



**GENETIC, MORPHOLOGICAL, AND AGRONOMIC EVALUATION OF  
COWPEA (*VIGNA UNGUICULATA* (L.) WALP.) GENOTYPES UNDER  
MOISTURE LIMITED AREAS OF SOUTHERN ETHIOPIA**

**PhD DISSERTATION**

**YASIN GOA CHONDIE**

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

MARCH, 2022

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**YASIN GOA CHONDIE**

**A DISSERTATION SUBMITTED TO THE SCHOOL OF PLANT AND  
HORTICULTURAL  
SCIENCES, COLLEGE OF AGRICULTURE, SCHOOL OF GRADUATE  
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**(SPECIALIZATION: AGRONOMY)**

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**MARCH, 2022**

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(Submission Sheet – 1)

This is to certify that the thesis entitled “Genetic, Morphological, and Agronomic Evaluation of Cowpea (*Vigna Unguiculata* (L)Walp) Genotypes Under Moisture Limited Areas of Southern Ethiopia” submitted in partial fulfillment of the requirements for the Doctor of Philosophy (Ph.D) degree with specialization in Agronomy Graduate program of the School of **Plant and Horticultural Sciences**, College of Agriculture, and is a record of original research carried out by **Yasin Goa Chondie**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore I recommend that it be accepted as fulfilling the thesis requirements.

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(Submission Sheet – 1)

This is to certify that the thesis entitled "Genetic, Morphological, and Agronomic Evaluation of Cowpea (*Vigna Unguiculata* (L)Walp) Genotypes Under Moisture Limited Areas of Southern Ethiopia" submitted in partial fulfillment of the requirements for the Doctor of Philosophy (Ph.D) degree with specialization in Agronomy Graduate program of the School of Plant and Horticultural Sciences, College of Agriculture, and is a record of original research carried out by **Yasin Goa Chondie**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore I recommend that it be accepted as fulfilling the thesis requirements.

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## **DEDICATION**

This work is dedicated to my father Goa Chondie and mother-in-law Muchuche Chumburo who suddenly passed away while I was doing my research. May their soul rest in eternal peace!

## **STATEMENT OF THE AUTHOR**

First, I declare that this dissertation submitted in partial fulfillment of the requirements for the PhD degree in Agriculture (Agronomy) to Hawassa University, is my original work and has not been submitted to any institution anywhere for the award of any academic degree or diploma. All sources of materials and financial support used for this dissertation work have been properly acknowledged. This dissertation can be deposited at the University Library to be made available to the readers or borrowers under the rule of the Library. Brief quotations from this dissertation are allowable without special permission provided that accurate acknowledgment of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of school or the Dean of the School of Graduate studies when in his or her judgment the proposed use of the materials in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

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## **LIST OF ABBREVIATIONS AND ACRONYMS**

- AARC: Areka Agricultural Research Center
- ACA: Awassa College of Agriculture
- AMMI: Additive Main Effects and Multiplicative Interaction
- ANOVA: Analysis of Variance
- ASV: AMMI Stability Value
- CV: Coefficient of Variation
- DF: Degrees of Freedom
- FAO: Food and Agriculture Organization of the United Nations
- GCV: Genotypic Coefficient of Variance
- GEI: Genotype by Environment Interaction
- GGE: Genotype +Genotype by Environment
- GLM: General Linear Model
- HU: Hawassa University
- IBPGR: International Board for Plant Genetic Resources
- ICRISAT: International Crops Research Institute for Semi-Arid Tropics
- IITA: International Institute of Tropical Agriculture
- IPCA: Interactions of Principal Component Analysis
- MARC: Melkasa Agricultural Research Center
- MoA: Ministry of Agriculture
- MoARD: Ministry of Agriculture and Rural Development
- PCA: Principal Components Analysis
- PCV: Phenotypic Coefficient of Variance
- PPB: Participatory Plant Breeding
- PRA: Participatory rural appraisal
- PVS: Participatory variety selection
- RCBD: Randomized Complete Block Design
- SAS: Statistical Analysis System
- SNNPR: Southern Nations, Nationalities, and People's Region

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## LIST OF ARTICLES

The Dissertation contains the following manuscripts /articles in chapters:

1. Production constraints, farmers' perceptions, farmers' preferred traits, and production systems of cowpea in southern Ethiopia
2. Assessment of Genetic Diversity in Cowpea (*Vigna unguiculata* (L.) Walp) Genotypes in Southern Ethiopia based on Morpho-Agronomic traits

This article has been published in the International Journal of Agricultural Technology, 17(4): 1631-1650.

3. Genotype by Environment Interaction and Yield Stability of Cowpea (*Vigna unguiculata* (L.) Walp.) Genotypes in Moisture Limited Areas of Southern Ethiopia

This article has been published in the Heliyon, 8(3):1-11.

4. Performance and Farmers Participatory Selection of Cowpea Varieties in Southern Ethiopia

# **GENETIC, MORPHOLOGICAL, AND AGRONOMIC EVALUATION OF COWPEA (*VIGNA UNGUICULATA* (L.) WALP.) GENOTYPES UNDER MOISTURE LIMITED AREAS OF SOUTHERN ETHIOPIA**

## **THESIS ABSTRACT**

*Cowpea (*Vigna unguiculata* (L.) Walp.) is a legume predominantly grown in lowland areas of Ethiopia for grains, income source, feed, and to a lesser extent as a vegetable crop. However, several biotic and abiotic constraints and lack of improved varieties suited to different agro-climatic conditions limit its production. Therefore, the objectives of this dissertation work were to: i) Assess farmers' perceived production constraints, farmers' perceptions, farmers traits of preferences, and the production systems of cowpea in southern Ethiopia ii) Estimate the genetic diversity among cowpea genotypes based on morpho-agronomic traits iii) Assess the magnitude of genotype by environment interaction and yield stability of cowpea genotypes and thereby identify broad and/or narrowly adapted genotypes for production in south Ethiopia and; iv) Assess and select superior cowpea variety/varieties that meet farmers' needs and preferences using farmers' participatory variety selection (PVS). The study was conducted in southern Ethiopia from 2016 to 2018. Firstly, a participatory rural appraisal (PRA) approach was undertaken in the year 2016 in Konso, Kindo koyisha, Humbo, and Gofa districts, to identify farmers perceived cowpea production constraints, farmers' perceptions, farmers' traits of interest, and its importance in production systems. Semi-structured interviews, focused group discussions and discussions with key informants were used for data collection. Descriptive statistics, cross-tabulations and chi-square tests were used to analyze the data. The results revealed that the majority of farmers (92.7%) grow local landraces in the area and 12 production constraints were identified and prioritized. Diseases and insect pests, drought, lack of improved varieties, poor access to extensions, poor access to credit services, low soil fertility, farmland shortage, sub-optimal agronomic practices, and storage pests (mainly weevils) were some of the factors limiting cowpea production in south Ethiopia. The criteria used by farmers to select cowpea varieties included high grain and above-ground biomass yield, early maturity, resistance to diseases and insect pests, resistance to drought, good taste, seed color, large seed size, short cooking time, resistance to storage pests (weevils), resistance to shattering, marketability, leaf shedding, and suitability to*

*intercropping of the variety. This study implies that different types of varieties need to be developed for different areas. A field experiment was conducted at the Gofa research station during the 2016/17 main cropping season using 36 cowpea genotypes arranged in a simple lattice design. The Shannon diversity index ranging from 0.633 to 0.953 with a mean of 0.84 revealed a high degree of variation in qualitative traits of cowpea genotypes. Cluster analysis based on 14 quantitative traits grouped the 36 cowpea genotypes into six clusters, indicating that agro-morphological diversity exists. Clusters III and IV were found to be promising for yield and its major component traits, while the genotypes in Cluster VI had genotypes for earlier flowering and maturity. Therefore, clusters III, IV, and VI genotypes could be used directly in multi-location trials for their suitability to be released for successful cowpea production or could be source materials for obtaining desirable new recombinants for early maturity and higher yield in south Ethiopia. Thirdly, twenty cowpea genotypes were tested at Gofa, Kucha, and Humbo in Meher seasons of 2016 and 2017 (E1 to E6) and Belg seasons of 2017 and 2018 (E7 to E12) to investigate the influence of genotype by environment interaction and yield stability on cowpea genotypes. The experiments were laid out in a Randomized Complete Block Design (RCBD) with three replications. Environment, Genotype, and GEI effects were highly significant ( $P < 0.001$ ) for the grain yield indicating differences between genotypes and variation of the environments. Additive Main Effects and Multiplicative Interactions (AMMI) and Genotype plus Genotype by Environment interaction (GGE) biplot, AMMI stability value (ASV), and Genotype Selection Index (GSI) were used for stability analysis. AMMI and GGE biplot, ASV and GSI indices identified G16 (IT-89KD), and G14 (IT93K-293-2-2) as the highest yielding with better stability across environments, suggesting that it can be recommended for all cowpea growing areas of southern Ethiopia with weather conditions similar to the areas used in this study. The advanced lines, G12 (IT96D-604), G13 (93K-619-1), G20 (IT97K-569-9), and G15 (IT99K-1060) had higher grain yields than the checks and were suggested for further inclusion in the breeding program to boost cowpea production. Lastly, PVS was designed to assess and select superior cowpea varieties that meet farmers' needs and preferences using farmers' participation. In this study, eight cowpea varieties were laid out in an RCBD using three replications at Gofa research station and across three selected kebeles at three villages from each kebele(site) comprising a total of nine farmers' fields during the 2016 and 2017 main cropping*

seasons. Combined mean values showed that Brazil-3 (1.65 t/ha), Brazil-2 (1.62 t/ha), Kenketi (1.53 t/ha), and bole (1.52t/ha) were high-yielding varieties with a yield advantage of 3.9 to 12.2% more than a check variety white wonderer trailing. These varieties also got high farmers' overall preference. Therefore, considering data on farmer preferences and field performance, two released varieties, kenekti and Bole, were selected as farmers' first choice and can be recommended for further demonstration, popularization, and dissemination on farmers' fields, while the two Brazilian varieties, Brazil-2 and Brazil-3 are preferred as the second category of choice by farmers must be registered according to national regulations of the country. Overall, this study documented the present cowpea production constraints, farmers' perceptions, and farmer-preferred traits; indicated the presence of considerable genetic diversity among tested genotypes; identified cowpea genotypes with farmers' preferred traits. Also, advanced lines with high yields across environments were identified that can be recommended for release. In general, the research serves as the basis for designing further research and development programs by using the expressed farmers' concerns and the identified promising genotypes to enhance sustainable cowpea production by smallholder farmers in southern Ethiopia and similar areas.

**Keywords:** AMMI, Cowpea, GGE, PRA, PVS, South Ethiopia, Stability

# CHAPTER ONE

## 1. GENERAL INTRODUCTION

### 1.1. Introduction

Cowpea (*Vigna unguiculata* (L.) Walp), a member of the Phaseoleae tribe of the Leguminosae family, is one of the most important versatile and nutritive grain legume crops native to Africa (Sivakumar *et al.*, 2013; Francisco *et al.*, 2014). It is one of the most important pulse crops native to West Africa (Vavilov, 1951) and Steele (1976) suggested Africa as the primary and secondary centers of diversity. Cowpea exhibits different morphological forms such as erect, semi-erect, climbing, prostrate or creeping, and usually indeterminate under favorable environmental conditions (Timko *et al.*, 2007).

Agriculture is an important economic sector in Africa, including Ethiopia. The sector accounts for 25% of Africa's GDP, 21% of exports, and 70% of the workforce, which supports 90% of the population (Mukasa *et al.*, 2017). In Ethiopia, agriculture contributes 44% of GDP, 70% of export earnings, and 80% of employment opportunities (FAOSTAT, 2014). Cowpea is grown mainly for its grain, which is highly prized as a source of food, for fodder in livestock feeds, and an important but cheaper means of improving and boosting soil fertility through biological nitrogen fixation (Omomowo and Babalola, 2021). The annual world cowpea production area was estimated at 14.4 million ha with 8.9 million metric tons of cowpea dried grains; over 95% (or 11.4 million ha) of which is grown in sub-Saharan Africa, of which 52% is used for food, 13% as animal feed, 10% for seeds, 9% for other uses, while 16% is wasted (FAOSTAT, 2015; FAOSTAT 2020).

According to FAOSTAT (2020), among the top six major world cowpea producers, five are located in Africa that including Nigeria, Niger, Burkina Faso, Senegal, and Mali. In many African countries including Ethiopia, where grains, fresh pods, and tender leaves (vegetables) are major sources of food, and family income, particularly for resource-poor households (Alemu *et al.*, 2016). Cowpea has the largest usable protein content of about 25% in the grain (dry weight basis) (Lephale *et al.*, 2012; Nwosu *et al.*, 2013), and serves as a cheap source of plant protein in the diet of people that cannot afford protein foods such as meat and fish. Iqbal *et al.* (2006) and Elhardallou *et al.* (2015) also suggested that the crop enhances the quality of the cereal-based diets when its high lysine content is combined with the high content of methionine and cysteine of cereals. Some people eat both fresh pods and leaves;

however, the dried seeds are popular ingredients in various dishes indicating the diversified uses of the crop.

Apart from its importance for food and family income, cowpea is a shade-tolerant crop, hence compatible as an intercrop, in rotations or relay cropping with cereals such as sorghum, millet, and maize and root/tuber crops, as well as cotton and sugarcane ( FAOSTST, 2013; Kassaye *et al.*,2013; Belay *et al.*, 2017). The dry haulms of cowpea are used as fodder for livestock particularly during the dry season when animal feed is scarce making the crop an essential and integral part of sustainable crop-livestock farming systems in sub-Saharan Africa (FAOSTAT, 2013; Owusu *et al.*,2018). According to Agyeman *et al.* (2014), cowpea can be regarded as a pivot of sustainable farming in regions characterized by systems of farming that make limited use of purchased inputs like inorganic fertilizer. It also contributes to the sustainability of cropping systems due to its capability to recover marginal lands through atmospheric nitrogen fixation and as a cover crop, suppressing weeds, and its decaying residues contribute to soil fertility (Pungulani *et al.*, 2012; Beshir *et al.*, 2019; Kebede *et al.*, 2020). In addition, the crop fixes 80% nitrogen for its growing demand from the atmosphere (Asiwe *et al.*, 2009), thereby reducing nitrogen fertilizer demand and cost for the crop. The crop can fix between 20 and 100 kg ha<sup>-1</sup> of atmospheric nitrogen and make available about 10 to 80 kg ha<sup>-1</sup> nitrogen for succeeding crops grown in rotation with it (Kamara *et al.*, 2018). Hence, for resource-poor small-holder farmers, the crop serves as a source of food, animal feed, cash, and green manure (Agyeman *et al.*, 2014).

Nearly 70% of the Ethiopian arable land falls within dryland environments where rainfall is usually inadequate, poorly distributed, and varies with years and seasons (UNDP, 2014). To support crop production in dryland areas of the country, there is a need for the selection of drought-tolerant crop genotypes that fit the growing season of such areas. Cowpea is a drought-tolerant food legume crop that is adapted to the semi-arid regions of the tropics and sub-tropics. It does well and is most popular in semiarid and hot areas of Africa where other crops may fail due to poor adaptation to heat, drought, and low soil fertility conditions (Sankie *et al.*, 2012). In Ethiopia, cowpea is a warm-weather crop grown in the lowlands of Ethiopia with an optimum elevation of 350 to 1500 meters above sea level with an average annual rainfall of 350 to 1500 mm (FAO, 1984; Bilatu *et al.*, 2012). Minimum and a maximum temperature range from 20<sup>0</sup>C to 30<sup>0</sup>C for growth and development (FAO, 1984; Dugje *et al.*, 2009). It works well on a wide variety of soil conditions but works best on sandy loams or well-drained sandy soils, where soil pH levels between 5.5 and 8.3 tend to be

less restrictive on root growth (Bilatu et al., 2012). Ethiopia is a center of diversity for cowpea (Steele, 1976), and the crop is of vital importance to the livelihood of many of the people in Ethiopia. From its production, rural families derive food, animal feed, and cash income. It provides nutritious grain and an inexpensive source of protein.

In Ethiopia, cowpea is grown in drier areas of the rift valley and dry highlands of Hararghe (Oromiya region) usually intercropped with sorghum and in the north-eastern part of the country around Shewrobit, Kobo, and Waghimira (Amhara region) areas (Kassaye *et al.*, 2013). Additionally, it is grown in low rainfall areas of Southern Nations, Nationalities, and Peoples' Region (SNNPR) and Sidama region especially in Konso, Derashe, Humbo, Hammer Bako, Loka Abaya, Gofa, and Loma districts (Tesema and Esthetayehu, 2003). Production statistics for cowpea in Ethiopia are not available, and the crop is often confounded with common beans, but, based on the survey conducted in five major producing regional states (Amhara, Gambella, Oromia, SNNPR, and Tigray) indicated the documented area under this crop in Ethiopia is 69,500 ha with a production of 55,600 tons (Beshir et al., 2019).

Cowpea yield under traditional farming in Ethiopia is about 0.4 t ha<sup>-1</sup> (Beshir *et al.*, 2019) whereas the yield potential of cowpea is high, averaging 2.2 to 3.2 t ha<sup>-1</sup> depending on genotype and environment (Ashinie *et al.*, 2020). Some factors attributed to low yields in Ethiopia include unavailability of improved varieties leading to use of local varieties which are generally low yielding coupled with low soil fertility, the prevalence of insect pests and diseases, limited research work, sub-optimal crop management practices, and drought conditions are major ones identified in recent studies.

In this respect, there are opportunities for enhancing productivity and adoption of the crop through taking measures that help to tackle the constraints. To this end studies on genetic diversity, farmers' participatory variety selection, genotype evaluation across diverse environments could play a crucial role. The performance of a crop variety is the resultant effect of its genotype and the environment in which it is grown. The relative performance of genotype(s) across environments has raised important and challenging issues among plant breeders, geneticists, and agronomists (Babic *et al.*, 2008). The presence of genotype by environment interaction should be of great concern to plant breeders because, large interactions can reduce yield and even make the selection of superior cultivars difficult (Rashidi *et al.*, 2013).

These authors noted that the presence of genotype by environment interaction (GEI) in the evaluations complicated not only the selection of superior cultivars but also the best site that could be used to identify superior and stable genotypes. Therefore, knowledge of the pattern and magnitude of GEI and stability analysis is important for understanding the response of different genotypes to varying environments and for the identification of stable and widely adopted, and unstable but specifically adapted genotypes.

Genetic diversity in plant genetic resources provides an opportunity for researchers to develop new and improved cultivars with desirable characteristics including farmers' preferred traits (Govindaraj *et al.*, 2015). It is a prerequisite for the identification of superior genotypes, which may be recommended for direct release as commercial cultivars for wider production, but also for the identification of desirable parents to use as source materials in breeding programs (Rajaravindran and Natarajan, 2011). The studies of the genetic diversity of plants are very important for developing high-yielding varieties and for maintaining the productivity of such varieties in plant breeding strategies. To develop promising genotypes, knowledge of genetic diversity is essential. Assessment of genetic diversity in cowpea genotypes would facilitate the development of cultivars for adaptation to specific production constraints. Therefore, better knowledge of the genetic differences of breeding materials could help to maintain genetic diversity and help in the development of breeding strategies. Genetic diversity is analyzed by using various methods such as morphological, biochemical, and molecular markers depending availability of resources. Information on characterizations of genotypes through morphological markers for their genetic variation helps plant breeders to utilize them for developing improved varieties. Previous studies reported genetic diversity among different varieties of cowpea (Nwosu *et al.*, 2013; Gbaguidi *et al.*, 2015 and Vaibhav *et al.*, 2015). However, no study has been so far conducted on the characterization and genetic diversity of cowpea genotypes in the southern region of Ethiopia.

Some studies have been conducted to investigate the effect of genotype by environment interaction on agronomic traits of cowpea genotypes (Horn *et al.*, 2018; Odeseye *et al.*, 2018; Abiriga *et al.* 2020; Nassir *et al.* 2021). The selection of stable cultivars that perform consistently across environments can reduce the effect of genotype by environment interactions. Hence, the stability of yield of a cultivar across a range of production environments is very important for a variety of recommendations. However, due to the diverse agroecology of the country, past research information on the extent and pattern of

GEI and performance stability on cowpea covered only limited areas in Ethiopia. It is hoped that a further understanding of GEIs in cowpeas leads to a more efficient allocation of resources in our multi-environment cultivar testing programs.

Agricultural research has focused on a few crops and relatively little research attention has been given to cowpea in Ethiopia in the last three decades. As a result lack of improved varieties, and top-quality seeds for planting further worsen the limitations to cowpea production in such regions. In a participatory approach, it is important to start with knowledge of what the farmers already have or have not in their existing cultivars. Participatory rural appraisal (PRA) approaches and methods enable local people to express, enhance, share and analyze their knowledge of life, experiences, and conditions, to plan, and to act (Chambers, 1994). It has been used extensively and successfully in developing countries to elucidate systems in rural areas. Horn *et al.* (2015) and Salifou *et al.* (2017) used PRA techniques to elucidate production constraints, preferred traits, and farming systems of cowpea in northern Namibia and Niger, respectively. A lot of the agronomic, socioeconomic, and environmental constraints of cowpea might be attributed to low yields in the growing areas of southern Ethiopia, but are not systematically documented. To determine the extent of these problems and suggest a way forward for cowpea improvement, it is essential to conduct a needs assessment survey among the cowpea production areas of southern Ethiopia.

Participatory techniques applied in plant breeding can have an impact on the development of improved crop varieties, making them faster and more cost-effective. Participatory crop improvement emerged as an alternative plant breeding approach for developing countries in response to the recognition that conventional breeding by formal sector institutions had brought little benefits to small-scale farmers in agro-ecologically and socioeconomically marginal and variable environments (de Boef and Ogliari, 2008). Farmer participatory variety selection is an approach designed to ensure that farmer preferences are included in a breeding program. There is a need to identify cultivars by including farmers' preferences to meet their demand (Yadaw *et al.*, 2006). Lack of suitable varieties for farmers' needs and conditions have been pointed as one of the reasons for low productivity and low rate of acceptance of improved varieties by farmers (Nkongolo *et al.*, 2009). The reasons, among others, include inadequate exposure to new varieties, lack of suitable ones, or the varieties are not adequate to satisfy farmers' needs. To alleviate this problem, one approach that has been practiced, mainly in resource-poor farming communities, is participatory varietal selection (PVS). On

the other hand, there is a lack of comprehensive performance and farmers' evaluations work on released and introduced cowpea genotypes in southern Ethiopia.

## **1.2. Statement of the problem, justification, objectives, and research questions**

### **1.2.1. Statement of the problem and justification**

Cowpea production notably contributes to food security and livestock feed, as an income source; farmers often sell the grain and leaves in the local markets and forms a major component of tropical farming systems because of its ability to improve soil fertility through nitrogen fixation and as a cover crop in Ethiopia (Alemu et al., 2016; Beshir et al., 2019). Cowpea grains are a favorable source of protein (19-25%), carbohydrates, B vitamins, and minerals, compared to animal products such as meat, fish, and egg, and cowpea plays an important role in human nutrition and the fight against malnutrition (Stoilova and Perira, 2013). They are therefore an affordable alternative protein source to the people of the poor, rural communities in Ethiopia and other developing countries. In addition, being a drought-tolerant and warm-weather crop, it is a promising food and forage species in a typical tropical lowland climate (Alemu et al., 2016; Belay et al., 2017). Even though cowpea is a multipurpose grain legume, a large gap exists between the production potential of improved cowpea varieties in the research environment (2.2 to 3.2 t ha<sup>-1</sup>) (Ashinie *et al.*, 2020) and the yield obtained at farm level 0.4 t ha<sup>-1</sup> only (Beshir et al., 2019), which is very low, in Ethiopia. Low yields (0.4 t ha<sup>-1</sup>), at farmers' fields, were due to some factors, including the absence of improved stable high-yielding farmers' preferred varieties, biotic and abiotic stress (Horn et al., 2015) are a growing threat to cowpea production as they reduce crop quality and quantity, which in the end affects the production and productivity of the cowpeas. Although this much production and productivity is comparably very low, the crop has a significant contribution to the food security of the smallholder farming communities' particularly residing in a lowland area of the country where food insecurity is prevalent.

Nationally, both haricot bean and cowpea researches are coordinated by Melkasa Agricultural Research Centre (MARC). The research program on both crop breeding aims to develop widely adapted, stable, and high-yielding genotypes to improve the production and productivity of the crop in the country. So far about 50 (fifty) haricot bean varieties have been released from MARC and other research centers whereas only six cowpea varieties from various research centers of the country. Though Ethiopia has a tremendous capacity for the production of cowpea, agricultural research so far has focused on a few staple crops such as peas, beans, chickpeas, and lentils (Alemu et al., 2016; Belay and Fisseha., 2021) and

relatively little research attention has been given to cowpea. There is only a little research work has been conducted in the field of cowpea improvement in southern Ethiopia. Thus, Ethiopian farmers in general and those in SNNPR, in particular, are unable to exploit the potential yield of the crop. Therefore, the present study was carried out with the following objectives.

### **1.2.2. OBJECTIVES OF THE STUDY**

1. To assess farmers' perceived production constraints, farmers' perceptions, farmers' traits of preferences, and the production systems of cowpea in Southern Ethiopia
2. To estimate the genetic diversity among cowpea genotypes based on morpho-agronomic traits
3. To assess the magnitude of genotype by environment interaction and yield stability of cowpea genotypes and thereby identify broadly and/or narrowly adapted genotypes for production in South Ethiopia and
4. To assess and select superior cowpea variety/varieties that meet farmers' needs and preferences through farmers' participatory selection and to identify farmers' selection criteria.

### **1.2.3. Research Questions**

1. What are the farmers' perceived production constraints, farmers' perceptions, farmers' traits of preferences, and the production systems of cowpea in Southern Ethiopia?
2. Is there genetic diversity among cowpea genotypes based on morpho-agronomic traits?
3. Is there high grain yield performance stability in the cowpea genotypes in South Ethiopian production environments?
4. What are the superior cowpea variety/varieties that meet farmers' needs and farmers' selection criteria in the study area?

### **1.2.4. Research hypotheses**

The research tested the following hypotheses:

1. Farmers' have different perceptions, production constraints, preferred traits, and production systems of cowpea in Southern Ethiopia
2. There is no genetic difference exists among promising and released cowpea genotypes
3. There is a difference in cowpea genotypes in their response to varying environments; some are widely adapted; some have specific adaptation while the others are not adapted to the tested environments.

4. Farmer-focused participatory varietal selection enables the identification of improved cowpea varieties that meet farmers' needs and preferences.

### 1.3. Summary of the thesis

1. **Chapter one:** provides a general introduction, and objectives.
2. **Chapter Two:** Literature review
3. **Chapter Three:** presents production constraints, farmers' perceptions, farmers' preferred traits, and production systems of cowpea in southern Ethiopia
5. **Chapter Four:** Assessment of Genetic Diversity in Cowpea (*Vigna unguiculata* (L.) Walp) Genotypes in Southern Ethiopia based on Morpho-Agronomic traits
6. **Chapter Five:** presents Genotype by Environment Interaction and Yield Stability of Cowpea (*Vigna unguiculata* (L.) Walp.) Genotypes in Moisture Limited Areas of Southern Ethiopia.
7. **Chapter Six:** discusses Performance and Farmers Participatory Selection of Cowpea Varieties in Southern Ethiopia;
8. **Chapter Seven:** presents the summary, conclusions, recommendations, and future research needs. All the chapters, except three Chapters 1, 2, and 7, follow the IMRAD format (Introduction, Materials and Methods, Results and Discussion). Chapters 3 to 6 are written as scientific papers, in a publishable format, and some of the text and references may therefore overlap.

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## CHAPTER TWO

### 2. LITERATURE REVIEW

#### 2.1. Origin, domestication, and distribution

Cowpea [*Vigna unguiculata* (L.) Walp., Fabaceae ( $2n = 2x = 22$ )] is an essential leguminous crop in less-developed countries of the tropics and subtropics, especially in sub-Saharan Africa, Asia, and Latin America (Singh *et al.* 1997). Cowpea belongs to the class *Dicotyledonea*, order *Fabales*, family *Fabaceae*, subfamily *Faboideae*, tribe *Phaseoleae*, subtribe *Phaseolinae*, and genus *Vigna* (Padulosi and Ng, 1997). The genus was divided into sub-genera based upon morphological characteristics, the extent of genetic hybridization, and the geographical distribution of the species. The major groups consist of the African sub-genera *Vigna* and *Haydonia*, the Asian sub-genus *Ceratotropis*, and the American sub-genera *Sigmoidotropis* and *Lasiopron* (Timko and Singh, 2008). Cowpea most likely originates from Africa, as wild cowpeas only exist in Africa and Madagascar (Steele, 1976). The center of diversity of cultivated cowpea is found in West Africa, in an area encompassing the savannah region of Nigeria, southern Niger, parts of Burkina Faso, northern Benin, Togo, and the northwestern part of Cameroon and it is considered to have been domesticated in Africa from its wild ancestral form, *V. Unguiculata subsp. dekindtiana* (Harms) Verdc. (Ng and Marechal, 1985). Africa is the origin of cowpea where domestication took place as well. Centers of diversity have been identified in both Africa and Asia; however, the exact region of domestication is still under speculation (Angessa, 2006). Currently, cowpea is grown throughout the tropic and subtropics areas of the world.

#### 2.2. Morphology and biology

Cowpeas are generally more vigorous in appearance than common beans with better-developed root systems and thicker stems and branches. According to Fox and Young (1982) cowpea is an annual herb reaching heights of up to 80 cm with a strong taproot and many spreading lateral roots in the surface soil. Types of cowpea in terms of growth habits could be erect or sub-erect, trailing, climbing, or bushy. The prostrate or indeterminate type and the erect or determinate type can be distinguished from one another by different factors such as seed size and color, taste, yield, and time to maturity. The indeterminate that is also spreading type is both early and late-maturing with large and small seeds being produced, while determinate types of cowpea are early maturing types with small leaves and seeds (Duke, 1981). Keding *et al.* (2007) report for Tanzania that the prostrate types mature in 140 days

allowing repeated leaf picking without compromising seed yield, while the erect types take about 80 days to mature, and leaf picking affects seed yield. In Malawi, the prostrate or indeterminate types are grown for subsistence farming with grain and leaves being harvested while, on the other hand, the erect, or determinate types are in most cases suitable for commercial farming in mono-cropping systems with main grain being harvested (Nkongolo, 2003).

Variability in the morphology of different cowpea accession is very high. There are three types according to their uses: for grain, forage, or dual purpose. Seeds are relatively large (0.2-1.2 cm long) and weigh 5-30 g/100 seeds. They are variable in size and shape: kidney, ovoid, crowder, globose and rhomboid (IBPGR, 1983).

### **2.3. Production and roles of cowpea in Ethiopia**

In Ethiopia, cowpea production under small-scale farming is mostly in the Gamogofa zone especially in districts of Gofa, Konso, Derashe, and Hamerbako as well as in some pocket areas of Showa, Gojam, Wellega, and Hararghe (Tessema and Eshetayehu, 2003). According to Eshte *et al.*, (2015), cowpea is one of the major pulse crops grown in the South Omo zone (South Ari, and Benatsemay district) and Segen people's area zone (Konso special district).

In southern parts of Ethiopia intercropping of cowpea with maize is a common practice among traditional farmers of the Gofa area. Cowpea has the potential to serve as a key legume species for intensifying the crop and livestock production systems by supplying protein in human diets and fodder for livestock, as well as bringing nitrogen into the farming system through biological fixation (Bilatu *et al.*, 2012; Ayana *et al.*, 2013). Bilatu *et al.*, (2012) also stated that the average grain yield for the seven cowpea varieties was 2.22 t ha<sup>-1</sup> which varied among varieties in three districts of Metekel zone, Ethiopia. Being an excellent protein source for both animals and humans, cowpea can positively impact on food security of the society in the study area where the bulk of the diet is mainly starch. In previous studies on cowpea grain yield ranged 0.371 t ha<sup>-1</sup> to 1.14 t ha<sup>-1</sup> in Ethiopia Ayana *et al.* (2013), 1.74 t ha<sup>-1</sup> to 3.53 t ha<sup>-1</sup> (Solomon and Kibrom, 2014), 1.72 t ha<sup>-1</sup> to 3.47 t ha<sup>-1</sup> ( Bilatu *et al.*, 2012), 1.5-3 t ha<sup>-1</sup> in Nigeria under good management (Blade, *et al.*,1997) and 3 t ha<sup>-1</sup> in Senegal (Anthony, 2012) which was nearly equivalent to the yield recorded in another country while the actual yield is the country lowest among pulse crops averaging 0.4 t ha<sup>-1</sup>. Another important feature of cowpea is also its ability to suppress weeds, particularly *Striga* species on sorghum fields (Dawit *et al.*, 2009) where it highly infests the western zone of Tigray with great yield loss. Hence, the integration of cowpea with the existing farming system could

have significant importance in improving feed quality and soil fertility, and productivity. Although cowpea could give promising grain yield even higher than other countries and the staple crop sorghum (*Sorghum bicolor* L.) in our country, thus it is imperative to create more awareness of people towards the importance of cowpea in Ethiopia as well as in the southern region. Presently, there is a trend of cowpea production in some localities of Southern Ethiopia, such as the Konso areas and some parts of the South Omo zone are increasing, since these zones are endowed with good potential for cowpea production (Yoseph, 2014).

## **2.4. Production constraints to cowpea**

### **2.4.1 Biotic constraints**

#### **2.4.1.1. Fungal diseases**

Bailey *et al.*, (1990); (Singh, 2005) reported leaf smut (false smut or black spot), caused by *Protomyces phaseoli* is one of the most destructive fungal diseases of cowpea. Fungal diseases cause leaf smut, stem rot as well as root rot (Bailey *et al.*, 1990). A study on fungal diseases conducted by Mbeyagala *et al.*, (2014) has been reported Yield losses of 20 to 100%. Sources of resistance to fungal pathogens have been recognized, and screening techniques are well developed (Gbaguidi *et al.*, 2013; Pujari *et al.*, 2015). Yield losses because of fungal diseases have been reported in some African countries. Conversely, serious epidemics were reported in Nigeria, the Sudan savanna, and Sahel (Adejumo *et al.*, 2001; Singh, 2005). Even though rust was a commonly observable disease under the cowpea experimental field, so far no study has reported fungal diseases of cowpea in South Ethiopia. There is no information available on fungal diseases of cowpea in Ethiopia.

#### **2.4.1.2. Bacterial diseases**

The common and serious bacterial diseases of cowpea reported in the literature are bacterial blight caused by *Xanthomonas campestris* pv. *vignicola* and bacterial pustule caused by *Xanthomonas campestris* pv. *vignaeuguiolatae* (Viswanatha *et al.*, 2011). According to Viswanatha *et al.* (2011), the two pathogens were reported to cause yield reductions reaching up to 71% in the pod, 68% in seed, and 53% in fodder in susceptible varieties in India. During moderate infection, the bacteria cause yellowing of the leaves increasingly showing irregular to round spots. This will lead to senescence and the dropping of leaves. Reddy *et al.*, (2013) further reported that some bio-control agents are effective in controlling bacterial blight disease of cowpea. So far no study has reported bacterial diseases of cowpea in South Ethiopia.

### **2.4.1.3 . Insect pests**

Cowpea suffers serious insect pest infestation from the time of planting through harvesting and during storage (Obeng-Ofori, 2007). Insect pests attack cowpea both in the field and in stores are associated with the crop, which if not controlled could lead to total crop failure. The pest problem is more serious in Africa than in Asia or Latin America (Singh and Jackai, 1985). In Africa, the major field pests of cowpea are aphid (*A. craccivora*), legume flower thrips (*M. sjostedti*), bruchids (*Callosobruchus maculatus* (Fabricius), legume pod borer (*M. vitrata*), and pod-sucking bugs (*C. tomentosicollis*, *Leptoglossus spp*, and *N. viridula*) (Obeng-Ofori, 2007; Boukar and Fatokun, 2009; Dugje *et al.*, 2009). The pests occur throughout the vegetative growth stages of the plant, feeding on the leaves and also acting as virus vectors. In southern Ethiopia, farmers described the predominant field pests causing yield losses in cowpea to include aphids, pod borers, and bruchids. In SSA bruchids are the leading pests of cowpea affecting stored grains. Bruchids damage cowpea grains which may lead to losses reaching up to 100% (Stejskal *et al.*, 2006; Gbaguidi *et al.*, 2013; Horn *et al.*, 2015). Swella *et al.*, (2007); Ilesanmi and Gungula, (2011) reported some effective control methods such as treating seeds with Actellic dust and black pepper powder to have significantly lower percentages of seeds damages in cowpea. Black pepper powder and coconut oil were also recommended for their potential in protecting cowpea against bruchid damage. Studies to determine the effects of neem (*Azadirachta indica* (A. Juss)) and moringa (*Moringa oleifera*) seed oils by Ilesanmi and Gungula, (2011) revealed that treated seeds with various concentrations were not infested by bruchids.

#### **2.4.1.3.1. Aphids**

Insect pests are major constraints in limiting the productivity of cowpea. Insect pests belong to the major biotic stresses in cowpea growing regions in both developing and developed countries (Dauost *et al.*, 1985). Singh and Allen, (1980) reported under severe infestation insect pests, 100% yield loss has been observed. Some insect pests are associated with cowpea crops, *viz.*, aphid, *Aphis craccivora* Koch; pod borer, *Maruca testulalis* (Geyer); galerucid beetle, *Madurasia obscurella* (Jacoby); cowpea curculio, *Chalcodermus aeneus* (Boheman), etc. Among these, the aphid *A. craccivora* (Hemiptera: Aphididae) has been reported as a major insect pest of cowpea (Attia *et al.* 1986; Dhaliwal 2008). In many cowpea growing areas, aphids are the major causing factor for significant yield losses. Both nymphs and adults cause damage by sucking the cell sap on the tender portions of plants including the lower side of the leaves. In case of severe infestation, all parts of the plants including the

Pods are covered. The high infestation results in stunted growth and decreased yield. The honeydew secretion of the aphid provides suitable media for the development of sooty mold which ultimately hampers the process of photosynthesis (David and Kumarswami, 1982). Early infestation, especially during the seedling stage, often results in total crop failure. Their feeding especially on the fruiting stems reduces the number of nutrients available for pod and seed development. Foliage infested with aphids turns yellow and dies. So far there is limited information available on aphids of cowpea in south Ethiopia.

#### **2.4.2. Abiotic constraints**

Drought and poor soil fertility are the major abiotic factors affecting cowpea production and productivity. The negative effects of drought stress in sub-Saharan Africa including Ethiopia have been reported. Abiotic stresses led to the loss of many land-races varieties of crops including pearl millet, sorghum, and legumes (Hall, 2004). According to Hall (2004), Cowpeas are sensitive to severe droughts, especially during pod setting and grain filling stages. Poor soil fertility is another major constraint limiting cowpea production. In Namibia, cowpea production is carried out in soils with poor fertility levels and most farmers did not apply fertilizers (Horn *et al.*, 2015). A recent survey report from southern Ethiopia indicated that cowpea production is carried out in soils with poor fertility levels and most farmers did not apply fertilizers.

#### **2.4.3. Socio-economic constraints**

Horn *et al.* (2015) and Sabo *et al.* (2014) suggested some socio-economic constraints detrimentally affecting cowpea production in sub-Saharan Africa (SSA). These include non-availability of market preferred varieties, low yield potential, high cost of farmland preparation, lack of improved production and harvesting tools, high cost and absence of labor, high cost and adulteration of pesticides, poor harvest prices, and underdeveloped marketing channels.

Additional major constraints to cowpea production in many SSA countries are the lack of a defined value chain and poor development of cowpea as a commodity crop. According to Fakayode *et al.*, (2014), there are no efficient transport systems, and cowpea trading is not organized due to limited value addition and lack of cowpea enterprises. Aboki and Yuguda, (2013) have been reported that farmers merely survive on cowpea farming which is the major economic mainstay and business in Nigeria and other West African countries. Fakayode *et al.*, (2014) also reported in West Africa cowpea trades enable farmers to buy other cereal grains and farm inputs such as fertilizers making it easy to have access to agricultural inputs.

In southern Ethiopia, farmers earn cash incomes from sales of cowpea grains and to some extent from fodder (Sisay, 2015) though the economic values of cowpea products are low. According to Waddington et al. (2010), converting cowpea into baby food might bring about a rise in the price of the commodity which will also bring higher returns to the producer. Cowpea is an important weaning food in many communities in Africa and Asia. In SSA its demand is particularly high (Ibro *et al.*, 2014). Raising the average yield per hectare of the crop will therefore increase the annual global production and hence the revenue.

Several reports indicated that the potential yields of cowpea can reach up to 3 t ha<sup>-1</sup> if most of the constraints are alleviated (Aboki and Yuguda, 2013; Diriba *et al.*, 2014). Therefore, a targeted cowpea improvement program is needed to improve the production and productivity of the crops incorporating farmers' and consumers' preferences. The introduction of new cowpea genotypes with desirable traits/ improved cowpea production technology into the production system would significantly raise incomes from cowpea production.

