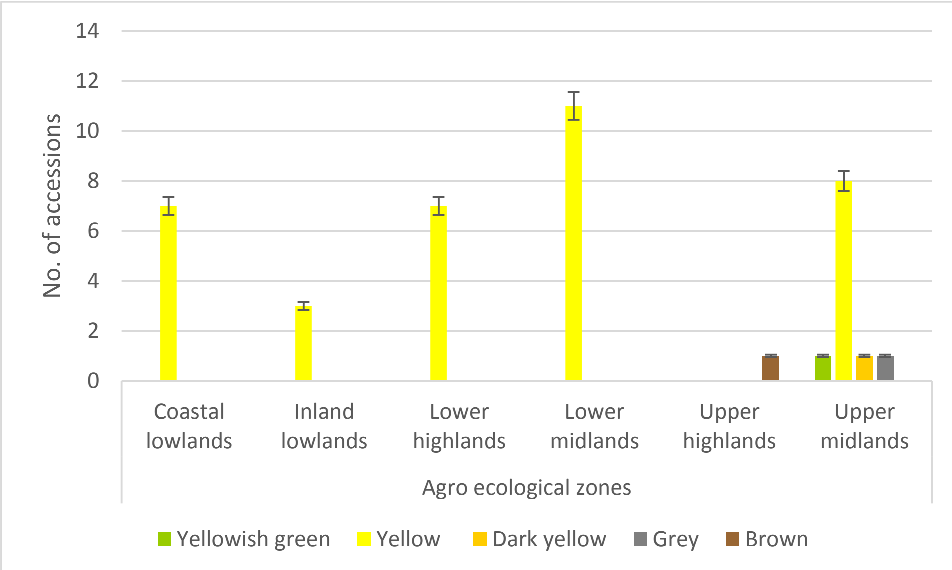

Figure 4.11: Colour variation in mature fruit across six agro-ecological zones

4.1.12 Shape of mature or nearly mature fruit

Shapes of the fruits were either round, spindle or spindle-wide shaped as shown in (see figure 4.12 and plate 8), with the majority being spindle shaped. Over half of the accessions (57.5%) had a spindle shape while 40% were round and 2.5% were spindle-wide shaped.

Variation in shape of cross section of mature or nearly mature fruits was found in four (4) AEZs namely inland lowlands, lower midlands, upper midlands and upper highlands while coastal lowlands and lower highlands had no variation as indicated in figure 4.12. Accessions from coastal lowlands were all round in shape while those from lower highlands were all spindle shaped. Lower midlands' accessions were majorly round (accession KI-01 and KI-02) and spindle shaped and few spindle-wide shaped while majority of accessions in upper highlands, upper midlands and inland lowlands were spindle shaped with few round in shape.

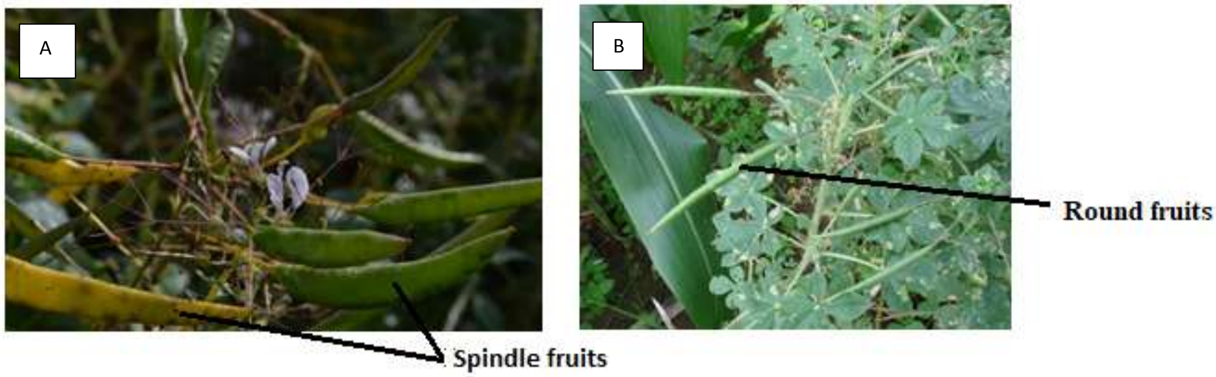

Plate 8*:* Shape of mature or nearly mature fruit of *Gynandropsis gynandra;* A-Spindle shaped fruits and B-round fruits

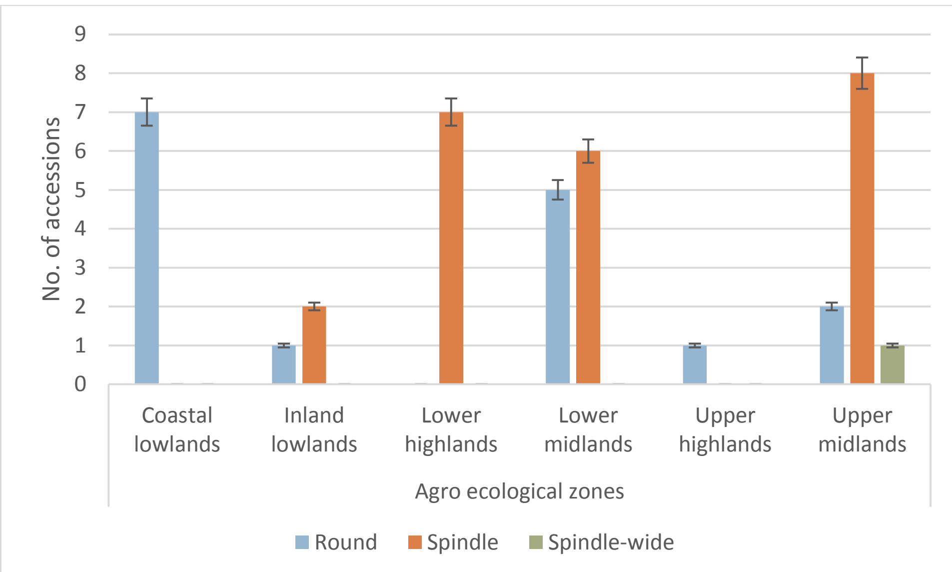

Figure 2: Variation in shape of mature or nearly mature fruit across six agro-ecological zones

4.1.13 Surface texture of the fruit

Spider plant fruit's surface was either scabrid or slightly scabrid (see figure 4.13). Slightly over half of the accessions (55%) were scabrid while 45% of the accessions were slightly scabrid. Accessions from coastal lowlands, upper highlands, lower highlands and lower midlands were predominantly slightly scabrid with few accessions being scabrid while those from upper midlands and inland lowlands were majorly scabrid with few being slightly scabrid as indicated in figure 4.13.

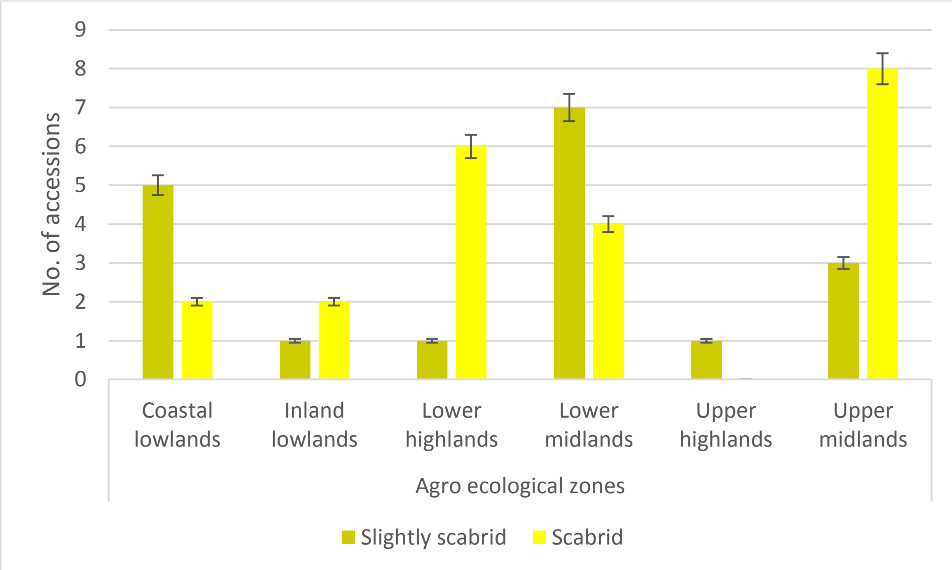

Figure 3: Variation in surface texture of the fruit across six agro-ecological zones

4.1.14 Presence of folds on fruits

Spider plant fruits exhibited four (4) characters across the agro-ecological zones; those with no folds, few folds, many folds and those with mixed shapes as depicted in figure 4.14 and plate 9. Majority of the accessions had few folds (37.5%), followed by those with no folds were 35% then those with many folds were 22.5% and lastly those with mixed shapes were 5%.

Most of accessions from coastal lowlands had no folds while few had few folds. Accessions from inland lowlands had no variation, they had few folds only while those in upper highlands had majority with many folds and some with few folds. Upper midlands had the highest variation with four (4) variations; majority having few folds, and other fruits had no folds, many folds and fruits with mixed shapes. Lower highlands and lower midlands accessions were varied with three (3) variations with those in lower highlands having majority with few folds and others with no folds and many folds. Those in lower midlands had no folds, while others had few folds and many folds.

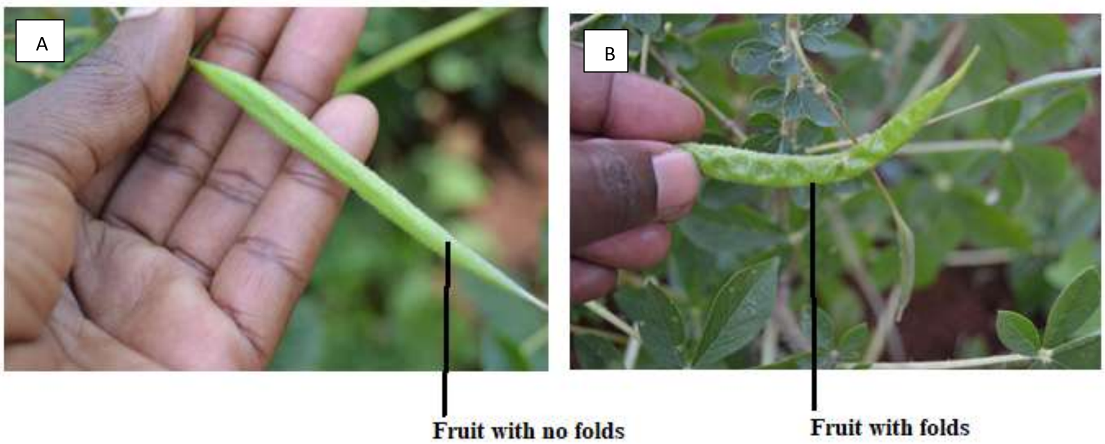

Plate 9: Presence of folds on fruits of *Gynandropsis gynandra;* A-fruit with no folds and B-fruit with folds

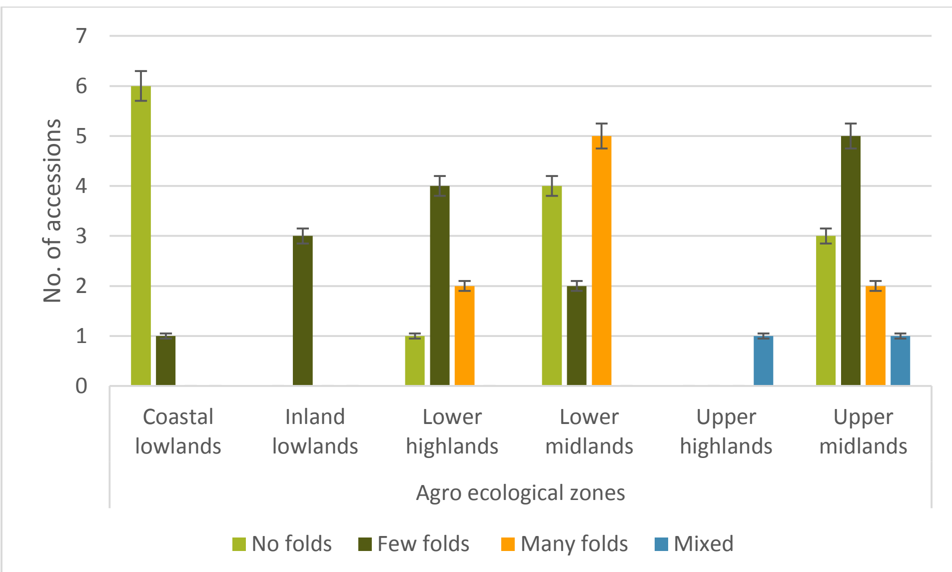

Figure 4: Variation in presence of folds on fruit across six agro-ecological zones

4.1.15 Colour of mature healthy seed

Colour of mature healthy seeds varied from brown to grey to black. Over half the accessions (57.5%) had seeds which were black in colour, 22.5% were grey, 12.5% were brown, 5% were greyish black while 2.5% were light brown (see figure 4.15).

Black colour was dominant across the agro-ecological zones as shown in figure 4.15. Accessions from coastal lowlands had two (2) colour variations with majority being black while others were light brown in colour. Inland lowland accessions were black and greyish black while those from the lower highlands were grey and black. Those in lower midlands had four (4) colours; grey, and greyish black, brown and black. Upper midlands accessions were grey, brown and black with majority being brown and grey in colour. Majority of accessions in upper highlands were black with few grey in colour.

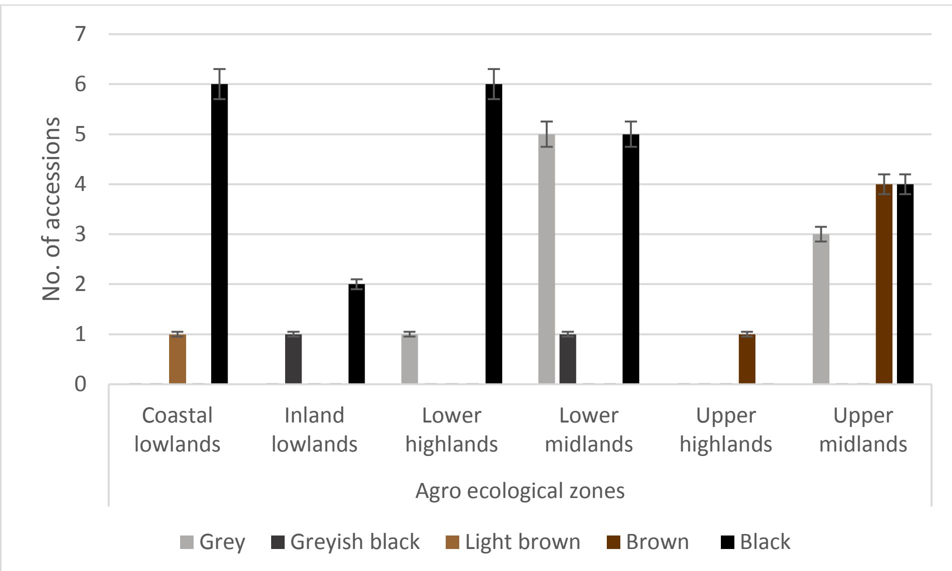

Figure 4.15: Colour variation of mature healthy seed in six agro-ecological zones

4.1.16 Leaf waxiness

Leaf waxiness varied across different agro-ecological zones. They were recorded as not waxy, fairly waxy, waxy and very waxy. Almost half of the accessions (45%) were very waxy, 40% fairly waxy, 12.5% not waxy and the least were waxy (2.5%) (see figure 4.16).

Accessions from upper midlands had the highest variation and were majorly very waxy, and other leaves were fairly waxy, not waxy and waxy. Upper highlands, lower midlands and lower highlands had three (3) variations, with lower midlands being very waxy, and others not waxy and fairly waxy. The lower highland types were fairly waxy and very waxy and one accession was not waxy while those in upper highlands were not waxy, fairly waxy and very waxy. Those in coastal lowlands had two (2) variations which were majorly fairly waxy and some accessions were very waxy (see figure 4.16).

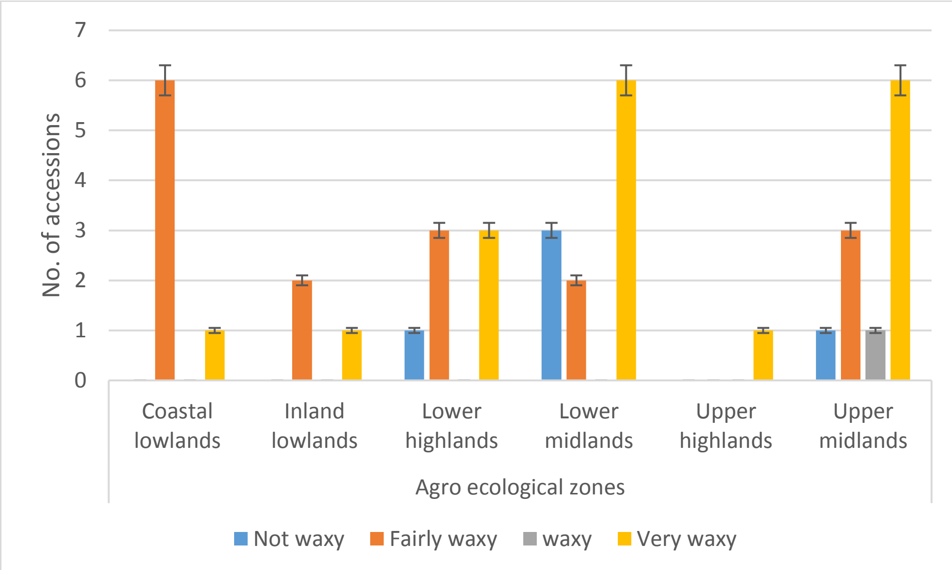

Figure 4.16: Variation in leaf waxiness across six agro-ecological zones

4.2 Morphological characterization of quantitative characteristics

Quantitative characters varied in different accessions across agro-ecological zones. They were; plant height (cm), stem circumference (cm), number of branches, number of leaf blade leaflets, terminal leaflet length (cm), terminal leaflet width, petiole length (cm), fruit length (cm) and fruit width (mm). Spider plant accessions also showed significant differences ($p<0.05$) in quantitative characters in plant height ($p= 0.0500$) and fruit length ($p= 0.0001$) as shown in appendix 2. No significant differences were shown in leaf width, number of leaf blade leaflets, terminal leaflet length, petiole length and fruit width.

4.2.1 Plant height

Plant height varied across different agro-ecological zones and was significant ($p= 0.0500$) as shown in figure 4.17. Accession UAG 1907C was the tallest among the accessions while KF-5 and KF-11 were the shortest each measuring 30 cm. Among the agro-ecological zones, accessions from lower highlands were the tallest ranging from 100-160 cm while the shortest were from coastal lowlands ranging from 30-95 cm. Accessions from lower highlands were the tallest with a mean of 144.2, followed by upper midlands (113.4), upper highlands (105.5), inland lowlands (94), lower midlands (78.9) and lastly coastal lowlands with a mean of 55.7.

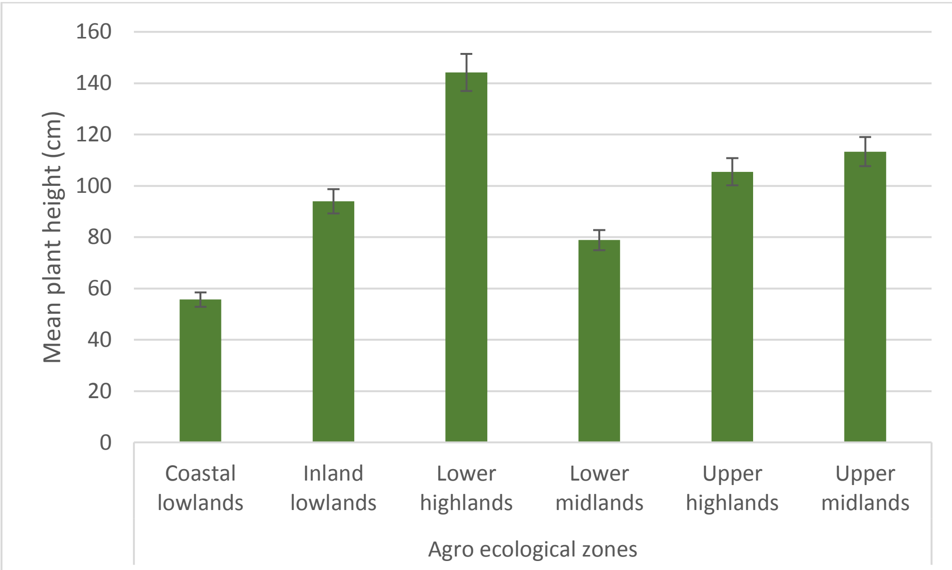

Figure 4.17: Variation in plant height across six agro-ecological zones

4.2.2 Stem circumference

Stem circumference varied in the six (6) agro-ecological zones as shown in figure 4.18. Upper highlands had the widest stem circumference which ranged between 3.3-6.1 cm while the accessions from coastal lowlands had the narrowest stem circumference of 2.0-4.0 cm. Upper highlands, inland lowlands, lower midlands and lower highlands had the widest stems with means of 4.9, 4.6, 4.5 and 4.0 respectively while coastal lowlands had the narrowest stem circumference of 2.9 cm.