### **2.5. Genotype by environment interaction and yield stability in cowpea**

Multi-environmental trials are helpful in plant breeding programs primarily to determine the relative performance and stability of cultivars and make recommendations with specific or wide adaptation (Becker, 1988). The development of new genotypes involves breeding of genotypes with desired characteristics such as high economic yield, tolerance or resistance to biotic and abiotic stresses traits that add value to the product, and the stability of these traits in target environments (Horn et al., 2018). Inconsistent genotypic responses to environmental factors such as temperature, soil moisture, soil type, or fertility level from location to location and year to year are a function of genotype-environment interactions (GEI) (Kang, 1998; Abiriga et al., 2020). The relative performance of genotype(s) across environments has raised important and challenging issues among plant breeders, geneticists, and Agronomists (Babic *et al.*, 2008; Kuruma et al., 2019). The presence of genotype × environment interaction necessitates the evaluation of genotypes in a wide range of environments to find desirable genotypes (Rasul *et al.*, 2005; Horn et al., 2018). The differences between the locations for the performance of genotypes for traits are an indication of the reaction of genotypes to environmental changes.

Genotype x environment interaction for yield has been studied in several crops. Some research institutions are working and able to screen out cowpea varieties for yield that resist harsh environmental conditions and produce consistently better grain yield. Cowpea performance, like any crop, however, vary with the environment (Aremu and Ojo, 2005;

Aremu *et al.*, 2007; Francis, 2007; Yousaf and Sarwar, 2007; Matova and Gasurae, 2018), several varieties have to be evaluated in multiple environments for the identification of suitable genotype for a specific environment. There are many cowpea varieties available, which makes selection a challenge because of the genotypes response variation across different environments. *i.e.* the so-called genotype by environment interactions. The genetic yield potential is realized only when management and environmental conditions are complementary (Ehlers and Hall, 1996). In Ethiopia Kassaye *et al.* (2013) observed significant genotype by environment interaction in early maturing cowpea variety trials undertaken in different agro-ecologies of Ethiopia. However, no information on the effect of GEI for the yield performance of elite introduced and released cowpea genotypes under Southern low land growing conditions is limited. When GEI is present, one of the best things that a breeder can do is to use stability analyses to identify the highest and most stable yielding cultivars (Beyene *et al.*, 2012).

Several methods have been proposed to analyze and interpret the genotype  $\times$  environment interaction. These include contrasts (Yan and Hunt, 1998), linear regression (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966), multivariate analysis such as principal component analysis (Zobel *et al.*, 1988) and additive main effect and multiplicative interaction (AMMI) (Gauch and Zobel, 1997). Therefore identifying genotypes with stable grain yield and evaluating genotype  $\times$  environment (GEI) interaction requires a more sophisticated statistical tool. Additive main effects and multiplicative interaction (AMMI) compared to other models, was however espoused/supported by Gauch (2006) thus affirming its importance in environment-based selection for genotype breeding and selection for optimum performance. In addition, it was observed that AMMI uniquely separates G, E, and GE as required for most agricultural research purposes, and also separates structural variation from noise as well as any other method to gain accuracy (Anandan *et al.*, 2009).

Grain yield and other plant traits of cowpea are usually influenced by growing conditions ultimately creating a genotype by environment interaction (GEI) (Akande, 2007). Multi-environment trials are typically used in plant breeding programs to evaluate materials across a range of sites representing target environments for the crop (Berger *et al.*, 2007). GEI is the relative change in the performance of genotypes across sites, which can be classified as noncrossover (Quantitative) and crossover (Qualitative). A noncrossover (GEI) interaction is said to occur when one genotype (G1) consistently outperforms another genotype (G2) across the test Environment. The differential and the nonstable response of Genotypes to diverse

Environments is referred to as a crossover interaction when the ranks of Genotype change or switch from one Environment to another (Tesfaye et al., 2011). Crossover interaction implies that no Genotype is superior in multiple Environments. Thus it is important to understand the nature of GEI strategies for testing and selecting superior varieties. A key concept in genotype by environment (G x E) analysis is genotype stability and by definition, genotypes exhibiting a high degree of GEI are unstable across sites (Berger *et al.*, 2007). In GEI studies genotypes adapted to specific and to a wide range of environmental conditions could be identified.

The stability performance of cowpea varieties across contrasting environments is essential for the successful selection of stable and high-yielding varieties (Ariyo and Ayo-Vaughan, 2000). Moreover, the stable genotypes concerning the grain yield under variable environments may be useful for direct release as a variety or in a breeding program for evolving high-yielding and stable cowpea genotypes adapted to this variable environment (Horn *et al.*, 2018). In crop improvement programs usually, tests of variety performance across a wide range of environments are conducted to minimize the effect of GEI and to ensure that the selected genotypes have a high and stable performance across several environments. Some studies have been conducted to analyze the effect of GEI on cowpea genotypes in Ethiopia. However, the changing environmental conditions of Ethiopia as well as southern parts and inadequate cowpea varieties available for the different environments require a careful and continuous study of GEI for a dynamic crop improvement program.

## **2.6. Genetic diversity in cowpea**

Genetic diversity of crops plays an important role in sustainable development and food security, as it allows the cultivation of crops in the presence of various biotic and abiotic stresses. Knowledge of phenotypic variation and relationships among genotypes will assist breeders to develop appropriate breeding strategies and creating the most adaptive and productive cultivars. The use of genetic diversity in breeding programs is important to decrease crop vulnerability to abiotic and biotic stresses (Ibrahima *et al.*, 2014). Generally, cowpea varieties that have large variability will be good candidates for varietal improvement. Genetic diversity is analyzed by using various methods such as morphological and molecular tools.

### **2.6.1. Morphological diversity in cowpea**

Morphological markers help to visually characterize qualitative and quantitative phenotypic characters. A quantitative assessment of the genetic diversity among the collection of

germplasm and their relative contribution of different traits towards the genetic variation provide essential and effective information to breeders in hybridization programs and thereby genetic improvement of yield (Nagalakshmi *et al.*, 2010; Selamawit *et al.*, 2020). The study among genotypes for variation in morphological, phenological, and agronomic traits would be useful in the development of new varieties with better adaptation to biotic and abiotic stress factors, as well as for high yield potential (Stoilova and Pereira, 2013). The bigger number of cowpea accessions/lines allows selecting the most appropriate of them for respective breeding objectives after a complex evaluation of samples (Hamidou *et al.*, 2007; Agbicodo *et al.*, 2009). The use of morphological markers is the earliest genetic marker used for the assessment of variation and still has great importance. Increasing major components of grain yield such as pods/plant, pod length, seed/pod, and seed size will allow improving cowpea yield potential. Diriba *et al.* (2014) reported high phenotypic and genotypic coefficient of variation, heritability in a broad sense, and genetic advance estimated for the characters viz., yield per plant, number of pods per plant, and 100-seed weight. Hobdari *et al.* (2012) characterized *L. Sativum* genotypes using quantitative and qualitative morphological characters and proved the presence of significant variation among studied genotypes. Tesfaye *et al.* (2019) found highly significant differences among 324 cowpea landraces for the morphological traits. The results published by Stoilova and Pereira (2013) confirmed increasing major components of grain yield such as pods/plant, pod length, seed/pod and seed size of 48 genotypes of cowpea will allow improving cowpea yield potential. The variability of these morphological traits has been reported by different authors, such as Mishra *et al.* (2002), Carnide *et al.* (2007), and Belay and Fisseha, (2021). Knowledge of phenotypic variation and relationships among genotypes will assist breeders to develop appropriate breeding strategies and creating the most adaptive and productive cultivars. The study on cowpea genotypes variation in morphological, phonological, and agronomic traits would be useful in the development of new varieties with better adaptation to biotic and abiotic stress factors, as well as for high yield potential.

#### **2.6.1.1. Quantitative traits**

Quantitative traits are influenced by environmental factors, implying that these traits show continuous variation (Melese, 2005). These results in high genotype and environment interactions that make it difficult to determine genetic variation based on morphological traits accurately. Tesfaye *et al.* (2019) also revealed highly significant variation among studied cowpea genotypes for all the quantitative morphological characters. Stoilova and Pereira

(2013) also stated that the phenological stages (days to flowering and days to maturity) showed a lower coefficient of variation. Similar results were reported by Hedge and Mishra (2009). Most of the studied quantitative traits were influenced by environmental conditions. The findings of Stoilova and Pereira (2013), however, showed that pod length, number of seeds per pod, seed thickness, and 100 seed weight were less affected by external conditions. These results suggest that these four descriptors should be useful in the coming evaluation studies. Belay and Fisseha (2021), reported that, a high value of genetic gain and heritability for seed weight, number of pods, seed yield, number of seeds/plant, and days to flowering. The variability of these morphological traits has been reported by different authors, as (Mishra *et al.*, 2002; Carnide *et al.*, 2007; Diriba *et al.*, 2014) on cowpea; Selamawit *et al.* (2019) on cowpea.

Zerihun (2011) reported the higher magnitude of mean squares due to genotypes were higher for biological yield, grain yield, number of seeds per plant, and harvest index and lower for the number of primary branches per plant. Belay *et al.*, (2017) also reported the higher magnitude of mean squares of genotypes of cowpea in biological yield, grain yield number of seeds per plant, and harvest index. This indicated that these traits were relatively sensitive to environmental effects and reflected insignificant variability. Traditionally, diversity is estimated by measuring variation in phenotypic or quantitative agronomic traits such as yield potential, stress tolerance (Kameswara, 2004). Knowledge of phenotypic variation and relationships among genotypes will assist breeders to develop appropriate breeding strategies and creating the most adaptive and productive cultivars.

#### **2.6.1.2. Qualitative traits**

Physiological, morphological, or phenological criteria could be implemented to select the improved adaptation to environments (Blum, 1988). Traditionally, diversity is estimated by measuring variation in phenotypic or qualitative traits (plant type, flower color, seed type, seed color, seed size, hilum color) and quantitative agronomic traits (Stoilova and Pereira, 2013). Qualitative traits are less influenced by environmental factors, unlike quantitative (Melese, 2005; Singh *et al.*, 2008). Tesfaye *et al.*, (2019) evaluated 324 cowpea accessions and reported that qualitative morphological traits such as growth habit, seed shape, seed color, and seed texture had high diversity ranges. Conventionally, diversity is estimated by measuring variation in phenotypic or qualitative traits such as flower color, seed color, seed size, and growth habit (Kameswara, 2004). Stoilova and Pereira (2013) reported that for the consumers and farmers, the most important characteristics of cowpea seed as in all food

legumes are seed color, seed size, and seed coat. Omoigui *et al.* (2006) and Stoilova and Pereira (2013) also confirmed that the seed size was not influenced by the duration of the reproductive phase; it is governed by other genetic factors. In general, qualitative morphological markers are extremely useful to plant breeders for the selection of superior yielding varieties (Collard *et al.*, 2005; Belay and Fisseha, 2021).

## **2.7. Participatory rural appraisal (PRA) and participatory variety selection (PVS)**

In an effective participatory approach, it is significant to start with knowledge of what the farmers already have or have not in their existing cultivars. Participatory rural appraisal (PRA) approaches and methods enable local people to express, enhance, share and analyze their knowledge of life and conditions, to plan, and to act (Chambers, 1994). It has been used extensively and successfully in developing countries to elucidate systems in rural areas. Horn *et al.* (2015) used PRA techniques to elucidate production constraints, preferred traits, and farming system of cowpea in northern Namibia. Salifou *et al.* (2017) also used PRA techniques to evaluate farmers' Preferred Traits and Perceptions of Cowpea Production and Constraints in Niger. In Ethiopia, varietal selections of cowpea have usually been dominantly based on grain yield. Even though some breeding lines have been developed at research stations and their performance evaluated across multi-location tests over several years so far only six varieties released. A few years ago varietal evaluation and decisions were only made by researchers. However, this did not lead to the expected speed of variety release, or their dissemination afterward. Presently there is an involvement of some model farmers in the variety selection process though these participations may be of interest to only a few farmers. These illustrate the existing communication gap between breeders and farmers. The importance and complex nature of agricultural research demand coordinated effort among biological scientists, extension agents, and farmers to ensure that appropriate technology is developed and promoted (Rao *et al.*, 2004). Therefore, adding information that takes farmers' perspectives and preferences into consideration would be helpful to the variety selection process. Research costs can be reduced and adoption rates increase if the farmers are allowed to participate in variety testing and selection (Yadaw *et al.*, 2006). However, these useful tools have not been extensively applied to cowpea production, especially in Southern Ethiopia.

According to Alam and Ihsan (2012), participatory research techniques have been successfully used to identify farmers' perceived production constraints, preferred crop varieties, and traits for the deployment of production packages and suitable crop varieties.

The development of high-yielding cowpea varieties with enhanced resistance to biotic stress and tolerance to major abiotic stress requires the involvement of all relevant stakeholders so that suitable varieties can be developed. There has been an increased awareness of the role of farmers' participation in agricultural research. Information obtained from different sources has suggested that the involvement of farmers in agricultural research can provide useful information that can contribute to increasing crop productivity and the adoption of new improved varieties (Bellon, 2001). Nkongolo *et al.*, (2008) also stated that based on the breeding goal and the environment, farmers could contribute significantly at different stages of crop cultivar design, development, release, and adoption.

PVS is a more rapid and cost-effective way of identifying farmer preferred cultivars if a suitable choice of cultivars exists. Nadiso *et al.* (2016) defined participatory varietal selection (PVS) as a simple way for breeders and agronomists to learn which varieties perform well on-station and on-farm and to obtain feedback from the potential end-users in the early phases of the breeding cycle. It is a means for social scientists to identify the varieties that most men and women farmers prefer, including the reasons for their preference and constraints to adoption (Paris *et al.*, 2011). Numerous researchers including (Hoffmann *et al.*, 2007; vom Brocke *et al.*, 2010; Nadiso *et al.*, 2016; Horn *et al.*, 2018) have reported the importance of PVS. Rusinamhodzi and Delve (2011) suggested that understanding farmers' requirements and trait preferences, as well as their farming systems, is essential for the wide adoption of newly developed crop varieties and production technologies. In PVS, the participants are selected based on their indigenous knowledge, and selection is done based on farmers' selection criteria such as diseases, pest and drought tolerance, yield, grain characteristics (vom Brocke *et al.*, 2010). Besides, Nkongolo *et al.* (2008) stressed that field extension workers and the village chiefs are more familiar with farmers in the study sites and are often helpful during PVS.

In Ghana and Cameroon for instance, consumers "pay a premium" if their preferences are met, regardless of their economic status (Langyintuo *et al.*, 2004). Consequently, Langyintuo *et al.* (2003) advised that cowpea breeders develop varieties taking into account the regional differences in terms of farmers' preferences. Experience from a maize project in Mexico also indicated that using participatory methods it was possible to improve crop productivity and at the same time maintain or enhance maize diversity (Bellon, 2001). Similarly, in Ethiopia, efforts have been made to develop and popularize improved varieties of maize through participatory variety selection (Daniel *et al.* 2014). Participatory methods have also been used

in other crops including common bean (Fekadu, 2013), Malt barley (Yetsedaw et al., 2013), and cowpea (Nkongolo *et al.*, 2009; Nadiso *et al.* 2016; Horn *et al.*, 2018). Participatory variety selection has shown success in identifying the number of preferred varieties by farmers in a shorter time (than the conventional system), in accelerating their dissemination, and increasing cultivar diversity (Weltzien *et al.*, 2003). To date, only limited efforts have been made to promote and popularize improved cowpea varieties through participatory variety selection (PVS) and the farmers' selection criteria for varieties were not adequately assessed and well documented, especially in southern Ethiopia.

Therefore, it is recommended for present and future improvement programs to be carried out towards meeting the specific farmers' needs and preferences. Moreover, an improvement program aiming at specific agricultural practices and production constraints for specific areas and generating cultivars with wide adaptation is encouraged.

## 2.8. References

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## CHAPTER THREE

### 3. PRODUCTION CONSTRAINTS, FARMERS' PERCEPTIONS, FARMERS' PREFERRED TRAITS, AND PRODUCTION SYSTEMS OF COWPEA IN SOUTHERN ETHIOPIA

#### Abstract

*Cowpea is an important lowland legume crop of the Fabaceae family. It has a considerable contribution to the Livelihoods of smallholder farmers yet remained poorly researched and unimproved crop. The study was conducted in the Gofa, Humbo, Kindo Koyisha, and Konso districts of South Nation, Nationalities, and Peoples' Region (SNNPR) in the year 2016 to assess the limitations on cowpea production conceived by farmers, farmers' traits of interest, and the cowpea production system. This information is crucial for crop improvement. In light of this, participatory rural appraisal tools, which include seven focus group discussions, key informants, and surveys with 150 individual farmers, were used to generate data. Data recorded were analyzed on SPSS software and descriptive statistics were applied. Results showed that cowpea was mainly grown in small plots of 0.24 ha with 0.503 t ha<sup>-1</sup> as an average grain yield, mainly by men (85.3%) and the size of families ranged from 6 to 9 people at the household level. The majority (87.4 %) of farmers agreed that cowpea helps to achieve food security, but 12.6% disagreed about the contributions of cowpea for food security. A range of 55.3% of farmers produced cowpea for household consumption, while 12.7% declared their food and income. The results revealed that few farmers (7.3%) grew local varieties and improved varieties, but 92.7% grow only their local landraces, whose seeds are recycled for many consecutive years. Cowpea was cultivated as an intercrop with maize or sorghum. Results showed that the key cowpea production constraints were disease and insect pests, drought, lack of improved varieties, poor access to credit services, poor access to extension, sub-optimal agronomic practices, low soil fertility, farmland shortage, and storage pests. Farmers also said they had developed few management mechanisms to counter the constraints. Farmers identified poor soils as the major constraints on cowpea production. To solve the problem of soil infertility, only 13.3% of the respondents in the surveyed area applied some kind of fertilizer, while most of the farmers (86.6%) were aware of the role of cowpea in soil fertility improvement. The traits of cowpea varieties preferred by farmers were high yield, early maturity, resistance to insect pests (aphids, weevils) and diseases, tolerance to drought, good taste, large seed size, fast cooking, and white/red seed color. Therefore, it is recommended that there be a cowpea improvement program capable of addressing the aforementioned constraints and the preferences of farmers for sustainable cowpea production. The research serves as the basis for designing research and development programs for sustainable cowpea production and productivity by smallholder farmers in southern Ethiopia and similar areas.*

**Keywords:** Cowpea, Farmers preferred traits, Identification, production constraints

### 3.1. INTRODUCTION

Cowpea is an important food legume cultivated in the semi-arid tropics, covering Africa, Asia, Southern Europe, and Central South America (David *et al.*, 2013). There are more than 12.61 million hectares of cowpea acreage worldwide, with an annual grain production of about 5.59 million tons. Of these, 94% of grain production is found in Africa (FAO, 2014). Nigeria is the world's largest producer of cowpea, accounting for more than 2.5 million tons of grain production from an estimated 4.9 million hectares (FAO, 2014).

In Ethiopia, cowpea is grown in most of the lowlands of the North, the South, Gambella, and the Eastern parts of Ethiopia (Kassaye *et al.*, 2013); however, the key production complexes are situated in the southern and western parts of the country (Beshir *et al.*, 2019). Cowpea can be a multi-purpose crop that provides grain and fodder haulms that contain about 20 % protein with high digestibility and low fiber. Cowpea fodder is used to feed livestock, especially during the dry season, when feeds are scarce, so the crop provides excellent supplements to the lower nutritional content in cereals, roots, and or tubers that are often consumed in most of the resource-poor households (Chiulele *et al.*, 2011). Cowpea also improves soil fertility, thereby reducing fertilizer costs, especially for low-input smallholder farming households (INIA, 2000).

Despite its versatility and economic value for the lives of lots of subsistence farmers, the national mean yield of cowpea in Ethiopia is estimated to be 0.4 t ha<sup>-1</sup> (Beshir *et al.*, 2019) while the yield potential of cowpea averaged 1.5 to 6 t ha<sup>-1</sup> depending on genotype (Asiwe *et al.*, 2008). Therefore, there is a large gap between the actual and potential yield of a crop; and hence this calls for efficient research approaches or interventions to narrow down this gap.

Information obtained through participatory rural appraisal (PRA) studies can help researchers to outline their improvement programs to suit farmers' preferences. In developing countries, the PRA has been widely used successfully to create clear systems in rural areas. Horn *et al.* (2015) used PRA techniques as well to elucidate cowpea farming systems, production constraints, and traits of preference as an implication for breeding in northern Namibia. Ibitoye *et al.* (2018) used the PRA technique to identify the impact of drought stress on cowpea production and farmers' income, production constraints, and preferred traits in Kano state, Nigeria, to be included in breeding for improved varieties. Gonné *et al.*, (2018) conducted PRA studies in Cameroon on cowpea and reported that farmers preferred high yield, insect resistance, large seed size, *Striga* tolerance, and drought tolerance. The researcher also stated cowpea production constraints that included insect pests, lack of

improved varieties, *Striga* infestation, drought, declining soil fertility, and diseases. Tekalign *et al.* (2016) used PRA techniques to evaluate threats to production, farmers' desired traits, and Faba bean selection criteria. Salifou *et al.* (2017) used PRA to gain insight into farmers' views and favorites about cowpea cultivation and its limitations in Niger. In southern Ethiopia, cowpeas are grown by smallholder farmers. Conversely, no report systematically documented constraints of cowpea production, farmers' perception, the uses of the crops, and the traits preferred by smallholder farmers for sustainable cowpea production in resource-poor farmers' conditions. This information will be useful to set cowpea improvement strategies aimed at developing high-yielding varieties that incorporate other traits of interest to farmers. The objective of this study was to assess cowpea production limitations observed by farmers, farmers' traits preferences, and the cowpea production system in southern Ethiopia.

## **3.2. Materials and Methods**

### **3.2.1. Study area description**

The study was carried out from May to June 2016 in the districts of Gofa, Kindo Koyisha, and Humbo while from September to October 2016 in the district of Konso in southern Ethiopia (Fig. 3.1). Gofa is one of the 17 districts of the then Gamo Gofa zone of SNNPR located at a distance of 340 km from Hawassa City, capital of SNNPR, and 240km via Wolayta from Arbamich, the capital town of Gamo Gofa Zone. Gofa district lies 6° 18' N latitude and 36° 54'E longitude elevated at 1100 to 2600 meters above sea level (masl) with annual average precipitation of 1500 mm and the average temperature ranges from 14.8 to 35.1° C. The then district consists of 38 rural kebeles. Two kebeles (Boreda and Suka) were selected from the then Gofa district for this study. The town of Gofa district is Sawula. The area of land in the district is estimated to be 979 square kilometers, of which 7.9%, 10.5%, and 81.6% are in agro-ecological zones of Dega, Woyina Dega, and Kola respectively (Source; Gofa district office of agriculture and natural resource development). Cowpea was cultivated in 31 kebeles (Source: Gofa district office of agriculture and Natural resource development). The major economic activities taking place in the district are crop and livestock production. Major food crops such as maize, cassava, common bean, sweet potato, and cash crops Teff, groundnut, mung bean, tomato, onion, and pepper are produced in the district. Maize, common bean, and cowpea ('wohe') are produced for both food and cash in the district.

Kindo koyisha is one of the 13 woredas in Wolayta Zone, which is situated in SNNPR. It is about 410 kilometers from Addis Ababa to the south and about 36 kilometers from Wolayta Soddo to the west. The woreda is bounded by Boloso Sore and Boloso Bombe woredas in the North, Damot Sore and Soddo Zuria woredas in the East, River Omo and Dawro Zone in the West, and Kindo Didaye and Ofa woredas in South (Mekonen and Teklu, 2017). Kindo Koyisha district, on the other hand, lies between 6° 57'N latitude and 37° 32'E longitude elevated between 700- 2280 meters above sea level (masl) with average annual temperature varies from 25 °C to 40 °C, and average annual rainfall ranging from 900-1300mm. Kindo Koyisha district has a total land area of 77,641 hectares of which 48,678 hectares are cultivated, 5,703ha is cultivable, 8,041 hectares are Forest and bush Land, and 1,227 hectares are used for grazing areas. The major economic activities taking place in the district are crop and livestock production. Major food crops such as maize, sorghum, sweet potato, cassava, mung bean, pigeon pea, Taro, and cash crops Teff, Haricot bean, and vegetables are produced in the district. Cowpea production is a new introduction and only a few kebeles started their production in the district (Source: Kindo Koyisha district office of agriculture and Natural resource development).

Konso district is one of 12 districts found in the then Segen people's area Zone of SNNPRS, Ethiopia (Fig. 3.1). The location is geographically coordinated at 5° 21'N latitude and 37° 27'E longitude elevated at 601-2000 meters above sea level (masl) with an annual average rainfall of 601-1200 mm and average annual temperature varies from 17.6°C to 35°C. Based on the data from the district, the total land area of Konso is 202,286 hectares. The district is divided into 41 rural kebeles, two of which, namely Dogatu and Turayte were selected as survey kebeles. Among the food crops, sorghum is the most important crop followed by maize. The major economic activities taking place in the district are crop and livestock production. Sorghum, Maize, mung bean, cowpea (Ohoda), and haricot Bean are major food as well as cash crops produced in the district. Cowpea was an old crop cultivated by most farmers during the Belg and Meher seasons (source: Konso district office of agriculture and Natural resource development).

Humbo district is one of 13 districts found in the Wolayta Zone of SNNPRS, Ethiopia (Fig. 3.1). The district of Humbo (6° 39'N, 37° 48'E) is characterized by an altitude of 1100 to 2335 meters above sea level with rainfall ranging between 841.3-1434.1mm, average annual temperature varies from 21 °C to 30 °C and clay soils. All the districts are suitable for the production of cowpea with a bimodal rainfall pattern of short rains (from March to June) and

long rains (from June/July to November/December). The total area of the district is estimated to be 86,646 ha. (Source: District office of agriculture and Natural resource development). The major economic activities taking place in the district are crop and livestock production. Major food crops such as maize, sweet potato, potato, cassava, Taro, and cash crops Teff, Haricot bean, cowpea, pigeon pea, and hot pepper are produced in the district. Cowpea was cultivated in 23 kebeles with area coverage of 1637 ha; its area mainly compounded with common bean during Belg and Meher seasons (Source: Humbo district office of agriculture and Natural resource development).

### **3.2.2. Sampling procedures and sample size determination**

Both formal and informal approaches were used to collect data for the study. To select a representative sample, a multi-stage sampling procedure was implemented to select farmer household respondents for the survey. In the first stage, three zones, namely, the then Gamo gofa, Wolayta, and the then Segen people's area, were purposively selected based on the production status of cowpea. In the second stage, the districts of Gofa, Konso, Humbo, and Kindo koyisha were selected purposively from the zone based on their current high levels of cowpea production and secondary data sources. The districts were identified as the main cowpea-producing areas in the regions (Tesema and Eshetayehu, 2003). In this study, cowpea-producing districts were selected with the help of the Bureau of agriculture and natural resources (BANR) offices of the respective districts. In the third stage, all cowpea producer kebeles were identified with the collaboration of the district bureau of agriculture. In the fourth stage, among the identified kebeles, seven kebeles, viz., Suka and Boreda were selected from Gofa, Abela Sipa, and Abela Farcho from Humbo, Turyte, and Dogatu from Konso, and one kebele, viz., Mundena was selected purposively from Kindo koyisha districts. Finally, simple random sampling was employed and a total of 150 representative farmers were selected randomly from each of the selected kebele using Yamane (1967) sample size determination formula as indicated in the formula given below:

$$n = \frac{N}{1 + N(e)^2} = \frac{N}{1 + N(0.08)^2} \quad (1)$$

Where N= total number of cowpea producers (3,750), n = sample size, and e = margin of error or the accepted sampling error (level of error deviation of the sample value from the population parameter); hence 8% in this study are with 92% confidence interval level and N=3,750; hence

$$n = \frac{3,750}{1 + 3,750(0.08)^2} = 150 (2)$$

At this stage of sampling, 18-26 farmers were selected in each kebele and this provided a total of 150 households (128 men and 22 women) were selected from all districts by a simple random sampling method (Tables 3.1 and 3.2). Accordingly, the number of respondents in each kebeles in the different districts is presented in Table 3.1. The individual interviews were conducted using a semi-structured questionnaire (appendix 4.4).

Table 3.1. Number of cowpea producer households selected from each kebele

District	Kebeles	Cowpea producers	Proportion	Sample Size
Gofa	Boreda	450	0.12	18
	Suka	550	0.15	22
Konso	Turyte	575	0.15	23
	Dogatu	650	0.17	26
Humbo	Abela Sipa	500	0.13	20
	Abela Farcho	525	0.14	21
Kindo Koyisha	Mundena	500	0.13	20
Grand Total		3,750	1.00	150

Source: Computed from secondary data

Table 3.2. Number of farmers who participated in the individual household interviews and focus group discussions

Districts	Key informants			Focus Group discussions			Household interviews		
	kebeles	Men	women	Men	Women	Total	Men	Women	Total
Gofa	Suka	3	0	10	2	12	16	2	18
	Boreda			8	4	12	20	2	22
Konso	Dogatu	2	1	11	1	12	20	3	23
	Turayte			9	3	12	21	5	26
Humbo	Abela sipa	3	0	8	4	12	15	5	20
	Abela Farcho			7	5	12	18	3	21
Kindo/k	Mundena	2	1	11	1	12	18	2	20
Total		10	2	64	20	84	128	22	150
%		80	20	76.2	23.8	100	85	15	100

Note: Kindo/K=Kindokoyisha

Furthermore, seven focus group discussions (FGDs) were held, two in Gofa, two in Humbo, two in Konso, and one in Kindo koyisha districts with a total of 84 farmers for focus group discussions. Each focus group involving 12 cowpea growers including female, male, model farmers, youth, and elder, was carried out in each kebele using an interview guide. A checklist was prepared for the FGDs, which focused mainly on cowpea production constraints, cropping systems, uses, cowpea variety preferences, and socioeconomics aspects.

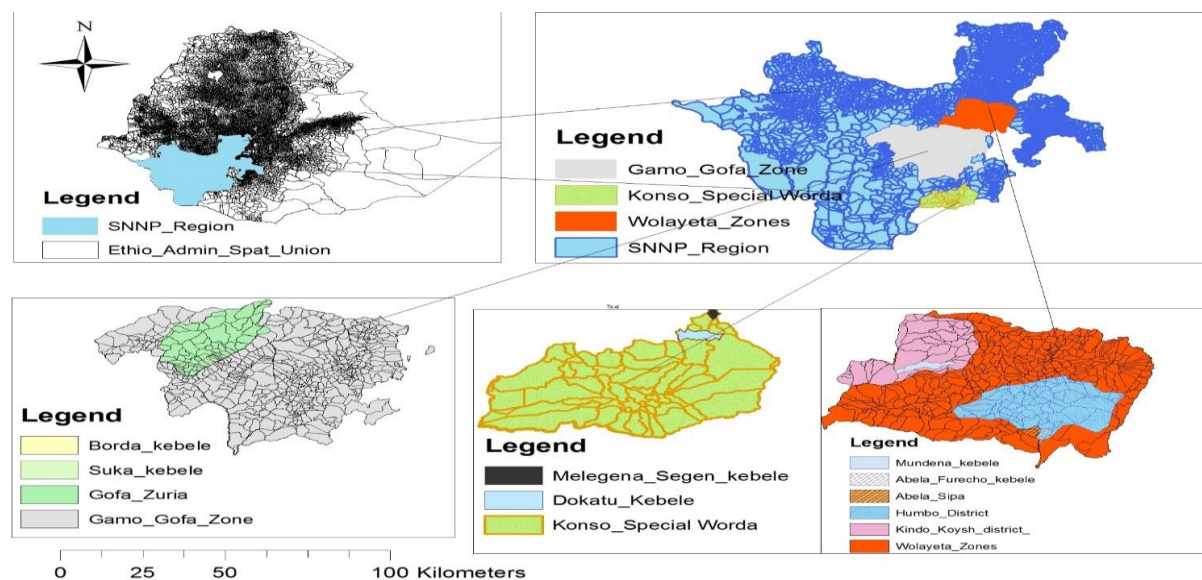


Figure 3.1. The map of SNNPR shows the three zones of the survey: Konso, Wolayta, and Gamo Gofa

### **3.2.3. Data collection**

The data used for the present study were collected from May to June in the districts of Gofa, Kindo Koyisha, and Humbo while in September to October 2016 in the district of Konso. Two types of data were used in this study, primary and secondary data. The primary data were collected from the households by using a semi-structured questionnaire survey, focus group discussions (FGDs), and Key informants (KII) while secondary data were collected by reviewing documents of the various offices in the respective district. Development agents (DAs) and district extension experts facilitated the FGDs and data collection. Data for a semi-structured survey were collected on socioeconomic and demographic characteristics of households (e.g. gender, education status, family size, and farm size), knowledge on cultivation and management (production systems), farmer preferred traits in cowpea, perceived production constraints, and strategies used to control problems (coping mechanisms). Interviews were conducted using the local languages (Wolaytigna, Gofigna, Konsonigna, and Amharic) translated with the help of local people and agricultural extension staff stationed in the respective areas. Quantitative data further describing the areas regarding altitude, geographic position, rainfall pattern, annual rainfall, and temperature were obtained from the respective districts' Bureau of Agriculture and Natural Resources (BoANR) offices.

### **3.2.4. Data analyses**

The data collected through the questionnaires were processed and analyzed using the Statistical Package for Social Sciences (SPSS) version 20.0 (SPSS, 2011). Analysis was performed for descriptive statistics such as mean, and percentage. Cross tabulations were performed for the data summary. Further, Chi-square ( $\chi^2$ ) was conducted to determine statistical significance among the test parameters across districts. The desirable traits of cowpea varieties were subsequently ranked using the pair-wise ranking method.

## **3.3. Results and discussion**

### **3.3.1. The respondents' demographic and socio-economic characteristics**

#### **3.3.1.1. Demographic characteristics of the households**

This study emphasized the socio-economic features of cowpea farmers in southern Ethiopia using variables of gender, marital status, age, household size, and education status (Table 3.3). During the household survey, a total of 150 individual farmers were interviewed. Of the 150 interviewed farmers, 15% were women and 85% were men, implying that cowpea production in the entire survey district is predominantly men-dominated. Men play an indispensable role in food security, while most women tend to feed children and take care of

the family. Similar results are earlier reported by Sabo et al. (2009) among cotton farmers in Adamawa State, and among vegetable farmers in Mubi zone (Sabo and Dia, 2009). On the other hand, the greater participation of women farmers compared to men was recorded in cowpea cultivation (Nkomo et al., 2020). There was no significant difference ( $p > 0.05$ ;  $\chi^2 = 1.92$ ) in gender representation among the four districts. Women's participation in cowpea production was relatively higher in the Humbo district (20%) than in Gofa (10%). Districts vary significantly in demographic characteristics, such as age ( $\chi^2 = 24.7$ ;  $p = 0.004$ ), education level ( $X^2 = 31.9$ ;  $p = 0.0010$ ), marital status ( $X^2 = 27.3$ ;  $p = 0.001$ ) and family size ( $X^2 = 26.1$ ;  $p = 0.003$ ) (Table 3.3). In Gofa and Kindo Koyisha districts, 90% of the households were male-headed. Likewise, 80 and 84 percent of households in the Humbo and Konso districts, respectively, were male-headed. The age of the farmers ranged from 21 to over 60 years. Forty-one percent of participants were under the age of 30 years old, while 51 % were between 31 and 60 years old with a mean age of 47.1 years, which represents that farmers are still in their economically active age group capable of carrying out various agricultural activities. Only 8% of farmers had passed the productive age of 60 years. This finding is consistent with Awotide et al. (2015) reported 47 years as the mean age of farmers interviewed in their study on the use of inputs and profitability of arable crops in Nigeria. This finding revealed the active participation of south Ethiopian active age group farmers in farming or those interested in various agricultural activities.

The majority (60.9%) of respondents had formal primary, junior or secondary education, while the remaining 39.3% had no formal education. This finding is in line with Abdullahi and Tsowa (2014) who stated that 43.0% of small-scale farmers in rural areas of Nigeria have no formal education. Due to the low level of education in some areas of the survey, researchers had to communicate with farmers through the local language to convey the latest technical knowledge promotion. This underlines that farmers who have achieved a certain level of formal education are likely to increase their productivity through the innovative use of technologies.

There were significant differences ( $P < 0.05$ ;  $\chi^2 = 26.1$ ) in family size among districts (Table 3.3). In Humbo, 61% of the respondents had a family size of 6 to 9 people, whereas, in Kindo Koyisha, 50% of the respondents had a family size of  $\geq 10$  people with an average family size across the districts of 6.97. This was nearly equivalent to the average household size of 9 for Niger state of Nigeria (Abdullahi and Tsowa, 2014). The implication is that farmers with large family sizes will, however; also need to increase their productivity to meet the

consumption needs of the family. Additionally, about 93 percent of those surveyed in the study area were married couples, and this is an indication of their chances of obtaining family labor to use on their farm operation including cowpea farms.

### **3.3.1.2. Socio-economic characteristics of the households**

The distribution of respondents by farm size is shown in Table 3.4. The sizes of the farms owned varied significantly across the districts ( $\chi^2 = 38.4$ ;  $p = 0.001$ ). About 59% of respondents owned a farm of  $\leq 2$  ha, whereas 23% owned a 2.1 to 3 ha farm and 18% owned a farm of  $>3$  ha. Konso district was dominated by farmers who owned less than 2 ha (82%), while 49 and 35% of Humbo and Kindo Koyisha farmers, respectively, owned between 2 and 3 hectares of land. In Humbo and Kindo Koyisha, there was a significantly higher proportion (20%) of farmers who owned more than 3 hectares of land compared to 17.4% in Konso and 17.5% in Gofa. The size of the farm determines the extent to which other resources (capital, labor) are used to achieve a high yield. Land use analysis revealed that overall 392 hectares were cultivated by total respondents and the size of individual plots ranged from 0.125 to 5 hectares with a mean of 2.61 hectares (Table 3.4).

This indicates that the majority of the farmers in the study area were smallholders. This situation where many farmers cultivated only small plots of land that will not promote agricultural production beyond subsistence level. Furthermore, the result exhibited that 60-90% of farmers cultivated up to 0.25 ha or less of cowpea, 10-33% used between 0.26-0.5 ha, and only none of the farmers (0%) at Kindo koyisha to 14.6% at Humbo district (0-14.6 %) were cultivated at 0.5 ha or more. This means that most farmers (68%) in this part of the country cultivate cowpea majorly within 0.1-0.25 hectares of land with an average farm size of 0.24 hectares (Table 4). Nevertheless, an average land area of 0.24 ha cultivated with cowpea per household was lower than the 0.5-2 ha of cowpea area by (Sanni *et al.*, 2014; Saka *et al.*, 2018; Ibitoye *et al.*, 2018) for the state of Kano in Nigeria. Only a few farmers often rented or shared land to address the land shortage. This indicates farmers grow cowpea just for their daily consumption rather than for market supply.

Table 3.3. Demographic information about the farmers in the study areas.

Variable	Category	Gofa	K/K	Humbo	Konso	% Mean	df	$\chi^2$	P-value
Gender	Male	36(90)	18(90)	33(80)	41(84)	86	3	1.92	0.59
	Female	4(10)	2(10)	8(20)	8(16)	14			
Marital status	Single	1(2.5)	4(20)	0(0)	0(0)	6	6	27.3	0.001
	Married	9(97.5)	15(75)	1(100)	9(100)	93			
	Divorced	0(0)	1(5)	0(0)	0(0)	1			
Age (year)	21–30	8(19)	16(80)	11(27)	18(37)	41	6	24.7	0.0004
	31–60	27(68)	3(15)	28(68)	26(53)	51			
	>60	5(13)	1(5)	2(5)	5(10)	8			
	Mean age	43	60	48	44	47.1			
Family size	≤5	10(25)	4(20)	8(20)	14(29)	23	6	26.1	0.0001
	6–9	21(53)	6(30)	25(61)	27(55)	50			
	≥10	9(23)	10(50)	8(20)	8(16)	27			
	Mean	7	9	7	6.1	6.97			
Education status	illiterate	11(27.5)	3(7.5)	14(35)	31(63.3)	39.3	9	31.9	0.0002
	1–4	6(15)	5(12.5)	10(25)	12(24.5)	22.1			
	5–8	16(40)	5(12.5)	10(25)	4(8.2)	23.3			
	9-10	7(17.5)	7(17.5)	7(17.5)	2(4.1)	15.3			

Own field survey result, 2016, P=Probability values based on chi-square test

There were significant differences ( $P < 0.001$ ) in the farmers' response among the four districts regarding the area allocated to cowpea production during the last five years. In Humbo and Gofa districts, 54% and 50 % of the respondents have declared having increased their land allocation for cowpea production, while in Konso and Kindo koyisha districts 51 % and 10%, respectively have declared having decreased their land allocation (Table 3.4). During the last five years (2011-2015), of all the interviewed farmers across the districts, 48% of the farmers have declared having increased their land allocation to cowpea production, while 37% and 15% of the respondents have declared having decreased or not changed their land allocation, respectively (Table 3.4). The reasons given for the decrease of land allocation for cowpea were the shortage of land, lack of improved varieties, and biotic and abiotic problems. The cowpea seed sources also showed significant differences among the four districts ( $p < 0.001$ ;  $\chi^2 = 53.4$ ). Cowpea seeds were commonly sourced from local markets (54.7 %) while 36% obtained their seed mainly from farm-saved seed in each of the survey areas (Table 3.5). Other sources are seeds from the research (2.7%); provided by the agricultural office (3.3%); provided by NGOs (0.7 %); obtained from a neighbor (2.7%).

Nearly 40% of farmers reported using recycled seeds for more than four years, probably due to poor support of the extension, which resulted in absence of technical advice on improved cowpea packages.

Among the farmers surveyed, on average 96.7% of the farmers planned to expand cowpea production, while only 3.3% said they did not have any expansion plan. Almost all respondents expressed their willingness to expand cowpea production by increasing yields through the utilization of improved varieties and agronomic practices. The results suggest that cowpea production is still on a small scale and needs improvement in terms of yield and production constraints.

Table 3.4. Socio-economic information about the farmers in the study areas.

Variable	Category	Gofa	KK	Humbo	Konso	% M	df	$\chi^2$	P-value
Farm size (ha)	$\leq 2$	30(75)	9(45)	13(32)	40(82)	61.3	6	38.4	0.001
	2.1–3.0	3(7.5)	7(35)	20(49)	2(4)	21.3			
	$>3$	7(17.5)	4(20)	8(20)	7(14)	17.4			
	Total	66	100	148	78	392			
	Mean	1.65	5	3.6	1.6	2.61			
Cowpea farm size trends (2011-2015)	Increasing	25(50)	2(10)	22(54)	23(47)	72(48)	6	78.7	$<0.001$
	Decreasing	12(30)	2(10)	16(39)	25(51)	55(37)			
	Constant	3(15)	16(80)	3(7)	1(2)	23(15)			
Cowpea farm size (ha)	$\leq 0.25$	30(75)	18(90)	25(60)	30(61)	68	6	11.7	0.069
	0.26-0.5	9(22.5)	2(10)	10(24.4)	16(33)	25			
	$>0.5$	1(2.5)	0(0)	6(14.6)	3(6)	7			
	Total	8	2.6	10.7	15.2	36.5			
	Mean	0.2	0.13	0.26	0.31	0.24			
Sources of seed	Research	4(10)	0	0	0	2.7	15	53.4	0.0001
	Market	30(75)	7(35)	15(36.6)	30(61.2)	54.7			
	Neighbor	0	0	0	4(8.2)	2.7			
	NGOs	0	0	0	1(2)	0.7			
	BoA	3(7.5)	0	2(4.9)	0	3.3			
	saved seed	3(7.5)	13(65)	24(58.5)	14(28.6)	36			
Willing to expand cowpea	Yes	39(97.5)	19(95)	40(97.6)	47(95.9)	96.7	3	0.44	0.9307
	No	1(2.5)	1(5)	1(2.4)	2(4.1)	3.3			

Own field survey result, 2016. Values outside and inside the bracket indicate the frequency and proportion in percentage, respectively

### 3.3.2. Cowpea production systems and practices

The main livelihoods of farmers in all study districts were both crop and livestock production as major sources of food, feed, and income. According to farmer declaration (82.7 %) have been growing cowpea for more than five years, while the average years of farmers' experience in cowpea production were 19.65 (Table 3.5). Intercropping was the predominant (78%) cropping system in all the districts (Table 3.5). Among the interviewed farmers, 57% intercrop cowpea with sorghum, 31% intercrop cowpea with maize, 12% of the farmers grow cowpea sole in Konso. In the Humbo district, 68% grow cowpea with maize, 27% of the farmers grow cowpea sole, and 5% practice cowpea/sorghum. Likewise in Gofa, 25% cultivate cowpea sole, 70% intercrop cowpea with maize, and 5% intercrop cowpea with cassava. In Kindo Koyisha, 60% intercrop cowpea with maize, 10% cultivate cowpea sole, and 30% practice cowpea/sorghum intercropping system (Table 3.5).

Across the districts of the survey region, 55 % intercrop cowpea with maize, 21% intercrop cowpea with sorghum, 2% intercrop cowpea with cassava, 22% practiced sole cowpea production (Table 3.5). The practice of intercropping cowpea and cereals is common in southern parts of Ethiopia. This elucidates the importance of cowpea as a companion crop in cereal-legume cropping systems, which are common practices adopted by farmers in sub-Saharan Africa to avert risk, crop failure, and distribution of farm labor (Olufajo and Singh, 2002). The findings of the study showed that farmers grow cowpea in both monocropping and intercropping production systems. This finding is similar to that of a study carried out in Oromia (West Hararge), SNNPRS, Gambella, and Dire Dawa regions where farmers in various agro-ecological zones grew cowpeas in both intercropping and monocropping systems (Sisay et al. 2019; Mulugeta et al., 2016). This has been reported by Salifou et al. (2017) in Niger ' stating that cowpea is mostly sown with pearl millet or sorghum; however, some farmers grow it on sole cropping for seed multiplication purposes and to test new released or promising varieties. This also points to the need to develop varieties suitable for intercropping systems, sole cropping, as well as crop and livestock integration.

Farmers in the four survey areas presented the cropping calendar. The survey areas were experienced by bimodal rainfall systems. Two production seasons (*Belg*, and *Meher*) were characterized in the study areas. *Meher* appeared to be the most appropriate cropping season for cowpea according to 50% of farmers (Table 3.5). In all districts, a quarter of farmers (26%) grew cowpeas twice in a year, by planting in both *Meher* and *Belg* seasons, while 74% cultivate once in a year either in *Belg* or *Meher* (Table 3.5). The majority of the

farmers (47%) in Konso grew in the *Belg* season, while 70% of the farmers grew in the *Meher* season in the Kindo Koyisha district. In the study areas, the planting times for cowpea were from the end of February to March for *Belg* and from the end of June to July for *Meher*. Sometimes *Belg* season production constraints with aphid infestation thus *Belg* season production should be supplemented with proper pest control measures or use of aphid resistant variety.

Of the interviewed farmers, 81.3% practiced the broadcast method of planting, 14.7% said they used the row method of planting while 4 % reported that they used both methods of planting. None of the interviewed farmers use herbicides to control weed on cowpea and more than 75% of farmers use manual weed control on cowpea. Farmers identified poor soil fertility as a cowpea production constraint. Fertilizer use is one of the widely accepted practices for increasing agricultural productivity. In contrast, recent results of the cowpea survey showed that only very few farmers (4%) in the study areas used fertilizers on their cowpea farms, while over 96% of farmers across the study areas in south Ethiopia did not use fertilizers for cowpea production (Table 3.5). Soil fertility levels were reported to be very low across districts, and most of the farmers did not apply any fertilizers on cowpea as they believed it does not need much N-fertilizer as it fixes nitrogen unless the soil is markedly exhausted of nutrients. Similar findings were reported by Horn et al. (2015) who found that poor soil fertility in Nambia was an important cowpea production constraint. In general, the use of chemical fertilizer is limited for legume crops, especially in Ethiopian agriculture. It is therefore of paramount importance for cowpea breeders to develop cultivars that are adapted to poor soils, particularly cultivars that are capable of producing acceptable grain yields under low nitrogen conditions. Farmers indicated that cowpea production is limited due to various field pests and diseases (Tables 3.5) which commonly led to crop damages.

Table 3.5. Cowpea production systems and cultural practices in survey districts

Variable	Category	Gofa	Kk	Humbo	Konso	Mean %	df	X <sup>2</sup>	P-value
Farming experience	≤5	2(5)	20(100)	2(5)	2(4)	17.3	6	140.8	<0.0001
	6-20	13(32)	0	34(83)	19(39)	44.0			
	>20	25(63)	0	5(12)	28(57)	38.7			
	Mean	22.3	2.3	24	20.9	19.65			
Cropping system	Mono cropping	8(20)	2(10)	16(39)	7(14)	33(22)	3	9.9	0.019
	Inter cropping	32(80)	16(90)	25 (61)	42(86)	117(78)			
Crops intercropped with cowpea	Sole	10(25)	6(30)	11(27)	6(12)	33(22)	9	61.5	<0.0001
	Cowpea/maize	28(70)	12(60)	28(68)	15(31)	83(55)			
	Cowpea /sorghum	0	2(10)	2(5)	28(57)	32(21)			
	Cowpea /cassava	2(5)	0	0	0	2(2)			
Fertilizer use	Yes	2(5)	0	2(4.9)	2(4.1)	6(4)			
	No	38(95)	20(100)	39(95.1)	47(95.9)	144(96)	3	1.02	0.796
Planting seasons	Belg	5(12.5)	2(10)	6(14.6)	23(47)	36(24)	6	33.5	0.0001
	Meher	23(57.5)	14(70)	21(51.2)	17(35)	75(50)			
	Both	12(30)	4(20)	14(34.1)	9(18)	39(26)			
Method of weeding	Manual	32(80)	16(80)	30(73)	38(78)	116(77)	9	2.18	0.980
	Hoeing	4(10)	2(10)	8(20)	7(14)	21(14)			
	Both	2(5)	1(5)	1(2)	2(4)	6(4)			
	Not weeded	2(5)	1(5)	2(3)	2(4)	7(5)			
Planting methods	Broad cast	34(85)	16(80)	25(60)	47(94.9)	122(81)	6	20.1	0.0026
	Row	5(12.5)	4(20)	12(30)	1(2.6)	22(14.7)			
	Both	1(2.5)	0	4(10)	1(2.6)	6(4)			
Insect pests and diseases control	Traditional	6(15)	1(5)	7(17.1)	20(40.8)	34(22.7)	6	27.5	0.0001
	chemicals	2(5)	1(5)	8(19.5)	11(22.5)	22(14.7)			
	No action	32(80)	18(90)	26(63.4)	18(36.7)	94(62.6)			

Own field survey result, 2016. KK=Kindo koyisha, Values outside and inside the bracket indicate the frequency and proportion in percentage, respectively

Traditional practices and chemical control methods were among the methods used by a few farmers against diseases and insect pests (Table 3.5). Across the districts, more than sixty percent (62.6 %) of the respondents do nothing to control insect pests and diseases

(Table 3.5). The majority of the interviewed farmers usually do not use production inputs such as fertilizers and pesticides for growing cowpeas in southern Ethiopia.

### **3.3.3. Cowpea usage, varieties grown, and yield under smallholder cropping system**

Results from the survey indicated that farmers in the various districts grow cowpea, mainly, for food, feed, and as a cash crop. There were significant differences among the reasons across districts ( $P \leq 0.001$ ). The statistic showed 55.3% of farmers grow cowpea for household consumption, 14.7% for market and feed, and 12.7% for market and food, 10% for the market only, 4% for feed, and 3.3% for vegetables (Table 3.6). In Gofa and Konso districts, cowpeas were predominantly grown for household consumption (62.5%; 61.2% respectively) (Table 3.6). In Humbo and Kindo Koyisha, respondents did not indicate any use of cowpea for vegetable purposes. In this study, interviewed farmers reported that farmers grow cowpea for multiple purposes including foods, feeds, and cash income. These results correspond to Horn *et al.* (2015) findings who stated that 59 % of farmers grew cowpea for home consumption or food while 23.4% grew for home consumption and sale, some 13.5% use the crop foliage for animal feed during excess production.

The names of cowpea cultivars grown in the four districts were recorded using their local names (Table 3.6). In the study areas, particularly in the Gofa district, few farmers have grown improved varieties such as white wonderer trailing. Information on varieties cultivated in the survey area revealed that farmers grow a small number of local cowpea landraces (Table 3.6). Most of the farmers were unaware of the improved cowpea varieties in the survey districts. Across districts, 92.7% grow predominantly local landraces, while only 2.4 % cultivate improved varieties, commonly in addition to local landraces (Table 3.6). This is inconsistent with Horn *et al.* (2015) who reported that 70.2 % of farmers cultivate local unimproved cowpea varieties and 29.8 % utilized improved varieties either singly or in the combination of two or three.

In study areas, farmers grew two to three cowpea cultivars: reddish-brown, gray, and white seeds (Table 3.6). Konso farmers grew three local cultivars of cowpea (Tambara, Saritota, and Bekada) with Tambara being the dominantly cultivated variety in the area. Most of Konso's farmers (51%) grew Tambara variety, followed by Saritota variety (26.5 %) (Table 3.6). Tambara was appreciated in the past, due to the large pod size and high yield. According to the farmers, although the pod size is a preferred trait, the number of pods per plant has decreased, resulting in poor yields.

Most of the farmers (87.5%) in Gofa, 73.2% in Humbo and 60% in Kindo Koyisha grew landrace 'Bota wohe'. Some farmers grew the cultivars Zo'o wohe, Bulla, and Bekada. In the study areas, the local name for cowpea varies. Cowpea is generally called "Ohoda" in Konso, 'Wohe' in Gofa district, while it is known as 'Eka wohe' in the wolayta zone, respectively (Table 3.6). The improved cowpea varieties presently cultivated in the survey districts are very limited and 92.7% of the respondents in the four survey districts used local cowpea varieties. Cowpea yields in the study areas were expressed in local measurements per plot. Table 3.6 shows the number of cowpea varieties grown in the four districts, along with their mean yields of mono-cropped and intercropped together. Although the study identified low productivity of the prevailing cowpea cultivars as another production constraint in Southern Ethiopia. Regardless of the varieties, the estimated mean yield across districts ranged from 626 kg ha<sup>-1</sup> for Gofa to 423 kg ha<sup>-1</sup> for the Konso district performed poorly with an average yield of 503.5 kg ha<sup>-1</sup>(Table 3.6). There was a significant difference ( $p < 0.006$ ;  $\chi^2= 12$ ) in cowpea yield among the four districts. This investigation as estimates given by the farmers was based on memory recall and the use of local measures. The overall low yields can be attributed to the ongoing use of relatively low-yielding landrace varieties, biotic and abiotic (susceptible to disease and insect pest) stress, grown on fragmented, a small piece of land of less than 0.25 ha. This yield level is significantly low when compared to achievable yields of 1500 to 3000 kg ha<sup>-1</sup> reported in Egypt and Malawi (Nabirye *et al.*, 2003). This is in line with the findings of (Gbaguidi *et al.*, 2013; Saka et al (2018) where he reported that farmers used poor genetic materials which are prone to many biotic and abiotic factors.

Farmers also reported that cowpeas are grown for their versatile use because the leaves and seeds, during different times of the cultivating period, were so vital that there is a potential in developing multi-purpose varieties with good productivity, gives high yield in terms of both fodder and seeds. Hence, it is also obvious that cowpea growers in the survey areas required new improved cowpea varieties with desired traits. Thus, there is a basic need for research intervention to introduce/generate cowpea varieties that are high yielding, early maturing, drought tolerance, diseases, and insect pests resistant to meet the expectations of farmers.

Thus, there is a fundamental need for research intervention to introduce/generate high-yielding, early maturing, diseases, and insect pests' resistant cowpea varieties that can be cultivated during the *Belg* and *Meher* seasons, to meet farmers' expectations. In all districts, cowpea was the important food and to some extent cash crop. During the focus group discussion (FGDs), farmers explained that they used a low amount of inorganic fertilizers for cereal crops grown after cowpea, due to its ability to fix valuable nitrogen into the soil.

Table 3.6. Cowpea usage, varieties grown and types of cowpea seeds cultivated by farmers

Practices	variables	Gofa	KK	Humbo	Konso	Overall	DF	X <sup>2</sup>	P-value
Varieties	Local	35(87.5)	20(100)	38(92.7)	46(94)	139(92.7)	6	5.25	0.51
	Improved	1(2.5)	0	1(2.4)	2(4.1)	4(2.4)			
	both	4(10)	0	2(4.9)	1(2.0)	7(4.9)			
Purpose of growing cowpea	Consumption	25(62.5)	8(40)	20(48.8)	30(61)	83 (55.3)	15	26.5	0.033
	Market	4(10)	2(10)	5(12.2)	4(8.2)	15(10)			
	Feed	1(2.5)	1(5)	2(4.9)	2(4.1)	6(4)			
	Vegetable	1(2.5)	0	0	4(8.1)	5(3.3)			
	M+C	7(17.5)	3(15)	2(4.9)	7(14.3)	19(12.7)			
	Market & feed	2(5)	6(30)	12(29.3)	2(4.1)	22(14.7)			
Landraces	Bota wohe	35(87.5)	12(60)	30(73.2)	0	77(51.3)	18	176	0.0001
	Bulla wohe	0	0	5(12.2)	0	5(3.3)			
	Zo'oo wohe	4(10)	8(40)	6(14.6)	0	18(12)			
	Tambara	0	0	0	25(51)	25(16.7)			
	Saritota	0	0	0	13(27)	13(8.7)			
	Bekada	0	0	0	11(25)	11(7.3)			
Improved	WW	1(2.5)	0	0	0	1(0.7)			
		Cowpea yield (kg/ha)							
Mono cropped	≤200	1(2.5)	0(0)	2(4.9)	1(2)	4(2.7)			
	201-500	2(5)	1(5.6)	8(19.5)	1(2)	12(8.1)			
	>500	5(12.5)	1(5.6)	6(14.6)	5(10.2)	17(11.5)			
Intercropped	≤200	27(67.5)	12(66.7)	18(43.9)	38(77.6)	95(64.2)			
	201-500	3(7.5)	2(11.1)	4(9.8)	2(4.1)	11(7.4)			
	>500	2(5)	2(11.1)	3(7.3)	2(4.1)	9(6.1)			
Over all	<b>mean</b>	<b>626</b>	<b>452</b>	<b>505</b>	<b>423</b>	<b>503.5</b>	6	12.0	0.006
Local name	cowpea	“Wohe”	“Eka wohe”		“Ohoda”				

Own field survey result, 2016; BA=Beru of agriculture. Key: Values outside and inside the bracket indicate the frequency and proportion in percentage, respectively, M=market, +=and, C=consumption, KK=Kindo koyisha, DF=degrees of freedom, X<sup>2</sup>=chi-squares=non-significance; \* and \*\* denote significance at 5% and 1%, respectively.

### 3.3.4. Trends of cowpea production in the study areas

Cowpea is recognized for a variety of uses in the study area. However, it is still difficult to obtain complete information on agronomic packaging and production practices. A lack of comprehensive information on cowpea production status in Africa, including Ethiopia, has also been reported elsewhere (Karine and Kilkenny, 2009), supporting the findings of this study. During this study, only five years of data (2011-2015) were the respective district

collected from departments of agriculture and rural development and were available to use for trend analysis. The five years data showed a slightly decreasing trend in cowpea production area in Konso, while an increasing trend in cowpea production area in Gofa and Humbo districts (Figure 2a-c). The lack of comprehensive and long-term data may be attributed to the low level of education of the farmers, the low government’s research interest, and the ineffectiveness of the agricultural extension system to have well-organized data systems. As a result, the lack of information and extension support on production systems has prevented farmers from expanding cowpea production and benefiting from multiple roles the crops can play for the rural poor.

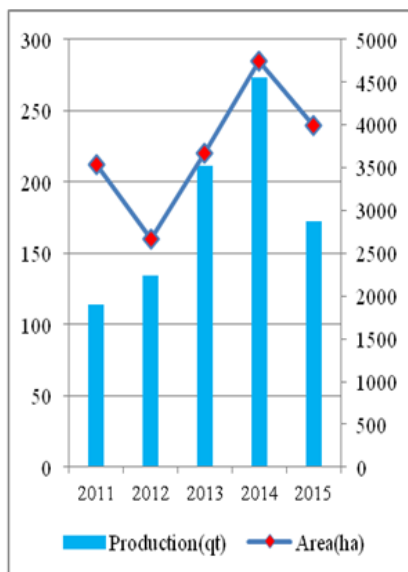


Fig.2a. Cowpea production trends in Konso

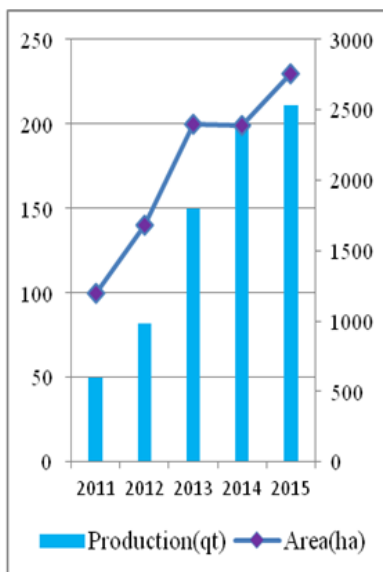


Fig.2b. Cowpea production trends in Humbo

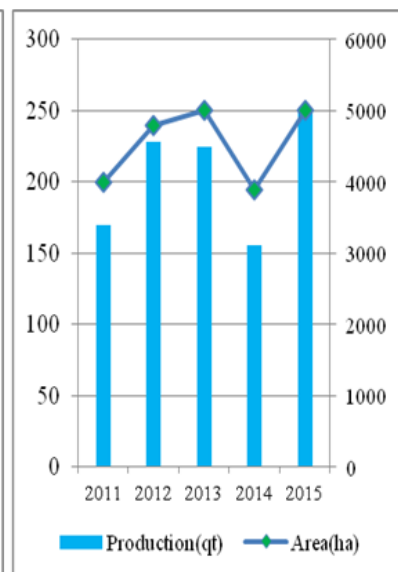


Fig.2c. Cowpea production trends in Gofa

Figure 3.2. Cowpea production trend at Konso, Humbo and Gofa Districts (2011- 2015): Note: qt: - quintal, 1qt is equivalent to 100 kg Source: respective districts Beru of agriculture and Rural Development, 2017

The results from the secondary data sources are also consistent with the data obtained from the household survey. Farmers were also asked to describe the trend in cowpea production in the past five years (2011-2015). The estimated yield data reported for the sole crop system was comparable to the secondary data collected from the BoA of each district, while it was higher than that for the intercropping system. Therefore, the yield differences of the two cropping systems reported by the surveyed farmers should be validated by the research system. Across districts, of all respondents, 55% of the farmers' levels of cowpea cultivation showed an increasing trend over this period. Conversely, 48% of the farmers thought that cowpea production had been decreasing over this period. According to 15 % of the farmers, the area under cowpea had remained relatively unchanged and production was associated with cereal crops primarily with maize and sorghum (Table 3.4). A similar finding where lack

of extension support affects crop yields has been reported elsewhere (Mengesha, 2009). The focus group also said that "although cowpea had many uses, it has not yet received adequate attention from relevant administrative units". Along with the interview results, the focus groups highlighted the lack of extension support and lack of improved varieties, increasingly erratic rainfall; delayed onset rains, and sometimes the rains falling outside the growing season; poor soil fertility; aphids' infestations, and lack of access to credit services, as priority issues for farmers for reduced cowpea production in the study areas.

### **3.3.5. Criteria in choosing varieties of cowpea**

In the survey districts, an evaluation of farmers' preferred traits in cowpea ranking was performed (Table 3.7). Though the criteria for variety selection were relatively similar in the four study sites, there were significant variations in the traits of the chosen varieties. These differences varied from site to site. Farmers confirmed high yield potential, early maturity, resistance to diseases, and insect pests, drought resistance, short cook ability, white/red seed color, large/medium seed size, good taste, resistance to weevils, fodder yield, and marketability as the vital preference criteria when selecting cowpea varieties (Table 3.7). The most significant desired traits by a farmer across study areas were high yield, insect pests, and diseases resistance, drought tolerance, earliness, short cook ability, and seed color. Moreover, farmers did not appear to experience any problem with shattering except in Konso. On the contrary in all districts, most of the reported landraces are low yielding, small seed size, and are susceptible to diseases and insect pests, and drought, which requires research intervention to introduce or generate problem-solving cowpea technology.

Farmers were asked to rank traits of cowpea, which they preferred to be incorporated into cowpea varieties that would improve the adoption rate by the farmers (Table 3.7). In Gofa and Kindo Koyisha, high yield and tolerance to diseases, and insect pests came first followed by early maturity.

In Konso and Humbo, early maturity, high yield, and drought tolerance were tied in rank as the main traits. In another study, Horn et al.(2015) found that the most important traits used by farmers to select good cowpea cultivars were a straight pod shape (61.4%), a long pod size, bearing at least 10 seeds (68.4%), white grain color (22.2%) and fodder in Nambia. Farmers in Gofa and Kindo koyihsha ranked high yield in the first place due to their relatively large land area and better rainfall distribution, while in Konso and Humbo early maturity was a preferred feature among farmers due to fragmented landholding and erratic rainfall. Similarly, in Uganda, Orawu, (2007) stated that preferred traits for the same crop were white seed color, earliness, yield potential, good taste, and tolerance to insect pests and

diseases. The results of the survey show that the requirements of farmers can be met if newly improved varieties are generated with the following traits: early maturity, high yield, resistance to insect pests, and diseases, drought tolerance, short cooking time, seed color, seed size, good taste, resistance to weevils, high market value, high fodder yield, suitability to intercropping (upright or prostrate growth habit), and leaf shedding were tied in rank as the preferred traits followed by shattering resistance (Table 3.7). High ranking of yield and culinary traits indicate that farmers in the study districts of Southern Ethiopia grow cowpea for their food security and income source. These observations are consistent with the findings of Gonné et al. (2018) who reported that cowpea contributes considerably to family food security and domestic market in the Sudan-Sahelian zone of Cameroon. The direct implication of these results is that combining yield and earliness traits as well as the resistance to cowpea insect pests (aphid) should be the first goal when breeding for new improved cowpea varieties or introducing improved varieties having above mentioned desired traits. Such varieties can help to mitigate yield losses and guarantee food security to resource-poor farmers in South Ethiopia. Furthermore, future cowpea research programs could also take into account the incorporation of other traits like drought tolerance, white seed color, large seed, good taste, and fast cooking.

Table 3.7. The desirable traits of cowpea varieties, as pair-wise ranked by farmers in four survey districts

Preference traits	Gofa	k/k	Humbo	Konso	Total score	Rank
High yield	11(1)	10(1)	10(2)	12(2)	43(1)	1
Fodder yield	4(7)	4(8)	6(4)	4(7)	18(10)	10
Seed size	8(4)	6(7)	4(6)	3(9)	21(7)	7
Seed color	3(8)	7(5)	4(6)	10(3)	24(5)	5
Disease and insect pests	11(1)	10(1)	8(4)	9(5)	38(3)	3
Suitability for inter cropping	2(9)	2(8)	3(7)	3(9)	10(12)	12
Good taste	2(9)	7(5)	4(6)	7(6)	20(8)	8
Short cook ability	6(5)	4(8)	7(3)	7(6)	24(5)	5
Drought tolerance	9(3)	9(3)	9(3)	10(3)	37(4)	4
Resistance to weevils	6(5)	4(8)	5(5)	4(7)	19(9)	9
Leaf shedding	1(10)	2(9)	2(8)	2(10)	7(13)	13
Shattering resistance	NA	NA	NA	3(9)	3(14)	14
Earliness	10(2)	9(3)	11(1)	13(1)	43(1)	1
Marketability	5(6)	4(8)	5(5)	4(7)	18(10)	10

Values outside and inside the bracket indicate the total score for each trait obtained from the pair-wise ranking of traits preferred by farmers (data not shown) and rank, respectively. Rank; low score = high rank and indicates that the trait is less important; K/K=Kindokoyisha; NA = not a criterion in the area.

### 3.3.6. Perceptions of farmers on constraints of cowpea production

Cowpea production constraints varied according to the socio-economic conditions of the households. In this study, numerous production constraints of cowpea were identified (Table 3.8). Among the limitations identified, insect pests and diseases at 87.3%, drought (86.7%), lack of improved varieties (80%); poor credit services (73.3%); suboptimal agronomic practices such as plant spacing, weeding, soil management (71.3%), poor extension services (73.3%), land shortage (62.7%), low soil fertility (66%), storage pest (57.3%), dik-dik (14.7%), shattering (10.7%) and the combination of ape and porcupine (11.3%), were important. There was a significant difference ( $P < 0.001$ ;  $\chi^2 = 162.7$ ) in production constraints between the four districts (Table 3.8). Farmers listed the most important constraints in their areas and ranked them as per priority (Table 3.8). Insect pests (aphids) and diseases ranked first, followed by drought and the lack of improved varieties. This finding is consistent with previous studies carried out by Baidoo and Mochiah (2014), Gonne *et al.* (2018), and Kenneth (2014), in which farmers had reported disease and insect pests as a major restraint to cowpea production. Furthermore, previous investigations carried out by Mohammed and Mohammed (2014), in which 89.47% of respondent farmers had described disease and insect pests as a major limitation to cowpea production.

Other constraints mentioned were weak credit services, suboptimal agronomic practices, poor extension services, land shortage, storage pests, wild goat, shattering, the combination of ape and porcupine. Farmers in Kindo Koyisha perceived the ape and porcupine as the seventh most important constraint followed by land shortage while in Humbo, the wild goat was ranked seventh followed by the land shortage (Table 3.8). This study revealed the insistence of the disease and insect pests, shortage of improved varieties, and drought problems in cowpea production as confirmed by farmers' responses. Egbadzor (2013) also specified that insects, drought, and weeds are the most important constraints for cowpea production in Ghana. Regarding the storage pests (weevils) attack, farmers reported that all cowpea local cultivars could be completely infested within one month of harvest. Some of the constraints mentioned cannot be solved from the cowpea improvement programs. However, resistance to drought, pests, diseases, aphids, low soil fertility, shattering, weevils, low palatability, long cook ability, and seed size (Table 3.8) are quite possible in the research on the development of cowpea varieties.

The development of cowpea weevils' resistant cultivars is however still very limited since few high-resistance sources have been identified (Singh *et al.*, 1985; Dongre *et al.*, 1996; Amusa *et al.*, 2014). Amusa *et al.*, (2014) assessed Bruchid (*Callosobruchus maculatus*)

Tolerance of ten cowpea varieties in Nigeria and recommended TVu 11953 as a promising alternative for breeding programs concerning bruchid infestation management to minimized postharvest losses of stored cowpea grains. However, periodic evaluation of seed resistance to bruchid infestation is essential for the continuous establishment of the durability and intactness of cultivar or varietal resistance to this storage insect pest.

In all the study areas, out of the twelve constraints listed by all respondent farmers, disease and insect pests, drought, lack of improved varieties, poor credit services, weak extension services, suboptimal agronomic practices, and poor soil fertility were observed as the most important constraints for the production of cowpea across all the districts and shattering occupied the last position. Mohammed and Mohammed (2014) also reported similar findings and suggested the most vital restraints in cowpea production in Nigeria were disease and insects, drought, inadequate credit facilities, insufficient research and promotion, and lack of improved seeds. Drought was the second most important limitation stated by farmers across the districts of the south region, while the lack of improved varieties was third for farmers in the study areas. This was in line with the findings of Muchero *et al* (2009) who reported that quite some farmers in Ghana believe that drought is one of the most limiting factors to cowpea cultivation, although, cowpea is a short season crop with relatively high drought tolerant capacity. These limiting factors from first to the eighth ranking by respondent farmers across the four study areas are important as an urgent matter that needs research to address as a priority or should be included in further research programs. Therefore, there is a need to generate or introduce resistant cowpea varieties to biotic (insect pests and diseases) and biotic stress (drought and adaptability to poor soil fertility) to increase yield and sustain cowpea productivity. This could then boost and improve the sustainable food supply, increase income generation opportunities and improve the living standard for the farmers who cultivate cowpea.

Table 3.8. Major constraints of cowpea production across the four districts

Constraints	Gofa	K/koyisha	Humbo	Konso	Overall	OR	DF	X2
Lack of improved varieties	36(90)	18(90)	30(73.2)	36(73.5)	120(80)	3	33	162.7**
Drought	38(95)	16(80)	32(78)	44(89.8)	130(86.7)	2		
Diseases & insect pests	38(95)	16(80)	32(78)	45(91.8)	131(87.3)	1		
Weak credit service	35(87.5)	14(70)	26(63.4)	35(71.4)	110(73.3)	4		
Poor agronomic practices	33(82.5)	15(75)	29(70.7)	30(61.2)	107(71.3)	6		
Poor extension service	34(85)	13(65)	28(68.3)	34(69.4)	109(72.7)	5		
Storage pest	30(75)	0(0)	24(58.5)	32(65.3)	86(57.3)	9		
Low soil fertility	29(72.5)	12(60)	27(65.9)	31(63.3)	99(66)	7		
Shattering	0(0)	0(0)	0(0)	16(32.7)	16(10.7)	12		
Land shortage	32(80)	10(50)	22(53.7)	29(59.2)	93(62)	8		
Ape & porcupine	0(0)	11(55)	6(14.6)	0(0)	17(11.3)	11		
Dik-dik	0(0)	0(0)	23(56.1)	0(0)	23(15.3)	10		

Multiple responses; Source: Field Survey result, 2016; Values outside and inside the bracket indicate the frequency and proportion in percentage, respectively Calculated chi-square value is 162.7 and DF= (12-1) x (4-1) = 33,12,9, the numbers in parenthesis indicates the percentage," respectively.", \*=significance at 5% and ns= non-significance, OR=Overall rank

### 3.3.7. Some constraints and farmers' control strategies

The majority of farmers (> 60%) could not apply any strategy to mitigate the effects of drought, aphids, and poor soil fertility. 80% of farmers across districts have not used any strategy to cope with the stress of drought. Conversely, mulching the soil, using ridges, and adjusting planting dates are coping mechanisms that have been used by a few farmers to alleviate the effects of drought stress. For control of bruchids, a few farmers used ash (reported by 2.7 % of respondents), sand (reported by 4 % of respondents), and hot pepper (reported by 12.24 % of respondents) (Table 3.9). However, overall, 86 % of the farmers in all the districts did not use any bruchids control strategy. Most farmers (77.5%, 80.5%, 90%, and 59.2%) in Gofa, Kindo koyisha, Humbo, and Konso districts, respectively, reported that they had no option for the control of aphids. Horn et al. (2015) reported that under high aphid

infestation, traditional aphid management practices, such as the use of hot pepper extract, Garlic extract, Cowpea urine, and intercropping, were insufficient to protect pulse crops. Few farmers (9.3%) adopted aphids reducing practices, such as the use of organic and inorganic fertilizers (4%), intercropping of host plants with cereals, and the use of chemicals (14.7%), such as Malathion. To control insect pests and diseases, few farmers used traditional (22.7%) and chemical (14.7%) control methods as management strategies. These indicate the need to generate or introduce resistant cowpea varieties or farmers' control measures should be scientifically supported by research to these important biotic and biotic stresses to increase yield and sustain cowpea productivity. This could be followed by an increase and improvement in the supply of sustainable food, an increase in employment generation, increased income-generating opportunities, and an improvement in the living standard of farmers who cultivate cowpea in the region.

Table 3.9. Farmers' coping options for drought and insect pests' management in cowpea.

Constraints	strategy	Gofa	K/k	Humbo	Konso	% mean	df	$\chi^2$	P-value
Drought stress	Soil mulching	2(5)	1(5)	1(2.4)	6(12.24)	16(10.7)	9	14.4	0.11
	Use of ridges	0(0)	1(5)	1(2.4)	6(12.24)	9(6)			
	AP dates	4(10)	0(0)	3(7.4)	4(8.2)	5(3.3)			
	No option	34(85)	17(85)	36(88)	33(67.3)	120(80)			
Bruchids	Ash	1(2.5)	0	0	3(6.12)	4(2.7)	9	18.3	0.032
	Sand	2(5)	1(5)	1(2.4)	2(4.08)	6(4)			
	Hot pepper	1(2.5)	0	1(2.4)	9(18.4)	11(7.3)			
	No option	36(90)	19(95)	39(95)	35(71.4)	129(86)			
Aphids	Hot pepper	4(10)	4(9.8)	0(0)	2(4.1)	10(6.7)	12	19.2	0.08
	Garlic extract	2(5)	2(4.9)	0(0)	4(8.2)	8(5.3)			
	Cow urine	1(2.5)	1(2.4)	1(5)	4(8.2)	7(4.7)			
	intercropping	2(5)	1(2.4)	1(5)	10(20.4)	14(9.3)			
	No option	31(77.5)	33(81)	18(90)	29(59.2)	111(74)			

df, degrees of freedom;  $\chi^2$  = chi-square , AP = Adjusting planting date

### 3.3.9. Knowledge and perception of farmers on cowpea benefit

Most (86.6%) farmers knew cowpea improved soil productivity, while 13.3% had no knowledge or disagreed. The majority (87.4 %) of farmers agreed that cowpea helps to achieve food security, but 12.6% disagreed about the contributions of cowpea for food security. A small number of farmers (13.6%) disagreed that cowpea contributes to improved nutrition, but 87.3% agreed that cowpea improves nutrition (Table 3.10). In all districts, most (94 %) farmers agree that cowpea is suitable for their farming system, while 6% said it is not suitable for their farming system.

Table 3.10. Farmer's general perception of Cowpea in the study area

Characteristics	Category	Gofa	KK	Humbo	Konso	Overall	DF	$\chi^2$	P-value
Cowpea improve soil productivity	Strongly agree	20	10	24	26	80(53.3)	9	4.23	0.89
	Agree	15	5	14	16	50(33.3)			
	Disagree	3	3	2	4	12(8)			
	Strongly disagree	2	2	1	3	8(5.3)			
Cowpea help improvement in nutrition	Strongly agree	24	5	22	20	71(47.3)	9	12.3	0.19
	Agree	14	10	16	20	60(40)			
	Disagree	1	2	2	3	8(5.3)			
	Strongly disagree	1	3	1	6	11(7.3)			
Cowpea help to attain household food security	Strongly agree	22	8	16	18	64(42.7)	9	8.42	0.49
	Agree	14	10	16	27	67(44.7)			
	Disagree	2	1	5	2	10(6.7)			
	Strongly disagree	2	1	4	2	9(6)			
Cowpea is compatible to farming system	Strongly agree	20	6	22	26	74(49.3)	9	10.9	0.28
	Agree	15	13	19	20	67(44.7)			
	Disagree	2	1	0	1	4(2.7)			
	Strongly disagree	3	0	0	2	5(3.3)			

Own field survey result, 2016; Key: Values outside and inside the bracket indicate the frequency and proportion in percentage, respectively DF=degrees of freedom, X<sup>2</sup>=chi-squares=non-significance; \* and \*\* denote significance at 5% and 1%, respectively.

### 3.4. Conclusions and Recommendations

This research confirmed the importance of cowpea as a source of food for humans, feed for animals, soil fertility improvement, and as a source of income in southern Ethiopia.

Cowpea has a significant role in the production systems and food cultures in Southern Ethiopia. This study might serve as a basis for interventions that could guide cowpea production and improvement programs. This would in the long run improve the contribution of cowpea to food security and as the source of income for smallholder farmers. The interviewed farmers helped to identify the key production constraints and farmers' preferences for cowpea. Farmers also said they had developed few management mechanisms to counter the constraints. Farmers in the study areas depend on agricultural activities such as animal husbandry and growing a variety of crops, in addition to cowpea, for food and income. Thorough scientific research and technical advice are needed to direct cowpea improvement programs. Therefore, cowpea improvement programs should include farmer-focused research designs that address the aforementioned constraints, and research findings that improve farmers' livelihoods in their rural communities. In addition to the improved and sustainable technologies, it is also recommended that the Ethiopian government should create an encouraging environment for researchers and extension workers to attend to cowpea research and extension services to improve cowpea production.

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## CHAPTER FOUR

### 4. ASSESSMENT OF GENETIC DIVERSITY IN COWPEA (*VIGNA UNGUICULATA* (L.) WALP) GENOTYPES IN SOUTHERN ETHIOPIA BASED ON MORPHO-AGRONOMIC TRAITS

#### **Abstract**

*Field research was conducted at Gofa research station during the 2016/17 main crop season to estimate the genetic diversity between cowpea genotypes based on morpho-agronomic characteristics. Thirty-six cowpea genotypes were tested using a 6x6 simple lattice design with two replications. The data were recorded based on five qualitative and fourteen quantitative traits. Shannon diversity Index value ranged from 0.633 to 0.953 with a mean of 0.84 confirming that there was a high degree of deviation in the qualitative traits among cowpea genotypes. Analysis of variance for fourteen quantitative traits showed significant differences ( $P < 0.05$ ) among the cowpea genotypes. Yield and other agronomic traits showed high to moderate phenotypic (PCV) and genotypic coefficient of variation (GCV). Based on cluster analysis, 36 cowpea genotypes, based on the fourteen quantitative traits, were categorized into six clusters. I, II, IV, V, III, and VI, each with 9, 8, 7, 7, 3 and 2 genotypes respectively. The highest inter-cluster distance was noticed between cluster III and VI (4265.10) followed by cluster III and V (3569.30), cluster IV and VI (3365.38) suggesting wide diversity between them. Cluster III was found to be promising for yield and its major component traits, Cluster V was found to be promising for long pod length and large seed size, while Cluster VI had genotypes for earlier flowering and maturity. Therefore, clusters III, V, and VI genotypes could be used directly in multi-location trials for their suitability to be released for successful cowpea production or could be source materials for obtaining desirable new recombinants for early maturity and higher yield in south Ethiopia. In general, the diversity obtained in this study can further be exploited for the improvement of cowpea in south Ethiopia as a measure of food security.*

**Keywords:** *Cowpea, Cluster analysis, Shannon Weaver diversity index*

## 4.1. Introduction

Cowpea (*Vigna unguiculata* L. Walp.) is a dicotyledonous self-pollinated plant belonging to Fabaceae and native to Central Africa (Nameirakpam and Khanna, 2018). It is vital for the existence of many individuals in developing countries in the tropics, particularly in Africa and Asia (IITA, 2011). Cowpea seeds are high in protein (23-32%), carbohydrate (60%), fat (2%), and also a good source of essential compounds like vitamins B, C, iron, phosphorus, calcium,  $\beta$  carotene and zinc (Chopra *et al.*, 2011; Adeyemi, *et al.*, 2012; Srivastava *et al.*, 2016). This crop is also important for human food. It may be also used for green manure, animal feed attracts unprecedented attention in the sub-Saharan Africa for its medicinal value and may have great economic importance to poor farmers as a source of income from grain sales in the local market (Langyintuo *et al.*, 2003). Like other legumes, cowpea has nitrogen-fixing capacity from the atmosphere, which supports sustaining soil fertility for future use and can therefore be used in intercrop systems with cereal crops such as maize and sorghum (Dakora and Keya, 1997).