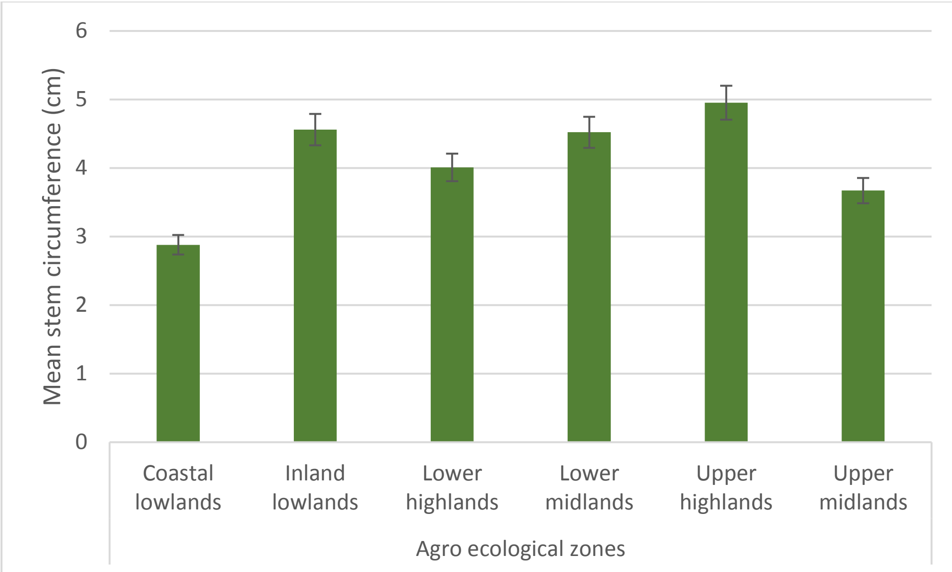

Figure 4.18: Variation in stem circumference across six agro-ecological zones

4.2.3 Number of branches

Accessions which were highly branched (with ten (10) branches) were 55% while 25% of the accessions were sparsely branched with less than five (5) branches and 20% of the accessions had 6-10 branches (moderately branched) (figure 4.19). Accession GA-01 had the highest number of branches which were 16, while accessions KF-05, MK-01 and KF-09 had the least number of branches with two (2) branches each. Figure 20 shows variation in number of branches in which upper midlands had the highest means (14.3), followed by inland lowlands (9.7), lower highlands (8.0), upper highlands (6.2), lower midlands (5.8) and lastly coastal lowlands (5.0).

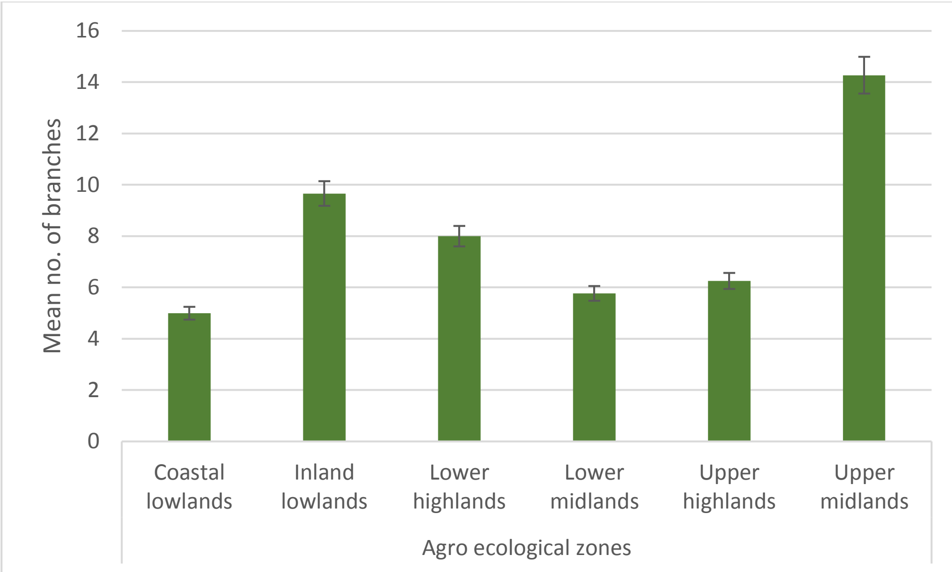

Figure 4.19: Variation in number of branches across six agro-ecological zones

4.2.4 Variation in number of leaflets

The leaflets number varied from 3-7 in different accessions (see plate 10). The most common number of leaflets was five (5), while three (3) was the least common. Moreover, some accessions had different numbers of leaflets while other accessions had same number of leaflets in each accession. Some accessions had two (2) types of leaflets, while others had three (3) types of leaflets.

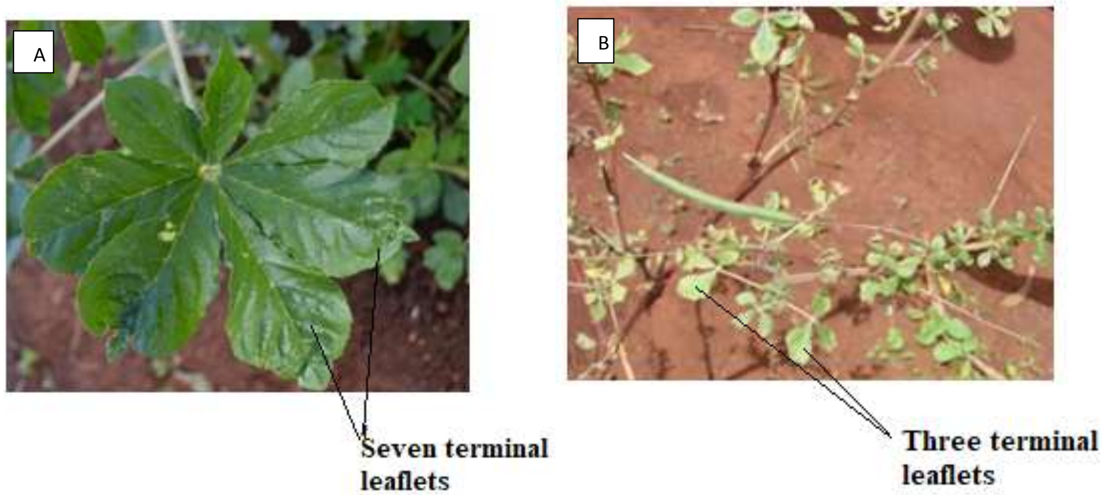

Plate 10: Number of leaflets in *Gynandropsis gynandra;* A-seven terminal leaflets and B-three terminal leaflets

4.2.5 Terminal leaflet length

Lower highlands had the longest leaves which ranged from 3.7-9 cm while coastal lowlands had the shortest leaves which ranged from 2.2-5.0 cm as shown in figure 4.20. Accession KRC 2507A had the longest leaves while KF-01 had the shortest leaves measuring 2.2 cm. Accessions from lower highlands and inland lowlands had the longest leaves with means of 7.3 and 7.1 respectively. Those from upper midlands, upper highlands and lower midlands were moderately long with means of 5.8, 5.6 and 4.7 respectively. Accessions from coastal lowlands had the shortest leaves with a mean of 3.3.

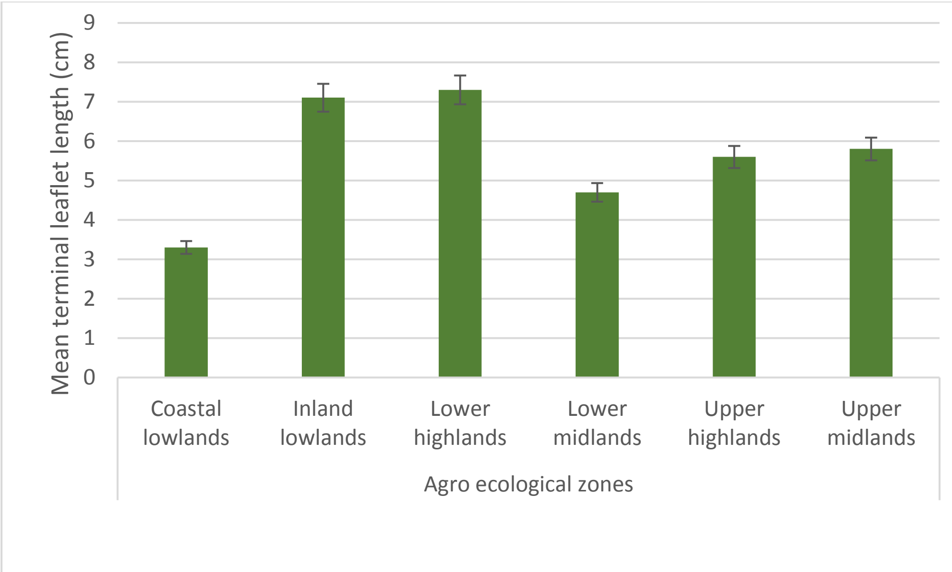

Figure 4.20: Variation in terminal leaflet length across six agro-ecological zones

4.2.6 Terminal leaflet width

Accessions in lower highlands had the widest leaf width which ranged from 1.7-7.5 cm with a mean of 4.3 while those from lower midlands had the narrowest width which ranged from 0.5-2.3 cm with a mean of 1.5 as shown in figure 4.21. Accessions from lower midlands and upper midlands had a means of 3.7and 2.5 respectively while inland lowlands and upper highlands had similar means of 2.8. KRC 2507A had the widest leaflet width while accession KF-05A had the narrowest leaves.