Cowpea is widely grown in drier regions of the world where it is one of the drought-tolerant legumes (Fabunmi *et al.*, 2012). Similarly, in Ethiopia, cowpea is grown in drier areas of the Rift Valley and the dry highlands of Hararghe (Oromiya region), central Tigray usually intercropped with sorghum/crop rotation and in the Northeastern part of the country around Shewrobit, Kobo, South Wello, and Waghimira (Amhara region) areas (kassaye *et al.*, 2013; Mulugeta, 2015). In Southern Nations, Nationalities, and Peoples' Region State (SNNPRS), Gambella and central Oromia Region sole-cropping and intercropping were practiced, while farmers' in the Eastern Oromia and West Harerge zones experienced intercropping of cowpea with sorghum and maize to increase soil fertility, to produce a diverse product and use it as a supporting mechanism for cowpea (Sisay, 2015; Beshir *et al.*, 2019). It is grown in low rainfall areas of SNNPRS, especially in Segen people's area zone (Konso and Derashe), South Omo, Humbo, Hammer Bako, Loka Abaya, Goffa, and Loma districts (Tesema and Esthetayehu, 2003).

In Ethiopia, cowpea yield under traditional farming is on average 0.4 t/ha (Beshir *et al.*, 2019), while cowpea yield potential is high, averaging 1.5 to 6 t/ha depending on genotype, but the actual yields are low (FAO, 2007). Despite its significance, the shortage of high-yielding varieties, poor agronomic practice, and insect pest attacks remain the most severe constraints on cowpea cultivation and storage. In this case, there are expectations to increase

productivity and crop acceptance by the use of appropriate measures that help overcome problems. To boost the potential for cowpea harvest, it is necessary to identify varieties with improved productivity and additional desirable traits to solve the problem of hunger and starvation, especially in the lowlands of southern Ethiopia.

Genetic diversity is a raw material for evolution and is essential for populations to survive, succeed, and cope with environmental changes, new diseases, and pest outbreaks (Hegde and Mishra, 2009). Genetic diversity researches on plants are very important in terms of developing superior varieties and stabilizing the yields of these varieties in plant breeding plans. Genetic diversity is being studied using various methods such as morphological, biochemical, and molecular markers. Research evidence on the categorization of genotypes using morphological markers for their genetic difference helps researchers to use them to generate modern varieties. To achieve a higher yield quantitative assessment of the transmissible variability parameters accompanied by the understanding of genetic diversity is a prerequisite to the researcher to select genetically different parents with the prospective to produce high heterotic combinations. A better knowledge of the genetic diversity in cowpea will facilitate crop improvement. Concerning diversity studies, many researchers from various countries, namely Aysun *et al.* (2013); Gbaguidi *et al.* (2015), and Vaibhav *et al.* (2015) studied genetic variation on cowpea genotypes. However, insignificant research has been done in assessing the agro-morphological diversity of cowpea genotypes in the southern region. Keeping this view in mind, 36 cowpea genotypes were subjected to variability parameters and genetic diversity analysis to be used in the forthcoming cowpea improvement program. Hence, this study was carried out to assess the genetic diversity among cowpea genotypes using morpho-agronomic traits, and identify best performing genotypes for further cowpea improvement.

## **4.2. Materials and Methods**

### **4.2.1. Description of the study area**

The trial was carried out in 2016/2017 at the experimental farm of the Gofa research station, 7 km in the north of Sawula, the town of the Gofa Zone. Gofa is 520 km south of Addis Ababa at an altitude of 1317 meters above sea level and lies 6° 20'N latitude and 36° 55'E longitude. The soil is mainly made up of sandy loam. The rainfall during the crop period varies from 40.1mm to 246.5 mm with major precipitation from September to October

(Figure 4.1). The minimum and maximum temperatures ranged between 16.4 ° C and 28.2 ° C, respectively. The crops grown by the small-farm sector include cereals (sorghum, maize, and tef), pulses (haricot beans, Mung bean, pigeon pea, and cowpea), and oil crops (groundnut and sesame). Livestock production also plays a crucial role in the study area farmer’s economy. Recent survey results indicated that the production status of cowpea was increasing in the past five years (2011-2015) for cowpea cultivation.

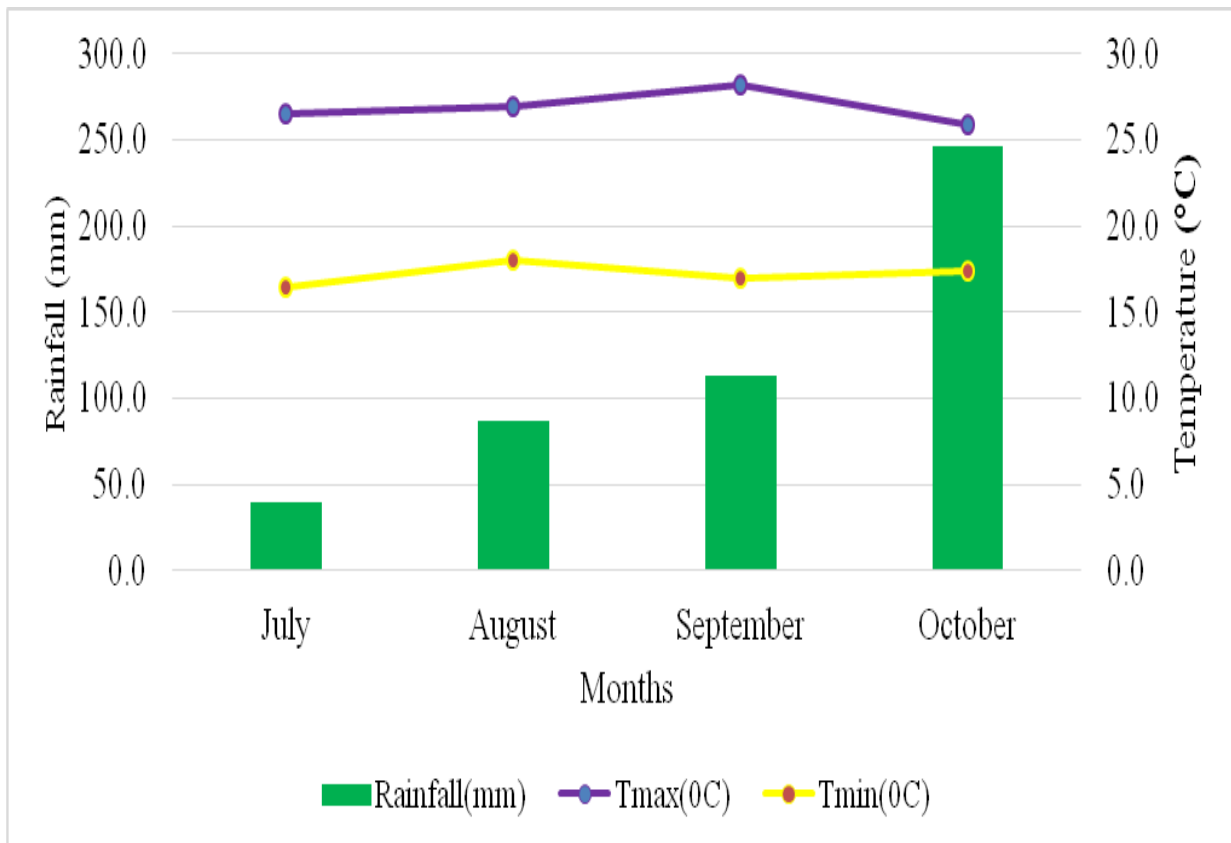


Figure 4.1. Total rainfall, mean maximum and minimum temperature of the experimental site during the experimental period. Source: Ethiopian Meteorology Agency, 2017

#### 4.2.2 Source of Experimental Materials

Thirty-six cowpea genotypes including 2 local checks were used in the study. The seeds of the cowpea genotypes were obtained from Melkasa Agricultural Research Centre of the Lowland Pulse Improvement Program. Seeds of the local materials were obtained from the farmers near the study area. The experimental materials for this study are presented in Table 4.1.

Table 4.1. List of cowpea genotypes tested

No	Genotype	Type	Source	No	Genotype	Source	Type
1	KB	Introduced	MARC	19	IT97K-449-38	MARC	elite
2	Bole	released	MARC	20	IT99K-316-2	MARC	elite
3	Kenketti	released	MARC	21	IT96D-719	MARC	elite
4	86D-378	elite	MARC	22	IT97K-356-1	MARC	elite
5	IT-89KD	elite	MARC	23	IT98K-506-1	MARC	elite
6	MEL-NURL-96-3	elite	MARC	24	IT00K-901-5	MARC	elite
7	IT96D-610	elite	MARC	25	IT97K-499-38	MARC	elite
8	IT93K-556-4	elite	MARC	26	IT95K-268-1-4	MARC	elite
9	IT97K-568-18	elite	MARC	27	BEB	HARC	released
10	95K-1095-4A	elite	MARC	28	Brazil-3	MARC	Introduced
11	IT87D-1137	elite	MARC	29	Brazil-1	MARC	Introduced
12	IT-960-604	elite	MARC	30	IT93k-293-2-2	MARC	elite
13	Tvu	released	MARC	31	W/W/T	MARC	released
14	OT-03L-2046-2	elite	MARC	32	IT-87D-721	MARC	elite
15	IT93K-2046-1	elite	MARC	33	93 K-619-1	MARC	elite
16	IT93K-452-1	elite	MARC	34	IT99K-1060	MARC	elite
17	IT98K-1111-1	elite	MARC	35	Gofa local (white)	Farmer	local
18	IT97K-569-9	elite	MARC	36	Gofa local(red)	Farmer	local

Note: MARC, Melkasa Agricultural Research center, W/W/T=white wonderer trailing

#### 4.2. 3. Experimental design and field management

The study was conducted using 36 cowpea genotypes of which 34 were sourced from Melkasa Agricultural Research Center, Ethiopia, and two local checks from farmers in the study area. The experiment was carried out in a simple 6 X 6 lattice design where each experimental unit consisted of a rectangular plot (1.2 m x 3.0 m) of 3.6 m<sup>2</sup>. Cowpea seeds were sown in two rows of 3 m long per plot providing 20 cm between seeds in the same row and 60 cm between rows. Di-ammonium phosphate (DAP) fertilizer was applied during planting at the rate of 100 kg/ha equally for all experimental units. All the cultural operations such as field preparation, weeding, and crop protection were carried out equally for all experimental units according to the recommendations to raise a successful crop. Data on various agro-morphological traits were recorded during growth based on the descriptors available for cowpea (IBPGR, 1983). Qualitative and quantitative data were collected using

the descriptors. Qualitative variables including flower color, growth habit, seed color, seed shape, and seed sizes were also scored using the standard descriptors for cowpea germplasm characterization (IBPGR, 1983). Data on flower color and growth habits were assessed on a plot basis while seed color, seed shape, and seed sizes were scored visually from seed samples. Data on the plant height, number of pods per plant, number of seeds per plant, pod length, number of primary branches per plant, number of secondary branches per plant, and number of seeds per pod were recorded on five randomly selected plants from each plot while other characters such as days to first flowering, days to 50% flowering, days to maturity, harvest index, above-ground biomass yield, 100 seed weight, and grain yield were recorded on the plot basis. Likewise, the grain yield sample is taken from the net area of the plot adjusted to the storage moisture content (10%) based on the value of actual grain moisture read by using Digital Grain Moisture Meter (DRAMINSKI, POLAND). Seed weight (g) was determined by randomly counting 100 seeds from each plot yield and weighed using an electronic sensitive balance (Mark: Cosmo digital scale).

#### 4.2.4. Data Analyses

Statistical parameters such as ANOVA, phenotypic and genotypic variances, genotypic and phenotypic coefficient of variation, cluster analysis, and genetic distance between clusters were computed for 14 quantitative traits and Shannon-Weaver diversity index ( $H'$ ) for 5 qualitative traits were computed using the SAS computer program, version 9.0 (SAS, 2002) and Minitab 17 (Mintab,2007). The phenotypic and genotypic variances of each trait were estimated from the simple lattice analysis of variance. The expected mean squares under the assumption of the random-effects model were computed from linear combinations of the mean squares and the phenotypic and genotypic coefficients of variations were computed as per the methods suggested by Burton and Devane (1953).

$$\text{Genotypic variance } (\sigma^2_g) = \frac{\text{MSG (genotype)} - \text{MSE (Error)}}{\text{Replication}}$$

$$\text{Environmental variance } (\sigma^2_e) = \text{MSE}$$

Where, MSG and MSE are the mean sum of squares for the genotypes and error in the analysis of variance, respectively.  $r$  is the number of replications. The phenotypic variance was estimated as the sum of the genotypic and environmental variances.

$$\text{Phenotypic variance } (\sigma^2_{ph}) = \sigma^2_g + \sigma^2_e$$

The phenotypic and genotypic variability of each quantitative trait was estimated as phenotypic and genotypic variances and coefficients of variation. The phenotypic and genotypic coefficients of variation were computed using the formula suggested by Burton and de Vane (1953) as follows.

$$\text{Genotypic variance } (\sigma^2_g) = \frac{\text{MSG (genotype)} - \text{MSE (Error)}}{\text{Replication}}$$

Where,  $\sigma^2_g$  = genotypic variance

Msg= mean square of genotype

Mse = mean square of error

r = number of replications

Phenotypic Variance ( $\sigma^2_p$ ) =  $\sigma^2_g + \sigma^2_e$ . The phenotypic variance was estimated as the sum of the genotypic and environmental variances.

Where  $\sigma^2_g$  = Genotypic variance

$\sigma^2_e$  = Environmental variance in which Environmental variance = mean square of the error

Genotypic Coefficient of Variation (GCV) =  $(\sigma_g/\text{grand mean}) \times 100$

Phenotypic Coefficient of Variation (PCV) =  $(\sigma_{ph}/\text{grand mean}) \times 100$

Where,  $\sigma_g$  and  $\sigma_{ph}$  are genotypic and phenotypic standard deviations, respectively.

PCV and GCV were classified as suggested by Shivasubramanian and Menon (1973) into low (0 – 10%), Moderate (10.1 – 20%), and High (>20%). Descriptive value, frequency of traits, and frequency distribution for total genotypes were determined. The Shannon-Weaver diversity index ( $H'$ ) for qualitative traits that were estimated to characterize the phenotypic frequencies of the characters was estimated as follows: The Shannon-Weaver index is calculated using the following formula:

$$H = - \sum_{i=1}^n P_i \ln P_i$$

H = Shannon and Weaver diversity index  $P_i$  = Frequency of each phenotypic class  $I$  of a given character  $n$  = Number of phenotypic classes of each character. The index (H) is converted towards the relative phenotypic diversity index ( $H'$ ) by dividing it by its maximum value:  $H / \max(\ln(n))$  to obtain 0 to 1 values.

$$H' = - \sum_{i=1}^n P_i \ln P_i / \ln(n)$$

The relative diversity index ( $H'$ ) reaches its minimum value, which is zero for monomorphic characters. Moreover, the value of this index increases with the degree of polymorphism and reaches a maximum value (1) when all the phenotypic classes are present in equal frequencies. Where  $n$  is the number of phenotypic classes for a trait and  $P_i$  is the proportion of the individuals in the  $i$ th classes. The estimated  $H'$  values of each qualitative trait were divided by  $\log_e n$  for standardization if values of  $H'$  within 0 to 1 interval. The standardized Shannon and Weaver (1949) diversity index was classified as low (0-0.33), intermediate (0.34-0.66), and high (0.67-1).

### 4.3. Results and discussion

#### 4.3.1. Qualitative characters and nature of their distribution

Cowpea genotypes differed significantly in their qualitative morphological characters. In our study, various classes of these characters have been discussed and used. The frequency, percentage, and diversity index estimates for qualitative characters are given in Table 4.2.

There was a significant qualitative trait deviation between the cowpea genotypes tested, which is shown in Table 4.2. On the seven growth habit patterns of the International Board for Plant Genetic Resources (IBPGR) (1983) cowpea descriptor, three of them were observed in all the genotypes. This study demonstrated that genotypes were identified based on plant growth habits at six weeks after planting and grouped into three categories (erect, semi-erect, and prostrate) for crop growth habits with prostrate growth habits (44 %) were considered to be more dominant type compared to other traits. Differences in the growth habit of the genotypes are due to genetic characteristics of the genotypes. Growth habit is very important in the cropping system of cowpea in southern Ethiopia; most farmers from this region use varieties in both mono cropping and intercropping that have either erect, prostrate, or semi-prostrate growth habits. Lazaridi *et al.* (2017) also classified 48 cowpea genotypes based on growth habits such as acute erect, semi-erect, intermediate, semi-prostrate, prostrate, and climbing. Similar classification based on plant growth habits (erect, semi-erect, and spreading) in cowpea was earlier reported by Brahmaiah (2013).

We also observed in this study that the frequency of the genotypes with seed color showed a trend to decrease the order which was cream brown (72.2%), holstein white and black (13.89%), brown (5.56), and others (8.3%) respectively (Table 4.2). The observed seed colors of the genotypes used in this study showed that about 72.2% of the genotypes had cream brown, 13.89% produced holstein white and black, 5.56% had brown seed color and 8.3% had produced others seed color which is in agreement with the observation of Mishra (2013) and Brahmaiah (2013) who found in their study the higher percentage of cream brown seed color followed by holstein white and black. The variation in flower color, with the percentage of violet, white, mauve-pink, and other flower color cowpea genotypes were 47.22%, 19.44%, 2.78%, and 30.56%, respectively. The study has also shown that the basis of flower color genotypes is divided into four categories. Seven genotypes showed white flowers, one genotype expressed Mauve-pink, 11 genotypes had other flower colors, and the remaining 17 genotypes showed violet flower color (Table 4.2). A wide range of floral color variations of the cowpea genotypes have been reported, from white to other types. The importance of

flower color in genotypic classification was earlier reported by Brahmaiah (2013) and Mishra (2013) in cowpea. Lazaridi *et al.* (2017) also reported that three groups differentiate by their flower color: White (65.8%), Violet (24.3%), and Mauve-pink (9.9%).

The majority of the evaluated cowpea genotypes had possessed rhomboid and kidney seed shape (61.1%) and bold seed size (63.91%) as seen in Table 4.2. Seed shape is highly polymorphic and is another useful attribute of cowpea genotype for characterization. The genotypes had five distinct seed shapes (ovoid, kidney, rhomboid, Crowder, and Globose). A marked difference in seed shape for different cowpea genotypes was observed in the current study. Makanur *et al.* (2012) classified 35 cowpea genotypes based on seed shape as ovoid (three), kidney-shaped (seven), and remaining as rhomboid. The proportions of genotypes in seed size boldness were 63.91 %, 25 %, and 14. 1% for large, medium, and small, respectively (Table 4.2). Similarly, seed size also had three different classes (large, medium, and small). Based on seed size, the genotypes were grouped large, medium, and small with twenty-three, nine, and four genotypes respectively in each group. Kumar and Shrikant (2016) classified which based on the 100-seed weight; the genotypes were classified as bold seeded, medium seeded, and small-seeded. It suggested that the cowpea genotypes assessed in the study exhibited high variability in almost all of the studied qualitative traits.

#### **4.3.2. Diversity analysis using qualitative characters**

The diversity estimation for specific qualitative characters is given in Table 4.2. Polymorphism was prevalent in varying degrees for most characters, thus suggesting the existence of a wide range of variability in genotypes. For the five qualitative traits investigated, large dissimilarities were exhibited among cowpea genotypes, and the estimated diversity ( $H'$ ) for specific traits ranged from 0.633 for seed color to 0.953 for growth habit and overall mean of 0.84 for qualitative traits (Table 4.2).

In the present research, the diversity between cowpea genotypes was observed. High diversity indices were calculated with growth habit ( $H'=0.953$ ) being the most diverse, followed by seed shape ( $H' = 0.927$ ) as shown in Table 4.2. Most genotypes had a cream brown seed color in the form of a rhombic seed shape. On average, the qualitative traits had high variability with a value of 0.84 diversity index. All traits had high diversity indices except for seed color. The result means that there are differences among the characters regarding qualitative characters considered in this study. Toscani *et al.* (2017) found low (0.00) to high (0.996) diversity in cowpea for qualitative traits.

Table 4.2. Qualitative morphological traits, class partition, frequencies of traits, and estimation of diversity indices of the entire cowpea genotype

Trait	Classes	No of class	No of genotypes	Frequency (%)	H'
Growth habit	1: Acute erect		0	0.00	0.95
	2: Erect	3	13	36.1	
	3: Semi-erect		7	19.4	
	4: Intermediate		0	0.00	
	5: Semi-prostrate		0	0.00	
	6: Prostrate		16	44.4	
	7: Climbing		0	0.00	
Flower colour	1: White	4	7	19.44	0.82
	2: Violet		17	47.22	
	3: Mauve-pink		1	2.78	
	4: other		11	30.56	
Seed shape	1: Kidney		10	27.8	0.93
	2: Ovoid	5	7	19.4	
	3: Crowder		3	8.3	
	4: Globose		4	14.1.1	
	5: Rhomboid		12	33.3	
Seed colour	1: cream	4	0	0.00	0.63
	2: Cream brown		26	72.2	
	3: Brown		2	5.56	
	4: Brown ochre		0	0.00	
	5: brown olive		0	0.00	
	6: holstein white and black		5	13.9	
	99: other		3	8.3	
Seed size	1: small	3	4	14.1.1	0.88
	2: Medium		9	25.0	
	3: Large		23	63.9	
Mean					<b>0.84</b>

**Note:** No=number

### 4.3.3. Quantitative traits

#### 4.3.3.1 Analyses of variance

Mean squares due to genotypes were significant ( $P < 0.01$ ) for days to first flowering opening, days to maturity, hundred seed weight, above-ground biomass yield, grain yield, seeds per plant; however, only significant differences ( $P < 0.05$ ) among the genotypes were depicted for the eight traits studied *viz.*, number of primary branches per plant, number of secondary branches per plant, pod length, number of seeds per pod, number of pods per plant, plant height, days to 50% flowering and harvest index (Table 4.3). These findings suggest that the genotypes studied had sufficient genetic variability which can be exploited through selection. The findings are consistent with those of Bertini *et al.* (2009) and Manggoel *et al.* (2012), who showed significant genetic variations between evaluated cowpea genotypes. Therefore, it is argued that there has been sufficient variability in the material used for their study, which provides ample scope for selecting superior and desired genotypes by the researcher for further improvement. The mean values of the 36 genotypes for 14 quantitative characters are presented in Table 4.4. Statistically significant differences were found among the genotypes for all the analyzed traits. Maximum average yield was recorded for the genotype G9 (3003 kg ha<sup>-1</sup>), followed by the genotypes G4, G10, and G11 (Table 4.4). The cowpea genotypes included in the present study exhibited a wide range for means and coefficient of variances for almost all the characters studied.

Table 4.3. Mean squares of various traits of the cowpea genotypes

Characters	Replication (df=1)	Genotypes (df=35)	Error (df=25)	CV%	Mean
DF	2.72	19.88**	4.22	4.29	48
FD	7.34	12.01*	3.6	3.53	54
DM	6.13	94.96**	2.23	4.64	91
HSW	4.10	19.11**	3.36	10.91	17
GY	146259.36	801575.31**	105554.4	19.16	1695
BY	376477.68	2454774.20**	320478.71	13.32	4249
HI	20.66	64.82*	26.86	13.47	38
PL	7.93	14.62*	5.32	15.17	15
PB	4.39	6.66*	2.36	14.22	11
SB	16.25	120.89*	36.89	26.59	23
PH	209.10	990.58*	307.60194	20.47	86
SD	45.44	7.69*	2.51	13.43	12
PT	164.11	208.10*	83.94	23.76	39
SDP	83995.34	56165.61**	10628.84	24.92	470

\*\* and \*significant at 1% and 5% probability levels, respectively. DF= Days to first flower FD=Days to 50% flowering PL=pod length BY=Above-ground biomass yield per ha (kg) DM= Days to maturity PB=number of primary branch SD= number of seeds per pod GY =grain yield per ha (kg) SDP=Number of seeds per plant HSW=100-seed weight SB= number of secondary branch PH=plant height PT= number of pods per plant HI=Harvest index

### 4.3.3.2 Estimation of variability traits

#### 4.3.3.2.1 Range and means

Genotypes showed a wide range of variability for all quantitative traits used in the study (Table 4.5). A wider range (746 - 3003 kg/ ha) was exhibited by grain yield following plant height (37 –132 cm), above-ground biomass yield (2407-6334 kg/ha), and the number of seeds per plant (186 - 880). Days to 50% flowering ranged from 48 for (IT87D-721) to 59 days for (IT97K-568-18), having 11 days between the earliest to the late maturing genotypes. Days to first flower opening ranged from 42 to 54 days, and days to maturity from 84 to 106 days. 100 seed weight ranged from 10 to 23 g. Harvest index from 24 to 48 %; pod length from 11 to 23 cm; primary branches per plant from 6 to 14; secondary branches per plant from 7 to 40; the number of seeds per pod from 8 to 16 and number of pods per plant from 17 to 57. Therefore, it could be concluded that most of the quantitative characters measured showed broad variability.

Table 4.4. Mean performance of 36 genotypes of cowpea for 14 quantitative characters

GC	DF	DF	DM	HW	GY	BY	HI	PL	PB	SB	PH	SD	PT	SDP
G1	46	52	89	19	1134	3353	34	11	11	28	109	11	46	501
G2	44	54	85	18	1674	4452	38	13	10	28	64	9	49	458
G3	43	52	84	14	1333	3692	35	16	10	29	78	13	31	411
G4	51	57	89	13	2737	6334	43	16	12	23	107	14	39	548
G5	47	53	87	14	2351	5386	43	19	12	33	105	15	48	694
G6	49	54	106	14	2378	5435	44	12	13	40	111	14	38	539
G7	50	54	86	18	1461	3686	40	12	10	25	52	10	29	301
G8	46	52	89	20	2061	4974	41	15	14	27	87	10	39	393
G9	54	59	87	20	3003	6307	47	11	14	31	88	13	52	693
G10	48	54	88	18	2625	5393	47	13	12	33	92	12	50	631
G11	47	52	88	13	2576	5487	45	17	12	39	103	15	57	880
G12	46	52	87	14	2437	6051	39	23	12	16	95	13	54	730
G13	51	58	87	10	2429	5057	48	15	14	25	76	11	36	427
G14	49	54	101	15	891	3650	24	14	11	31	65	9	36	370
G15	45	50	100	18	1184	3508	33	14	12	21	75	13	35	439
G16	43	51	84	18	1239	3176	39	18	12	16	59	11	34	377
G17	49	55	89	19	1081	2737	39	18	9	15	65	10	32	316
G18	53	58	89	17	1715	4614	37	13	13	21	82	12	51	594

**Table 4.4. Continued...**

GC	DF	DF	DM	HW	GY	BY	HI	PL	PB	SB	PH	SD	PT	SDP
G19	54	58	97	21	1219	2865	42	18	9	14	90	8	43	358
G20	50	54	87	18	752	2541	32	15	9	11	68	11	25	267
G21	49	53	98	18	1087	3157	34	15	8	17	60	11	23	248
G22	47	54	98	19	1415	4042	35	18	11	16	67	10	38	386
G23	47	52	101	17	1806	4574	39	19	11	19	131	11	46	541
G24	49	53	101	17	1179	3668	31	15	12	30	75	12	42	545
G25	49	54	101	17	1325	3800	34	15	11	15	109	10	21	210
G26	50	55	89	17	2122	4892	43	17	9	28	90	11	41	426
G27	49	53	101	21	955	3022	31	19	10	13	99	12	24	298
G28	46	52	97	23	1862	5176	36	14	12	32	132	14	38	564
G29	48	54	103	22	1285	3378	39	15	12	18	96	16	35	581
G30	49	55	89	16	1957	4295	45	15	10	22	88	11	49	532
G31	53	58	87	11	2389	5168	46	15	12	24	117	12	51	671
G32	42	48	84	18	1009	3209	31	17	8	18	62	11	31	332
G33	43	51	85	20	746	2407	31	16	6	7	37	10	22	220
G34	52	58	86	13	2361	5541	42	17	12	19	97	15	45	704
G35	50	55	88	12	1942	4705	41	11	10	25	97	14	43	565
G36	44	52	86	15	1312	3242	38	12	8	16	57	10	17	186
GM	48	54	91	17	1695	4249	38	15	11	23	86	12	39	470
CV	4	4	2	11	19	13	13	15	14	27	20	13	24	22
LSD (5%)	4.4	4.1	3.3	3.8	669.1	1165.9	10.7	4.7	3.2	12.5	37.1	3.3	18.9	254.8

GC=Genotype code, GM=Grand mean, CV=coefficient of variation, LSD(5%)=Least significant differences at 5% Note: G=genotypes, G1=KB,G2= Bole,G3= Kenketi,G4=86D-378,G5= IT-89KD,G6= MEL-NURL-96-3,G7= IT96D-610,G8= IT93K-556-4,G9= IT97K-568-18,G10=95K-1095-4A,G11= IT87D-1137,G12= IT96D-604,G13= Tvu,G14= OT-03L-2046-2,G15= IT93K-2046-1,G16= IT93K-452-1,G17= IT98K-1111-1,G18= IT97K-569-9,G19= IT97K-449-38,G20= IT99K-316-2,G21= IT96D-719,G22= IT97K-356-1,G23= IT98K-506-1,G24= IT00K-901-5,G25= IT97K-499-38,G26= IT95K-268-1-4,G27= BEB,G28= Brazil-3,G29= Brazil-1,G30= IT93k-293-2-2,G31= White wanderer trailing,G32= IT87D-721,G33=93 K-619.-1,G34= IT99K-1060,G35=Local 1(white seed color) & G36=Local 2(red/brown seed color)

#### 4.3.3.3.2 Phenotypic and genotypic variations

Assessment of different genetic parameters is presented in Table 4.5. Shivasubramanian and Menon (1973) were classified PCV and GCV as low (0 – 10%), Moderate (10.1 – 20%), and High (>20%). In the present study, high values of PCV and GCV were observed for grain yield per hectare, number of seeds per plant, number of secondary branches per plant, number of pods per plant, plant height, above-ground biomass yield per hectare, indicating a greater scope for improvement of these traits through simple selection. These observations are consistent with (Manggol *et al.* 2012; Sivakumar *et al.*, 2014; Viswanatha and Yogeesh, 2017) but are slightly contradictory (Adewale *et al.*, 2010) who reported higher PCV and moderate GCV for grain yield among 11 cowpea genotypes evaluated in Nigeria. Many previous researchers have also stated high GCV and PCV for plant height and primary branches per plant (Khan *et al.* 2015), seed yield per plant (Rakesh *et al.*, 2013). However, moderate PCV and GCV were recorded for the weight of one hundred seeds, the harvest index, the number of primary branches per plant, the number of seeds per pod. Pod length recorded high PCV but moderate GCV. Low GCV and PCV were recorded for days at 50% flowering, days until first flowering, and days until maturity representing low variability which limits the possibilities of improvement of these traits by selection. Moderate PCV and GCV values were reported for pods per plant (Khan *et al.*, 2015), seeds per pod, and test weight (Viswanatha and Yogeesh, 2017), while low GCV and PCV were also reported for days to 50% flowering (Manggol *et al.* 2012) and days to maturity and plant height (Viswanatha and Yogeesh, 2017).

The assessment of genetic variability revealed higher values (>20%) for the phenotypic coefficient of variation (PCV) for grain yield per hectare (39.7%), number of seeds per plant (38.9%), number of secondary branches per plant (38.9%), number of pods per plant (34.3%), plant height (29.9%), above-ground biomass yield per hectare (27.7%), pod length (20.8%) and moderate (between 10 to 20%) for hundred seed weight (19.9%), number of primary branches per plant (19.7%), harvest index (17.5%), number of seeds per pod (19.1%) and low phenotypic coefficient of variation (less than 10) recorded for the first flowering days (7.4%), 50% flowering days (5.3%) and maturity days (7.5%).

Similarly, the magnitude of genotypic coefficient of variation (GCV) was also high (>20%) for grain yield per hectare (34.8%) followed by the number of seeds per plant (32.1%), number of secondary branches per plant (28.4%), above-ground biomass yield (24.3%), plant height (24.7%), pods per plant (20.4%) and moderate (between 10 to 20%) for hundred seed

weight (16.7%), pod length (14.2%), harvest index (14.3%), number of primary branches per plant (13.6%), number of seeds per pod (13.6%) and low genotypic coefficient of variation (less than 10%) recorded for the first flowering days (5.8%), 50% flowering days (3.9%) and maturity days (7.3%). The magnitude of PCV ranged from 5.3% (50% flowering days) to 39.7% (grain yield per hectare), while the magnitude of GCV ranged from 3.9% for days of 50% flowering to 34.8% for grain yield per hectare (Table 4.5).

Table 4.5. Estimates of mean, range, variance components, genotypic and phenotypic coefficient of variability for the 14 characters of cowpea genotypes

Traits	Mean	Range	$\sigma^2_g$	$\sigma^2_e$	$\sigma^2_{ph}$	PCV (%)	GCV (%)
DF	48	42-54	7.6	4.7	12.4	7.4	5.8
DF	54	48-59	4.5	3.5	8.0	5.3	3.9
DM	91	84-106	44.9	2.2	47.1	7.5	7.3
HSW	17	10-23	7.9	3.4	14.2	19.9	16.7
GY	1695	746-3003	348010.5	105554.4	453564.9	39.7	34.8
BY	4249	2407-6334	1067146.3	320478.7	1387625.0	27.7	24.3
HI	38	24-48	19.0	26.9	45.8	17.6	14.3
PL	15	11-23	4.7	5.3	10.0	20.8	14.2
PB	11	6-14	2.2	2.4	4.5	19.7	13.6
SB	23	7-40	42.0	36.9	78.9	38.9	28.4
PH	86	37-132	344.5	307.6	649.1	29.9	24.7
SD	12	8-16	2.6	2.5	5.1	19.1	13.6
PT	39	17-57	62.1	83.9	146.0	34.3	20.4
SDP	470	186-880	22768.4	10628.8	33397.2	38.9	32.1

DF=Days to first flower opening, DF= Days to 50% flowering, DM=Days to 50% maturity, HSW= Hundred seed weight, HI= Harvest index, PL=Pod length(cm), PB=number of primary branches per plant, SB= number of secondary branches per plant, PH=plant height (cm), PT= Number of pods per plant, SD= Number of seeds per pod, Number of seeds per plant, BY = Above ground biomass yield (kg/ha), GY= grain yield (kg/ha),  $\sigma^2_g$ , = Genotypic variance,  $\sigma^2_e$ = Environmental variance,  $\sigma^2_{ph}$ = Phenotypic variance, GCV= Genotypic coefficient of variability, PCV= Phenotypic coefficient of variability

#### 4.3.4. Diversity studies of the quantitative traits

##### 4.3.4.4.1. Cluster analyses

The genotypes were categorized into six distinct clusters (Table 4.6) using the Pseudo F and Pseudo t<sup>2</sup> procedure of SAS (2002). Estimation of genetic diversity based on the D<sup>2</sup> value publicized that the 36 genotypes of cowpea were clustered into six groups (Table 4.6). This

designated the existence of diversity on the tested genotypes. Cluster I was the largest with 9 genotypes (25 %), Cluster II consisted of 8 genotypes (22.2 %), cluster IV and V had 7 genotypes (19.44%) each, cluster III had 3 genotypes (8.3%) and cluster VI had 2 genotypes (5.5 %). While considering the inter-cluster distance, it ranged from 605.99 to 4265.1 as shown in Table 4.7. The highest inter-cluster distance was found between clusters III and cluster VI (4265.1), followed by cluster III and cluster V (3569.28), cluster VI and cluster IV (3365.37). Selection of parents for hybridization from clusters with high inter-cluster distances may give a high amount of heterosis effect and may generate useful recombinants in segregating populations. Therefore, the genotypes from these clusters can be selected for an efficient breeding program for high yield and other desirable traits improvement. The results are a close confirmation of the findings of Nath and Tajane (2014) categorized forty-four cowpea genotypes based on six quantitative traits were grouped into six clusters revealing a sufficient amount of variability among the varieties. Meena *et al.* (2015) grouped 72 cowpea genotypes by using quantitative traits *viz*, days to 50% flowering, days to maturity, plant height, primary branches per plant, number of pods per plant, pod length, pod wall proportion, 100 seed weight and yield per plant. These observations were in agreement with those of Dalsaniya *et al.* (2009).

Table 4.6. Clustering of cowpea genotypes based on D2value

cluster	No. geno	Percentage	Name of genotypes
I	9	25	Kenketti, IT96D-610, KB ,Brazil-1, IT93K-2046-1, IT00K-901-5 ,IT97K-499-38 ,IT97K-356-1, OT-03L-2046-2
II	8	22.2	IT93K-556-4, IT95K-268-1-4, IT97K-569-9, IT98K-506-1, Bole, local check (white seed), IT93k-293-2-2, Brazil-3
III	3	8.33	86D-378, IT97K-568-18, IT96D-604
IV	7	19.44	IT-89KD, IT99K-1060, MEL-NURL-96-3, 95K-1095-4A, IT87D-1137, Tvu, White Wonder Trailing
V	7	19.44	IT96D-719, IT87D-721, IT98K-1111-1, IT97K-449-38, BEB, IT93K-452-1, Local check ( brown seed)
VI	2	5.55	IT99K-316-2, 93 K-619.-1

Table 4.7. Distances between different cluster centroids of cowpea genotypes.

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Cluster I	0.00	1252.83	2994.95	2102.07	605.99	1280.85
Cluster II	1252.83	0.00	1739.92	858.15	1834.93	2526.02
Cluster III	2994.95	1739.92	0.00	922.17	3569.30	4265.10
Cluster IV	2102.07	858.15	922.17	0.00	2667.41	3365.38
Cluster V	605.99	1834.93	3569.30	2667.41	0.00	699.52
Cluster VI	1280.85	2526.02	4265.10	3365.38	699.52	0.00

Considering the cluster average performance shown in Table 4.8, cluster IV, which contains the genotypes IT89KD, MEL-NURL-96-3, 95K-1095-4A, and IT87D-1137 had a high mean value for the number of seeds per pod, plant height, harvest index, number of secondary branches per plant. Genotypes IT97K-568-18 and 86D-378 from cluster III were found to be higher in obtaining top-grain yield (3002.95 kg ha<sup>-1</sup>; 2737 kg ha<sup>-1</sup>) and biological yield (6307 kg ha<sup>-1</sup>; 6334.03 kg ha<sup>-1</sup>) from 36 genotypes studied (Table 4.4). Therefore, the selection of parental material from these clusters can be used to develop superior varieties.

Table 4.8. Cluster means for fourteen quantitative characters in cowpea.

Character	Cluster number					
	C-I	C-II	C-III	C-IV	C-V	C-VI
DFF	47.00	47.63	50.17	49.29	47.00	46.5
DF	52.89	53.38	55.50	55.00	53.21	52.5
DM	95.72	90.69	87.50	89.64	94.07	85.5
HSW	17.60	17.58	15.48	13.41	18.39	18.625
GY	1245.23	1892.45	2725.65	2444.03	1128.79	749.075
BY	3644.84	4710.30	6230.56	5352.52	3058.38	2474.17
HI	33.83	39.92	43.13	45.08	36.26	34.09
PL	14.35	14.60	16.33	15.16	16.54	15.175
PB	10.89	14.11	12.62	12.25	9.13	7.175
SB	23.54	25.17	23.17	30.29	15.63	9.075
PH	80.73	96.425	96.433	100.07	70.19	52.7
SD	14.64	14.42	13.33	13.59	10.36	10.375
PT	34.74	44.38	48.30	46.28	29.18	23.65
SDP	415.96	509.12	656.93	649.22	304.99	243.65

## 4.5. Conclusion and recommendation

The estimate of genetic diversity and characterization of cowpea was based on 5 qualitative and 14 quantitative phenotypic descriptors. For the trait seed shape, five different phenotypic classes were detected, followed by seed color and flower color each with four different phenotypic classes. Most genotypes had prostrate growth habits and violet flower color, based on the qualitative traits. Variation was observed in 5 qualitative traits among 36 cowpea genotypes evaluated. Diversity among cowpea genotypes was observed with growth habit ( $H'=0.953$ ), seed shape ( $H'=0.927$ ) being the most diverse, and the seed color of seed being the intermediate diverse ( $H'=0.633$ ). Analysis of variance showed highly significant to significant differences among the tested genotypes for all 14 quantitative traits, signifying the existence of genetic variability in the traits studied. A wide range of values had been observed in quantitative traits of the studied cowpea genotypes. Four genotypes out yielded ( $> 25\text{qt/ha}$ ) the test genotypes and two local checks indicating the possibility of finding superior genotypes for release or the presence of broad difference among the cowpea genotypes evaluated that would provide ample opportunities for the genetic improvement of the crop through genetic recombination by hybridization of genotypes with desirable traits. Comparatively, rapid progress can be achieved through selection. A perusal of genetic variability parameters revealed high phenotypic and genotypic coefficients of variation for the number of seeds per plant, number of secondary branches per plant, plant height, number of pods per plant, above-ground biomass yield, and grain yield. PCV and GCV estimation showed that these characters with high variability and the prominence of the characters.