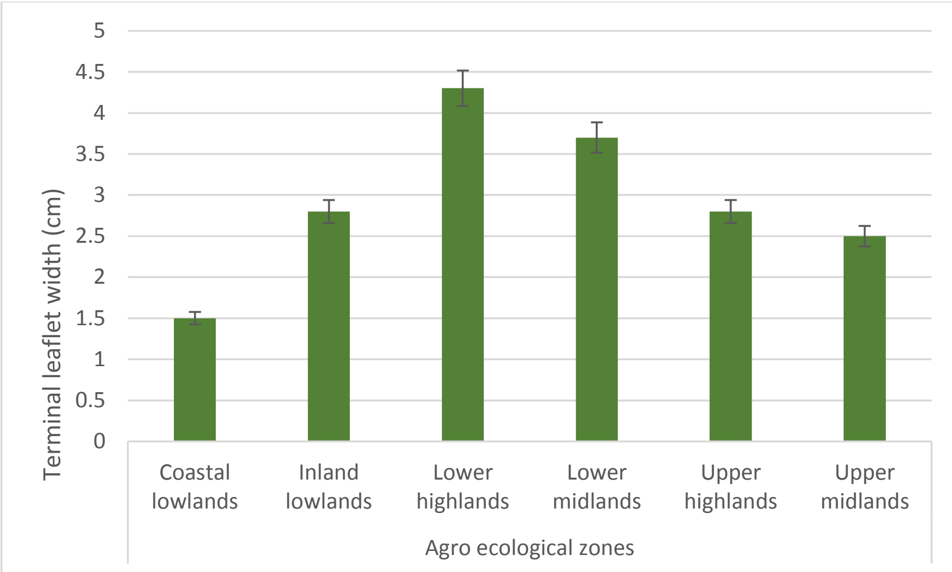

Figure 4.21: Variation in terminal leaflet width across six agro-ecological zones

4.2.7 Petiole length

Accessions from lower highlands and inland lowlands had the longest petiole length with a mean of 11 and 10.9 respectively while coastal lowlands had the shortest petiole length of 5.7 as shown figure 4.22. Those from upper highlands, upper midlands and lower midlands had a means of 8.1, 7.6 and 7.1 respectively. Accession GA-01 had the longest petiole length while KF-01 had the shortest petiole length.

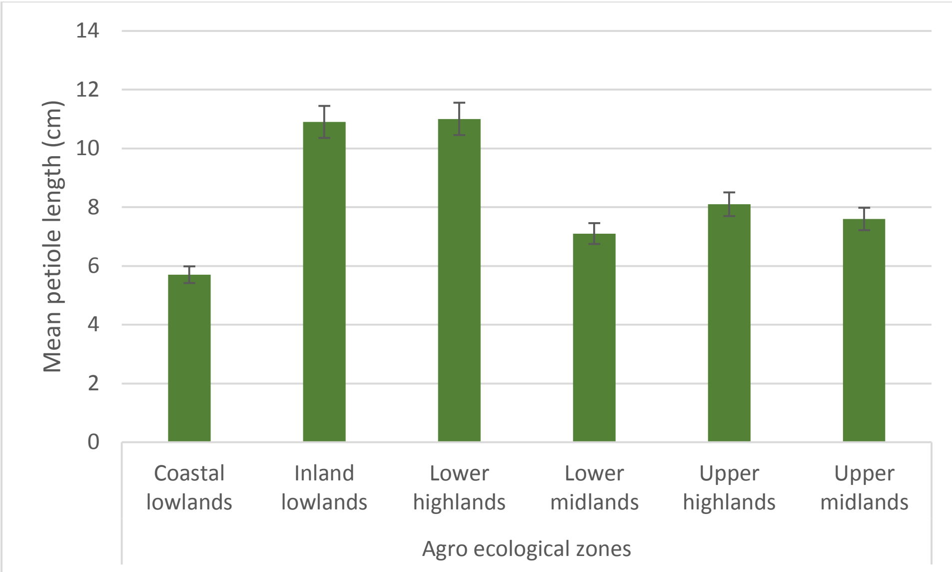

Figure 4.22: Variation in petiole length across six agro-ecological zones

4.2.8 Fruit length

Fruit length varied significantly (p= 0.0001) across the AEZs. Accessions from lower highlands had the longest fruit length with a mean of 9.05 while coastal lowlands' accessions were shortest with a mean of 5.6 as shown in figure 4.23. Those from upper midlands, upper highlands, inner lowlands and lower midlands had means of 8.4, 7.57, 7.2 and 6.7 respectively. Accession NKR 2407 had the longest fruit length while KF-01, KF-05, KF-07 had the shortest fruit lengths.

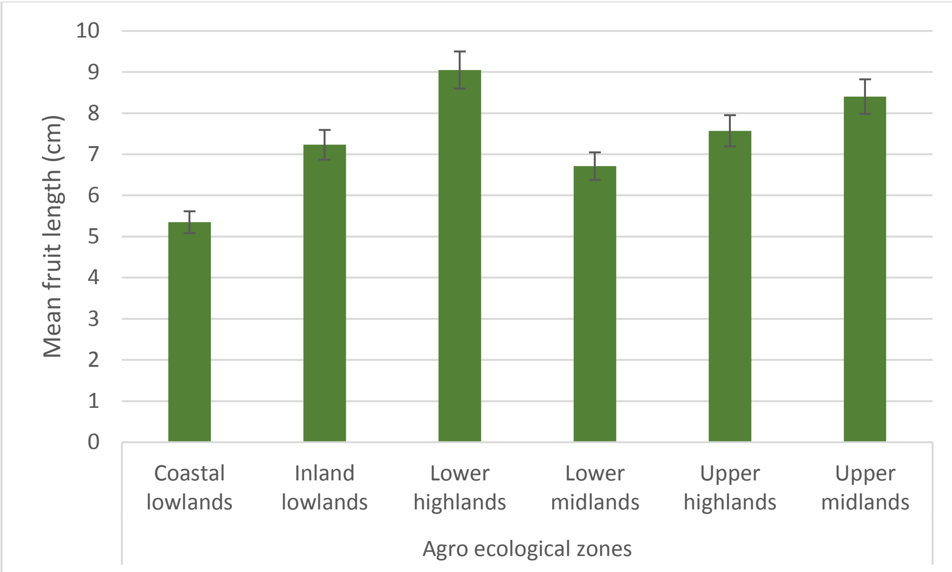

Figure 4.23: Variation in fruit length across six agro-ecological zones

4.2.9 Fruit width

Accessions from inland lowlands had the widest fruit width which ranged from 7.0-15.0 mm with a means of 10.3 while the narrowest fruits were from coastal lowlands with a ranged of 1.0-5.0 mm with a mean of 3.4 (figure 4.24). Those from upper midlands, lower midlands, lower highlands and upper highlands had means of 7.4, 6.7, 6.5 and 3.7 respectively. Accession GA-01 had the widest fruits while ELG 1907A, ELG 1907B and KF-11 had the narrowest fruits.

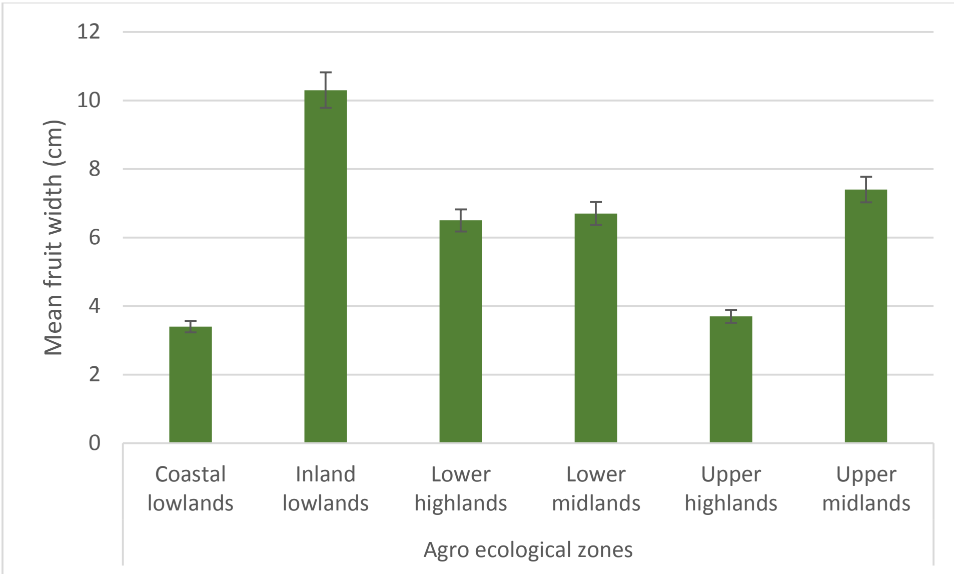

Figure 4.24: Variation in fruit width across six agro-ecological zones

4.3 Seed propagation of spider plant accessions

A total of 56 accessions of spider plant seeds were collected from the field mission and planted as shown in table 2 in the methodology. Of the 56 accessions, only 40 accessions (71.4%) germinated and grew. Accessions that did not grow included; KF-02, KF-03, KF-04A, KF-04B, KF-06, KF-08, KF-10, KF-12, KW-01, KF-13, KIR-1707, WPK-2007B, WPK-2007C, BGM-2107B, KIS-2407A, KRC-2507C.

4.4 Organoleptic characterization of leaf bitterness

Level of leaf bitterness in *Gynandropsis gynandra* grown in the botanic garden steadily increased from the upper highlands to lower highlands then upper midlands and lastly lower and coastal lowlands (see figure 4.25).

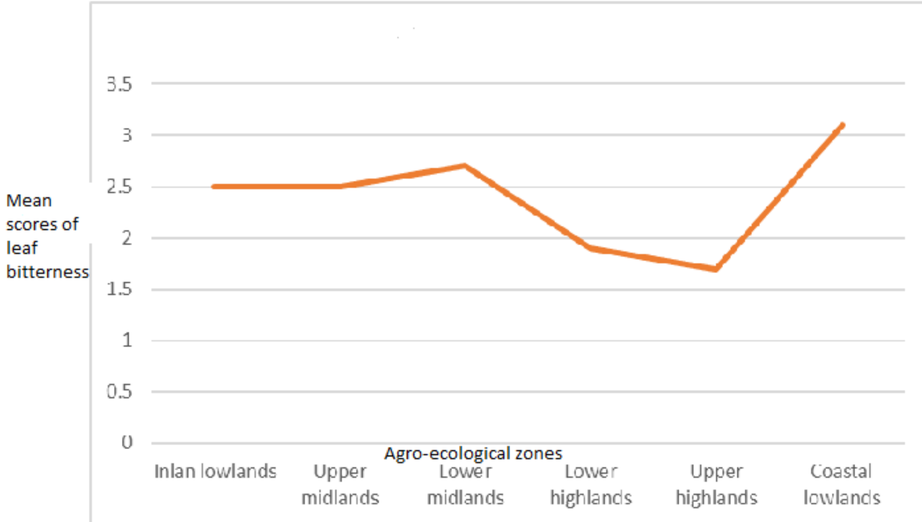

Figure 4.25: Mean level of leaf bitterness in spider plant in six agro-ecological zones

Accessions from upper highlands, lower highlands and inland lowlands scored the least leaf bitterness while those from lower midlands and coastal lowlands showed the highest leaf bitterness (table 4.1). Leaf bitterness ranged from 4.2 (very bitter) which was the highest score in lower midlands to 1.0 (not bitter), the lowest score in the upper highlands. Accessions which had the highest level of bitterness were KF-05, KI-01, KW-02, GA-01 and TT-01 termed as very bitter to extremely bitter (4-5) while accessions which had the lowest level of bitterness were UAG1907A, UAG1907B, UAG1907C, KRC2507A, HBY2307B and KF-07 were termed as not bitter to mild (1-2). KF-07 was not bitter (1.4) yet it was from the coastal lowlands. Agro-ecological zones which exhibited high bitterness levels were lower midlands and coastal lowlands. The upper midlands' accessions had a wide bitterness range (1.7-4.1) which ranged from mild, bitter to very bitter but majority were bitter. Very bitter types in upper midlands were from Taita. The bitterness levels in the lower midlands were regarded as mild to very bitter and ranged from 1.6 in Homabay to 4.2 in Kitui, while those in the coastal lowlands ranged from 1.4-4.0. Accessions from inland lowlands were also considered as mild to bitter which ranged from 2.0-3.5. Accessions from lower highlands ranged from 1.7-2.4 (not bitter to mild) while those in upper highlands ranged from 1.0-2.4 (not bitter to mild).