The 36 genotypes of cowpea were clustered into six distinct groups. The maximum inter-cluster distance (4265.10) was noticed between cluster III and VI followed by III and V (3569.30) and IV and VI (3365.38), while it was low between cluster V and I (605.99), followed by cluster IV and II (858.15). Cluster III (86D-378, IT97K-568-18) and IV (95K-1095-4A, IT87D-1137) had genotypes with the highest above-ground biomass and grain yield, while the genotypes in Cluster I (kenketi), VI (93 K-619.-1), and V (IT87D-721, IT93K-452-1) matured much earlier. Crossing between genotypes within these groups could produce highly productive and early maturing cowpea genotypes. Based on the inter-cluster distances, the crosses between the genotypes of cluster III and cluster VI, cluster III and V, cluster IV and cluster VI can be attempted to generate desirable recombinants for yield improvement.

Cluster analysis further strengthened our findings in selecting the better performing genotypes by grouping them based on the traits. A group of genotypes in clusters III and IV was identified as being different from others for the number of traits including grain yield. Similarly, based on mean performance, IT97K-568-18 (G9) and 87D-378 (G4) clustered together (cluster III) were the highest yielding genotypes (3,002.9 and 2,736.6 kg/ ha, respectively), followed by the genotypes 95K-1095-4A (G10) and IT87D-1137 (G11) in Cluster IV appeared most promising and could be directly tested in multi-location trials for release to have successful cowpea production or can be recommended for future cowpea improvement program for obtaining desirable new recombinants for early maturity and higher yield in South Ethiopia. Hence, these promising genotypes could be very useful in enriching the cowpea varieties that would be suited to the different types of farmers/consumers' preferences and utilizing these valuable genotypes for varietal improvement under different cowpea improvement programs. In general, the diversity obtained in this study could be further exploited to improve cowpea in south Ethiopia as a measure of food security.

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## CHAPTER FIVE

### 5. GENOTYPE BY ENVIRONMENT INTERACTION AND YIELD STABILITY OF COWPEA (*VIGNA UNGUICULATA* (L.) WALP.) GENOTYPES IN MOISTURE LIMITED AREAS OF SOUTHERN ETHIOPIA

#### ABSTRACT

*Genotype by environment interaction (GEI) markedly influences the success of breeding strategies in crops including cowpea (Vigna unguiculata (L.) Walp.). Twenty cowpea genotypes were tested in a randomized complete block design (RCBD) using three replications at Gofa, Kucha, and Humbo in Meher seasons of 2016 and 2017 [(Gofa, Meher, 2016(E1); Humbo, Meher, 2016(E2); Kucha, Meher, 2016(E3); Gofa, Meher, 2017(E4); Humbo, Meher, 2017(E5) and Kucha, Meher, 2017(E6)] and in Belg season of 2017 and 2018 [(Gofa, Belg, 2017(E7); Humbo, Belg, 2017(E8); Kucha, Belg, 2017(E9); Gofa, Belg, 2018(E10); Humbo, Belg, 2018(E11) and Kucha, Belg, 2018(E12)]. The study was conducted to quantify and evaluate the effects of genotypes, environments, and their interactions for grain yield of cowpea genotypes and to identify stable and high-yielding genotypes. The environment, genotype, and genotype by environment interaction (GEI) effects were significant ( $p < 0.001$ ), with a contribution of 42.3%, 23.0%, and 34.7%, respectively to the treatment sum of squares (TSS). Additive main effects and multiplicative interactions (AMMI) model, genotype plus genotype by environment interaction (GGE) biplot model, AMMI Stability Value (ASV), and genotype selection index (GSI) were used to identify stable genotypes. The GGE-biplot model showed that the twelve environments used for the study clustered into three mega-environments include: E2, E4, E5, E6, E8, E9, E10, and E11 as mega-environment-I, E3, E7, and E12 as the mega-environment-II, and E1 as the mega-environment-III. Our results showed that the six high-yielding genotypes IT96D-604, IT-89KD, IT93K-293-2-2, 93K-619-1, IT97K-569-9, and IT99K-1060 could be recommended for inclusion in the improvement program or variety verification trials for release as new varieties to increase the variety portfolio of this scarcely researched crop for which only six cowpea varieties have been released so far. Also, advanced lines, IT99K-1060 (G15) and IT97K-569-9 (G20) can be recommended for Meher and Belg environments with short growing seasons and with terminal moisture stress such as E3, E7, E8, E11, and E12. IT96D-604 can also be recommended for all cowpea growing areas avoiding E2 (85 days) and E12 (80 days). 93K-619-1 and IT93K-293-2-2 can also be recommended for all cowpea growing Meher and Belg environments avoiding E1, E2, and E3 and E12. The analyses identified IT-89KD (G16) and IT93K-293-2-2 (G14) as the stable and high-yielding genotypes across environments and can be recommended for all cowpea growing areas in southern Ethiopia. The genotypes G12, G13, G15, and G20 were suggested for inclusion in the breeding program of cowpea due to their high grain yield and intermediate stability. Moreover, our results denoted the effectiveness of AMMI and GGE biplot techniques in the selection of genotypes that are stable, high-yielding, and responsive.*

**Keywords:** AMMI, ASV, cowpea [*Vigna unguiculata* (L.) Walp.], GGE biplot, GSI

## 5.1. Introduction

Cowpeas are grown on 12 million hectares worldwide; over 95% (or 11.4 million ha) of which are grown in sub-Saharan Africa (FAOSTAT, 2015). The world production statistics of cowpea stands at 4.46 million metric tons with total production for Africa was estimated at 4.24 million metric tons (FAO, 2015), of which 52% is used for food, 13% as animal feed, 10% for seeds, 9% for other uses, and 16% is wasted (Baysah, 2013). Cowpea is a vital food legume in many African countries, including Ethiopia where tender leaves, young/fresh pods, and grains are used for human food, while the foliages are an important livestock feed (Olawale and Bukola, 2016; Mulugeta *et al.*, 2016). It is an inexpensive source of protein and is used as an excellent substitute for animal proteins by many low-income Africans in the low-land humid and dry savannah tropics (Nwosu *et al.*, 2013). Cowpea is primarily used for human food in the form of boiled grains (Nifro), bread (Kita) and as a constituent for various sauces like Shiro *wot* in Amhara Region (Mulugeta *et al.*, 2016)

Cowpea does well and is most popular in the semiarid parts of the tropics where other food legumes do not perform well (Sankie *et al.*, 2012). It is a hardy crop and well adapted to drought-prone areas (Badiane *et al.*, 2012). It has deep roots and a dense foliage cover that not only stabilizes the soil but also protects the ground and retains moisture. These traits are of particular importance in the dry zones where moisture is limited (NRC, 2006). The environmental advantage of cowpea is also arising from its ability to cope in semi-arid regions with low external inputs (Boukar *et al.*, 2018). Like other legumes, cowpea also fixes atmospheric nitrogen, compensating for the loss of nitrogen absorbed by cereals, replenishing the nitrogen status of the soil, and restores soil fertility (Tesema and Esthetayehu, 2003; Sanginga *et al.* 2003).

In Ethiopia, cowpea is grown in the drier areas of the Oromiya region (the Rift Valley, highlands of Hararge), Amhara region (Shewarobit, Kobo and Waghimira areas), South Nation, Nationalities, and Peoples Regional State (SNNPRS) (Konso, Derashe, Humbo, Hammer Bako, Loka Abaya, Gofa, and Loma districts and South Omo zone), Tigray, and Gambella regions (Kassaye *et al.*, 2013; Tesema and Esthetayehu, 2003). Nearly 70% of the arable land in Ethiopia falls on dry land environments where rainfall is usually inadequate, poorly distributed, and varies over years and seasons within a year (UNDP, 2014). Despite its significance and production, cowpea has been identified as a neglected and

underutilized crop species, with further research required in some parts of Africa including Ethiopia where there is limited information on its cultivation, agronomic practices, and seed handling (Chivenge *et al.*, 2015; Mfeka *et al.*, 2019; Selamawit *et al.*, 2020). In Ethiopia, only six varieties have been released so far (MOA, 2018). Statistical data on cowpea area coverage and bulk production is not available in the country which usually is reported with that of haricot beans (*Phaseolus vulgaris* L.). The average national cowpea yield in the farmers' field in Ethiopia is estimated to be 0.4 t ha<sup>-1</sup> (Beshir *et al.*, 2019), a range far below the average yield of 2.2–3.2 t ha<sup>-1</sup> recorded in research farms with proper crop management and protection practices (Ashinie *et al.*, 2020). The low average national yield is often associated with the use of unimproved local varieties, poor soil fertility, biotic and abiotic stresses, and inadequate technological interventions.

There is an urgent need to increase cowpea yields by developing superior genotypes in the south region, as it is one of the major production complexes in the country (Beshir *et al.*, 2019). A major challenge of cowpea production in these parts of the country is the lack of stable varieties. For the last decades, a few cowpea varieties (only six) were developed and released for growing in these areas. The promising lines and released cowpea varieties should be tested for stability and adaptability. Researchers are interested in developing genotypes that not only have superior yield but also show better adaptation to multiple environments. Adaptability is defined as the ability of genotypes to show high and constant yields in certain environments, while stability refers to the ability of genotypes to show predictable behavior against environmental fluctuations (Lin and Binns, 1994; Cruz, 2014). Stable genotypes show superior performance and stability in yield across different environments (Becker and Leon, 1988). The development of stable genotypes and corresponding management components can only be assessed through GEI research. Genotype stability has a pivotal role and simply means how consistent the yield of a genotype is compared with other genotypes. However, Eberhart and Russell (1966) proposed that genotypes with minimal interaction with the environment could be regarded as stable genotypes. Enhanced adaptability of a genotype to different environments promotes wide cultivation by farmers. However, different genotypes respond differently to environmental variations. Altered performance of a genotype for a given trait across different environments is defined as genotype by environment interaction (GEI) (Kang, 1997). GEI explains that not only the genetic potential of a genotype but also its interaction with environmental factors (climate, soil type, planting methods, and management technology) affects the phenotypic expression of a trait.

Several authors have reported inconsistency in the performance of cowpea genotypes over different environments or failure of genotypes to achieve the same relative performance in different environments (Baker and Léon, 1988; Ceccarelli, 1996) due to a phenomenon known as GEI Interaction (Kassaye *et al.*, 2013; Agbahoungba *et al.*, 2016; Odeseye *et al.*, 2018). Selection for yield under moisture stress is generally less effective than selection for yield under well-watered conditions due to large GEI, which notoriously hinders the identification and release of a superior crop variety (Rosielle and Hamblin, 1981). This means that selection for yield is relatively less efficient and, therefore, conventional breeding programs need to be supplemented by molecular genetic engineering, climate-smart agricultural (CSA) practices, and applying agricultural conservation techniques. A crop variety is best when it performs consistently with a high mean yield when grown across diverse environments (Eberhart and Russell, 1966). Knowledge of the magnitude and pattern of GEI and stability analysis is important for understanding the response of different genotypes to changing environments and for identifying widely adapted and/or unstable but specifically adapted genotypes. GEI can be reduced by identifying the most stable genotypes (Eberhart and Russell, 1966; Horn *et al.*, 2018) or by dividing the production area of the crop into mega-environments where homogenous locations can be identified. Evaluation of genotypic performances in multi-location experiments provides valuable information about the adaptation and stability of the varieties to be released (Dagnachew *et al.*, 2014).

Though much works have been reported on stability in southern Ethiopia (Asfaw *et al.*, 2012); those on cowpea are rather few. The performance of these released varieties and promising lines in the pipeline has not been studied under the moisture limited areas. There is also limited information on the extent and pattern of GEI interaction and the stability of these genotypes when grown in the region. Therefore, the objectives of the present study were to assess the magnitude and pattern of GEI interaction, assess the stability of the cowpea genotypes, and identify stable and high-yielding varieties for broad or narrow adaptation to enhance productivity in southern Ethiopia.

## **5.2. MATERIALS AND METHODS**

### **5.2.1. Experimental sites**

The present study was carried out at three locations in southern Ethiopia, namely Gofa, Kucha, and Humbo, during the 'Meher' in 2016 and 2017 (E1 to E6) and the 'Belg' in

2017 to 2018 (E7 to E12). These three locations represent cowpea growing agro-ecologies of southern Ethiopia. They have a bimodal rainfall pattern with the 'Meher' or the main crop season, which extends from July to October/November, and 'Belg' or a short growing season, which lasts from March to May/June (Fig. 5.1). Long-term (2001-2018) meteorological data showed that Kucha has annual rainfall ranging from 664.8 to 1266.2 mm with a mean of 1060 mm, an average annual temperature ranging between 17.7°C and 31.4°C, with a mean of 24.6 °C. Gofa has annual rainfall that ranged between 868 and 1634 mm with an average of 1116 mm, mean annual temperature between 17.9°C and 30.9 °C with a mean of 24.4 °C, while Humbo has annual rainfall between 541 and 1096 mm with a mean of 844 mm and with mean annual temperature between 18.7°C and 32.1 °C with an average of 25.4 °C (Table 5.1, Appendix 3a-b and Fig.5. 1).

Table 5.1. Characteristics of the three sites used to test 20 cowpea genotypes during 2016-2018

Location	Zone	Latitude	Longitude	Altitude( mas l)	Annual RF (mm)	Soil Type	Mean annual (T°C)
Gofa	Gamo Gofa	6°20' N	36°56' E	1305	1116	Sandy Clay loam	24.4 °C
Humbo	Wolayita	6°39' N	37°48' E	1379	844	Clay	25.4 °C
Kucha	Gamo Gofa	6°29'N	37°28'E	1354	1060	Clay	24.6°C

Note: RF=rainfall, masl=meters above sea level

At Gofa and Kucha, Belg rain started in March, while in Humbo it started in April (Figure 5.1 and Appendix 3a and b). Precipitation in March at Humbo was very low. Therefore, the Belg season at Humbo was shorter than that in Gofa and Kucha. All three locations experienced maximum rainfall in April. Rains were usually irregular and come as few heavy showers. Long dry spells occurred during the growing season. Bimodality is more vivid in Gofa where rainfall in June was low (about 70 mm). However, there was a dry spell in June in all three locations. At Humbo and Kucha higher rainfall was obtained in June (90 mm and 100 mm, respectively) as compared to Gofa (70 mm). The Meher rains (July to September/October) were more even, decreasing gradually in September and October at Humbo and Kucha. At Gofa, the second-highest rainfall after April was reached in October (180 mm), with some rains (80 mm) in November, too. Gofa is lying adjacent to the lowlands of Borana in Oromiya Regional State, which are characterized by “Hagayya” rains (August to

November).

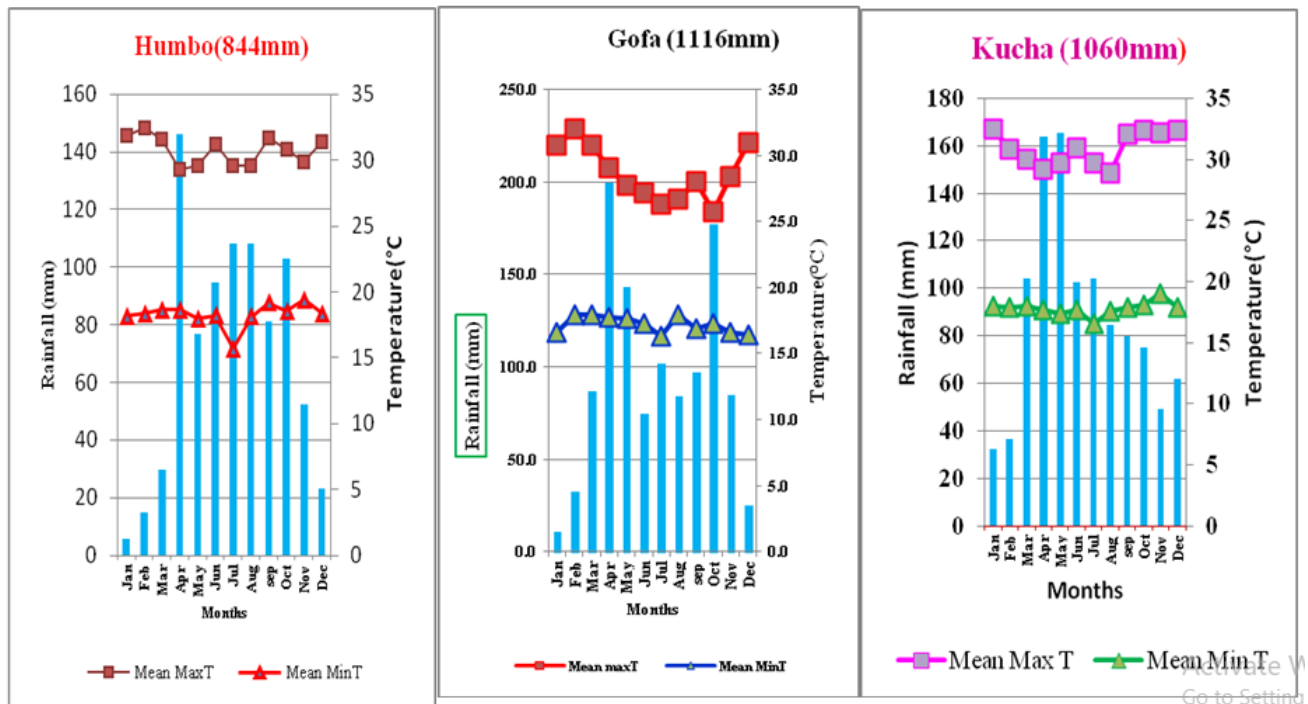


Fig. 5.1. Monthly rainfall, minimum and maximum temperature at the three-test sites

Source: Ethiopian Meteorology Agency, Awassa Branch, 2018

### 5.2.2. Experimental materials

Twenty cowpea genotypes (five released varieties, five introduced materials, nine advanced lines, and a local check) were tested in 12 environments (season-year-location combinations) (E1-E12) (Table 5.2). Experiments conducted during Meher of 2016 were designated as E1-E3; those conducted during Meher of 2017 were designated as E4-E6. The experiments of Belg 2017 were designated as E7-E9 while those of Belg 2018 were named E10-E12 (Table 5.2).

Table 5.2. The crop growing seasons rainfall of 12 Environments (E1-E12) were used to evaluate 20 cowpea Genotypes

Locations	Code	year	Season	Months	RF (mm)
Gofa	E1	2016	Meher	July-November	487
	E4	2017	Meher	July-November	889
Humbo	E2	2016	Meher	July-November	376
	E5	2017	Meher	July-November	813
Kucha	E3	2016	Meher	July-November	640
	E6	2017	Meher	July-November	887
<b>Meher Total</b>					<b>682</b>
Gofa	E7	2017	Belg	March-June	391
	E10	2018	Belg	March-June	357
Humbo	E8	2017	Belg	March-June	291
	E11	2018	Belg	March-June	600
Kucha	E9	2017	Belg	March-June	531
	E12	2018	Belg	March-June	974
<b>Belg Total</b>					<b>524</b>

Source: For rainfall data, Ethiopian Meteorology Agency, Awassa Branch, 2018

The released varieties and introduced lines were obtained from Areka Agricultural Research Center, which initially was obtained from Melkasa Agricultural Research Center (MARC). The advanced lines were obtained from Melkasa low land pulse crops improvement program. Local checks have been taken from the farmers of the respective sites. The list of the genotypes is given in Table 5.3.

Table 5.3. Cowpea genotypes tested during 2016-2018 at 12 Environments

No	Genotype	Code	Status	YR	Source
1	Brazil-1	G1	Introduced	-	MARC
2	Bole	G2	Released	2005	MARC
3	White wonderer trailing	G3	Released	1976	MARC
4	Kenketi	G4	Released (standard check)	2012	MARC
5	Brazil-2	G5	Introduced	-	MARC
6	Brazil-3	G6	Introduced	-	MARC
7	Brazil-4	G7	Introduced	-	MARC
8	KB	G8	Introduced	-	MARC
9	BEB	G9	Released	1976	MARC
10	TVU-1977-DD1	G10	Released	1978	MARC
11	Local check	G11	Farmers seed (local check)	-	Farmers
12	IT96D-604	G12	Advanced line	-	MARC
13	93K-619-1	G13	Advanced line	-	MARC
14	IT93K-293-2-2	G14	Advanced line	-	MARC
15	IT99K-1060	G15	Advanced line	-	MARC
16	IT-89KD	G16	Advanced line	-	MARC
17	IT97K-499-38	G17	Advanced line	-	MARC
18	IT93K-452-1	G18	Advanced line	-	MARC
19	IT98K-1111-1	G19	Advanced line	-	MARC
20	IT97K-569-9	G20	Advanced line	-	MARC

Note: YR=Year of release; MARC= Melkasa Agricultural Research center

### 5.2.3. Design of the experiment and trial management

The experimental design was RCBD with three replications. Cowpea seeds were sown in plots consisting of four rows each 3m long with a spacing of 60 cm between rows and 20 cm between plants in a row. Each experimental plot had an area of 7.2 m<sup>2</sup>. During planting, a rate of 100 kg ha<sup>-1</sup> of Di-ammonium Phosphate (DAP) was applied. All other field management practices such as weeding and chemical spray for cowpea seedlings against aphids were carried out uniformly for all experimental units. Aphid control was carried out at the seedling stage and during pod formation to prevent aphid damage through the application of insecticide Malathion, applied at 1.0 liter a.i./200 liters of water

using knapsack Sprayer. Experiments were planted from early to end of July for Meher season and from mid to end of March for Belg season each year.

#### 5.2.4. Data collection

The middle two rows of each plot were used for collecting data on phenology (Days to 50% flowering and maturity), growth parameters (plant height), and seed yield and its components (Number of pods per plant, seeds per pod, hundred seed weight). The grain yield of each genotype was harvested from a net plot area of 3.6 square meters, and adjusted to storage moisture content (10%) based on the value of actual grain moisture read by Digital Grain Moisture Meter (DRAMINSKI, POLAND). Seed weight (g) was determined by counting 100 seeds randomly from each plot yield using an electronic sensitive balance (Mark: Cosmo digital scale).

#### 5.2.5. Data analyses

Out of the collected parameters, this paper mainly focused on grain yield data. Each location-season-year combination was considered as a separate environment in this study, producing twelve environments that were considered random. The General Linear Model (GLM) of SAS software (SAS, 2008) was used for ANOVA of data from individual locations and the combined data. Bartlett's test (1937) was used to assess the homogeneity of error variances before combined analysis was done over the twelve environments. The model for the combined data analysis of variance of an experiment conducted in twelve environments (location-year-season-combination) using randomized complete block design, the linear model used was;

$$Y_{ijk} = \mu + G_i + E_j + (GE)_{ij} + R_k(S) + e_{ijk}$$

Where,  $Y_{ijk}$  = the observed value of the trait Y for the  $i$ th genotype in the  $j$ th year and  $k$ th block  
 $\mu$  = the grand mean of trait Y in the experiment

$G_i$  = the effect of the  $i$ th genotype

$E_j$  = the effect of the  $j$ th Environment

$(GE)_{ij}$  = the genotype-by-environment interaction effect

$R_k(s)$  = effect of block across year

$e_{ijk}$  = experimental error

Stability analysis was conducted using the SAS program developed by Hussein et al., (2000).

The mathematical statement of the AMMI model is given by the following formula:

$$\bar{Y}_{ijk} = \mu + G_i + E_j + \sum_{k=1}^m \lambda_k \alpha_{ik} \gamma_{jk} + P_{ij}$$

Where;  $\bar{Y}_{ijk}$  = the yield of the  $i$ th genotype in the  $j$ th environment in  $k$ th axis,

$G_i$  = the mean of the  $i$ th genotype minus the grand mean,

$E_j$  = the mean of the  $j$ th environment minus the grand mean,

$\lambda_k$  = the square root of the eigenvalue of the  $k$ th IPCA axis,

$\alpha_{ik}$  and  $\gamma_{jk}$  = the principal component scores for IPCA axis  $k$  of the  $i$ th genotypes and the  $j$ th environment,

$P_{ij}$  = the deviation from the model

Yield stability statistics were calculated across twelve environments using AMMI Stability Value (ASV) and genotype selection index (GSI). In addition, AMMI's stability value (ASV) was calculated to rank genotypes in terms of stability using the formula suggested by Purchase et al. (2000) as shown as follows:

$$\text{AMMI stability value(ASV)} = \sqrt{\left[ \frac{\text{SSIPCA1(IPCA1score)}}{\text{SSIPCA2}} \right]^2 + [\text{IPCA2 score}]^2}$$

Where SSIPCA1 and SSIPCA2 are the sums of squares by the IPCA1, IPCA2, respectively, and the weight given to the IPCA1 value is computed by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger the IPCA1 score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller IPCA1 scores indicate a more stable genotype across environments. Similarly, the IPCA2 score near-zero revealed more stability, while large values indicated more responsive and less stable genotypes. Smaller ASV scores indicate a more stable genotype across environments. In addition, a genotype selection index (GSI) was used to determine the genotype's adaptability by combining both yield and stability in the environment/location. The GSI as described by Farshadfar (2008) was computed by the following formula:

$$\text{GSI} = \text{RASV} + \text{RY}$$

RASV is the rank of the genotypes based on the AMMI stability value; RY is the rank of mean cowpea yields in all environments (RY). GSI incorporates both mean yield and stability in a single criterion. Low values of GSI showed desirable genotypes with high mean yield and stability. GSI is relevant when looking for the most stable genotypes that do not always have the best yield performance.

GGE-biplot method was employed to analyze the GE interaction and to assess grain yield stability if there was a significant difference in GE interaction. It is expressed by the following formula:

$$Y_{ij} - Y_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \epsilon_{ij}$$

Where,  $Y_{ij}$  is the average yield of genotype  $i$  in environment  $j$ ;  $Y_j$  is the average yield overall genotypes in environment  $j$ ;  $\lambda_1$  and  $\lambda_2$  are the singular values decompositions for the first and

second principal components Axis PCA1 and PCA2, respectively;  $\xi_i 1$  and  $\xi_i 2$  are vector scores of genotype  $i$  on PCA1 and PCA2, respectively;  $\eta_j 1$  and  $\eta_j 2$  are vector scores of environment  $j$  on PCA1 and PCA2, respectively;  $\varepsilon_{ij}$  is the residual of the model associated with the genotype  $i$  in environment  $j$ . The genotype plus genotype by environment interaction (GGE) biplot analysis (Yan,2001) was used to generate a biplot graph showing (i) ranking of genotypes on basis of mean yield and stability and (ii) which genotype won where pattern (Yan *et al.*2007). Two multivariate analytical tools, AMMI (Zobel *et al.*, 1988) and (GGE) biplots, were also used to shed more light on the significant GEI interaction and determine the stability and adaptability of each genotype.

### **5.3. RESULTS AND DISCUSSION**

#### **5.3.1. ANOVA of Grain Yield**

Results of ANOVA for grain yield at each of the 12 environments are provided in Table 6.4. There was a significant difference among the 20 cowpea genotypes at each of the environments, pointing to the presence of wide genetic variance which can be exploited in the improvement of grain yield in the major cowpea producing areas of southern Ethiopia. Error variances were almost homogenous across the 12 environments ranging from 0.021 to 0.058 (ratio of 2.8). The combined ANOVA revealed a significant difference among the 12 environments and also the 20 cowpea genotypes. The Genotype by Environment Interaction (GEI) was also significant (Table 5.5). Environment explained 42.3 %, while Genotypes (G) and GEI captured 23.0% and 34.7% of the treatment sum of square (G+E+GEI), respectively (Table 6.5). Therefore, the environment was the main source of variation which had a big effect on the yield of cowpea genotypes. The GEI sum of squares was about 1.5 times as large as that of the genotypes. Kuruma *et al.* (2019) and Yan and Kang (2003) also reported that the environment had the largest effect on grain yield. The three locations differed in soil properties and in annual and seasonal (Belg and Meher) rainfall. The three years (2016, 2017, and 2018) during which the experiments were conducted also differed in terms of rainfall. The two seasons within each year also differed in terms of rainfall amount and distribution. Rainfalls in Belg were lower and more erratic than in Meher. All these were components of the Environment. Mohammed *et al.* (2017) evaluated nine elite cowpea breeding lines at nine different locations during two growing seasons and reported significant genotype, environments, and GEI effects. Kuruma *et al.* (2019) evaluated nine advanced cowpea lines and three local checks at three different locations over two years and reported significant variances due to genotypes, environments, and GEI.

### 5.3.2. Comparison of mean grain yields

The big environmental effect on grain yield indicated that environments were diverse with the large difference among environmental means. The mean grain yield of the environments ranged from 0.82 t ha<sup>-1</sup> (E11, Humbo, Belg, 2018) to 1.88 t ha<sup>-1</sup> (E4, Gofa, Meher, 2017) (Table 5.4). E2, E8, and E11 (all at Humbo) yielded below the grand mean of 1.3 t ha<sup>-1</sup>. Only one environment of Humbo (E5, Meher, 2017) yielded higher than the grand mean. E4 (Gofa, Meher, 2017) and E6 (Kucha, Meher, 2017) yielded 1.88 t ha<sup>-1</sup> and 1.641 t ha<sup>-1</sup>, respectively. Except for E12 (Kucha, Belg, 2018, 1.03 t ha<sup>-1</sup>), all environments of Gofa and Kucha yielded above-average grain yield.

Mean grain yields were higher at Gofa (1.55 t ha<sup>-1</sup>) and Kucha (1.33 t ha<sup>-1</sup>), but low at Humbo (1.02 t ha<sup>-1</sup>) (Table 6.4). Humbo has generally lower annual rainfall (844 mm) and shorter growing season both during the Belg and the Meher seasons (Figure 5. 1) and produced low grain yield. Gofa has a high annual mean rainfall of 1116 mm and sandy loam soils and was the most favorable location for cowpea production.

Yields were higher during the Meher season as compared to those during the Belg season by 11.7 %, 35.8 %, and 25.9%, at Gofa, Humbo, and Kucha, respectively. All Meher environments (E1 to E6), except E2, produced above-average grain yields (>1.30 t ha<sup>-1</sup>), while only half of the Belg environments (E7, E9, and E10) produced above-average grain yield. The reason for the low yield at E2 (Humbo, Meher, 2016) was that there was insufficient rainfall, which is characterized by low and unreliable rainfall from flowering (August) to pod-filling (September), resulting in a reduction in grain yield. Previous studies in cowpea showed that water shortage during the flower and pod production stages led to significantly reduced grain yield (Ahmaed and Suliman, 2010). Rainfall was higher and the growing season was longer during the Meher season (Table 5.2 and Fig. 5.1).

Yield responses of each genotype at different environments varied. The mean grain yield over twelve environments ranged from 0.92 (G9) to 1.67 t ha<sup>-1</sup> (G12) with a grand mean of 1.3 t ha<sup>-1</sup> (Table 5.4). Thirteen genotypes (G2, G3, G4, G5, G6, G7, G10, G12, G13, G14, G15, G16, and G20) yielded above the grand mean (1.3 t ha<sup>-1</sup>) and the remaining 7 were below the average yield. In addition, G12 (IT96D-604), G16 (IT-89KD), G14 (IT93K-293-2-2), G20 (IT97K-569-9), G13 (93K-619-1), and G15 (IT99K-1060) (1<sup>st</sup> to 6<sup>th</sup>) produced the highest average yields of 1.45 to 1.67 t ha<sup>-1</sup> over the 12 environments. These advanced lines had a 4.3 to 20.2%, and 38.1 to 59.7% yield advantage over the best standard check G4 (Kenketi), and the local check (G11), respectively. These genotypes

(G12, G16, G14, G20, and G13) are recommended to be included in the breeding program or variety verification trials for release as new varieties to increase the variety portfolio of this neglected crop for which only six varieties have been released so far in Ethiopia. Genotypes G17, G18, G19, G11 (local check), G8, G1, and the released variety G9 (BEB) were the lowest yielding genotypes, ranking 16<sup>th</sup> to 20<sup>th</sup>. Released varieties G2 (Bole), G3 (White wonderer trailing), G4 (Kenketi), and G10 (TVU-1977-DD1) ranked 10<sup>th</sup>, 8<sup>th</sup>, 7<sup>th</sup>, and 9<sup>th</sup> by mean grain yield over environments. Similar findings on the performances of cowpea genotypes (Horn *et al.*, 2018; Agbahoungba *et al.*, 2016) and soybean genotypes (Asfaw *et al.*, 2012) across environments were reported.

The strong GEI interaction showed the inconsistency of the performance of the genotypes over environments. There were large rank changes for some of the genotypes over the 12 environments. For example, genotype G6 was the highest yielding genotype at E1. However, it was one of the lowest yielding genotypes and ranked 15<sup>th</sup>, 16<sup>th</sup>, 15<sup>th</sup>, and 18<sup>th</sup> at E2, E3, E7, and E12, respectively. G7 ranked 1<sup>st</sup> at E10 but ranked 19<sup>th</sup> and 20<sup>th</sup> at E7 and E12, respectively. Large rank changes were also observed for G2, G3, G15, and G20. 90% of the GEI interaction was due to lack of correlations (rank change) and only 10% was due to heterogeneity of variances (analysis not shown). Large rank change due to lack of correlation is known as cross-over GEI. Whereas, non-crossover GEI is due to heterogeneity of variance but no rank change in the performance of genotypes. Matus-Cadiz *et al.* (2003) in wheat also observed cross-over type of GEI interaction.

These complex GEI interactions indicate the need for stability analysis which is given in the following sections. In agreement with this finding, using the AMMI model, different authors reported responses of cowpea genotypes for grain yield at varied environments (Horn *et al.*, 2018; Kuruma *et al.*, 2019). Several authors have also reported significant GEI pointed to the need for stability analysis in cowpea (Kassaye *et al.*, 2013; Agbahoungba *et al.*, 2016).

Table 5.4. Mean grain yield (t ha<sup>-1</sup>) of 20 cowpea genotypes at 12 environments

Code	E1	E2	E3	E4	E5	E6	MM	E7	E8	E9	E10	E11	E12	BM	GM
G1	1.12	0.92	0.87	1.53	0.87	1.27	1.10	0.80	0.44	1.31	1.21	0.45	0.39	0.77	0.93
G2	1.53	1.22	1.31	2.27	1.40	1.79	1.59	1.52	0.54	0.88	1.77	1.02	1.10	1.14	1.36
G3	1.70	1.62	1.78	1.42	1.21	1.26	1.50	1.64	0.92	1.48	1.30	0.81	1.49	1.27	1.38
G4	1.37	1.55	1.03	2.08	1.53	1.61	1.53	1.58	0.65	1.48	1.72	0.94	1.12	1.25	1.39
G5	1.95	0.95	1.19	2.08	1.59	1.64	1.56	0.92	0.91	1.48	1.71	0.69	0.63	1.06	1.31
G6	1.98	0.72	0.99	2.21	1.97	1.84	1.62	1.22	0.94	1.32	1.66	0.59	0.45	1.03	1.32
G7	1.92	1.40	1.21	1.57	1.30	1.65	1.51	0.85	0.90	1.94	1.95	0.88	0.35	1.14	1.33
G8	1.32	0.53	0.84	1.66	0.90	1.53	1.13	0.99	1.11	0.93	1.12	0.58	0.68	0.90	1.02
G9	1.11	1.08	0.83	1.32	0.58	0.87	0.96	1.48	0.52	0.89	1.01	0.45	0.90	0.88	0.92
G10	1.68	1.31	2.00	1.46	1.06	1.61	1.52	1.52	0.93	1.24	1.48	0.86	1.36	1.23	1.38
G11	0.91	0.66	1.32	2.03	1.07	1.73	1.29	1.15	1.05	0.67	0.86	0.33	0.76	0.80	1.05
G12	1.38	1.02	2.04	2.34	1.99	2.35	1.86	1.97	1.11	2.03	1.94	1.14	0.71	1.48	1.67
G13	1.37	0.66	1.56	2.50	1.97	1.93	1.66	1.85	0.94	1.50	1.55	1.13	1.12	1.35	1.51
G14	1.44	0.87	1.16	2.46	1.57	1.74	1.54	1.84	1.25	1.97	1.78	0.90	1.67	1.57	1.55
G15	0.94	0.65	1.40	1.84	1.75	1.76	1.39	1.93	1.17	1.61	1.35	1.43	1.62	1.52	1.45
G16	1.54	1.21	1.83	2.31	1.81	1.77	1.74	1.39	1.46	1.34	1.85	1.43	1.48	1.49	1.62

Table 5.4. Continued.....

Code	E1	E2	E3	E4	E5	E6	MM	E7	E8	E9	E10	E11	E12	BM	GM
G17	1.20	0.68	0.96	1.71	0.95	1.50	1.17	1.71	0.74	1.17	1.17	0.48	0.92	1.03	1.10
G18	1.19	0.80	1.05	1.37	1.12	1.41	1.15	1.73	0.68	0.91	1.02	0.50	0.97	0.97	1.06
G19	1.16	0.97	1.75	1.61	1.02	1.66	1.36	1.64	0.56	0.89	0.99	0.53	1.31	0.99	1.17
G20	1.14	0.86	1.48	1.84	1.65	1.90	1.48	1.84	1.36	1.56	1.67	1.32	1.54	1.55	1.51
EMS	0.025	0.029	0.036	0.045	0.031	0.058	-	0.028	0.035	0.028	0.030	0.039	0.021	-	-
EM	1.40	0.98	1.33	1.88	1.36	1.64	1.43	1.48	0.91	1.33	1.46	0.82	1.03	1.17	1.30
IPCA1	-17.2	0.7	11.5	-10.1	-10.7	-5.2	-	22.4	1.6	-11	-15.5	4.1	29.4	-	-
IPCA2	18.7	29.4	6.6	-18.1	-16.7	-11.5	-	-6.5	-5.5	2.3	3.4	-4	1.9	-	-
IPCA3	-7.3	-1.3	-20.5	-8.3	-0.1	-11.5	-	5	0.5	23	6.9	8.2	6.2	-	-
IPCA4	-9.3	-6.7	20.7	-17.1	1.6	4.6	-	-5.8	4	13.6	-1.2	5.7	-10	-	-
F-value	12.6	10.1	12.6	9.9	17	4.7	-	14.8	7	16.4	12.3	8.9	25	-	-
	GF	HB	KU	Mean	%	GF	%	HB	%	KU	%		2016	2017	2018
Meher	1.64	1.17	1.49	1.43	<b>22.4</b>	1.64	<b>11.7</b>	1.17	<b>35.7</b>	1.49	<b>25.9</b>		1.24	1.43	1.10
Belg	1.47	0.87	1.18	1.17		1.47		0.87		1.18					
<b>Mean</b>	<b>1.55</b>	<b>1.02</b>	<b>1.33</b>												

Note: GF=Gofa, HB=Humbo, KU=Kucha, EMS=Error mean square, EM=Environmental mean, Environments: E1, E2, E3 (Gofa, Humbo, and Kucha in Meher 2016), E4, E5, E6 (Gofa, Humbo, and Kucha in Meher 2017), E7, E8 and E9 (Gofa, Humbo, and Kucha in Belg 2017), E10, E11 and E12 (Gofa, Humbo, and Kucha in Belg 2018), GM=Grand Mean.

### 5.3.3. Additive Main Effects and Multiple Interaction (AMMI) Model

#### 5.3.3.1. AMMI analysis of variance

Four of the 11 IPCAs were statistically significant (Table 5.5). Hernandez and Crossa (2000), quoting Cornelius *et al.* (1996), stated that the Gollob F-test is very liberal and can result in many multiplicative terms judged significantly.

The presence of GEI was verified by the AMMI model when the interaction was partitioned among the first four principal components Axis (IPCA) as they were significant in a post-assessment. In our study, the first and second IPCAs explained 33.1% and 25.0% and cumulatively captured 58.1% of the sum of squares and 26.8% of the DF of GEI (Table 5.5). Though the plotting of more than two IPCA components in pairs is tedious and difficult to interpret, AMMI2 may be inadequate to explain the complex interaction of GEI in our study. The IPCA1 explained 33.1% of the interaction sum of the square in 13.87% interaction degree of freedom. Similarly, the second, third and fourth principal component Axis (IPCA 2-4) explained a further 25.0%, 10.8%, and 8.7% of the GEI sum of the square, respectively. AMMI4, which cumulatively captured 77.6% total GEI SS, using 104 degrees of freedom, would be, thus, considered adequate (Table 5.5). This implies that the interaction of 20 genotypes of cowpea with twelve environments was predicted by the first four principal components of genotypes and environments, which is in agreement with the recommendation of Sivapalan *et al.* (2000). This is also following the results of Kayode *et al.* (2009), whereas much as the first four IPCAs were significant. However, this contradicted the findings of Zobel *et al.* (1988) and Abiriga *et al.* (2020), which recommended that the most accurate model for AMMI, can be predicted using the first two IPCAs.

#### 5.3.3.2. AMMI Biplots

The graph of IPCA2 versus IPCA1 revealed that the Meher, 2016 environments (E1, E2, and E3) had positive IPCA2 values, while the Meher, 2017 environments (E4, E5, and E6) had negative IPCA2 values (Fig. 5.2). Belg environments (E7 to E12) had near-zero IPCA2 values. IPCA2 seems to be connected with the Meher of the two years, 2016 and 2017. IPCA1 can be considered a reflection of the productivity of an environment. All environments with a mean yield above the grand mean (E1, E4, E5, E6, E9, and E10), except E3 and E7 had negative IPCA1 values. All environments with below-average mean grain yield (E2, E8, E11, and E12) had positive IPCA1 values (Fig.5.2). IPCA3 has classified environments into two categories (Belg environments, E7 to E12) with positive IPCA3 values

and Meher environments (E1 to E6) with negative IPCA3 values (Table 5.4). IPCA3, therefore, classified environments into Meher and Belg environments. The Meher season had a longer mean growing period (91 vs 81 days) and higher rainfall (682 mm vs 524 mm) as compared to the Belg season. All Kucha environments (E3, E6, and E9, except E12) had positive IPCA4 values while all Gofa environments (E1, E4, E7, and E10) had negative IPCA4 values. The Humbo Environments (E2, E5, E8, and E11) had near-zero IPCA4 values (Table 5.4). IPCA4 is, thus a contrast of Gofa with Kucha (Table 5.4).