Table 4.1: Range in leaf bitterness across six agro-ecological zones

		Mode	Maximum	Minimum
Agro-ecological zones	Coastal lowlands	3.1	4.0	1.4
	Inland lowlands	2.1[a]	3.5	2.0
	Lower highlands	1.8	2.4	1.7
	Lower midlands	2.7	4.2	1.6
	Upper highlands	1.0	2.4	1.0
	Upper midlands	2.9 2.0[a]	4.1	1.7

a. Multiple modes exist. The smallest value is shown

4.5 Cluster analysis

The dendrogram is based on relationship on level of bitterness among accessions from different agro-ecological zones (see figure 4.26). The dendrogram, which clustered accessions sharing similar bitterness levels, separated the 40 accessions into two (2) major clusters A and B and eight (8) sub-clusters.

Group A consists of accessions whose bitterness level ranges from 'non-bitter to mild', while group B has accessions whose bitterness level ranges from 'bitter to extremely bitter'. Clusters one (1) to four (4) fall under group A, while clusters five (5) to eight (8) fall under group B. Cluster one (1) is the largest and is made of up of 10 clades, in which the accessions have bitterness range of 1.9-2.1 hence mild in taste. Cluster two (2) is further subdivided into five (5) clades with accessions which are non-bitter to slightly mild in taste (1.6-1.8). Cluster three (3) has five (5) clades in which the accessions have a bitterness level of 2.3-2.4 thus considered mild in taste, while cluster four (4) is subdivided into three (3) clades and has a bitterness range of 1.0-1.4 hence non-bitter in taste. It is a unique cluster because the cluster analysis indicates that accession NYR 2107B is a subgroup/variety of accession NYR 2107C and also accession KF-09 is closely related to accession NYR 2107C.

Cluster five (5) is subdivided into five (5) clades whose accessions have a bitterness range of 3.8-4.2 hence considered very bitter in taste. Cluster six (6) is divided into three (3) clades whose accessions are considered bitter (3.0-3.5). Cluster seven (7) consists of three (3) clades whose accessions are bitter in taste with a bitterness level of 2.7. Cluster eight (8) has six (6) clades in which the accessions have bitterness range of 2.9-3.1 and therefore bitter in taste.

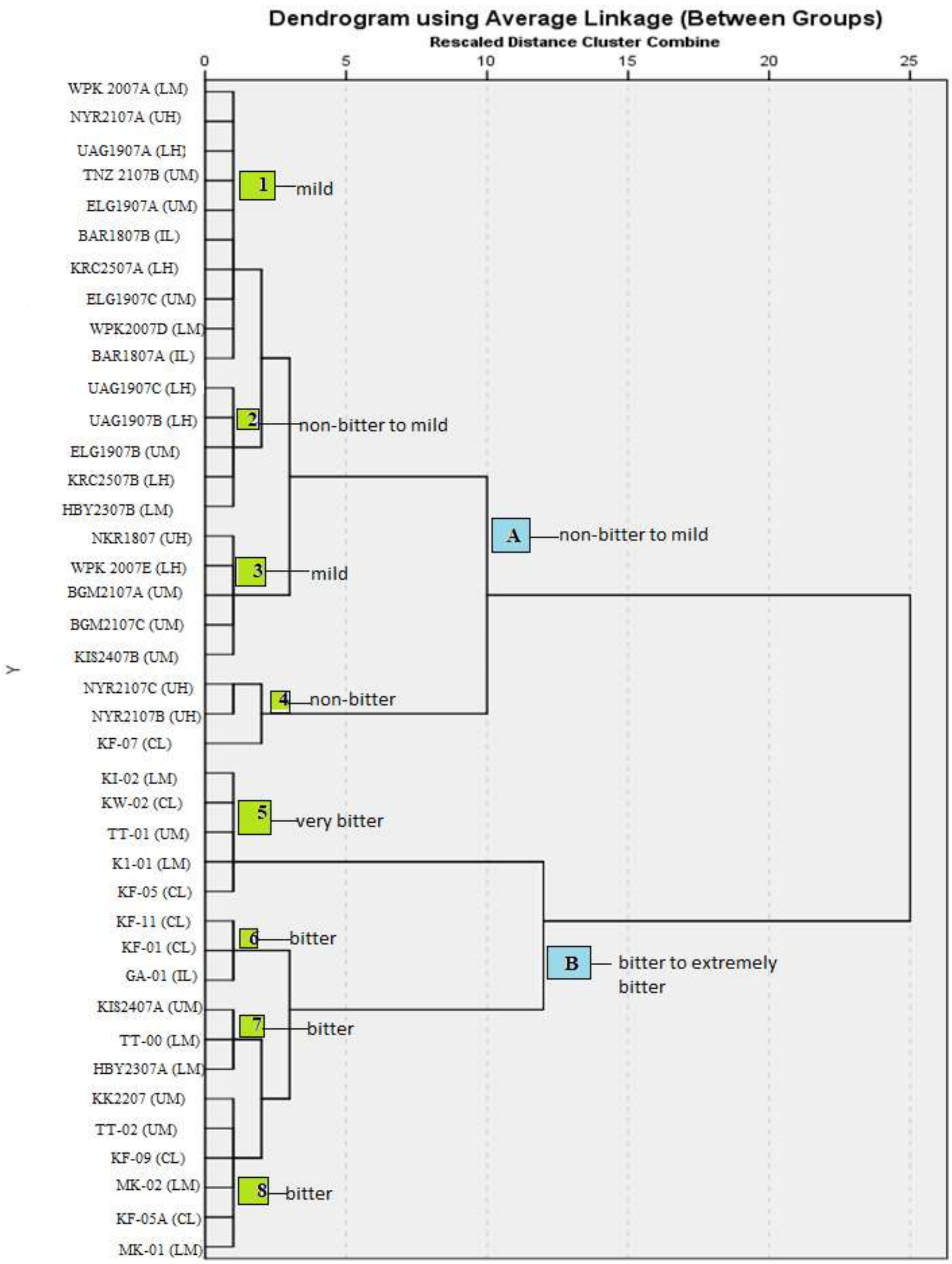

Figure 4.26: Relationship among accessions based on level of leaf bitterness

UH (Upper Highland), UM (Upper Midland), LH (Lower Highland), LM (Lower Midland), IL (Inland Lowland), CL (Coastal Lowland)

4.6 Correlation between predictors and level of leaf bitterness

The four (4) predictors; colour of leaf blade, colour of main stem, leaf waxiness and stem pubescence significantly correlated (p= 0.001) to leaf bitterness when combined together as shown in table 4.2.

Table 4.2: Statistical relationship between level of leaf bitterness and four (4) combined morphological traits

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11.057	4	2.764	6.037	.001*
	Residual	16.027	35	.458		
	Total	27.084	39			

*Significant differences

However, when the predictors were separated, colour of the main stem, stem pubescence, leaf waxiness showed moderate positive correlation with leaf bitterness but was not significant (see table 4.3). However, leaf blade colour significantly negatively correlated (p= -0.0001) with leaf bitterness (see table 4.3).

Table 4.3: Relationship between level of leaf bitterness and four (4) morphological traits

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Leaf waxiness	.108	.103	.150	1.050	.301
Colour of the main stem	.105	.063	.233	1.681	.102
Stem pubescence	.007	.131	.008	.056	.955
Colour of leaf blade	-.586	.144	-.532	-4.067	.0001*

* Significant differences

4.7 Consumption of spider plant across agro-ecological zones

The six (6) agro-ecological zones sampled were inhabited by a total of 18 ethnic community groups (see figure 1.1). They were El Njemps, Tugen, Nandi, Kipsigis, Marakwet, Keiyo, Pokot, Turkana, Malakote, Bukusu, Isukha, Taita, Giriama, Digo, Kisii, Kamba, Kikuyu and Luo. Majority of these communities consumed spider plant (88.9%) with the only exceptions being the Kamba and Kikuyu (11%).

CHAPTER 5: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Morphological diversity

According to the study, various characters were highly diverse. The qualitative characters displayed phenotypic classes which ranged from two (2) to seven (7) classes. Colour of the main stem had the highest number of phenotypic classes; seven (7) while surface texture of fruit had the lowest; two (2). Leaflet shape and petiole colour had six (6), colour of mature healthy seeds, colour of immature fruits, colour of mature fruits and growth habit had five (5), stem pubescence, petal colour, leaf venation had four (4), while fruit shape had four (4). Among the quantitative characters, plant height and number of branches were highly diverse while stem circumference, number of terminal leaflets, terminal leaflet length and width and petiole length were less diverse. The rich diversity is due to the fact that the accessions were collected in heterogeneous habitats such as the wild, farms and also diverse agro-ecological zones.

5.1.2 Qualitative characteristics

5.1.2.1 Growth habit

This study recorded five growth habits. These were erect, prostrate, semi-prostrate, spreading and mixed growth habit. Spreading and mixed growth habits were new characters recorded in this study. The diverse growth habits recorded in this study could be due to the fact that, this study comprised of many accessions collected from diverse agro-ecological zones and habitats. The different growth habits in spider plant could be attributed to its ability to survive in diverse habitats and the ability to adapt to environmental conditions to enhance its chances of survival. It could also be due to genetic constitution that determines its growth habit (K'opondo, 2011). Semi-erect types could be proposed for use in mixed cropping by small scale farmers while erect types are suitable for intercrop adaptability (Wasonga *et al.,* 2015).

5.1.2.2 Colour of the main stems and petioles

This study found out that spider plant is highly varied in colour of the main stem and petiole across agro-ecological zones as opposed to other studies which recorded three (3) colours only;

green, pink, or purple (Chweya and Mnzava 1997; Onyango *et al.,* 2013; Omolola *et al.,* 2019). Other colours distinguished in this study were; green tinged purple, purple tinged green and dark purple. The purple colour in the stems and petioles is due to accumulation of anthocyanins (plant pigment) responsible for attracting pollinators (K'opondo, 2011), protecting plant tissues against UV light especially those growing in the highlands (Agati, 2010) and chemical repellence of pests and herbivores. Accumulation of anthocyanins in plant tissues (stems and petioles) therefore increases the ability of purple coloured spider plants to thrive in high altitudes as purple and light purple colours were recorded in the accessions from lower highlands. Anthocyanins are plant pigments which are flavonoid in nature and therefore have anti-bacterial, anti-viral, antifungal (Lev-Yadun and Gould, 2008), anti-tumor and anti-oxidant (Wasonga *et al.,* 2015) properties which are powerful health promoting compounds when consumed in vegetables. On the other hand, green colour is caused by plant pigment chlorophyll responsible for intercepting light to fuel photosynthesis (Tanaka *et al.,* 2008).

5.1.2.3 Stem pubescence

The study recorded four (4) levels of stem pubescence which were sparsely hairy, hairy, very hairy and wooly which concurs with Chweya and Mnzava's (1997) findings which in addition also recorded glabrous stems. Glabrous trait was reported to be rare which concurs with this study as they were not reported in the accessions. Stem hairs recorded in various accessions reduce the rate of transpiration (Ehleringer *et al.,* 1976).

5.1.2.4 Leaf pubescence

Majority of accessions from coastal lowlands, lower midlands and upper midlands were hairy because leaf pubescence is an adaptive trait of plants in hot regions which facilitate reduction of transpiration rates by reducing leaf temperature (Ehleringer *et al.,* 1976). On the other hand, accessions from upper highlands and lower highlands were mainly glabrous because these AEZs are cool hence leaf transpiration rates are low. The hairs also protect underlying photosynthetic tissues against damage by UV radiation (Manetas, 2003).

5.1.2.5. Colour of leaf blade

There were three (3) variations in colour of leaf blade recorded in the study which were light green, green, and dark green which has not been reported in any other study although it partly concurs with Kwekwe (personal communication, December 6, 2017), in which the Duruma community in Kenya distinguished two (2) types of spider plants; light coloured and dark coloured spider plants. Green colour was the most common among the accessions. However, Chweya and Mnzava (1997) recorded brown coloured leaves which were not documented in the study. Light green colour in spider plant leaves is associated with hot temperatures and therefore reflect excess sunlight hence cooling the plant in coastal lowlands and lower midlands which are hot. On the other hand, dark coloured leaves in the highlands absorb most energy from sunlight for photosynthesis (Sajeevan *et al.*, 2017).

5.1.2.6 Shape of leaflet blade

This study documented an additional shape of leaflet blade (lanceolate) in accession TT-00 apart from elliptic and obovate shape which were the main leaflet shapes reported by Chweya and Mnzava (1997). On the other hand, Onyango *et al.* (2013) noted an additional oval shaped leaves in her study.

5.1.2.7 Petal colour

The study documented four (4) colour variations in petal colour; white (20), cream (2), pink (6) and white tinged purple (12). These colours concur with those documented by Chweya and Mnzava (1997), AVRDC (2009), Agnew (2013) and Omolola *et al.* (2019) who noted white and pink. The pink colour in petals was caused by accumulation of anthocyanins in petal epidermal cells. In this regard, anthocyanins play a significant role in selection of pollinators which is important for sexual reproduction (Berman *et al.*, 2016). Pink colour was recorded in lower midlands, inland lowlands and coastal lowlands which are hot AEZs an important trait for attracting pollinators.

5.1.2.8. Colour of immature fruits

The study noted that immature fruit colour were mainly green, which varied from shiny green to green. However, accession ELG 1907A was found to be unique because it had purple immature fruits which means that it had accumulated anthocyanins in the fruit tissues. Wenyika *et al.* (2015) also recorded purple and green colour in spider plant. However other studies by Chweya and Mnzava (1997), noted only the green colour of immature fruits. This means that purple colour is a rare character whereas green colour is dominant. The purple colour in fruits caused by flavonoids such as anthocyanins could be a protective measure against UV light for plants growing in higher altitudes (Agati, 2010) such as accession ELG 1907A at altitude 1247 m a.s.l. Fruit colour trait is therefore easy to use in distinguishing morph-types since it has only two types; green and purple (Wenyika *et al.*, 2015).

5.1.2.9. Colour of mature fruits

The study recorded variation in colour of mature fruits as yellow-green to dark yellow with some fruits that were turning brown at the time of data collection. This study further elaborates on colour of mature fruits that were previously described by Chweya and Mnzava (1997) as only yellow. This meant that there was minor variation in fruit development and maturation in different AEZs. Few accessions from lower midlands mature late compared to other AEZs upper midlands which mature early because brown colour was noted in few accessions.

5.1.2.10. Shape of fruits

This study revealed variation in shape of fruit which was round, spindle shape and spindle-wide. Spindle-wide was a new trait reported in this study in a few accessions. Round and spindle shapes had been noted in earlier study by Chweya and Mnzava (1997). The study also found out that fruits from coastal lowlands were largely round shaped and smaller in size as compared to those from highlands which were larger in size and spindle shaped. The small sized fruits in the coastal lowlands is due to lower rainfall levels received by coastal lowlands as opposed to the highlands which receive higher rainfall levels and are also more humid. This trend concurs with Schippers (2000) who noted that fruit shape in Tanzanian ecotypes varied between lowlands and inlands in which fruits from lowlands were short, thin and straight while those from inland are at least twice as large and deflated.

5.1.2.11 Leaf waxiness

The study noted that most of the spider plant accessions across the agro-ecological zones were waxy and this insulates plant surfaces as affirmed by Reicosky and Hanover (1977) by preventing them against excessive loss of water caused by transpiration, protection against pest damage and air pollutants. Leaf wax also protects the plant against excessive solar radiation and UV radiation hence prevent non-stomatal water losses in drought conditions (Sajeevan *et al.*, 2017).

5.1.2.12 Colour of mature healthy seed

Seed colour varied in this study (black and grey) and black was the dominant colour. This concurs with Chweya and Mnzava (1997) study who indicated that spider plant seeds are greyish to black in colour. In addition, Onyango *et al.* (2013) and Elffers *et al.* (1964) reported brown coloured seeds which also concurs with this study where brown colour was noted. Variation in seed pigmentation across the agro-ecological zones could be attributed to genetic variability.

5.1.3 Quantitative characteristics

5.1.3.1 Plant height

There was significant variation in plant height in accessions from highlands to lowlands. Plant height increased from the lowlands to highlands. The highlands receive higher levels of rainfall than lowlands hence morphotypes from highlands are taller than lowlands. Another factor could be due to selection by farmers in highlands because a lot of commercialized farming is done on varieties which are stout, taller, higher leaf yield and highly branched. Farmers practice a selection oriented to the consumers' preferential characteristics because the demand of *G. gynandra* is higher in urban centers than in rural zones as noted by Bosire (2014) in Kenya. Coastal and inner lowlands' accessions were shorter in height because short statured plants are able to translocate nutrients faster hence escape drought easily than tall types (Wasonga *et al.*, 2015)

5.1.3.2 Number of branches

Diverse branching numbers from the main stem which ranged from two (2) to 16 were recorded in the study. The variation in branching has not been evaluated before in spider plant which is important in horticultural production and selection (Wasonga *et al.*, 2015). Chweya and Mnzava (1997) only mentioned that spider plant was branched and stout. The number of branches is a measure of plant's vegetative productivity. Higher number of branches indicates high leaf yield and it is also a measure of a plant resilience to limited water conditions (Wasonga *et al.*, 2015). Accessions from upper midlands recorded higher numbers of branches compared to those from coastal lowlands because of high levels of moisture in the upper midlands while accessions from coastal lowlands had to adapt to low levels of moisture by having fewer branches.

5.1.3.3. Number of terminal leaflets and leaf length

Accessions from coastal lowlands had smaller number of terminal leaflets and smaller length compared to those from highlands and upper midlands. This has been noted by Osakabe *et al.* (2014) as an adaptation of escaping drought or saving water by plants growing in semi-arid regions.

5.1.3.4. Shape and size of fruits

Fruits of some accessions from inland lowlands and coastal lowlands were found to be round and averagely smaller in size while those from highlands were spindle in shape and bigger in size. This can be attributed to variation in rainfall and humidity in different agro-ecological zones. Accessions from highlands could be bred for seed production because they are bigger in size compared to lowlands.

5.1.4 Seed propagation of spider plant

During the field experiment, only 40 spider plant seeds out of 56 accessions germinated and grew to mature plants, thus organoleptic tests were conducted on 40 accessions. Lack of germination for the 16 accessions could be attributed to the fact that spider plant seed experiences poor germination due to dormancy which is broken after six (6) months of storage (Kamotho, 2004; Ochuodho, 2005). In this study, *Gynandropsis gynandra* seeds were planted two (2) months after harvesting and processing which may have caused germination failure. The prevailing agro-ecology in Nairobi may not also have been favourable or provided optimum conditions for the failed accessions to grow especially for accessions from coastal lowlands of Kwale and Kilifi. Other reasons were due to lack of storing spider plant seeds under low temperatures (sub-zero) probably -20°C for six months which enhances seed quality (Kamotho *et al.,* 2013). In this case they were stored under room temperature. The seeds may not have also been completely mature when harvested due to variation in fruit set and development in different accessions (Wasonga *et al.,* 2015; K'opondo, 2011).