Table 5.5. AMMI ANOVA of Grain Yield of 20 Cowpea Genotype grown across 12 Environments

Source of variation	DF	SS	MS	VE (%)	% GEI	Cumulative (%)
Treatments (G+E+GEI)	239	153087843	640535***			
Genotypes (G)	19	35204932	1852891***	23.0		
Environments (E)	11	64756683	5886971***	42.3		
Block	24	785002	32708			
Interactions(GEI)	209	53126227	254192***	34.7		
IPCA 1	29	17602987	607000***		33.1	33.1
IPCA 2	27	13277103	491745***		25.0	58.1
IPCA 3	25	5747041	229882***		10.8	68.9
IPCA 4	23	4625852	201124***		8.7	77.6
Residuals	105	11873245	113079		22.3	100.0
Error	456	15348006	33658			

Note: DF=Degrees of freedom, SS= Sum of squares, MS=Mean Squares, VE (%) = variation explained as % of Treatment SS, % GEI= Percentage of genotype by environment interaction sum of Squares, IPCA=Interaction Principal Component Axis. \*\*\*, significant at 0.01 probability level.

Table 5.6. Mean yield (t ha<sup>-1</sup>), ASV, GSI of 20 cowpea genotypes tested at 12 environments, and principal component analysis of the AMMI

Code	YD	RYD	ASV	RASV	GSI	RGSI	GIPCA1	GIPCA2
G1	0.931	19	14.1	9	28	15	-9.1	7.3
G2	1.363	10	2.2	1	11	3	-1.6	0.4
G3	1.384	8	24.7	17	25	14	10.9	20.0
G4	1.389	7	5.9	4	11	3	-2.7	4.6
G5	1.311	13	25.2	18	31	17	-18.9	2.7
G6	1.323	12	29.2	19	31	17	-21.3	-7.3
G7	1.326	11	34.0	20	31	17	-22.6	15.9
G8	1.015	18	5.5	3	21	9	-3.7	-2.3
G9	0.920	20	18.1	13	33	20	9.6	12.8
G10	1.376	9	19.7	14	23	11	9.2	15.5
G11	1.045	17	9.8	7	24	12	3.6	-8.6
G12	1.669	1	15.6	11	12	5	-7.8	-11.6
G13	1.506	5	17.1	12	17	7	-0.9	-17.0
G14	1.554	3	9.6	6	9	2	1.8	-9.3
G15	1.453	6	23.1	16	22	10	13.6	-14.4
G16	1.618	2	3.5	2	4	1	0.9	-3.3
G17	1.099	15	7.0	5	20	8	5.1	-1.9
G18	1.062	16	12.6	8	24	12	9.5	1.4
G19	1.175	14	20.8	15	29	16	15.4	4.0
G20	1.512	4	15.6	10	14	6	9.1	-9.0
GM	<b>1.302</b>		<b>15.6</b>		<b>21.0</b>		-9.1	7.3

YD=yield, RYD=Rank by Yield; ASV = AMMI stability value; RASV=Rank by ASV; RGSI=Rank by Genotype Selection Index; GM=Grand mean, E=Environment.

### 5.3.3.2.1. GEI Patterns of Environments and Genotypes

The plot of IPCA2 vs IPCA1 has divided the environments into six sectors (Fig.5. 2). Environments within the same sector had a small angle (<90<sup>0</sup>) between themselves and had a high positive correlation with each other. Genotypes at the vertex of a sector had the highest positive GEI interaction with environments in that sector and the largest in absolute value negative GEI with environments on the opposite side (at 180<sup>0</sup> with them).

Environments at  $90^0$  from each other are uncorrelated while an angle of  $> 90^0$  indicates a negative correlation between the environments.

**Sector I** had E3 (Kucha, Meher, 2016), E12 (Kucha, Belg, 2018), and E7 (Gofa, Belg, 2017). G19 had the highest positive GEI interaction with these environments. **Sector II** contained E2 (Humbo, Meher, 2016). G3 had the highest positive interaction with E2. **Sector III** contained E1 (Gofa, Meher, 2016), E9 (Kucha, Belg, 2017), and E10 (Gofa, Belg, 2018). **Sector IV** had E4, E5, E6 (Meher, 2017 environments of Gofa, Humbo, and Kucha). G6 had a maximum positive interaction with these environments. **Sector V** contained E8 (Humbo, Belg, 2017) with G13 at its vertex. **Sector VI** contained E11 (Humbo, Belg, 2018) and G15 had the most favorable interaction with this environment. The angle between environments of **Sector I** (E3, E7, and E12) and **Sector VI** (E11) was narrow and these environments were correlated and had similar GEI patterns. This correlation ranged from  $r=0.33$  (between E3 and E11) to  $r=0.89^{***}$  (between E7 and E11). Environments of the sector I except E3 were also positively correlated with E8 (sector V).

The underlying causes of the interaction observed may be due to the genetic differences between the genotypes (phenology, growth habit, predominant yield components, disease resistance, etc.) and the difference in the environments in edaphic factors, in seasonal rainfall and temperature, in the length of the growing season, in periods at which moisture stress occurred, and prevalence of the disease.

G6 and G12 had a large positive interaction with E4, E5, and E6, but large negative interaction with E2, E3, E7, and E12. These two genotypes were relatively late maturing (DF of 50 and 48 and DM of 91 and 89 days). The mean grain filling period of G12 and G6 under environments with longer growing seasons was 51 days. This was reduced to 39 and 42 days, respectively, under shorter growing seasons (E2, E3, E7, and E12), where they could not fill their grains properly (results not shown).

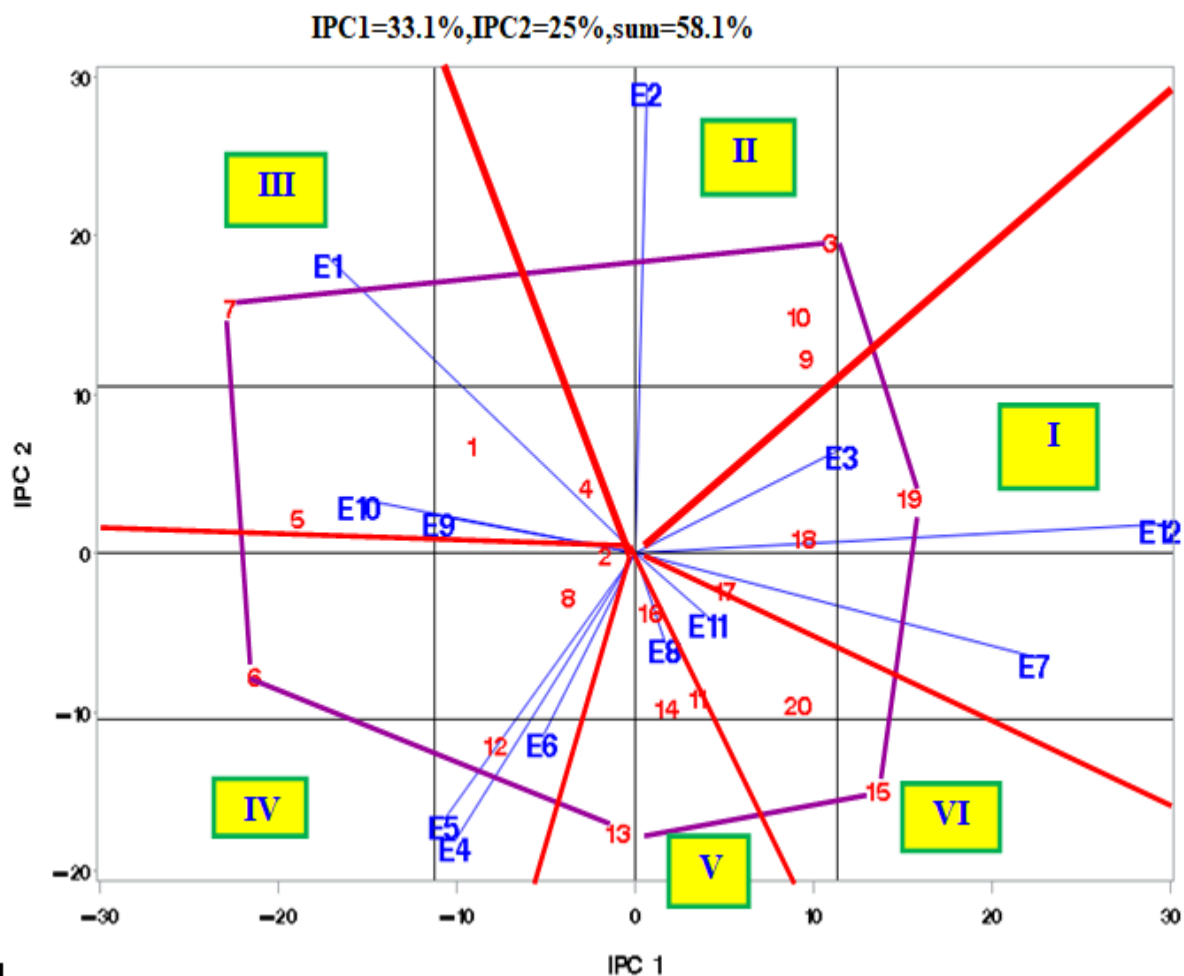


Figure 5. 2. AMMI Bi-plot of IPC2 versus IPCA1

On the contrary, genotypes G3, G9, G10, and G19 had opposite responses to the two groups of environments as they had large positive GEI interaction with environments that had a short growing season (E2, E3, E7, and E12), but large negative interaction with environments that had a long growing season (E4, E5, and E6). These genotypes were relatively early maturing (DF of 46 days and DM of 86 days and G9 with DM of 83 days). They might have been exposed to various diseases during the grain filling period under long rainy seasons. There was a negative correlation between the environments of sector VI (G4, G5, and G6) on one side and environments of sectors I and II (ranging between -0.19 (E7 with E6) to -0.91<sup>\*\*\*</sup> (E2 and E6).

Genotypes G5 and G7 had a positive interaction with E1, but they had a negative interaction with E7, E8, and E11. These were late-maturing genotypes (DM of 92 and 91 days). The

mean growing season of E1 was 91 days while the mean growing seasons of E7, E8, and E11 were 80, 82, and 82 days, respectively (Appendix 2). These genotypes could not fill their grains during these very short growing seasons and therefore had a negative interaction with these environments. On the contrary, G15 and G13 (DM of 84 and 85 days) interacted positively with E7, E8, and E11 but negatively with E1. The positive interaction of G5 and G7 and the negative interaction of G13 and G15 with E9 and E10 can be explained by days to flowering. Genotypes that flowered very early, much earlier than the average DF at E9 (46 days) and E10 (43 days) seem to have been exposed to pre-flowering moisture stress and interacted with them negatively. G13 and G15 flowered very early at E9 (43 days) and E10 (39 days) and were at disadvantage and hence interacted negatively with these environments while G5 and G7 flowered late at E9 (44, 48 days) and E10 (44 days) and had an advantage at these environments and interacted positively with them. The late maturity of these genotypes at E9 and E10 did not lead to negative interaction, probably because these genotypes had deep roots and have avoided moisture stress during maturity. A deep root system in cowpea could be an advantageous method to cultivate in areas where water deficits (Matsui and Singh, 2003; Yuka *et al.*, 2019). Response of G12 and G13 at E9 and E10 were opposite. G12 interacted positively while G13 interacted negatively; G12 flowered later at these environments while G13 flowered very early and was exposed to moisture stress at flowering (appendix 1). Their response to E4, E5, and E6 was the same (positive GEI). G5, G6, G7, G12, and G13 all interacted negatively with E7. However, G15 interacted positively with this environment.

#### **5.3.3.2.2. Grouping Genotypes by Stability and mean yield**

Genotypes within one standard deviation of both IPCA1 and IPCA2 were designated as stable and those outside this range as unstable (Fig. 5.2). Environments and genotypes close to the origin of the biplot had made a minimum contribution to GEI SS. G1, G2, G4, G8, G11, G14, G16, G17, G18, and G20, each contributed less than 5.2% to GEI SS. Cumulatively they have captured 33.5% of GEI SS (3.4% per genotype). They were the most stable genotypes and of these only G2, G4, G14, G16, and G20 (25% of the tested Genotypes) were among the high-yielding genotypes and ranked 10<sup>th</sup>, 7<sup>th</sup>, 3<sup>rd</sup>, 2<sup>nd</sup>, and 4<sup>th</sup> by mean yield over 12 environments (Table 5.6). G1, G8, G11, G17, and G18 gave low yields and were undesirable, although they were stable. E3, E6, E8, E9, E11, and E10 had

the shortest vectors and were near the center of the biplot, capturing from 3.6 to 9.1%, and cumulatively 35.8% of GEI SS (6.0% each). Thus had low discriminative power

Environments and genotypes furthest from the origin such as E1, E4, E7, E2, E5, and E12, and genotypes G5, G6, G7, G3, G10, G9, G12, G13, G15, and G19 made the largest contribution to GEI SS (Fig. 5.2). These ten genotypes were unstable and captured 66.6% of GEI SS (6.7% each). All, except G9 and G19, were high-yielding. The six environments (E1, E4, E7, E2, E5, and E12) captured from 6.8 to 14.2% and cumulatively 64.1% of GEI SS (10.7% each). These are the most discriminating environments. Other environments were also discriminating in the sense that the F-test for Genotype Mean Square was very highly significant at all 12 environments. The F-value varied from 4.69 (E6) to 25.0 (E12) with the F-required at a probability level of 0.001 to be 3.24. The 20 genotypes can be classified by yield and stability into four groups (Table 6.7). G3, G5, G6, G7, G10, G12, G13, and G15 ranked 8<sup>th</sup>, 13<sup>th</sup>, 12<sup>th</sup>, 11<sup>th</sup>, 9<sup>th</sup>, 1<sup>st</sup>, 5<sup>th</sup>, and 6<sup>th</sup> by average yield over 12 environments and need further evaluation to identify environments to which they are specifically adapted especially G3, G10, G12, G13, and G15.

Table 5.7. Productivity and Stability (within one STD of IPCA1 and IPCA2) of Genotypes

Stability	Yield	
	High	Low
Stable	G2, G4, G14, G16, G20	G1, G8, G11, G17, G18
Unstable	G3, G5, G6, G7, G10, G12, G13, G15	G9, G19

#### 5.3.4. Stability Analysis using AMMI stability value (ASV)

AMMI Stability Value (ASV) is the distance of genotype from point zero (IPCA1 and IPCA2) (Fig.5.2). Genotypes with low ASV are the most stable while those with high ASV are unstable (Purchase, 2000). ASV ranged from 2.2 for variety Bole (G2) to 34 for genotype Brazil-4 (G7) (Table 5.6). Therefore, G2, G16, G8, G4, G17, G14, and G11, with the lowest ASV, can be considered to be stable, while G7, G6, G5, G3, G15, and G19 were the most unstable. The remaining genotypes (G18, G1, G20, G12, G13, G9, and G10) had intermediate stability. Three of the seven most stable genotypes were low yielding while five of the six most unstable genotypes were high yielding. Therefore, stability should not be the only parameter for genotype selection, because the most stable genotypes would not necessarily give the highest yield (Mohammadi and Amri, 2008).

Olayiwola and Ariyo (2013) concluded that simultaneous selection of genotypes for high yield and stability was more useful in multi-environment trials. Horn et al. (2018) also found out that eight out of the thirty-seven cowpea genotypes grown across six environments in Namibia gave high yield and were stable. Odeseye *et al.* (2018) found out that three out of the 20 cowpea accessions grown across two locations in Nigeria gave high yield and possessed better stability.

### **5.3.5. Stability Analysis by genotype selection index (GSI)**

Farshadfar (2008) proposed Genotype Selection Index (GSI) as a selection criterion to identify the most desirable genotypes that are stable genotypes with high yield. GSI uses both ranks by yield and ranks by ASV, which is the sum of both ranks. The genotypes can then be ranked by GSI; the genotypes with the lowest GSI getting rank of 1 could be considered as the most desirable (stable and high yielding) ones.

GSI gives equal weight to grain yield and stability (ASV). Therefore, G3 (14<sup>th</sup> by GSI) with a higher grain yield of 1.384 t ha<sup>-1</sup> is less desirable than G17 (8<sup>th</sup> by GSI) with a lower grain yield of 1.099 t ha<sup>-1</sup> (Table 5.6). Out of the desirable genotypes, G16 had a high rank by both grain yield and ASV and this genotype ranked 1<sup>st</sup> by GSI. It is the most desirable genotype and can be recommended for wide adaptation. The ranking by GSI should, therefore, be performed separately for high-yielding and low-yielding genotypes. Taking the grand mean of ASV (15.6) and grand mean of grain yield (1.302 t ha<sup>-1</sup>) as cutting points, the 20 cowpea genotypes can be classified into four groups by RGSI: High-yielding and stable (most desirable), high-yielding but unstable (less desirable), low yielding and stable (undesirable) and low yielding and unstable (most undesirable). This classification gives the same result as those obtained in Table 5.7 above, except that G12 is in the first category.

GSI focuses on selection for wide adaptation and genotypes that give high yields in a specific group of environments (at a mega-environment) are discarded as undesirable. Various authors have integrated both mean yield and stability into a single selection criterion (Farshadfar, 2008; Mohammadi and Amri, 2008).

### **5.3.6. GGE biplot analyses**

The GGE biplot analysis of grain yield response and stability of 20 cowpeas showed that the first three components accounted for 44.8, 19.8, and 12.7 % of the GGE sum of squares, respectively, explaining a total of 77.3 % of the SS and 40.2% of the DF of GGE (Fig.5.3). Therefore, GGE-III seems to be appropriate to explain the complex GGE of 20 cowpea

genotypes tested at 12 environments in our study. The remaining nine components explained from 0.8 to 6% of GEI SS (eight of them captured <5% of GEI SS each). This suggested that the biplot of PC1, PC2, and PC3 adequately approximated the environment-centered data. The results disagree with the previous research results which showed the first two principal components to be adequate to explain the GEI (Matova and Gasurae, 2018; Horn *et al.*, 2018). The plot of the first principal component (GIPCA1) versus the second principal component (GIPCA2) revealed that GIPCA1 ranked genotypes according to their mean yield, i.e., GIPCA1 represents G. This is witnessed by the distribution of the 20 genotypes along the GIPCA1 axis (rank correlation by GIPCA1 and actual yield was 0.95<sup>\*\*\*</sup>). GIPCA2 (19.8%) should then be the expression of GEI.

GIPCA2 has divided the environments into those with no or minimal terminal moisture stress (E1, E2, E4, E5, E6, E9, and E10) with negative GIPCA2, and environments with severe terminal moisture stress (E3, E7, E8, E11, and E12) with positive GIPCA2 (Fig. 5.3). GIPCA3 (12.7%) seems to show the comparison of seasons within a year; comparison of Meher seasons in 2016 and 2017 and comparison of Belg seasons of 2017 and 2018 (only E9 is misplaced) (results not shown).

For this investigation, the polygon view (Figure 5.3) showed the “which-won-where” pattern of the ME trials data. The fitted GGE-biplot model indicated that the first two PCs explained 64.6 % of the variation for G+GE (Figure 5.3). The polygon view of the GGE biplot was drawn by connecting the vertices genotypes with straight lines so that all other genotypes were contained within the polygon. In GGE-2 vs GGE-1 biplot, red lines arising from the origin and perpendicular to the lines connecting the vertex genotypes G12, G15, G19, G9, G1, and G7, have divided the environments and genotypes into six different sectors (Fig. 5.3). The more favorable Meher environments, E4, E5, and E6, with E2, E9, and E10 on one side and E8 and E11 on the other side joining them, formed Sector I. E3, E7, and E12 formed a separate sector (Sector II) as in AMMI. In the GGE-biplot, E1 is separated from E9 and E10 and is placed alone in Sector VI.

In this case, the polygon connects all the farthest genotypes and perpendicular lines divide the polygon into sectors. In the mega-environment identification process, the furthest genotypes are connected to form a polygon, and perpendicular lines are drawn to form sectors which will make it easy to visualize the mega-environments. This means that winning genotypes for each sector are placed at the vertex. Environments in one sector having the best-performing

genotype can be considered as mega-environments for that genotype (Gebre et al., 2015). These results conform to the findings of Reddy et al. (2014) who observed high-yielding and stable genotypes. Biplots were divided into six sectors in Fig. 5.3; genotypes that fall in the same sector as with environment are said to be adapted to those environments. The pattern on the environment in the above biplot suggests the existence of three different mega-environments. However, this pattern may not be repeatable from year to year, therefore, to confirm the repeatability of mega- environmental results, multi-year data are required (Yan et al. 2000).

The cosine of an angle between the vectors of two environments approximates the genetic correlation between them (Yan 2002, 2001) and allows visualization of similarity between environments in ranking genotypes (Yan, 2001). According to the theory, an acute angle indicates a positive correlation, an obtuse angle indicates a negative correlation and a right angle shows the existence of no correlation (Yan and Kang, 2003; Yan and Tinker, 2006). The results for yield indicated that E4 and E5, E4 and E6, E4 and E10, E6 and E8, E6 and E5 are positively correlated since the angle between them is an acute angle (Fig 5.3). The cosine angle between the vectors of the two environments approximates the correlation between them (Yan and Rajcan, 2002). The presence of the acute angle between E4 and E5, E4 and E6, E4 and E10, E6 and E8, E6 and E5 suggests that the same information about the genotypes can be obtained from one of the two environments. The more acute the angle between any two vectors, the more strongly they indicate a strong positive correlation of genotypic yield among environments. If two test environments are closely correlated consistently across multiple years, one of them can be dropped without the loss of much information about the genotypes. The environment E1 and E12, E2 and E7 are negatively correlated. Environments in the same sector had similar GEI patterns. The correlation between E1 and environments of the sector I ranged between 0.21 (E1 with E11) to 0.81<sup>\*\*\*</sup> (E1 with E10). E1 can be considered as uncorrelated with E8 and E11 and as belonging to a different mega-environment. E1 in sector VI was negatively correlated with all environments of Sector II and the two sectors can be considered to belong to different mega-environments. The presence of a strong negative correlation (wide obtuse angle) among environments is an indication of a strong crossover which means genotype by environment interaction (Yan and Tinker, 2006). We, therefore, had three sectors, which can be considered to be three mega-environments; Sector I, with E2, E4, E5, E6, E8, E9, E10, and E11, sector II with E3, E7, and E12, and sector VI with E1.

G12 was the winning genotype in Sector I, while G15 and G7 were the winning genotypes in Sectors II and VI, respectively. However, G16 in sector I, G20 in sector II, and G5 and G6 in sector VI were also near the vertices and gave high yields in their respective sectors.

There were no environments in sectors III, IV, and V. All genotypes of these sectors (G9 (BEB), G11 (local check), and advanced lines G1, G8, G17, G18, and G19, gave below-average yields at all environments, except G19 at E2, E3, E7, and E12, G1 at E1 and G18 at E7 and E12 (Fig. 5.3). When genotypes give rise to vertices of polygons but do not contain any environment clustered in their respective sector, they are considered un-adapted to all test environments (Miranda *et al.*, 2009) and G9 was such a genotype.

Ranks of the highest yielding genotypes by mean grain yield estimated from GIPCA1, GIPCA2, and GIPCA3 were G12, G16, G14, G20, G13, G15, G4, G3, G10, G2, G7, G6, and G5. The late-maturing genotypes, G5 (Brazil-2), G6 (Brazil-3), and G7 (Brazil-4) gave high yield at E1, E2, E4, E5, E6, E9, and E10 (except G6 at E2 and G7 at E4 and E6) but low yield at E3, E7, E11, and E12 where they matured very late and could not fill their grain properly. All three late-maturing genotypes performed best at E1 where they ranked 2<sup>nd</sup>, 3<sup>rd</sup>, and 1<sup>st</sup>, respectively. G5 and G7 ranked 6<sup>th</sup> and 2<sup>nd</sup> at E2. These advanced lines were not the highest yielding under the favorable Meher environments, E4, E5, and E6, where they were very late. However, G6 ranked 6<sup>th</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> at E4, E5, and E6 and can be recommended for these favorable environments with a long growing period (100 to 110 days). G5, G6, and G7 also ranked 2<sup>nd</sup> to 7<sup>th</sup> at E9 and E10. All three can, therefore, be recommended for Meher seasons with the intermediate length of the growing period (91 days) and Belg seasons with a short growing period (77 to 82 days) but with no terminal moisture stress. G5 and G7 can also be recommended for Meher seasons with a short growing period (85 days) similar to E2. The early-maturing varieties, G3 (White wonderer trailing) and G10 (TVU-1977-DD1) had an opposite response as compared to G5, G6, and G7. They performed well at E3, E7, E11, and E12 but performed poorly at E4, E5, and E6, where they matured much earlier and might have been exposed to diseases during the grain-filling period. G3 ranked 1<sup>st</sup> at E2 and E3 while G10 ranked 3<sup>rd</sup> at both environments. They were 3<sup>rd</sup> and 4<sup>th</sup> at E12, 6<sup>th</sup> and 8<sup>th</sup> at E1, and 7<sup>th</sup> and 8<sup>th</sup> at E11, respectively. They can be recommended for Meher and Belg environments with short growing period and with terminal moisture stress such as E1 (91 days), E2 (85days), E3 (87 days), E7 (80 days), E11 (82 days), and E12 (79 days). The relatively early maturing advanced lines, G15 (IT99K-1060) and G20 (IT97K-569-9) also

performed best at environments with severe moisture stress during the grain-filling period such as E7 (80 days) and E12 (79 days), where G15 was 1<sup>st</sup> and G20 was 2<sup>nd</sup>. They also ranked 3<sup>rd</sup> to 7<sup>th</sup> at all remaining environments except at E1, E2, E9, and E10, where they were exposed to pre-flowering moisture stress. These advanced lines can, therefore, be recommended for all Meher and Belg environments, avoiding those with an intermediate growing period such as E1 and E2 and those with pre-flowering moisture stress but with no terminal moisture stress, such as E9 and E10

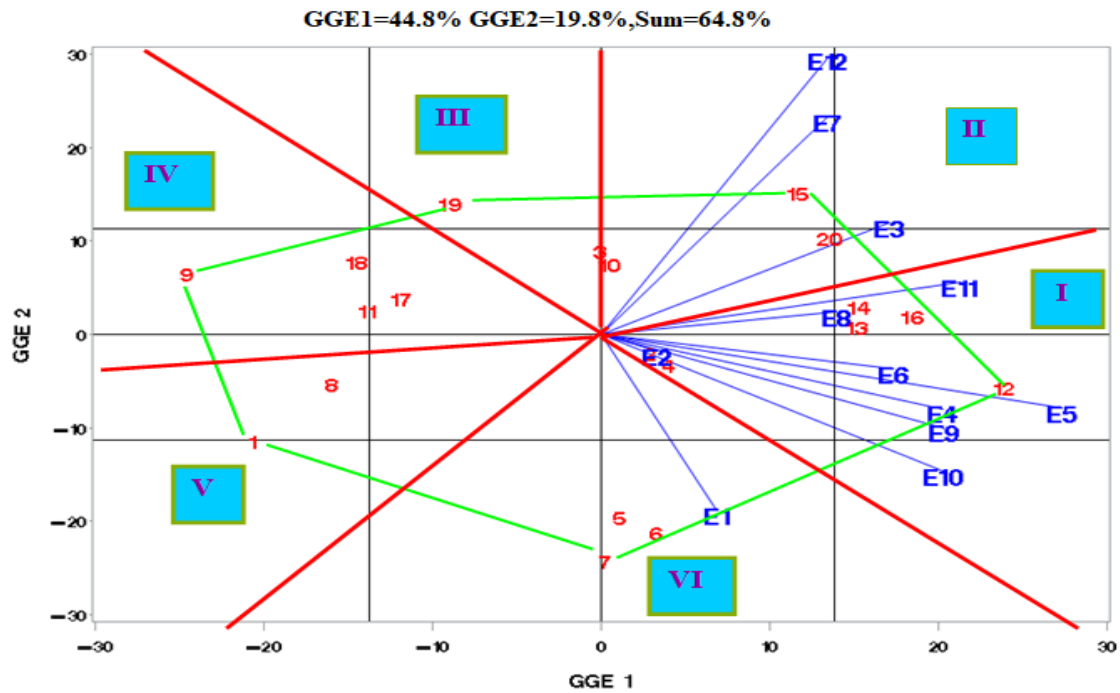


Figure 5.3. A plot of GIPCA2 vs GIPCA1 for 20 cowpea genotypes tested at 12 Environments

G12 and G16 gave high yields at all 12 environments while G13, G14, G15, and G20 also gave high yields at all environments except at E1 and E2. G2 also gave an above-average yield at all environments except at E12. G4 gave a below-average yield at only E4 and E7. Ranks of G16 (2<sup>nd</sup> to 7<sup>th</sup>) were more constant than those of G12 (1<sup>st</sup> to 9<sup>th</sup>). Therefore advanced line G16 (IT-89KD) and G14 (IT93K-293-2-2) can be recommended for all cowpea growing areas in southern Ethiopia. G12 was the highest yielding genotype (1<sup>st</sup>) in seven environments; under Meher seasons with a long and favorable growing period (100 to 110 days) such as E4, E5, and E6 and under Belg environments with no terminal moisture stress such as E9 and E10 and it also ranked 1<sup>st</sup> at E11. For G12 Meher and Belg environments

with short growing periods and with terminal moisture stress such as E2 (85 days) and E12 (80 days), where it ranked 9<sup>th</sup> should be avoided. G13 can also be recommended for all cowpea growing Meher and Belg environments avoiding Meher seasons with a short and intermediate growing period such as E1, E2, and E3 and Belg seasons with a very short growing period such as E12. The released variety G4 performed well under E1 and E2, which represent Meher seasons with a short and intermediate growing period where it ranked 5<sup>th</sup> and 4<sup>th</sup>. To assess genotypes that are well adapted to the diverse growing ecologies/environments and seasons of planting, it is necessary to identify traits that are needed in genotypes for adaptation and performance under the prevailing weather and soil conditions of the growing season.

#### **5.3.6.1. Mean Yield and Stability**

Yield and stability of genotypes were estimated using the Average Environment Coordinate (AEC), which is defined by a line passing through the origin of the bi-plot and the average of GIPC1 and GIPC2 scores (Yan and Kang, 2003). The best genotype (ideal genotype) can be defined as the one with the highest yield and highest stability across environments. Genotypes with high GIPC1 scores have high mean yield and those with low (in absolute value) GIPC2 scores have stable yield across environments (Yan and Tinker, 2006). A longer projection to the AEC ordinate, regardless of the direction, represents a greater tendency of the GEI interaction of a genotype, which means that its performance is more variable and the genotype is less stable across environments or vice versa.

The line perpendicular to the average environment coordinate is represented as a double-headed arrow and points towards lower stability in both directions (Fig. 5.4). Genotypes on the left side of the ordinate line (with double arrows) had yields less than the mean yield while those on its right side had above-average yield. G13 (93K-619-1) at the center of the first concentric circle, was the most desirable genotype for grain yield and stability followed by G14, G16, and G20, which are located in the subsequent concentric circles (Fig.5.4). The ideal genotype can be used as a reference for evaluating genotypes and identifying stable and high-yielding genotypes for wide adaptation. A genotype is desirable if it is closer to the ideal genotype (Yan and Hunt, 2002).

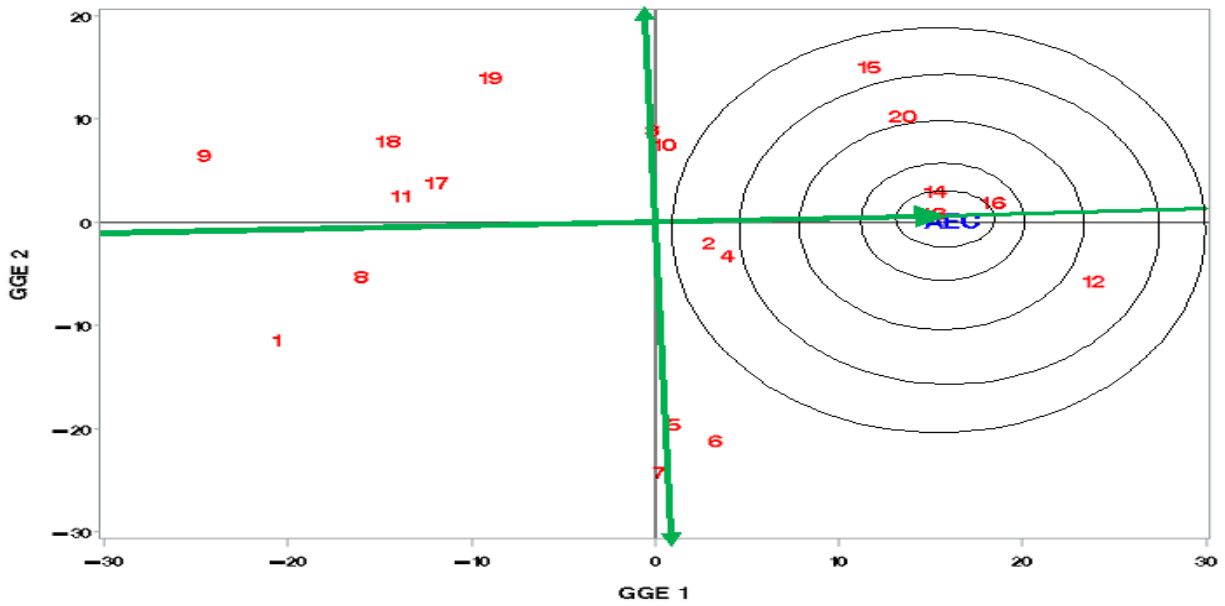


Figure 5.4. Comparison of Genotypes with an Ideal Genotype

Genotypes G2, G4, G13, G14, and G16 were high-yielding and stable, suggesting their adaptation to a wide range of environments, the most desirable situation for plant breeders (Fig. 5.4, Table 5.8). G3, G10, G5, G6, G15, G20, and G12 were high-yielding but unstable, which can also be considered desirable. Genotypes G9, G8, G11, and G17 were stable but at the low-yielding-3<sup>rd</sup> level in desirability. G1, G18, and G19 were low-yielding and unstable (fourth in desirability, i.e., most undesirable) (Table 5.8). This classification is similar to the one achieved by using the distance of the genotype from the center of the IPCA1-IPCA2 biplot of AMMI (Table 5.7).

Table 5.8. Classification of Genotypes by Desirability based on rank by GGE1 and GGE2

Desirability	Classification by Yield and Stability	Genotypes
1. Most Desirable	High yielding and Stable	G13, G16, G14, G2, G4
2. Desirable	High yielding and Unstable	G12, G20, G10, G15, G3, G6, G5, G7
3. Undesirable	Low yielding and Stable	G11, G17, G8, G9
4. Most undesirable	Low yielding and Unstable	G18, G19, G1

#### 5.3.6.4. Comparison of Environments with the Ideal Environment

An ideal environment (location, location-season or location-year combination, etc.) should be highly differentiating (discriminating) for the tested genotypes and at the same time be representative of the target environments (Yan and Kang, 2003; Yan and Tinker, 2006). The test environments should have a large GIPCA1 score to discriminate genotypes in terms of the genotypic main effect and should have small GIPCA2 scores in absolute value to be more representative of the overall environments (Yan and Rajcan, 2002).

The ideal environment is located in the first concentric circle drawn around the Average environment coordinate (AEC), and desirable environments are close to the ideal environment. Environment E8 (Humbo, Belg, 2017) was close to the ideal environment (Fig. 6.5). Seasonal rainfall was very low and the second-lowest yield ( $0.909 \text{ t ha}^{-1}$ ) was obtained in this environment. However, this environment had a positive correlation with all environments ( $r$  from 0.37 with E1 to 0.99 with E11) and is the most suitable environment to select high-yielding and widely adapted cowpea genotypes for SNNPRS. E6 (Kucha, Meher, 2017), a high-yielding environment on the second concentric circle, is the next most favorable environment to identify high-yielding and widely adapted cowpea genotypes. These two environments would identify stable and high-yielding cowpea genotypes with a wide adaptation which implies testing the genotypes at a favorable environment such as E6 and an unfavorable environment such as E8. Genotypes with high yield in both environments are believed to be widely adapted. These two environments are not the most discriminating. However, the difference between genotypes was significant at both locations and they were discriminating. On the other hand, E1 (Gofa, Meher, 2016) and E12 (Kucha, Belg, 2018), are at almost  $90^\circ$  to the ideal environment and are not correlated with it, and are not representative of the other 10 environments included in this

study.

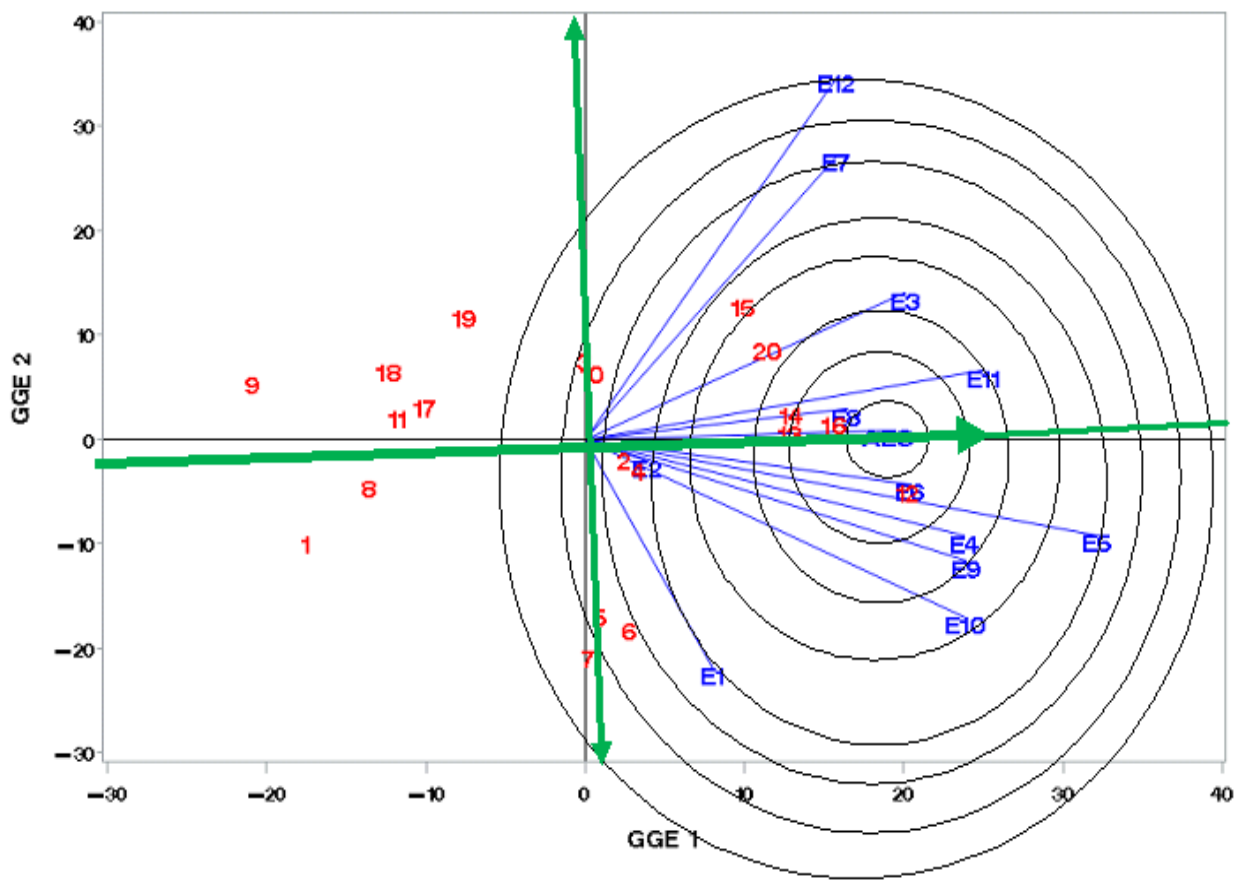


Figure 5.5. Comparison of Environments with an Ideal Environment

## 5.5. Conclusions and recommendations

The effect of genotype, environment, and their interactions were highly significant for grain yield of cowpea genotypes tested during the growing seasons of Meher and Belg in southern Ethiopia. The study showed that the magnitude of GEI for grain yield was larger than that of the main effects of the genotype. The GEI interaction was about 1.5 times as large as that of the genotype effect, indicating the presence of different environmental groups. The study also confirmed that higher yields were achieved at Gofa than Humbo during the study period.

Various stability models were used in the measurement of genotype stability such as AMMI Stability Value (ASV), GSI, and GGE. Grouping genotypes by Yield, ASV, and GSI gave G2 (Bole), G4 (Kenketi), G12 (IT-96D-604), G14 (IT93K-293-2-2), G16 (IT-89KD), G20 (IT97K-569-9) as stable and high-yielding genotypes. The GEIPCA2 vs GEIPCA1 biplot produced G13 (96K-619-1), G14 (IT93K-293-2-2), G16 (IT-89KD), G2 (Bole), G4 (kenketi) as stable and high-yielding genotypes. G5 (Brazil-2), G6 (Brazil-3), and G7(Brazil-4) can be recommended for Meher environments with the intermediate length of the growing period (91 days) and Belg seasons with no terminal moisture stress such as E9 and E10. The Meher environment at Gofa has a prolonged growing period. There is a high amount of rain in October and November. Since G5 (Brazil-2), G6 (Brazil-3), and G7 (Brazil-4) tend to extend their growing period under favorable conditions, we recommend adjusting the planting time of these genotypes at Gofa to take advantage of the rains of October and November.

G12 (IT-96D-604), G13 (96K-619-1), G15 (IT99K-1060), and G20 (IT97K-569-9) should be advanced further for wide adaptation except that for E2 (Humbo, Meher, 2016) and E12 (Kucha, Belg, 2018) environments with a short growing period of 85 and 80 days respectively should be avoided. For G12 (IT-96D-604) Meher and Belg environments with short growing periods and with terminal moisture stress such as E2 (Humbo, Meher, 2016; 85 days) and E12 (Kucha, Belg, 2018; 80 days) should be avoided. For G13(96K-619-1), Meher environments with short (85-87) and intermediate (90 days) length of the growing period and Belg environments with a short growing period of 80 days should be avoided. For G15 (IT99K-1060), and G20 (IT97K-569-9) Meher environments with short (85-87) and intermediate (90 days) length of the growing period should be avoided. Our results showed

that G12 (IT-96D-604), G13 (96K-619-1), G15 (IT99K-1060), and G20 (IT97K-569-9) had higher grain yields than the checks and were suggested for further inclusion in the breeding program to boost cowpea production. Generally, the present results indicated that, based on yield performance, AMMI, GGE biplot, ASV and GSI indices, genotypes G16 (IT-89KD) and G14 (IT93K-293-2-2) showed better grain yield with better stability across environments, which suggests that it can be recommended for all cowpea growing areas of southern Ethiopia with similar weather conditions to the areas used in this study.

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## CHAPTER SIX

### 6. PERFORMANCE AND FARMERS PARTICIPATORY SELECTION OF COWPEA VARIETIES IN SOUTHERN ETHIOPIA

#### ABSTRACT

*Farmers' participation in the varietal selection process is important to collect the actual feedback on their performance in the field and hastens promotion and popularization of technologies for a better acceptance and dissemination rate. The study was conducted in Gofa district of southern Ethiopia during 2016-2017 main cropping seasons to assess and select superior cowpea variety (ies) that meet the needs of farmers and preferences through their participation. Eight cowpea varieties were laid out in a randomized complete block design (RCBD) with three replicates in the grandmother trial on the Gofa research station while mother trials consisted of plantings in an unreplicated block at three nominated farmers' fields from each testing site. Representative farmers, including both men and women, were invited to participate in the selection process. The participant farmers' set 12 selection criteria to identify farmers' preferred varieties. All recorded agronomic and farmer set criteria were analyzed. Analysis of variance (ANOVA) showed the existence of significant differences ( $p < 0.05$ ) among the tested varieties for all the measured agronomic traits. According to the results observed in the field, varieties Kenketi and Bole were the earliest ( $< 81$  days) whereas Brazili-2 and Brazil-3 were late for maturity ( $> 89.5$  days). Combined mean values showed that Brazil-3 ( $1.65 \text{ t ha}^{-1}$ ), Brazil-2 ( $1.62 \text{ t ha}^{-1}$ ), Kenketi ( $1.53 \text{ t ha}^{-1}$ ), and bole ( $1.52 \text{ t ha}^{-1}$ ) were high-yielding varieties with a yield advantage of 3.9 to 12.2 % more than the check variety white wonderer trailing. In case of farmers' evaluation using direct matrix and pair-wise ranking methods showed that Kenketi, Brazil-3, Brazil-2, and Bole were the most preferred varieties. The rank correlation analysis between varieties' ranked by farmers and the varieties' grain yield rank was positive across the tested villages. Therefore, considering data on farmer preferences and field performance, two released varieties, kenekti and Bole, were selected as farmers' first choice and can be recommended for further demonstration, popularization, and dissemination on farmers' fields, while the two introduced Brazilian varieties, Brazil-2 and Brazil-3 are preferred as the second category of choice by farmers must be registered according to national regulations of the country. Simultaneously, it was suggested that the farmers' screening criteria need to be considered in conjunction with standard evaluation data for efficient cowpea improvement programs.*

**Keywords:** Cowpea, direct matrix, pair-wise, participatory variety selection

## 6.1. Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is a legume crop grown mainly in tropical and subtropical regions of the world for grains and vegetables and to a lesser extent as a fodder crop (Oyewale and Bamaiyi, 2013). Annual global cowpea production is estimated at 7,704,000 tons, of which more than 6.74 million tons (87.5%) are from Africa (FAO, 2018). It is also widely cultivated by poor farmers in developing countries with over 80% of its production coming from tropical Africa (Gbaguidi *et al.*, 2015). According to Néya *et al.* (2015) up to 200 million people in tropical Africa use cowpea.

Cowpea seeds contain a mean of 23-25 % protein and 63.6 % carbohydrates (Akyaw *et al.*, 2014). It is also a vital crop in the livelihoods of both humans and animals, where it serves as the closest source of animal protein, especially for those who cannot afford animal protein due to low income and large family size (Kwon-Ndung and Kwala, 2017). Therefore, it is considered very important to reduce the protein deficiencies in the human diets of malnutrition among children and resource-poor rural households, where it is considered the ‘meat of the poor’ (Owolabi *et al.*, 2012). In addition, the capacity to adapt to different soil types and intercropping systems, their drought tolerance, and the ability to restore soil fertility through fixation of nitrogen (Pungulani *et al.*, 2012; Néya *et al.*, 2015), and erosion precaution make cowpea an important economic crop in many developing regions (Ewansiha and Tofa, 2016). Being a drought-tolerant and warm-weather crop it adapts well to the drier region of the tropics where other food legumes do not perform well (Bashir *et al.*, 2018).

In Ethiopia, cowpea is grown in the drier areas of the Rift Valley and the dry highlands of Hararghe (east and west Haraghe zone, Oromiya region) usually intercropped with sorghum and in the Northeastern part of the country around Shewrobit, Kobo, north and south Wollo zone and Waghimira (Amhara region) areas, in southern and eastern Tigray zone, Ethio-Somali region, Afar region, Wolayita zone and Jinka zone (Kassaye *et al.*, 2013). Also, it is cultivated in low rainfall areas of Southern Nations, Nationalities, and Peoples' Region (SNNPR) especially in Konso, Derashe, Humbo, Hammer Bako, Loka Abaya, Gofa, and Loma districts (Tesema and Esthetayehu, 2003). In Ethiopia, although cowpea is grown in different regions (Oromiya, Amhara, Tigray, SNNPR, and Gambella) the area coverage hasn't been recorded by the Central Statistics Agency. In the

country, cowpea seeds are mostly used as a boiled grain or “nifiro” or converted to other food products like “Shiro”, and “purches grain” in the diet of the society in the growing areas (Tesfaye *et al.*, 2018). Cowpea is produced in Ethiopia for a long time in lowlands by smallholder farmers without using any chemical inputs. In the drier areas of the country, cowpea is an excellent source of protein, feed, and income for farmers and plays an imperative role in restoring soil fertility (Belay *et al.*, 2017; Tesfaye *et al.*, 2018).

Regardless of its significance, the average national yield of cowpea in Ethiopia remains low with an average yield of the resource-poor farmers at about 0.4 t ha<sup>-1</sup> (Beshir *et al.*, 2019), whereas in research farms yields of 2.2–3.2 t ha<sup>-1</sup> have been commonly recorded from improved varieties with proper crop management and protection practices (Ashinie *et al.*, 2020). Low yields (0.4 t ha<sup>-1</sup>), at farmers’ fields, were due to some factors, including the absence of improved high-yielding farmers preferred varieties, poor soil fertility, poor farmer participation, moisture stress, losses due to insect pests and diseases, and poor crop management practices.

In this respect, there is a potential for enhancing productivity and adoption of the crop through the application of measures that help to solve the constraints. To this end studies on farmers’, participatory variety selection may play a fundamental role. The reasons behind the use of PVS are that researchers tend to focus on increasing productivity and their goals may differ from those of farmers, including market value, quality (cooking ability, taste, color, size), and household use (Kamara *et al.*, 2010; Ndiso *et al.*, 2016). In addition, the results from the conventional research systems take longer to reach farmers. Selection of farmer acceptable varieties with better adaptability through a participatory methodology is an essential approach to meet the actual needs of the farmers in south Ethiopia. Close cooperation between researchers and farmers in the testing of varieties could enable the identification of crop genotypes preferred by farmers for large-scale production or targeted breeding (Horn *et al.*, 2017). A participatory approach improves the adoption of improved technologies and farmers’ knowledge and empowers traditional knowledge and innovations to be included in the research (Orawu *et al.*, 2013). The participation of low-income farmers in the selection of crop varieties helps ensure acceptance; and eventually for rapid adoption (Hailemariam, 2016). Furthermore, Abady *et al.* (2017) reported that the process of adoption of new improved varieties tended to be lower in areas where farmers were less involved in the research process. In this sense,

farmers' knowledge of the selection of suitable varieties for their areas needs to be acknowledged to include in future varietal improvement programs.

Horn *et al.* (2017) on elite cowpea genotypes have shown that farmers involvement in research enables them to select new and promising varieties for their areas based on larger seed size, white grain color, high pod setting ability, insect pest tolerance, early maturity, longer pod size, drought tolerance, high biomass and pod yields. Therefore, participatory variety selection is considered to be a friendly approach to the identification and dissemination of new improved varieties with preferred traits to the societies (Thapa *et al.*, 2009). It also enhances farmers' access to crop varieties, increases diversity, allows cost-effective varietal selection in targeted areas, and thus facilitates seed production and scaling-up at the community level (De Boef and Ogliari, 2008). Thus, the objectives of this research were to evaluate and select superior cowpea varieties that meet the requirements and choices of farmers through farmers' participation and to identify farmers' selection criteria for cowpea variety improvement in the study area.

## **6.2. Materials and methods**

### **6.2.1. Description of the study area**

The experiments were conducted at a research station and in three farmers' fields, each in Boreda, Suka, and Zuluze kebeles in Gofa district during the main cropping seasons of 2016 and 2017. Gofa is located at the coordinates of 6° 19'-20'N latitude and 36° 55'E longitude and has an elevation of 1317 meters above sea level (m.a.s.l). The soil is mostly sandy loam. The amount of rainfall received during the 2016 growing season was 487 mm with an average temperature of 22.04°C. In 2017, 692.8 mm of rainfall was obtained with an average temperature of 21.8°C (Fig.6.1, Fig.6.2). Long-term (15 years) rainfall of 500 mm was received over four months (July, August, September, and October) with a mean temperature of 21.9°C. During the crop growth period, the precipitation pattern was different from that of the long-term average; considering the total amount of precipitation during the whole crop growth period; it was less than the long-term average in 2016 while greater than that of the long-term average in 2017. Average relative humidity varied from 45.9 % to 66.7 % during the crop growth period (Fig.6.2).

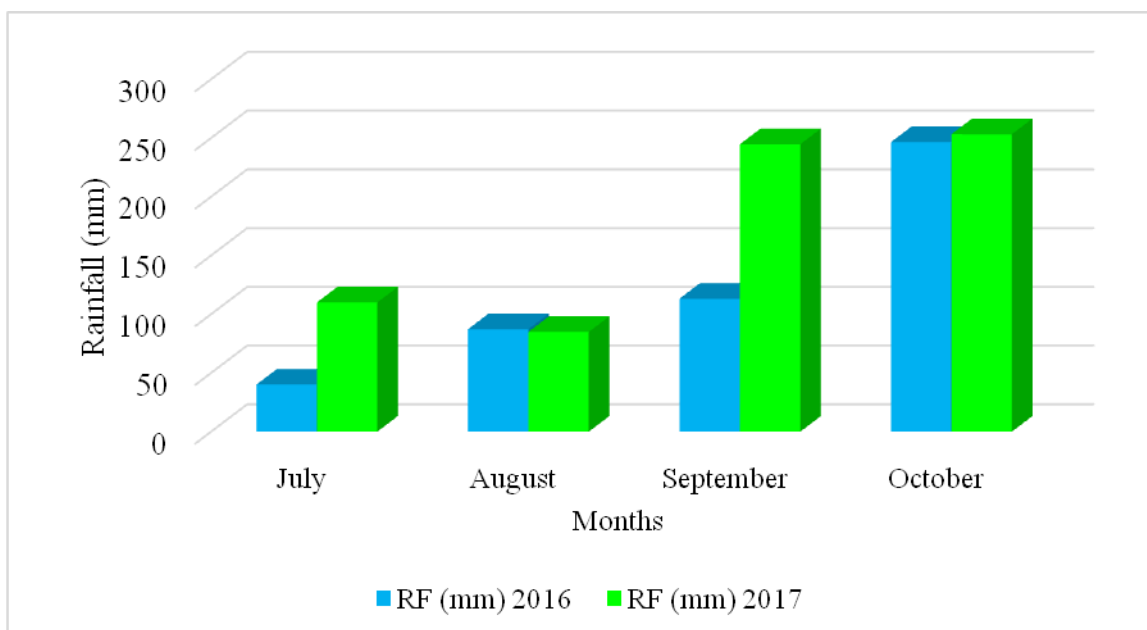


Figure 6.1. Total monthly rainfall (mm) of the study site during the trial years.

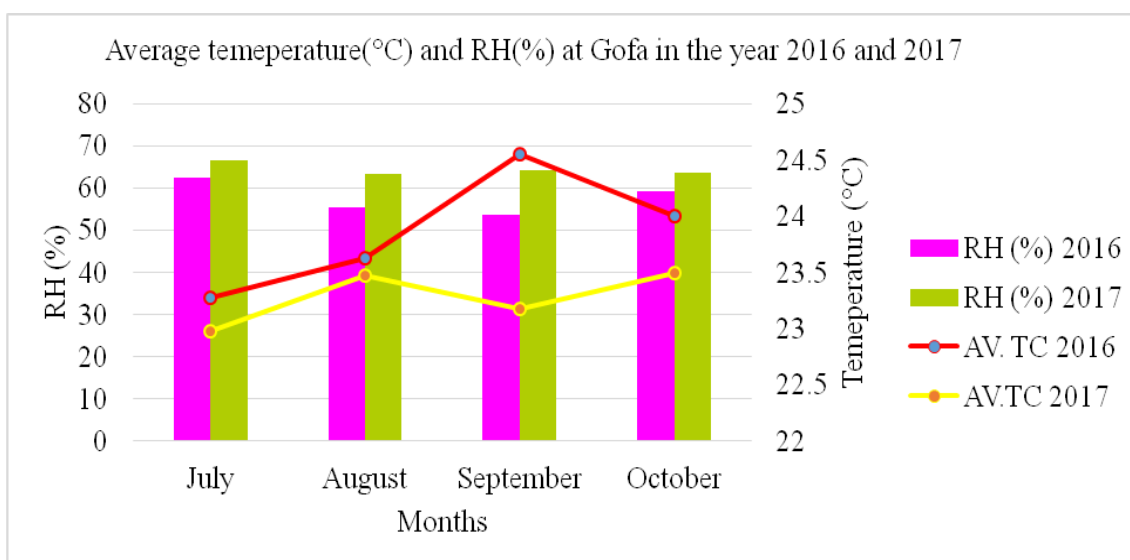


Figure 6.2. Average temperature and relative humidity (%) during the period of the experiment. Source: National Meteorology Agency, Ethiopia, 2018.

### 6.2.2. Treatments, Experimental Design and Agronomic Management

Four improved cowpea varieties obtained from the Melkasa Agricultural research center and four introduced varieties selected from the 2015 adaptation trial were further evaluated using participatory variety selection. Eight cowpea varieties including standard check variety were used in our investigation. Seeds for each of the varieties were initially sourced from Melkasa Agricultural Research Center. The varieties are listed in Table 6.1 below and, ‘white wonderer trailing’ was considered as a standard check.

Table 6.1. List of tested cowpea varieties

No	Variety	Year of release	Maintainer
1	Brazil-1	Introduced	MARC/EIAR
2	Bole	2005	MARC/EIAR
3	Kenketi	2012	MARC/EIAR
4	Brazil-2	Introduced	MARC/EIAR
5	Brazil-3	Introduced	MARC/EIAR
6	BEB	1976	MARC/EIAR
7	Brazil-4	Introduced	MARC/EIAR
8	White wonderer trailing (SC)	1976	MARC/EIAR

MARC-Melkasa Agricultural Research Center; SC-standard check; EIAR-Ethiopian Institute of Agricultural Research.

The varieties were sown in the mid to end of July 2016 and 2017 main cropping seasons and the trial was conducted using the grand mother-mother method (Berhanu *et al.*, 2018). The experiments were laid out in a randomized complete block design (RCBD) with three replicates in the grandmother trial on the Gofa research station while mother trials consisted of plantings in an unreplicated block at three nominated farmers' fields from each testing site (a total of nine farmers). Three host farmers at each testing site planted one replication each as a mother trial. On the station, the trial was planned and accomplished by the researcher while on-farm trials were designed by a researcher and managed jointly by the researcher and farmers. The grandmother trial was used to produce the researcher's data while the mother trials were used for participatory varietal selection and to value farmers' preferences during evaluation. Each experimental plot had an area of 7.2 m<sup>2</sup> with four rows of 3 m length spaced at 60 cm between rows and 20 cm between plants. Fertilizer Di-ammonium phosphate (DAP) was applied at a rate of 100 kg/ha during sowing. At Gofa trial station, the sowing dates were July 14, 2016, and July 19, 2017, respectively. At farmers' fields, planting was done from 13 to 15 July 2016 and 18 to 20 July 2017. Hand weeding was made two times over the growing season.

### 6.2.3. Data collection

#### 6.2.3.1. Agronomic data collected

Data on plant height, number of pods per plant, and pod length were collected from five arbitrarily chosen plants from each plot and the average value was considered per plant basis. Whereas data on days to 50% flowering, days to maturity, 100 seed weight, grain

yield, and above-ground biomass yield were recorded on a plot basis. Days to 50% flowering: Number of days from sowing to stage when 50% of plants in the plot have begun to flower. Days to maturity: Number of days from sowing to stage when 90% of plants in the plot have matured. The grain yield per plot was adjusted to storage moisture content (10%) determined using a digital Grain Moisture Meter (DRAMINSKI, POLAND). Data on insect (aphids) reactions were recorded as described by Obopile (2006) that the aphids damage was recorded and rated on a 1-9 scale, where: 1=resistant, 3= moderate resistant, 5= moderate susceptibility, 7= susceptible, 9=very/high susceptibility. In addition, grain yield data from the mother trials were collected.

### **6.2.3.2. Farmers' participatory varietal selection**

For the farmers' assessment; the researcher together with the agricultural development workers selected farmers and farms to lay experiments. The varieties selection process with farmers was done at maturity and threshing stages. Ninety-two farmers (72 men and 20 women) were selected in the kebele for field evaluations. Besides, field evaluations, the sensory evaluation, which was carried out by 40 panelists (16 men and 24 women) was performed. The criteria preferred by farmers were grain yield, earliness, aphid resistance, drought tolerance, white seed color, large seed size, pod number, pod length, short cooking ability, good taste, above-ground biomass yield, and growth habit were used to determine the best cowpea varieties.

PVS was performed using direct matrix and pair-wise ranking methods on tested cowpea varieties at maturity and threshing stages of cowpea. Direct matrix tables were prepared to evaluate tested cowpea varieties compared to traits reported by the farmers. Data were collected from studies involving eight varieties, in which each variety was equated with the other varieties for identified traits for varieties acceptability at a score of 1-5. A score of 1–5 was used to assess these characters, and genotypes were involved in all sites with the definition as follows: 5 = not preferred/poor, 4 = less preferred/below average, 3 = moderately preferred/Average, 2 = highly preferred/good, and 1 = very good. Farmers were asked to rate visually the wanted traits by assigning between one and five scores. Farmers as a group (10 to 15) were asked to put 1, 2, 3, 4, or 5 scores for a given trait and variety. The scores were counted and the smallest total count was ranked first. All the characters were determined by visual observation in the field except for taste and time of cooking. During threshing, a 1kg seed sample of all the varieties was boiled in dishes

before the organoleptic test. At cooking, the water was boiled in the dish first before the cowpeas were put. The time taken from when the cowpeas were placed in the boiling water to the time they were ready to eat was recorded. Farmers were later allowed to taste all the varieties and rank them by taste. A sensory panel consisting of 40 panelists, was conducted at one of the host farmer's homes, where an evaluation was performed (Ndiso *et al.*, 2016). The languages used in sensory testing were Amaharic and Gofigna (local language). The panelists had been screened for their understanding of the cowpea dish and their ability to determine differences among cowpea boiled grain from different cowpea varieties. Sensory attributes evaluated were short cooking ability and taste. Based on the selection criteria, they were asked to give the rank score of the varieties tested. At maturity and threshing, farmers were requested to evaluate each variety, using the same scoring method. To determine the scoring value of a variety against agronomic traits, the value of each site was summed and averaged. Finally, the overall performances of each of the varieties were determined. Then the values were arranged from the smallest to the largest; the smallest average value ranked first and vice versa. Furthermore, pairwise comparison was done, in which every variety was equated with the other genotypes for identified traits.

#### **6.2.4. Data Analyses**

Agronomic data were collected and subjected to statistical analysis using the SAS computer program, version 9.0 (SAS, 2002). The homogeneity of the individual variances was verified using the Bartlett test (1937) before the combined analysis. Then the combined analysis of variance over the years was done by the SAS statistical package. Mean separation was conducted using the Least Significance Difference (LSD) at the 0.05 probability level. The model for the combined data analysis of variance of an experiment conducted in one location over years using randomized complete block design, the linear model used was;

$$Y_{ijk} = \mu + G_i + y_j + (Gy)_{ij} + R_k(y) + e_{ijk}$$

Where,  $Y_{ijk}$  = the observed value of the trait Y for the  $i$ th genotype in the  $j$ th year and  $k$ th block  
 $\mu$  = the grand mean of trait Y in the experiment

$G_i$  = the effect of the  $i$ th genotype

$y_j$  = the effect of the  $j$ th year

$(Gy)_{ij}$  = the genotype-by-year interaction effect

$R_k(y)$  = effect of the block across the year

$e_{ijk}$  = experimental error

Table 6.2. Analysis of variance table for combined years

Source of variation	Df	MS	Expected MS	F ratio
Year(y)	y-1	MS <sub>y</sub>	s <sup>2</sup> <sub>y</sub> +gs <sup>2</sup> <sub>r</sub> (y)+rg s <sup>2</sup> <sub>y</sub>	MSE/MS <sub>r/y</sub>
Block with in year	y(r-1)	MS <sub>r/y</sub>	s <sup>2</sup> <sub>y</sub> +gs <sup>2</sup> <sub>r</sub> (y)	MS <sub>r/y</sub> /MSe
Genotypes(g)	g-1	MS <sub>g</sub>	s <sup>2</sup> <sub>y</sub> +gs <sup>2</sup> <sub>y</sub> +yrs <sup>2</sup> <sub>g</sub>	MS <sub>g</sub> /MSe
GyI	(y-1)(g-1)	MS <sub>gxe</sub>	s <sup>2</sup> <sub>y</sub> +gs <sup>2</sup> <sub>gy</sub>	MS <sub>gxe</sub> /MSe
Error	y(g-1)(r-1)	MSe		

Df =degree of freedom, MS= Mean squares, r =replication, g =genotypes, y= years, s<sup>2</sup> = variance, MS<sub>y</sub> = mean squares due to years, MS<sub>r</sub>= mean squares due to replications, MS<sub>r/y</sub>= mean squares due to replication (years), MS<sub>g</sub> = Mean squares due to genotypes, MS<sub>gxy</sub>= Mean squares due to genotype by year interaction (GyI) and MSe= Mean squares due to residual. To identify and decide on farmers' selection criteria on each of the cowpea varieties procedures such as pairwise ranking and direct matrix were applied. The degree of the correlation coefficient in farmers' trait preferences scores and data taken by the researchers (actual grain yield after measuring) were tested by using Spearman's correlation coefficient (Steel and Torrie, 1980) by using the following formula.

$$R_s = 1 - \left( \frac{6\sum d^2}{n^3 - n} \right)$$

Where, r<sub>s</sub>= correlation coefficient *d* = difference in the ranks assigned to the same individual or phenomenon and *n* = number of individuals or phenomena ranked.

### 6.3. Results and discussion

#### 6.3.1. Cowpea varieties performance in the study sites

Analysis of variance revealed that there were highly significant (P<0.01) to significant (P<0.05) differences among the tested cowpea varieties for all characters in the case of researchers managed field at Gofa research station (Table 6.3). The varieties showed statistical differences in all collected agronomic traits. Similar to this study, Belay *et al.* (2017) showed that there was significant variation among their cowpea varieties for all traits. Another study by Solomon and Kibrom (2014) demonstrated that most traits showed significant variation among the other cowpea genotypes. However, they reported different results for pods per plant and plant height against the present study.

Table 6.3: Analysis of Variance (ANOVA) for measured agronomic traits of cowpea varieties tested at Gofa district during 2016 and 2017

SOV	DF	FD	MD	HSW	PPP	PH	BY (t)	GY (t)	PL (cm)
Year	1	0.188	432	124.81	8629.6	87134.0	5089193	56835.7	0.035
Year (Rep)	4	1.938	4.1	1.34	27.7	100.03	756918.5	13407.7	1.84
Variety	7	50.9**	340.6**	93.1**	67.1**	1306.0*	4232557.2**	306519.4*	26.18**
Year*variety	7	3.9*	32.4**	14.3**	101.4**	1646.5*	5690351	159907.5**	1.06
Error	28	1.37	2.015	1.21	8.5	360.5	630229.3	18684.4	1.172

SOV=Source of variation, R=replication, DF=degree of freedom, FD=Days to 50% flowering, MD=days to maturity, HSW=Hundred seed weight, PPP=pods/plant, PH=plant height, BY=above-ground biomass yield, GY=grain yield, and PL=pod length

Table 6.4 shows the researcher's assessment for the mean values of different agronomic traits.

The average data showed that cowpea varieties differed significantly for all agronomic traits. The results of this study showed that the number of days to 50% flowering and the number of days to maturity of cowpea varieties varied significantly. For days to 50 % flowering, the earliest variety was BEB (45.3 days) whereas the late-flowering variety was Brazil-4 (52.8 days). Brazil-4 required 52.8 days for 50% flowering being statistically the most lately flowering followed by Brazil-2 (52.3 days) and Brazil-3 (52.2 days). The lowest days to 50% flowering was exhibited by variety BEB which was statistically similar with Kenketi and Bole. The difference in days to 50% flowering between the cowpea varieties tested could be due to varietal differences. For days to maturity, the earliest maturing varieties in terms of maturity time were Kenketi (79 days), Bole (80 days), and BEB (81 days). Kenketi took 79 days to mature, which is 17 days earlier than Brazil-2. Variety Brazil-2 took a relatively long period (95.8 days) to mature than other varieties and its maturity time was higher than 80 days as also reported by Singh *et al.* (2007) and Dugje *et al.* (2009) for other cowpea varieties. The attribute of maturity time denotes the number of days it takes for a variety to complete its growth cycle from sowing to full maturity ready for harvest in dry form. Experiences from the PVS activities showed that farmers have often revealed a preference for earliness in cowpeas for various reasons. In drought-stressed environments, short growth cycles enable cowpea varieties to grow with minimum rainfall and allow rapid food access to food-insecure families. After harvesting cowpea, they can plant a second crop in the same cropping season. Similar results supporting the current findings were reported by Kamai *et al.* (2014). In Namibia and other arid and semi-arid regions of sub-Saharan Africa, farmers prefer short cycle duration cowpea varieties (Abadassi, 2015; Horn *et al.*, 2015).

The maximum plant height was recorded for Brazil-3 (123.4cm) and was statistically identical to Brazil-4 (116.7 cm), Brazil-2 (111.4 cm), and Brazil-1 (103.2 cm). The shortest plant height (82.8 cm) was recorded for kenketi, but at par with Bole (84.6 cm).

A similar research result was also reported previously (Belay *et al.*, 2017; Solomon and Kibrom, 2014) that the authors perceived variations in plant height among the cowpea varieties. The pod length of Brazil-3, Brazil-2, and Brazil-4 were 19, 17.8, and 17.2 cm, respectively. Pod length was found to be highly significant with a maximum for variety Brazil-3 (19.0 cm), which was statistically at par with Brazil-2 (17.8 cm) and a minimum for a variety Bole (12.4 cm). The pod length of cowpea varieties was ranged from 12.4 to 19.0 cm (Table 6.4). The variation observed between varieties for the measured pod length was supported by Tesfaye *et al.* (2018) and Yama *et al.* (2006) who tested different cowpea genotypes and found a significant variation in pod length.

There were significant differences among cowpea varieties tested for above-ground biomass yield ( $P < 0.01$ ) (Table 6.3). The highest above-ground biomass yield ( $5.67 \text{ t ha}^{-1}$ ) was gotten from Brazil-2 which was statistically identical with Brazil-4, Brazil-3, and white wonderer trailing but numerically higher than a check variety (Table 6.4).

Table 6.4. Mean agronomic traits of grandmother experiment of cowpea varieties at Gofa, 2016 and 2017.

Varieties	FD	MD	HSW	PPP	PH	BY(t)	PL(cm)	AP
Brazil-1	52.2a	94.7a	19.9a	21.9cd	103.2abc	4.08bc	16.6bc	8.01a
Brazil-2	52.3a	95.8a	20.5a	24.9bc	111.4ab	5.662a	17.8ab	5.0d
Brazil-3	52.2a	95.3a	20.2a	27.6ab	123.4a	5.661a	19.0a	5.2cd
Brazil-4	52.8a	95.3a	19.8a	19.9d	116.7ab	5.61a	17.2b	5.3cd
Bole	50.2b	80.2c	15.5b	30.0a	84.6d	4.28bc	12.4f	5.2cd
BEB	45.3c	80.8c	20.0a	22.7cd	93.4dc	3.49c	15.2de	7.0b
Kenketi	46.5c	79.3c	13.9c	26.9ab	82.8d	4.35bc	14.2e	5.5c
WWT	52.0a	89.5b	10.4d	26.6ab	98.2bcd	4.84ab	15.8cd	5.2cd
Mean	50.4	88.9	17.5	25.1	101.7	4.7	16.0	5.8
CV (%)	2.3	1.6	6.3	11.6	18.7	16.7	6.8	10.4
LSD (5 %)	1.4	1.7	1.3	3.5	22.5	1.0	1.3	0.49

Means with the same letter within the same column are not significantly different, at 5% probability level, LSD=Least significant differences, CV= coefficient of Variation, WWT=white wonderer trailing (Standard Check), FD=Days to 50% flowering, MD=Days to maturity, HSW=hundred seed weight, PPP=pods per plant, PH=Plant height, BY= above ground biomass yield and PL=pod length. AP=Aphid score

Biomass is a vital trait as cowpea straw has high protein concentrates for animal feeds (Kamai *et al.*, 2014). Due to this reason, Brazil-2, Brazil-4, and Brazil-3 can take advantage

of the other varieties. On the contrary, the lowest above-ground biomass yield ( $3.49 \text{ t ha}^{-1}$ ) was recorded for a variety of BEB. Similar findings on the other cowpea genotypes were also reported by Solomon and Kibrom (2014), identifying different above-ground biomass yields for different cowpea genotypes.

As shown in Table 6.3, the performance of the tested cowpea varieties differed significantly ( $P < 0.05$ ) to highly significant ( $P < 0.01$ ) for yield and yield components. A variety Bole gave the highest number of pods per plant having a value of 30.0 which had statistically similar with varieties Brazil-3 (27.6), kenketi (26.9), and white wonderer trailing (26.5), while least for Brazil-4 (19.0). These findings are in agreement with that of Bhattarai *et al.* (2017), who also reported significant differences for this parameter among cowpea varieties.

The 100 seed weight was highly and significantly affected by cowpea varieties (Table 6.3). The highest 100 seed weight (20.48 g) was recorded for Brazil-2, which was statistically at par with Brazil-3 (20.22 g), Brazil-1 (19.96g), and Brazil-4 (19.9g), and the lowest (10.35 g) from check variety white wonderer trailing followed by Kenketi (13.98 g). These results are similar to those of other researchers who have reported that cowpea genotypes were significantly affected by 100 seed weight (Kamara *et al.*, 2018). Like the other traits, aphid resistance is the other important parameter that needs to be included in cowpea improvement programs. Except for varieties BEB and Brazil-1, all other cowpea varieties were found moderately susceptible to aphids (Table 6.4). The infestation of aphids was relatively lower for 6 varieties, i.e 75 % of varieties showed a moderately susceptible reaction, while variety Brazil-1 was highly susceptible. These might be occurred due to genetic variation of the varieties. The results verified the findings of Souleymane *et al.* (2013) and Gonné *et al.* (2013). Identification of cultivars with high grain yield combined with aphid resistance allows the use of cowpea as a potential alternative to help control aphids infestation.

Table 6.5: Grain yield (t ha<sup>-1</sup>) from grandmother and mother trials

Variety	Grandmother	Mother	Mean	Rank	% increase over standard check
Brazil-1	1.08d	1.07d	1.07c	8	-
Brazil-2	1.63ab	1.61ab	1.62a	2	10.2
Brazil-3	1.66a	1.64a	1.65a	1	12.2
Brazil-4	1.42c	1.44bc	1.43b	6	-
Bole	1.48bc	1.58abc	1.52ab	4	3.9
BEB	1.09d	1.06d	1.08c	7	-
Kenketi	1.61ab	1.45abc	1.53ab	3	4.3
WWT	1.54abc	1.39c	1.47b	5	-
Mean	1.44	1.40	1.42		
CV (%)	8.9	11.3	10.2		

Means with the same alphabet are not significantly different, at 5% probability level, CV= coefficient of Variation, WWT=white wonderer trailing (Standard Check), % of standard check =yield advantage over the combined mean.

The grain yield of cowpea is the combined effect of various yields attributing components. In the grandmother trial, the grain yield was ranged from the lowest yield of variety Brazil-1 (1.08 t ha<sup>-1</sup>) to the highest yield of variety Brazil-3 (1.66 t ha<sup>-1</sup>), while in the mother trial it ranged from 1.06 to 1.64 t ha<sup>-1</sup> for BEB and Brazil-3, respectively (Table 6.5). The varieties Brazil-3, Brazil-2, Kenketi, and Bole had the highest similar yields in both trials with a significant difference from the rest of the varieties (Table 6.5). The variety Brazil-3 was better in both trials compared to others, and the average yield of the grandmother and mother trials showed that varieties Brazil-3, Brazil-2, Bole, and Kenketi had 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup> ranks, respectively (Table 6.5). The maximum combined mean grain yield was recorded for Brazil-3 (1.65 t ha<sup>-1</sup>) and it was statistically similar to that of Brazil-2, Kenketi, and Bole but increased the grain yields numerically by an average of 3.9 to 12.2% yield advantage over the check variety white wonderer trailing (Table 6.5). The highest grain yield for variety Brazil-3 might be attributed to higher pods/plant, plant height, pod length, and 100 seed weight. The variation for grain yield and yield components among varieties might be due to the inherent genetic difference of the tested cowpea varieties. In concord with the current finding in the past, some researchers reported similar results in their investigations and stated the presence of significant differences among varieties for grain yield in cowpea ( Manggoel *et al.*, 2012; Nwosu *et*

*al.*,2013). Our results were also in line with those of Ndiso *et al.* (2016), who evaluated different improved cowpea varieties and reported that mean grain yield varied from 0.48 to 3.3 t ha<sup>-1</sup>.

### **6.3.2. Farmers preferred traits and selection criteria**

Farmers at all sites had the same experience in cowpea production and cowpea has been used as major food and to some extent as cash crops. The farmers who were involved and evaluated the genotypes were selected to be representatives of the area that had long experience in growing cowpea. Farmers first identified 12 criteria of cowpea varieties that influence their choice of varieties to cultivate and then ranked and scored (Table 6.6). Twelve different traits such as earliness to maturity, aphid's tolerance, drought tolerance, short cooking ability, seed color, taste, pod length, pod number, seed size, growth habit, grain, and above-ground biomass yield were used when evaluating cowpea varieties for selection. The rating was based on a scale of 1 to 5, 1 is being very good and 5 being poor. In Boreda, the important criteria in order of importance were: high yield, early maturity, aphid resistance, drought tolerance, taste, pod length, cooking ability, seed color, pod number, seed size, growth habit, and lastly biomass yield. Farmers at the Suka site followed a similar trend except for a slight variation in priority in Zuluze and on station sites. Important criteria used by Zuluze farmers were early maturity, high yield, resistance to aphids, resistance to drought, pod length, good taste, number of pods, seed size, and seed color. Analysis across the sites showed high yield, early maturity, aphid resistance, drought tolerance, short cooking ability, seed color, good taste, pod length, pod number, and seed size were ranked as the ten top criteria. Only a few traits were inconsistently ranked across all sites. For instance, the taste and length of the pods are more preferred by farmers in Boreda, ranked fourth, as compared to farmers from near station sites where it was ranked eighth. Likewise, the short cooking ability was important in Suka and station sites and was ranked fourth, as compared to Zuluze site where it was ranked tenth. Spearman's rank correlations ( $r_s=0.57-0.93$ ) showed that farmers' trait preferences were strong, positive, and significant (Table 6.6) indicating that the ranking order was roughly consistent among the four sites. Overall, the criteria for selecting a good cowpea variety were essentially the same across the four tested sites; suggesting that similar selection criteria can be applied for the cowpea improvement programs (Table 6.6). This implied that the farmers' variety selection criteria reveal the degree of importance given to different varieties as well as the choice of traits. This shows that grain yield is not the only selection criterion farmers use, but rather on the combination of agronomic and qualitative traits as farmers' interests. Thus, the result confirmed the importance of farmers'

knowledge to complement the researcher's perception in the selection of cowpea varieties for a specific area. Similar observations were made by Ndiso *et al.*, (2016) who reported that grain yield, drought tolerance, early maturity; ease of harvesting, leafiness, seed color, taste, and cooking duration as main criteria, and high grain yield was in the first place because all the farmers who participated in the evaluation used cowpea mostly for grain production. Previous studies by (Abadassi, 2015; Horn *et al.*, 2015) working on cowpea reported similar findings of farmers using a combination of traits when evaluating new genotypes.

### **6.3.3. Farmers' varieties selection based on direct matrix ranking**

Based on the selection criteria of farmers', a comparison was conducted among the tested cowpea varieties. Cowpea varieties were identified for their morphological performance and ranked as indicated in Table 6.7. At Gofa station farmers (Table 6.7) varietal assessment showed that variety Kenketi was ranked highest (2.10), followed by Brazil-3 and Brazil-2 with values of 2.33 and 2.72, respectively.

Similarly, in Boreda site farmers' evaluation of the varieties showed that their preferred varieties are Brazil-3, Brazil-2, and kenketi with values of 2.28 and 2.33 each, respectively. The farmers' evaluation of the varieties on the Suka site also showed that their preferred varieties were Kenketi, Brazil-3, and Brazil-2 with values of 2.19, 2.24, and 2.46, respectively. On the other hand, in the Zuluze locality, the varietal evaluation of farmers showed Brazil-3 (2.18) is the preferred variety, followed by Kenketi and Brazil-2 with values of 2.40 and 2.44, respectively. Across the selection criteria, based on farmers' direct matrix ranking for the varieties showed Kenketi and Brazil-3 with equal scores (2.26) and ranked first, followed by Brazil-2 (2.49) and Bole (2.6) (Tables 6.7 and 6.8). On the other hand, sensory evaluation (taste) showed that the variety Brazil-3 (1.2 score), Brazil-4 (1.48 score), Brazil-2 (1.65 score), Brazil-1 (1.86 score), and kenektii (1.85 score) have very good to good tastes and can therefore be consumed more than other tested varieties and standard check variety (Table 6.8).

Table 6.6. Direct matrix rank and scores of traits of cowpea variety across 4 sites in Gofa.