5.1.5. Organoleptic characterization of leaf bitterness

Organoleptic tests demonstrated that there is variation in leaf bitterness in *Gynandropsis gynandra* within and among different agro-ecological zones. This concurred with Schippers (2000) and Chweya and Mnzava's (1997) findings who reported presence of variation in bitterness. Variation in bitterness levels in different spider plant accessions is attributed to difference in concentration of condensed tannins as demonstrated by Kutsukutsa *et al.* (2014) study which showed that there was genetic variability in quantity of condensed tannins in spider plant. Bitter taste was shown to increase with increase in levels of quantity of condensed tannins (Kutsukutsa *et al.,* 2014). Variation in temperature across agro-ecological zones induced variability in level of condensed tannins in the spider plant accessions. Very bitter types dominated the coastal lowlands and lower midlands. Lower highlands and upper highlands had types ranging from not bitter to mild in taste. Spider plant was highly commercialized in the lower highlands and upper midlands where a lot of selection work had been done to achieve the preferential criteria of the consumers and producers (Bosire, 2014). Vegetable producers in the lower highlands provided spider plant for the large market town centers in the region and thus tended to select and propagate spider plant types with less or no bitterness. Accessions from upper highlands were non-bitter to mild in taste because the zone is sub-humid with relatively very cool temperatures which cause low concentration of tannins in the plant. Accessions from inland lowlands were mild in taste except for accession GA-01 which was a cultivated type sourced from an Agrovet shop. Inland lowland regions are semi-arid which may have caused bitter taste in the accessions yet they were not bitter. The non-bitter taste may have been caused by selection by communities living in this region who consume spider plant. On the other hand, spider plant types in the coastal lowlands were mostly bitter. This may be due to the effects of high temperatures occurring in the lowlands which cause increase in concentration of condensed tannins making the plants bitter, a strategy which protects the plant against herbivores and pests for survival purposes (Schweitzer *et al.,* 2008). Local communities in coastal lowlands have had a rich culture of consuming wild vegetables, spider plant included (Maundu *et al.*, 1999). They have conserved both bitter and non-bitter landraces of spider plant and are accustomed to and appreciate the flavour of the bitter landraces which they associate with high medicinal benefits (Abukutsa, 2010). They also have well-developed traditional vegetable recipes for preparing the bitter types which tone down the bitterness hence making the vegetable palatable (Maundu, 2011). Spider plant accessions from lower midlands and upper midlands scored a wide range of level of bitterness because of wide differences in humidity in some parts of regions sampled such as Homabay was more humid compared to less humid regions such as Kitui yet both fall under lower midlands. Less or no selection work has not been done in Kitui because spider plant is not or less consumed in this region. Regions such as Kakamega are more humid than Taita in upper midlands, hence variation in leaf bitterness. Cultivated types such as accession KF-07 from the coastal lowlands did not express bitter taste like other accessions from this agro-ecological zone because it was a cultivated type sourced from another agro-ecological zone probably upper highlands.

5.1.6 Cluster analysis

The clustering analysis in figure 12 clearly showed that accessions were distant from each other based on level of leaf bitterness across the six agro-ecological zones. It revealed clear cut groups namely; non-bitter, mild, bitter, very bitter and extremely bitter types. Accessions from agro-ecological zones such as inland lowlands did not cluster with other bitter types but were related with those from highlands (mild) probably due to selection by local community (Tugen) who consume spider plant. Accession GA-01 from inland lowlands expressed bitter taste (3) yet it was a cultivated type and therefore could have been sourced from a lowland region (associated with bitter types) through seed trade. Unique similarities were noted in cluster four (4) whereby accession KF-07 exhibited non bitter taste yet it was from coastal lowlands which were in group B made up of bitter to very bitter types. This may be attributed to the fact that it was a cultivated type obtained through seed trade probably from upper highlands. This was the reason why accession KF-07 was clustered together with NYR2107B and NYR 2107C indicating similar genetic background.

5.1.7 Correlation between colour of leaf blade and level of leaf bitterness

The study found out that colour of the main stem alone did not correlate with bitterness levels in *Gynandropsis gynandra*. This contradicts findings by Schippers (2000) and Wasonga *et al.* (2015) who reported that farmers associate leaf bitterness with colour of the main stem and are able to distinguish bitter types from non-bitter types of spider plant. However, colour of leaf blade was found to negatively correlate with bitterness levels in that the leaf's green colour intensity decreased as the bitterness levels increased. One exception noted was that accession GA-01 had dark green leaves yet it was bitter. This was attributed to the fact that it was a cultivated type.

5.1.8 Consumption patterns of spider plant across the agro-ecological zones

This study noted that spider plant was consumed by a large number of local communities. Reasons for consumption or non-consumption was attributed to different reasons such as food cultures and habits as well as the environment or agro-ecological zones in which the local communities inhabit. Spider plant was mostly consumed by communities in upper midlands i.e. (Luo, Bukusu, Isukha, Kisii, Teso), lower highlands (Kipsigis, Nandi, Keiyo, El Njemps, Turkana, Marakwet, Pokot) and the coastal lowlands (Digo, Giriama, Taita and Malakote). The plant was least consumed in upper highlands and eastern Kenya (lower midlands). Maundu *et al.* (2009) states that spider plant was originally an important vegetable to the Nilotic people who live around the Nile basin (midlands) and that it became part of the food culture to other neighbouring communities around this region. Spider plant is key in the diet of a recuperating individual in western Kenya (upper midlands) especially the Kisii (Bosire, 2014) where it is regarded as a powerful nutraceutical used to strengthen the immune system by boosting blood replenishment. On the other hand, Maundu (2011) noted that in the coastal lowlands, the Mijikenda are known to have a rich diversity in wild indigenous vegetables consumed (approximately 80 vegetables) in which spider plant is among the most important vegetables. Chweya and Eyzaguirre (1999) also affirmed that spider plant was among important vegetable to the Mijikenda food culture which is semi-cultivated and a large proportion of it collected from the wild. They have well developed recipes for preparing bitter vegetables such as marinating in coconut milk or mixing with other less bitter vegetables such as amaranth to lessen bitterness (Yang and Keding, 2009). Another reason is that some parts of the coastal lowlands receive low levels of rainfall and is prone to drought which does not support cultivation of exotic vegetables hence resulting to the local communities relying on indigenous wild food resources such as indigenous vegetables like spider plant which are well adapted to the local climate.

Contrastingly, communities in upper highlands and lower midlands of Kenya notably the Kikuyu and Kamba do not consume spider plant much, largely because it is not part of the culture and also probably because they associate spider plant with bitterness. Among the Kamba from Kitui (lower midlands), consumption of spider plant is hampered by extreme bitterness as noted in the organoleptic test and consumption of spider plant also is not part of food culture. In the upper highlands, spider plant was not bitter but still it was less consumed because it is not part of their eating habits or food culture. The highlands receive enough rainfall to support cultivation of other foods such as exotic vegetables and hence the communities are more accustomed to other introduced vegetables as opposed to indigenous types such as spider plant. This also concurs with the study of Ndenga *et al.* (2013) in Maragua (upper highlands) where spider plant production was negligible in the area, with the plant mostly collected from the wild and consumption rates very low compared to other parts of Kenya such as western Kenya. The spider plant types in the lower highlands are highly selected and cultivated for the market in towns.

5.2 Conclusion

The project set out to answer three (3) research questions on whether there was variation in morphological characters and leaf bitterness in *Gynandropsis gynandra* and whether there was significant relationship or correlation between levels of bitterness and specific morphological characters; colour of leaf blade, colour of main stem and leaf waxiness. Association between agro-ecology and variation in morphology and leaf bitterness was also assessed. It is concluded that;

1. *Gynandropsis gynandra* (spider plant) exhibited variation in morphological characters and level of bitterness across the six (6) agro-ecological zones sampled

2. The colour of leaf blade was a strong indicator for leaf bitterness and proved to be an important character for discriminating non-bitter types from bitter ones.

3. Accessions from coastal lowlands and lower midlands were morphologically distinct from those in other agro-ecological zones in the study. They were short, with light green leaf blade

and had smaller rounded fruits. In addition, the leaves had the highest bitterness levels compared to those from other AEZs.

4. Variation in leaf bitterness was caused by changes in temperature, moisture (rainfall) which affected level of condensed tannins in spider plant.

5.3 Recommendations

Based on conclusions above, the study recommends that;

1. Spider plant accessions or types from coastal lowlands and lower midlands of Kitui be treated as a distinct variety from the rest of accessions because they are uniquely small in stature and very bitter in taste.

2. Colour of leaf blade be used as an indicator of leaf bitterness in spider plant and therefore farmers and consumers should be taught how to use colour of leaf blade to distinguish types with low levels of bitterness which will reduce boiling or cooking time and hence preserve thermo-labile nutrients.

3. Further characterization be done to validate this variation by growing the plants in multiple sites under different environments. This can further be supplemented by use of molecular markers such as Simple Sequence Repeats (SSRs) to identify variation that is not due to environmental conditions. In contrast to morphological traits, molecular markers can reveal abundant difference among genotypes at the DNA level, providing a more direct, reliable and efficient tool for germplasm characterization, conservation and management, and untouched by environmental influence.

4. Accessions from Nyeri, Elgeyo Marakwet, Kericho and Uasin Gishu should be collected and used for propagation, production, consumption and commercialization of non-bitter types among the communities that traditionally do not consume the plant i.e. the Kamba, Kikuyu and other Central Bantu communities to enhance health and incomes. On the other hand, accessions from coastal lowlands and lower midlands of Kitui which are bitter be collected for conservation for breeder's sake and genetic enhancement of improving spider plant as they possess other qualities such as enhanced drought tolerance. They should also be

preserved because communities from coast and western Kenya have developed local traditional vegetable recipes which tone down the bitter taste. These bitter types include those accessions collected from Kitui, Kwale, Makueni, Taita, Kilifi and Garissa.

5. Spider plant be utilized as a suitable drought resistant plant for enhancing food security.

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APPENDICES

Appendix 1: Level of significance of qualitative characteristics of *Gynandropsis gynandra*

Variable	**P value**
Growth habit	0.108
Colour of main stem	0.590
Stem pubescence	0.207
Colour of leaf blade	0.000*
Shape of terminal leaflet	0.210
Leaf pubescence	0.979
Petiole colour	0.246
Petal colour	0.482
Upper leaf surface venation	0.145
Colour of immature fruit	0.000*
Colour of mature fruit	0.000*
Shape of mature or nearly fruit	0.019*
Surface texture of fruit	0.110
Presence of folds on fruit	0.001*
Colour of mature healthy seed	0.021*
Leaf waxiness	0.445

*Significant traits ($p<0.05$)

Appendix 2: Level of significance of quantitative traits of *Gynandropsis gynandra*

Variable	**P value**
Plant height	0.0500*
Leaflet length	0.546
Fruit length	0.000*
Stem circumference	0.143
No. of leaf blade leaflets	0.893
Number of branches	0.347
Fruit width	0.086

*Significant traits

Appendix 3: Stem characteristics of *Gynandropsis gynandra*

Accession no.	Growth habit	Colour of the main stem	Stem pubescence
BAR 1807B	Erect	green	sparsely hairy
BAR 1807A	mixture	Purple	sparsely hairy
BGM 2107A	Erect	green tinged purple	sparsely hairy
BGM 2107C	Erect	light purple	sparsely hairy
ELG/1907B	Erect	green tinged purple	sparsely hairy
ELG/1907C	Erect	green tinged purple	sparsely hairy
ELG/1907A	Erect	purple	sparsely hairy
GA-01	Spreading	dark purple	sparsely hairy
HBY 2307A	spreading	green	sparsely hairy
HBY 2307B	spreading	purple	sparsely hairy
KK 2207	Erect	purple tinged green	sparsely hairy
KRC 2507B	Erect	green	sparsely hairy
KRC 2507A	Erect	green tinged purple	sparsely hairy
KF-11	Spreading	dark purple	hairy
KF-05A	Erect	green tinged purple	hairy
KF-01	Erect	green	sparsely hairy
KF-05	Erect	green tinged purple	sparsely hairy
KF-09	Spreading	light purple	sparsely hairy
KF-07	Erect	purple tinged green	sparsely hairy
KIS/2407A	Erect	mixed (green, light purple)	wooly
K1-01	Erect	mixed (dark and light purple)	hairy

Accession no.	Growth habit	Colour of the main stem	Stem pubescence
K1-02	Spreading	purple	sparsely hairy
KW-02	spreading	purple tinged green	sparsely hairy
MK-01	Erect	Light purple	sparsely hairy
MK-02	spreading	purple	hairy
NKR 1807	Erect	green	sparsely hairy
KIS/2407B	Semi-prostrate	green tinged purple	wooly
TT-01	Spreading	green	sparsely hairy
TT-02	prostrate	green	wooly
TT-00	spreading	green tinged purple	sparsely hairy
TNZ 2107B	spreading	green	sparsely hairy
UAG 1907C	Erect	green tinged purple	Very hairy
UAG 1907A	Erect	Light purple	sparsely hairy
UAG 1907B	Erect	Light purple	sparsely hairy
WPK 2007A	spreading	green	sparsely hairy
WPK 2007D	spreading	green	sparsely hairy
WPK 2007E	Erect	green tinged purple	sparsely hairy
NYR 2107C	Erect	Green	hairy
NYR 2107B	Prostrate	Green	Sparsely hairy
NYR 2107A	Erect	Purple tinged green	Sparsely hairy

Appendix 4: Leaf characteristics of *Gynandropsis gynandra*

Accession no.	No. of Leaf blade leaflets	Colour of leaf blade colour	terminal leaflet shape	Leaf pubescence	Petiole colour	Upper surface leaf vein
BAR 1807B	5	dark green	Elliptic	glabrous	Purple	slightly depressed
BAR 1807A	5	green	Elliptic	sparsely hairy	green	slightly depressed
BGM 2107A	5,6	green	Elliptic	sparsely hairy	green	deeply depressed
BGM 2107C	5	green	Elliptic	sparsely hairy	green	deeply depressed
ELG/1907B	5,6	dark green	Elliptic	Hairy	purple	depressed
ELG/1907C	5	dark green	Elliptic	hairy	green	slightly depressed
ELG/1907A	5	dark green	Elliptic	Hairy	green	slightly depressed
GA-01	5,6,7	dark green	Elliptic	hairy	dark purple	deeply depressed
HBY 2307A	5	green	Elliptic	glabrous	green	slightly depressed
HBY 2307B	5	green	Elliptic	Sparsely hairy	green	slightly depressed
KK 2207	5,6	dark green	Elliptic	glabrous	green tinged purple	slightly depressed
KRC 2507B	5	dark green	elliptic	hairy	green tinged purple	slightly depressed
KRC 2507A	5	dark green	Elliptic	sparsely hairy	Purple	slightly depressed
KF-11	5	green	Elliptic tending towards obovate	glabrous	green	slightly depressed

Accession no.	No. of Leaf blade leaflets	Colour of leaf blade colour	terminal leaflet shape	Leaf pubescence	Petiole colour	Upper surface leaf vein
KF-05A	3,4,5	light green	Elliptic	hairy	purple	depressed
KF-01	4,5	light green	Obovate	sparsely hairy	green	Slightly depressed
KF-05	5	Light green	majority are obovate though some are elliptic	glabrous	green tinged purple	not depressed
KF-09	5	light green	Obovate	glabrous	green	slightly depressed
KF-07	3,4,5	green (bright)	Obovate	glabrous	green	Slightly depressed
KIS/2407A	5	green	Elliptic	glabrous	Purple	deeply depressed
K1-01	5,7	light green	some obovate but majority are elliptic	hairy	green	slightly depressed
K1-02	5,6,7	light green	Elliptic	hairy	green	depressed
KW-02	5	light green	Obovate	glabrous	green tinged purple	not depressed
MK-01	5,6	light green	Obovate	glabrous	light purple	not depressed
MK-02	5,7	green	elliptic with some tending to obovate	glabrous	green tinged purple	slightly depressed
NKR 1807	5	green	Elliptic	glabrous	Purple	deeply depressed
KIS/2407b	5	dark green	Elliptic	sparsely hairy	dark purple and green	deeply depressed
TT-01	5,6	green	elliptic towards obovate	glabrous	light purple	deeply depressed

Accession no.	No. of Leaf blade leaflets	Colour of leaf blade colour	terminal leaflet shape	Leaf pubescence	Petiole colour	Upper surface leaf vein
TT-02	5	green	Elliptic	glabrous	green	depressed
TT-00	4,5	light green	Oblong (lanceolate)	glabrous	green	not depressed
TNZ 2107B	5	green	Elliptic	glabrous	green	slightly depressed
UAG 1907c	5,6	dark green	Elliptic	glabrous	green	deeply depressed
UAG 1907A	5	dark green	Elliptic	hairy	light purple	slightly depressed
UAG 1907B	5,7	dark green	Elliptic	glabrous	green and purple	deeply depressed
WPK 2007A	5,6,7	green	Elliptic	sparsely hairy	light purple	slightly depressed
WPK 2007D	5	green	Elliptic	glabrous	purple, light purple	slightly depressed
WPK 2007E	5,6,7	dark green	Elliptic	glabrous	green, light purple	Slightly depressed
NYR2107C	6	green	Elliptic	glabrous	Green tinged purple	Not depressed
NYR2107B	5, 6	green	Elliptic	glabrous	Green tinged purple	Not depressed
NYR2107A	7	Dark green	Elliptic	glabrous	Purple	Slightly depressed

Appendix 5: Petal and fruit characteristics of *Gynandropsis gynandra*

Accession no.	Petal colour	Immature fruit colour	Mature fruit colour	Shape-of mature or nearly mature fruit	Fruit surface	Fruit shape	Colour of mature - healthy seed
BAR 1807B	White tinged purple	green	yellow	spindle	scabrid	few folds	black
BAR 1807A	White	green	yellow	round	scabrid	few folds	greyish black
BGM 2107A	White	green	greyish brown	spindle	scabrid	no folds	grey
BGM 2107C	White tinged purple	green	yellow	spindle	scabrid	no folds	grey
ELG/1907B	White tinged purple	green	yellow	round	scabrid	Mixed shapes	brown
ELG/1907C	White tinged purple	green	yellow	spindle	scabrid	no folds	grey
ELG/1907A	White tinged purple	purple, purplish green	deep yellow	spindle	scabrid	few folds	brown
GA-01	Light purple	green	yellow	spindle	slightly scabrid	few folds	black
HBY 2307A	White	green	yellow	spindle	scabrid	few folds	black
HBY 2307B	White	green	yellow	spindle	scabrid	many folds	greyish black
KK 2207	White tinged purple	green	yellow	spindle	scabrid	few folds	black
KRC 2507B	White tinged purple	green	yellow	spindle	scabrid	no folds	black
KRC 2507A	White tinged purple	green	yellow	spindle	slightly scabrid	few folds	black

Accession no.	Petal colour	Immature fruit colour	Mature fruit colour	Shape-of mature or nearly mature fruit	Fruit surface	Fruit shape	Colour of mature - healthy seed
KF-11	Light purple	green	yellow	round	slightly scabrid	no folds	black
KF-05A	White	green	yellow	round	scabrid	no folds	black
KF-01	White	green	yellow	round	slightly scabrid	few folds	black
KF-05	White	dark green	yellow	round	scabrid	no folds	black
KF-09	Light purple	green	yellow	round	slightly scabrid	no folds	black
KF-07	Cream	green	yellow	round	slightly scabrid	no folds	light brown
KIS/2407A	White tinged purple	green	yellow	spindle	Scabrid	few folds	brown
K1-01	Cream	green	yellow	round	slightly scabrid	no folds	black
K1-02	Light purple	green	yellow	round	slightly scabrid	no folds	black
KW-02	White	green	yellow	round	slightly scabrid	no folds	black
MK-01	Light purple	green	yellow	round	slightly scabrid	no folds	grey
MK-02	White	green (shiny)	yellow	round	slightly scabrid	no folds	grey
NKR 1807	White	green turning yellow	brown fruits	round	slightly scabrid	no folds and few folds	brown
KIS/2407B	White	green	yellowish green	spindle-wide	slightly scabrid	few folds	brown

Accession no.	Petal colour	Immature fruit colour	Mature fruit colour	Shape-of mature or nearly mature fruit	Fruit surface	Fruit shape	Colour of mature - healthy seed
TT-01	White	green	yellow	spindle	slightly scabrid	many folds	black
TT-02	White	green	yellow	round	slightly scabrid	many folds	black
TT-00	Light purple	green	yellow	round	slightly scabrid	few folds	grey
TNZ 2107B	White	green	yellow	spindle	scabrid	few folds	black
UAG 1907C	White	green	yellow	spindle	scabrid	few folds	black
UAG 1907A	White	green	yellow	spindle	scabrid	few folds	black
UAG 1907B	White	green	yellow	spindle	scabrid	few folds	black
WPK 2007A	White	green	yellow	spindle	scabrid	many folds	grey
WPK 2007D	White	green	yellow	spindle	scabrid	many folds	grey
WPK 2007E	White	green	yellow	spindle	scabrid	many folds	grey
NYR2107C	White tinged purple	green	yellow	spindle	slightly scabrid	many folds	black
NYR2107B	White tinged purple	green	yellow	spindle	slightly scabrid	many folds	black
NYR2107A	White tinged purple	green	yellow	spindle	scabrid	many folds	black