Sites	Boreda		Suka		Zuluze		Station		FR		
Trait	score	rank	score	rank	score	rank	score	rank	MS	rank	
Grain yield	1	1	1	1	2	2	1	1	1.3	1	
Aphid resistance	2.7	3	2.7	3	2.3	3	2.7	4	2.6	3	
Earliness	2	2	2	2	1	1	2	2	1.8	2	
Drought tolerance	3	4	3	4	2.7	4	2.3	3	2.8	4	
Pod length	3	4	4	7	3	5	4	10	3.5	7	
Growth habit	4.3	10	4.3	9	4.7	11	4	10	4.3	11	
Biomass yield	4.7	11	5	12	5	12	3.9	8	4.7	12	
Seed color	3.3	7	3.3	6	4	8	3	6	3.4	6	
Seed size	4	9	4.7	10	4	8	3.7	7	4.1	10	
Pod number	3.7	8	4.7	10	3.7	7	3.9	8	4.0	9	
Good taste	3	4	4	7	3	5	4	10	3.5	7	
Short cooking ability	3.1	6	3	4	4.3	10	2.7	4	3.3	5	
Rank correlation (rs)	0.89* <sup>1</sup>		0.93* <sup>2</sup>		0.61* <sup>3</sup>		0.76* <sup>4</sup>		0.78* <sup>5</sup>		0.57* <sup>6</sup>
Total participants	35		32		30		35		132		

Preference ranking score is based on a scale of 1 to 5: 1 = Very good, 2 = Good, 3 = Average, 4 = below average and 5 = Poor/low priority; participants (M=88; F=44); 1 Spearman's rank correlation coefficient (rs) between boreda and suka farmers' preference ranking; 2 rs between boreda and Zuluze farmers' preference ranking; 3 rs between boreda and near station farmers' preference ranking; 4 rs between suka and zuluze farmers' preference ranking; 5 rs between suka and near station farmers preference ranking; 6 rs between Zuluze and near station farmers preference ranking; R=Rank, mscore=mean score, FR=farmers overall rank

The standard check variety white wonderer trailing had average palatability in taste with a mean score of almost 3. In addition to taste, the cooking time of cowpea samples was between 50 and 71 minutes. The cooking time for each variety revealed that the variety Brazil-3 (50 minutes), Brazil-2 (51 minutes), Brazil-4 (52 minutes), and Brazil-1 (53 minutes), while Bole had the longest cooking time (71 minutes). Olapade et al., (2002) stated that the utilization of whole seeds of cowpeas is however limited due to the issue of it having a prolonged cooking time in Nigeria. The cooking time of cowpea seeds ranges from 35–120 min or more, depending on the variety and type of cooking water used (Olapade et al., 2002). This is a great challenge for both urban and rural consumers due to time and energy requirements. In this study, most of the test varieties were highly rated by the farmers (Tables 6.7 and 6.8). Overall, the farmers' responded positively to the improved varieties, they have evaluated. Table 6.7 showed that the rank of the researchers did not match with the rank of the farmers for the Kenketi and Brazil-2 varieties, which were ranked 1<sup>st</sup> and 3<sup>rd</sup> by a farmer while 2<sup>nd</sup> and 3<sup>rd</sup> by the researcher. The farmers' selection criteria were slightly different from those of researchers in that the earlier included traits such as good taste, seed size, short cooking ability, and seed color. Current investigation confirms the observation by Horn *et al.*

(2017) and Abadassi (2015) that farmers' perception about cowpea varieties is not always the same as researchers' and if given the opportunity, farmers can express their preferences differently.

Table 6.7. Farmers' average score (1-5) and rank for combined traits per variety

Sites	Boreda		Suka		Zuluze		Gofa station		FDW		RR	
	score	R	score	R	score	R	score	R	score	R	GY(t)	R
Brazil-1	3.08	6	3.07	7	3.94	8	2.9	5	3.25	7	1.07	8
Brazil-2	2.33	2	2.46	3	2.44	3	2.72	3	2.49	3	1.62	2
Brazil-3	2.28	1	2.24	2	2.18	1	2.33	2	2.26	1	1.65	1
Brazil-4	2.76	5	2.76	5	2.76	5	3.4	7	2.92	5	1.41	6
Bole	2.48	4	2.49	4	2.58	4	2.88	4	2.61	4	1.53	4
BEB	3.41	8	3.13	8	3.13	6	3.43	8	3.28	8	1.08	7
Kenketi	2.33	2	2.19	1	2.4	2	2.1	1	2.26	1	1.53	3
W/W/T	3.23	7	3.04	6	3.23	7	2.95	6	3.11	6	1.47	5

R=Rank, FDM=Farmers direct matrix Rank, RR=Researchers rank (grain yield)

### 6.3.4. Farmers' varieties selection based on pair-wise ranking

#### 6.3.4.1. Farmer Preferences

Using the pair-wise ranking method, farmers' selection criteria were prioritized to identify the most important attributes desired by farmers. The results of farmer preference and selection of varieties according to the pair-wise ranking method are presented in Table 6.9. At Boreda site, varieties that were highly preferred and selected by farmers by the pair-wise ranking method were Kenketi, Brazil-3, Brazil-2, and Bole (Table 6.9). Brazil-1 and BEB varieties were the least productive (Table 6.5) and least preferred by farmers.

Table 6.8. Farmers' rating of cowpea varieties at maturity and threshing stages across sites

Trait	Brazil-1	Brazil-2	Brazil-3	Brazil-4	Bole	BEB	Kenketi	WWT
Grain yield	4.58	1.68	1.50	3.50	2.55	4.75	1.75	3.75
Aphid resistance	3.63	2.95	2.58	3.80	3.75	4.65	2.65	2.68
Earliness	4.65	4.60	4.75	4.93	1.95	2.40	1.00	4.53
Drought tolerance	3.33	2.00	3.20	3.80	2.00	3.00	1.93	3.38
Pod length	2.35	2.05	1.00	1.60	3.30	3.13	2.15	2.15
Growth habit	4.00	3.43	4.03	4.30	1.70	2.73	1.45	4.20
Biomass yield	3.08	2.00	1.00	1.83	4.00	3.80	3.15	2.25
Seed color	2.75	3.00	3.55	3.38	1.13	3.38	3.05	1.80
Seed size	2.38	1.68	1.00	1.18	2.25	1.23	2.90	3.68
Pod number	3.58	2.60	2.00	3.18	1.00	4.53	2.55	2.93
Good taste	1.86	1.65	1.20	1.48	4.00	2.15	1.85	2.60
Short cook ability	2.83	2.23	1.33	2.08	3.63	3.58	2.75	3.40
Mean	3.25	2.49	2.26	2.92	2.60	3.28	2.26	3.11
Farmers rank	7	3	1	5	4	8	1	6
TC (minutes)	53	51	50	52	71	63	56	62

\*Overall Scores: (1 – 5) Scales; 1 = Very good, 2 = Good, 3 = Average, 4 = below average and 5 = Poor and

TC=Time of cooking

Pair-wise variety rankings for Gofa show similar patterns: Kenketi, Brazil-3, Brazil-2, and Bole were the most preferred varieties. However, there was variation with regards to preferences for individual sites. The Kenektii variety was co-ranked with Brazil-3 as the first most preferred varieties in Zuluze while Brazil-3 was the most preferred variety in Suka, followed by Kenketi and Brazil-2 (Table 6.9). New varieties Brazil-3, Kenektii, Brazil-2, and Bole were consistently among the top four preferred varieties that affirm their potential (Table 6.9). Whereas Brazil-1 and BEB had an equal score and ranked last by farmers. There was a high correlation between the general impression as observed by farmers using direct matrix and pair-wise ranking methods and the researchers' determined yield ( $r_s = 0.93^{**}$  and  $r_s=0.95^{**}$ ;  $n = 132$ ). A high correlation between the pair-wise and direct matrix ranking ( $r_s=0.98^{**}$ ) indicates their overlapping. Therefore, it is possible to use either of them as a method of cowpea varietal preferences.

### **The overall ranking of performance and farmers' preferences of cowpea varieties**

The performance ranking is based on the mean grain yield of the variety while preference ranking is the average rank of the variety based on selection criteria using direct matrix and pair-wise ranking methods. Overall ranking, used to identify the final best varieties based on the average rankings of performance and preferences (Tables 6.6 and 6.8). In the Gofa district, the overall rating identified four cowpea varieties based on the farmers' most preferred traits. Farmers classify them into two categories, in the first choice category, farmers preferred cowpea varieties for their early maturing (79-80 days), moderate susceptibility to aphids, erect growth habits (suitable for intercropping as well as mono-cropping), and comparable grain yield. Furthermore, cowpea varieties, Brazil-3 and Brazil-2 were the second farmers' choice category because of their desirable traits including high grain yield, high above-ground biomass yield, moderately susceptibility to aphids, large seed size, pod length, delicious taste, and short cooking ability. In addition, genotypes Bole and Brazil-3 were rated very good at providing higher pod numbers and white seed colors. Whereas the Brazil-1 and BEB varieties as the least preferred varieties by farmers. The different maturation classes are targeted to different seasons, where the shortest-maturing varieties promoted in a season receive the least rainfall, late-maturing varieties could be suitable for mono-cropping to be promoted in season receiving the long rainfall. So, farmers can cultivate these four varieties besides standard check variety with certain yield advantages and quality traits.

In addition to yield, other priority traits considered include days to maturity, aphids resistance, drought tolerance, pod number, pod length, and growth habit as well as culinary characteristics such as taste, cooking time, seed color, and seed size. In this study, the cooking time of tested cowpea varieties varied between 50 to 71 minutes when the dish was used as a cooking device (Table 6.8).

Table 6.9. Farmers pair-wise ranking of cowpea varieties studied at Gofa in 2016 and 2017.

Sites	Boreda		Suka		Zuluze		Gofa station		FPW		FDM	RR
Varieties	score	R	score	R	score	R	score	R	score	R	R	R
Brazil-1	1	7	1	7	0	8	0	8	2	7	7	8
Brazil-2	5	3	5	3	5	3	5	3	20	3	3	2
Brazil-3	6	2	7	1	6	1	6	2	25	2	1	1
Brazil-4	2	6	4	4	4	4	3	5	13	5	5	6
Bole	4	4	3	5	4	4	4	4	15	4	4	4
BEB	0	8	0	8	1	7	1	7	2	7	8	7
Kenketi	7	1	6	2	6	1	7	1	26	1	1	3
WWT	3	5	2	6	2	6	2	6	9	6	6	5
Rank correlation(rs)									0.95* <sup>a</sup>	0.91* <sup>b</sup>	0.98 <sup>c</sup>	

Pairwise preference ranking low score= high rank and least preferred; High score=low rank and most preferred; FPW= =all farmers pairwise preference rank; FDM= all farmers direct matrix preference rank, RR=Researchers rank; a Spearman rank correlation coefficient (r) between all farmers using the pairwise method and crop harvest results (grain yield); b rs rank correlation coefficient (rs) between all farmers preference using direct matrix method and researchers measured grain yield; c spearman's rank correlation coefficient (rs) between two ranking methods; WWT =white wonderer trailing (standard check)

Faster cooking cowpea varieties reduces the time taken to prepare cowpea relish and would also offer the potential to save the cost of fuelwood and time women spend in collecting firewood. Nkongolo *et al.*(2009) reported that using the averages cooking duration, the six genotypes tested were classified into the two cooking ability categories i.e genotypes cooked under two hours (71- 98 minutes) were fast cooking while slow cooking took more than two hours (138-174 minutes). This is in agreement with Nadis *et al.* (2016) who reported that the success of any newly introduced variety will depend not only on its production characteristics but also on its acceptability by consumers in terms of both sensory and usage traits. Hence, there is a need to breed improved cowpea cultivars for agronomic as well as culinary traits. It is critical, therefore, that farmers' traits preferences and desirable varieties are recognized and integrated into their improvement programs.

## 6.4. CONCLUSION

This experiment incorporated the knowledge of researchers and farmers to select potentially high-yielding cowpea varieties with farmers' traits preferences. The results on farmer preferences during the field and sensory evaluations of varieties have shown that farmers use complex traits related to agronomical and qualitative attributes when selecting cowpea varieties. Farmers may want various traits from a single crop such as cowpea.

Nevertheless, researchers may not be aware of the characteristics that are important to farmers and vice versa. The selection of varieties by participatory method plays a fundamental role in adapting technology and distribution in a shorter time than traditional ones. In our study, the selection criteria for farmers were relatively similar and were early maturity, aphids resistance, drought tolerance, grain yield, long pod length, good taste, short cooking time, seed color, large pod number, and seed size. Results of the PVS study showed that Brazil-3, Brazil-2, Kenketi, and Bole consistently produced higher yields in both grandmother and mother trials and got higher scores in the overall preferences of farmers. Depending on the criteria they set, their favorite varieties were Kenketi, Bole, Brazil-3, and Brazil-2.

Farmers preferred Kenketi and Bole for earliness along with high yield potential, moderate susceptibility to aphids, and an upright growth habit as the first choice category of farmers'. Additionally, two new varieties, Brazil-3 and Brazil-2, provided the highest grain and above-ground biomass yields, moderate susceptibility to aphids, good taste, short cooking, and long pod length as a second category of choice for farmers. Therefore, considering data on farmer preferences and field performance, two released varieties, kenekti and Bole, were selected as farmers' first choice and can be recommended for further demonstration, popularization, and dissemination on farmers' fields, while the two Brazilian varieties, Brazil-2 and Brazil-3 are preferred by farmers as the second category of choice must be registered according to national regulations of the country. Grain yields were important, but it was not the only reason for farmers to choose a variety. Farmers prefer cowpea traits that were somewhat different from those of the researchers in that farmers considered traits such as seed color, taste, and cooking duration. Therefore, farmers' preferences should be considered during the cowpea improvement programs.

## 6.5. References

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## CHAPTER SEVEN

### 7. SUMMARY AND CONCLUSION

#### 7.1. Introduction and research objectives

In Ethiopia, cowpea (*Vigna unguiculata* (L.) Walp.) is one of the important legume crops grown by small-scale farmers in lowland areas of the south region for grains, income source, feed for animals, in soil fertility restoration, and to a lesser extent as a vegetable crop. There are a lack of high-yielding, biotic and abiotic stress-tolerant crop varieties including cowpea in the region/country. Therefore, high-yielding cowpea varieties that combine farmers' preferences are required for sustainable production and to ensure food security in the region. The value of the newly improved cowpea variety depends on farmers' and end users' preferences. Cowpea varieties with enhanced yield, insect pests and diseases resistance, early maturity, and other desirable agronomic/culinary attributes would be possibly adopted by farmers. Thus, developing or introducing improved cowpea varieties and improved packages of technologies are an overriding consideration for sustainable production and productivity in south Ethiopia. This section presents the general description of the thesis and summarizes the research objectives and key findings of the study.

The objectives of this study were:

1. To assess farmers' perceived production constraints, farmers' perceptions, farmers' traits of preferences, and the production systems of cowpea in Southern Ethiopia
2. To estimate the genetic diversity among cowpea genotypes based on morpho-agronomic traits
3. To assess the magnitude of genotype by environment interaction and yield stability of cowpea genotypes and thereby identify broader and/or narrowly adapted genotypes for production in South Ethiopia
4. To assess and select superior cowpea variety/varieties that meet farmers' needs and preferences using farmers' participation, and to identify farmers' selection criteria.

#### 7.2. Summary of major findings

**The first study** focused on a survey using participatory rural appraisal tools in southern Ethiopia in the year 2016. This was conducted across four selected districts of southern

Ethiopia including Konso, Gofa, Kindo Koyisha, and Humbo. Data were collected using semi-structured interviews involving 150 households, 12 key informants, and 84 farmers who participated in focus group discussions.

The following were the main outcomes:

- Results indicated that 86% of the farmers interviewed were men (men dominant) and family sizes varied between 6-9 persons of the households.
- The study also revealed that landraces were the most prevalently grown by about 92.7% of farmers, whose seed they recycle for many seasons, whilst about 7.3 % grow both, often in addition to the local cultivars.
- Most farmers (55.3%) produced cowpea for home consumption, while 12.7% indicated its food and market value’.
- Soil fertility levels were low across the study districts and nearly all farmers (96%) did not apply any fertilizers on cowpea.
- Inter-cropping of cowpea with maize or sorghum (76%) was the dominant cowpea production system in southern Ethiopia.
- Cowpea is grown on 0.24 ha, out of the total average land possession per household of 2.61 ha in the study area;
- The average yield was 0.5 t ha<sup>-1</sup> ;
- There were numerous constraints encountered by the farmers some not necessarily of breeding nature. The main constraints considered for this study were diseases, insect pests (reported by 87.3% of respondents), drought (86.7%), and lack of improved varieties (80%) or low-yielding cultivars currently grown by farmers.
- The constraints, per order of importance, are: diseases and insect pests, drought, lack of improved varieties, poor access to extensions, poor access to credit services, low soil fertility, farmland shortage, sub-optimal agronomic practices, and storage pests;
- Farmers showed a strong preference for varieties with high yield, early maturity, resistance to disease and insect pests, resistance to drought, white seed color, seed size, short cooking time, resistance to storage pest, resistance to shattering, marketability, good taste, leaf shedding and suitability to intercropping as desirable traits of cowpea cultivars. The implications of these results are an obvious indication that breeding with a focus on only grain yield with less attention to culinary quality /farmers' preferences may result in poor acceptance. It, therefore, shows the

importance of initially interacting with farmers to understand their varietal preferences in an improvement program. Only then can farmers' views be comprehensively incorporated.

- Thus, the study assists as the basis for designing research and development strategies for sustainable cowpea production and productivity by resource-poor farmers in South Ethiopia.

**The second study focused** on the Assessment of Genetic Diversity in Cowpea (*Vigna unguiculata* (L.) Walp) Genotypes in Southern Ethiopia based on Morpho-Agronomic traits. The field experiment was conducted at the Gofa sub research station during the 2016/17 main cropping season to estimate genetic diversity among cowpea genotypes based on morpho-agronomic traits. Thirty-six cowpea genotypes were evaluated for 5 qualitative and 14 quantitative agro-morphological traits. Qualitative traits data were analyzed using Shannon-Weaver diversity Index ( $H'$ ). The study revealed a high degree of variation in agro-morphological traits of cowpea genotypes with Shannon diversity index ranging from 0.633 to 0.953 with a mean of 0.84. The analysis of variance for 14 quantitative traits revealed significant differences ( $P < 0.05$ ) among the genotypes. Grain yield and other agronomic traits showed a high to moderate phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV). Cluster analysis based on 14 traits grouped the 36 cowpea genotypes into six clusters, with 9, 8, 7, 7, 3, and 2 genotypes in clusters I, II, IV, V, III, and VI, respectively. The highest inter-cluster distance was observed between clusters III and VI followed by clusters III and V suggesting wide diversity between them and the genotypes in these clusters could be used in a hybridization program for obtaining a wide range of variation among the segregates. Cluster III had genotypes with high grain yield and other desirable traits, while the genotypes in Cluster VI flowered and matured earlier. Therefore, crosses between genotypes from different clusters could result in desirable segregants.

**The third study** determined the GEI interaction and yield stability of cowpea genotypes and representative test and production environments. The experiments were laid out in Randomized Complete Block Designs (RCBD) with three replications. In this study 20 cowpea genotypes including one local check variety were evaluated at three testing sites (Gofa, Kucha, and Humbo) in both Meher and Belg seasons over two years providing twelve environments. The following were the main outcomes:

- There were strong significant ( $P < 0.01$ ) environment, genotype, and GEI effects, and environment and GEI captured a larger portion of the treatment sum of squares,

which reveals the influence of the two factors in evaluating cowpea genotypes and, hence, the need for stability analysis.

- The significant environment, genotype main effects, and GEI for grain yield indicated that the genotypes were different, environments diverse and the performance of a genotype was affected by environmental conditions.
- In the current study, the AMMI model has shown that the environment effect was a predominant source of variation (42.3%) followed by GEI (34.7%) and genotype effect (23.0%). The GEI was about 1.5 times as large as that of the genotype effect, suggesting the possible existence of different environmental groups.
- GGE biplot analysis showed that the polygon views of the GGE biplot pointed out that there existed three possible mega environments.
- The study also confirmed that higher yields were realized at Gofa than Humbo during the study period.
- Grouping genotypes by Yield, AMMI model, ASV, and GSI gave G2, G4, G12, G14, G16, and G20 as stable and high-yielding genotypes.
- Biplot of GEIPCA2 vs GEIPCA1 produced G13, G16, G14, G2, and G4 as stable and high-yielding genotypes.
- G5, G6, and G7 can be recommended for Meher environments with the intermediate length of the growing period (91 days) and Belg seasons with no terminal moisture stress such as E9 and E10. The Meher environment at Gofa has a prolonged growing period. There is a high amount of rain in October and November. Since G5, G6, and G7 tend to extend their growing period under favorable conditions, we recommend adjusting the planting time of these genotypes at Gofa so that they use the rains in October and November.
- Our results showed that genotypes G12, G13, G20, and G15 had higher grain yields than the checks and were suggested for further inclusion in the breeding program to boost cowpea production.
- Overall, based on yield performance, the AMMI model, GGE biplot, ASV, and GSI indices identified G16 (IT-89KD), and G14 (IT93K-293-2-2) as high-yielding with better stability across environments and had higher grain yields than the checks, suggesting that it can be recommended for all cowpea growing areas of southern Ethiopia with weather conditions similar to the areas used in this study.

**The last study focused** on the participatory varietal selection using cowpea varieties in southern Ethiopia. Field evaluations were conducted across three selected villages in a farmers' field and Gofa Research station of southern Ethiopia involving 132 participating farmers for field and sensory evaluation. The following were the main outcomes:

- Analysis of variance (ANOVA) showed the existence of significant differences ( $p < 0.05$ ) among the tested varieties for all the measured agronomic traits.
- Combined mean values showed that Brazil-3 ( $1.65 \text{ t ha}^{-1}$ ), Brazil-2 ( $1.62 \text{ t ha}^{-1}$ ), Kenketi ( $1.53 \text{ t ha}^{-1}$ ), and bole ( $1.52 \text{ t ha}^{-1}$ ) were high-yielding varieties with a yield advantage of 3.9 to 12.2 % more than the check variety white wonderer trailing.
- The cowpea varieties Kenketi and Bole were favorably selected by all participating farmers for their early maturity, high yield, erect growth habit, and the first farmers' choice category.
- Furthermore, the two new varieties namely Brazil-3 and Brazil-2 gave the highest grain and above-ground biomass yields; good taste, short cook ability, having a prostrate growth habit, and the ability to smother weeds, and the second farmers' choice category.
- Genotypes Bole and Brazil-3 were rated very good providing higher pod numbers and white seed colors.
- Overall, considering data on farmers' preferences and yield, two released varieties, kenekti and Bole, were selected as farmers' first choice and can be recommended for further demonstration, popularization, and dissemination on farmers' fields, while the two Brazilian varieties, Brazil-2 and Brazil-3 are preferred by farmers as the second category of choice must be registered according to national regulations of the country.
- Integration of those officially released varieties into the production system is likely to improve cowpea productivity in the south region, Ethiopia.

### **7.3 .Recommendations and future prospective**

Based on farmers' response; and information generated from assessment of genetic diversity in cowpea (*Vigna unguiculata* (L.) walp) genotypes the following recommendations and associated future works are suggested:

- Involving farmers in the identification of their perceived production constraints, preferred traits, and the production systems of cowpea is very important to better

enhance and speed the acceptance of improved varieties in southern Ethiopia. Therefore, farmers' views and priorities will be considered in the cowpea improvement program.

- The existing cowpea cultivars grown in south Ethiopia which is traditionally passed from one farmer to another and across generations have poor yielding potential, yet, constraints need to be overcome and opportunities maximized. Hence, introducing new cowpea genetic materials with good yielding potential and resistance sources could have a significant contribution in addressing some of the challenges in cowpea production, such as productivity, quality, resistance to major pests or diseases, drought tolerance. Since most of the respondent farmers (92.7%) grow mainly low yielding local varieties thus the following recommendations are suggested:
- A well-designed breeding program that focuses on developing or introducing improved genotypes with farmers' priority traits such as high grain and above-ground biomass yields (dual purpose) and good culinary quality should be started by the research system.
- Government should give due attention to cowpea research
- The occurrence of insect pests and diseases was found to be among the major production constraints at the farm level. Hence, assessments should be made on the particulars of the prevalent insect pests and diseases together with the level of damage incurred and the research system should develop integrated management options (IPM) for the cowpea farmers.
- Promote drought escaping(early maturing) varieties such as Bole and Kenketi for the short rainy season and intercropping system
- Promote high grain cum above-ground biomass yielding varieties with good culinary traits such as Brazil-2 and Brazil-3 after registration for Meher season and sole cropping for crop-livestock farmers.
- Agricultural extension services should provide farmers with technical support to improve their practices regarding obtaining good quality seed, insect pests, and diseases control.
- Improving the provision of agricultural inputs (adequate extension services) and credit services should be considered.
- Farmers' association initiatives should be strengthened to solve improved seed availability and production-related issues.

The selected promising cowpea genotypes are valuable genetic resources for future genetic enhancement and breeding.

The best grain yields and biomass were recorded by 10 top cowpea genotypes under genetic diversity assessment trial and after adequate testing, across many locations in the target production environments, these genotypes can be recommended for commercial exploitation for grain production cum above-ground biomass yield.

Since there was a genotype by environment influence for character evaluated, it is important to conduct multi-location testing to select superior materials in cowpea.

The selected promising genotypes across locations can be recommended for adaptability and stability tests across representative agro-ecologies for large-scale production in south Ethiopia or similar environments.

## Appendices

**Appendix 1:** Days to 50% flowering of 20 cowpea genotypes at 12 environments

Code	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	VM
G1	51.0	51.0	48.7	51.0	46.7	48.7	48.3	49.0	45.3	44.0	45.0	42.3	<b>47.6</b>
G2	52.0	50.7	50.0	55.0	55.3	57.3	49.0	49.7	48.3	44.7	45.3	44.3	<b>50.1</b>
G3	51.0	45.3	48.7	55.3	56.7	58.7	48.3	49.0	46.3	44.0	42.3	42.7	<b>49.0</b>
G4	46.0	46.3	42.3	46.0	51.7	53.7	46.3	43.3	42.3	40.3	39.7	37.7	<b>44.6</b>
G5	51.0	46.7	52.3	59.7	54.3	56.3	48.0	51.0	44.3	44.0	43.7	43.7	<b>49.6</b>
G6	51.0	45.3	53.0	58.7	55.0	57.0	48.3	51.3	48.3	44.0	43.3	45.7	<b>50.1</b>
G7	51.0	45.3	51.0	56.7	52.0	54.0	48.7	50.3	48.3	44.0	42.7	45.0	<b>49.1</b>
G8	51.0	47.0	52.0	55.0	52.0	54.0	47.3	51.0	46.7	43.7	43.7	44.7	<b>49.0</b>
G9	44.7	47.0	37.0	48.3	44.3	46.3	44.3	40.0	45.0	38.7	38.3	36.3	<b>42.5</b>
G10	51.0	46.3	43.7	56.7	58.3	60.3	47.7	46.7	47.7	43.7	41.3	40.7	<b>48.7</b>
G11	54.3	46.3	48.3	53.3	51.7	53.7	50.0	50.7	45.3	46.3	43.3	42.0	<b>48.8</b>
G12	51.0	47.0	48.0	55.0	50.7	52.7	48.0	48.7	46.7	44.0	43.0	42.7	<b>48.1</b>
G13	44.7	43.0	40.0	46.7	44.7	46.7	45.0	41.3	43.0	39.3	37.3	36.7	<b>42.4</b>
G14	51.0	45.0	51.0	55.3	56.7	58.7	47.7	50.3	47.3	43.7	42.3	44.7	<b>49.5</b>
G15	44.3	43.7	41.0	47.7	43.0	45.0	45.0	41.7	43.3	39.0	37.7	37.7	<b>42.4</b>
G16	51.0	45.7	45.7	56.7	56.7	58.7	48.7	47.7	49.0	44.0	41.7	42.3	<b>49.0</b>
G17	43.0	46.3	38.3	51.3	43.7	45.7	46.3	40.0	42.0	39.0	38.0	35.3	<b>42.4</b>
G18	45.0	46.0	36.3	49.7	44.7	46.7	46.3	39.7	41.3	40.0	38.0	34.0	<b>42.3</b>
G19	43.0	46.7	35.3	51.7	46.3	48.3	45.3	38.3	41.3	38.3	37.3	33.3	<b>42.1</b>
G20	51.0	45.7	43.0	54.3	49.3	51.3	48.3	46.3	45.0	44.0	41.0	39.3	<b>46.6</b>
<b>EM</b>	<b>48.9</b>	<b>46.3</b>	<b>45.3</b>	<b>53.2</b>	<b>50.7</b>	<b>52.7</b>	<b>47.4</b>	<b>46.3</b>	<b>45.4</b>	<b>42.4</b>	<b>41.3</b>	<b>40.6</b>	<b>46.7</b>

**Appendix 2:** Days to maturity of 20 cowpea genotypes at 12 environments

Code	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	VM
G1	97.7	90.0	96.3	100.3	103.3	115.3	83.7	87.0	84.7	87.0	86.3	87.7	<b>93.3</b>
G2	91.0	86.0	83.0	93.7	102.0	104.3	80.0	80.3	74.3	80.3	81.0	74.7	<b>85.9</b>
G3	92.7	81.7	76.0	101.0	101.7	106.7	81.7	77.3	76.7	83.3	77.7	73.7	<b>85.8</b>
G4	78.3	83.3	76.7	87.0	88.3	100.0	69.0	71.0	74.3	70.0	75.0	72.7	<b>78.8</b>
G5	95.3	86.0	89.0	104.0	110.3	115.0	82.7	85.7	86.7	85.3	83.7	85.3	<b>92.4</b>
G6	92.7	83.0	88.7	104.0	109.0	114.7	82.0	84.0	87.0	83.7	81.7	85.0	<b>91.3</b>
G7	91.3	85.3	90.3	103.0	106.7	110.3	80.7	84.0	88.3	82.3	82.7	86.7	<b>91.0</b>
G8	91.3	81.7	92.7	100.3	102.3	110.3	80.3	85.3	73.3	82.0	81.7	80.3	<b>88.5</b>
G9	85.3	82.7	80.3	91.0	100.0	104.7	75.3	76.0	71.3	76.3	77.3	73.0	<b>82.8</b>
G10	85.3	88.3	87.7	105.0	100.3	111.7	71.7	73.0	75.3	74.7	78.3	78.7	<b>85.8</b>
G11	95.0	82.7	84.3	88.7	100.3	105.3	89.0	88.0	73.0	88.3	83.3	75.7	<b>87.8</b>
G12	90.7	86.0	89.3	100.3	103.0	109.3	80.0	83.3	75.7	81.7	82.7	80.0	<b>88.5</b>
G13	86.0	87.0	84.0	90.7	100.0	100.7	75.7	78.0	71.7	77.0	80.7	75.0	<b>83.9</b>
G14	88.3	81.7	91.3	101.0	101.7	109.0	78.7	83.0	77.7	79.7	80.3	81.7	<b>87.8</b>
G15	87.3	83.3	89.3	94.0	99.7	102.3	77.7	81.3	71.3	78.7	80.7	77.7	<b>85.3</b>
G16	102.3	88.7	92.0	105.0	106.3	107.7	84.3	88.7	77.0	89.7	87.0	81.7	<b>92.5</b>
G17	87.0	87.0	79.3	102.0	95.7	110.3	76.7	76.3	72.7	78.0	79.7	73.3	<b>84.8</b>
G18	98.0	85.0	88.3	94.3	94.0	104.0	86.7	86.7	73.3	88.7	83.3	78.3	<b>88.4</b>
G19	88.0	85.0	91.3	93.7	95.3	104.0	74.7	82.3	73.0	77.3	81.7	79.3	<b>85.5</b>
G20	98.0	87.0	86.0	104.0	93.3	105.3	86.7	85.7	74.0	88.7	84.3	77.0	<b>89.2</b>
<b>EM</b>	<b>91.1</b>	<b>85.1</b>	<b>86.8</b>	<b>98.2</b>	<b>100.7</b>	<b>107.6</b>	<b>79.9</b>	<b>81.9</b>	<b>76.6</b>	<b>81.6</b>	<b>81.5</b>	<b>78.9</b>	<b>87.5</b>

Note: EM=Environmental mean, VM=varietal mean, E=Environments: E1, E2, E3 (Gofa, Humbo, and Kucha in Meher 2016), E4, E5, E6 (Gofa, Humbo, and Kucha in Meher 2017), E7, E8 and E9 (Gofa, Humbo, and Kucha in Belg 2017), E10, E11 and E12 (Gofa, Humbo, and Kucha in Belg 2018).

**Appendix 3a:** Amount of rainfall during the growing season and long-term mean rainfall and temperature (mean) data (during 2016, 2017, and 2018 growing seasons) of the research locations.

Season	Months	Rain fall (mm)				Mean Temperature (°C)			
		2016	2017	2018	2001-2018	2001-2018	2016	2017	2018
Humbo Belg	January	0	0	0	4.5	28.7	26.5	31.7	25.6
	February	49.8	4	36.9	14.5	27.7	25.7	30.7	25.4
	March	13	14.6	62.9	28.1	27.9	25.8	30.9	25.5
	April	190.2	118.6	218.5	137.2	27.9	25.8	30.9	25.5
	May	113.3	134.9	242	74.2	27.5	25.5	30.5	25.2
	June	170.4	22.9	76.7	94.2	27.4	26.6	30.4	26.3
Belg	Total	<b>486.9</b>	<b>291</b>	<b>600.1</b>	<b>333.7</b>	<b>27.7</b>	<b>25.9</b>	<b>30.7</b>	<b>25.6</b>
Humbo Meher	July	108.5	261.7	156.1	113.4	26.5	27.3	24.5	26.5
	August	61.1	201.2	143	112.5	27.4	28.1	25.5	27.7
	September	81.5	104.5	43	82.7	30	30.7	26.3	29.1
	October	60.9	219.2	119.2	106.4	29.8	28	27.9	28.3
	November	64	26.4	12.1	53.2	29.6	30.5	27.6	28.3
	December	35.8	0	0	23.1	29.1	30.4	28.1	28.8
Meher	Total	<b>376</b>	<b>813</b>	<b>473.4</b>	<b>468.2</b>	<b>28.7</b>	<b>28.9</b>	<b>26.4</b>	<b>28.0</b>
Annual	Total	<b>949</b>	<b>1108</b>	<b>1110</b>	<b>844</b>	<b>28.3</b>	<b>27.6</b>	<b>28.8</b>	<b>26.9</b>
Gofa Belg	January	36.3	8.7	0	10.5	26.7	26.9	28.7	29.9
	February	10.4	49.3	43.1	30.5	28	28.1	29.9	31.2
	March	134.6	48.1	71.3	85.3	27.4	27.5	29.3	30.6
	April	249.4	94.1	130.2	217.7	26.4	26.6	28.4	29.6
	May	79.2	183.4	64.3	170.2	25.7	25.8	27.6	28.9
	June	53.8	65.1	91.1	72.8	25.2	25.4	27.2	28.4
Belg	Total	<b>517</b>	<b>390.7</b>	<b>356.9</b>	<b>546.0</b>	<b>26.2</b>	<b>26.3</b>	<b>28.1</b>	<b>29.4</b>

**Appendix 3b:** Amount of rainfall during the growing season and long-term mean rainfall and temperature (mean) data (during 2016, 2017, and 2018 growing seasons) of the research locations.

Season	Months	Rain fall (mm)				Mean Temperature (°C)			
		2016	2017	2018	2001-2018	2001-2018	2016	2017	2018
Gofa Meher	July	43.9	199.3	197.2	109.9	21.5	21.5	21.3	21.3
	August	144.2	201.3	194.9	110.5	22.5	22.5	22.3	22.3
	September	81.6	197.7	197.6	96.1	22.6	22.6	22.4	22.4
	October	136.9	206.2	206.9	122.0	21.7	21.6	21.5	21.4
	November	80.4	84.5	81.4	62.5	22.7	22.7	22.5	22.5
	December	62.8	29.5	0	28.0	23.9	23.9	23.7	23.7
<b>Meher</b>	<b>Total</b>	<b>487.0</b>	<b>889.0</b>	<b>878.0</b>	<b>501.1</b>	<b>22.2</b>	<b>22.2</b>	<b>22.0</b>	<b>22.0</b>
<b>Annual</b>	<b>Total</b>	<b>1114</b>	<b>1367</b>	<b>1278</b>	<b>1116</b>	<b>24.5</b>	<b>24.6</b>	<b>25.4</b>	<b>26.0</b>
Kucha Belg	January	13.1	0	0	10.1	27.3	30	26.9	23.5
	February	33.5	50.1	52.9	20.0	26.4	30	26.9	23.5
	March	41.5	37.5	241	79.0	25.7	26	27.8	24.8
	April	98	170	348	192.0	25.5	30	26	26.9
	May	31	250	270	158.1	25.6	24.9	26.3	23.5
	June	112	73.4	114.6	100.0	26.3	24.5	26.9	24.8
<b>Belg</b>	<b>Total</b>	<b>282.5</b>	<b>530.9</b>	<b>973.6</b>	<b>529.1</b>	<b>25.8</b>	<b>26.4</b>	<b>26.8</b>	<b>25.0</b>
Kucha Meher	July	139.5	203	113.5	114.0	26	26.7	26.9	27.9
	August	228.5	243	83.5	111.5	26.3	24.5	27.7	28.8
	September	140.5	227	117	80.3	28.2	25.8	25.6	27
	October	76.5	185.5	163.5	81.7	28.6	27.9	25.8	26.4
	November	55	28.5	0	51.2	28.7	24.5	27	27.3
	December	12	0	0	62.0	28.2	26.7	27	27.9
<b>Meher</b>	<b>Total</b>	<b>640.0</b>	<b>887.0</b>	<b>477.5</b>	<b>438.8</b>	<b>27.6</b>	<b>25.9</b>	<b>26.6</b>	<b>27.5</b>
<b>Annual</b>	<b>Total</b>	<b>981</b>	<b>1468</b>	<b>1504</b>	<b>1060</b>	<b>26.9</b>	<b>26.8</b>	<b>26.7</b>	<b>26.0</b>

Source: National Meteorological Agency (NMA, 2018), Southern Zone, Awassa branch, Ethiopia

**Appendix 4: Survey, field, and sensory evaluation photos**



Figure 1: Supervisors' student experimental field visit at Gofa (2016)



Figure 2: Key informants interviews at Konso district



a) Gofa



b) Kucha

Figure 3: Field view of cowpea GEI experimental field in Belg 2017



Figure 4: Farmers' preferences of cowpea seed size and seed color

## Appendix 5: Questionnaires for conducting a household survey on cowpea in southern Ethiopia

### 1. General information

- 1.1. Name of the enumerator \_\_\_\_\_
- 1.2. Date of interview \_\_\_\_\_
- 1.3. Data entry date \_\_\_\_\_
- 1.4. Zone \_\_\_\_\_
- 1.5. District (District) \_\_\_\_\_
- 1.6. Kebele (PA) \_\_\_\_\_
- 1.7. Village \_\_\_\_\_
- 1.8. Latitude \_\_\_\_\_
- 1.9. Longitude \_\_\_\_\_
- 1.10. Altitude \_\_\_\_\_

### 2. Respondent and general household information

- 2.1. Name of household head (HHH) \_\_\_\_\_
- 2.2. Sex of Household head 1) Male 2) Female
- 2.3. Age of HHH, in years \_\_\_\_\_
- 2.4. Educational level of head of the HH  
1)None (illiterate), 2)read and write, 3)Primary (1-4), 4)Junior (5-8), 5)Secondary (9-10),  
6)Tertiary
- 2.5. Name of respondent (if different from the HH head) \_\_\_\_\_
- 2.6 Sex of respondent (if different from HH) 1) Male 2) Female
- 2.7 Relationship to household head 1) Wife 2) daughter 3) son 4)= other (specify)
- 2.8. Marital status of the HH 1)Single, 2)Married, 3)Divorced, 4)Widowed

### 3. Family size

- 3.1. Male 1) age <15 years 2)15-65 years 3)>65 years 4)Total
- 3.2. Female 1) age <15 years 2)15-65 years 3)>65 years 4)Total
- 3.3. Male and female together 1)age <15 years 2)15-65 years 3)>65 years 4)Total
4. Year of farming experience: 1)1-5 2)6-10 3)11-15 4)16-20 5)>20
5. Are you willing to expand cowpea production? 1)yes 2)No
6. Land ownership: 1) Rental 2) Own 3) inherited 4) communal

### 7. Farm size

- 7.1. What is the total size of your farm? 1) <0.5ha 2)0.5-1ha 3)1.1-3ha 4)3.1-5ha 5)>5ha
- 7.2. What size of land do you grow cowpea (timad)? 1)≤ 0.25ha (timad) 2)0.25-0.5 3)0.6-1 4)1.1-1.25

7.3. On average how many bags (kg) of cowpea do you harvest from your farm? 1) ≤ 0.25ha (timad) 2) 0.25-0.5 3) 0.6-1 4) 1.1-1.25

7.4. How many timads of land have you cultivated for cowpea and how much have you produced over the last five years? (Fill in the following table)

Year (E.C)	2003	2004	2005	2006	2007
Area cultivated (timad)					
Amount produced (kg)					

7.5. If you produce cowpea tell us production trends on a decrease, increase, or constant of land allocated for cowpea production in the last five years (2003-2007E.C=2011-2015G.C)

Variables	Gofa	KindoKoyisha	Humbo	Konso
Area				
Increasing,				
Decreasing				
Constant				

## 8. Production practices

8.1. Do you grow cowpea? a) Yes b) No

8.2. Farming experience (Since you separated from your parents and started your own living) \_\_\_\_\_ years

8.3. When do you think that cowpea was introduced and cultivated in your area?

\_\_\_\_\_

8.4. How long is it since you started cultivating cowpea?

\_\_\_\_\_

8.5. Who introduced cowpea to your area?

\_\_\_\_\_

8.6. From where has cowpea been introduced to your area?

\_\_\_\_\_

8.7. Which type of cowpea cultivars do you plant most? 1. Improved, 2. Local, 3. Both

8.8. Where do you obtain cowpea seed? 1) Farmers' fields 2) Neighbour 3) local market 4) agricultural office 6) public research institutes 7) NGO's

8.9. For answer to Q 8.7 is 1, why? \_\_\_\_\_

8.10. For the answer to Q 8.7 is 2 or if you do not cultivate improved variety, describe the reason,

1. No improved variety introduced to the area,      2. Improved variety is inferior to the local ones,      3. The high price of seed      4. Other, specify, \_\_\_\_\_

8.11. List the name of cultivars grown in your area?

- 8.12. Are you planning to expand cowpea production? 1. Yes, 2. No
- 8.13. What is your primary objective of producing cowpea in order of importance?  
1) Household consumption 2) Income generation 3) Livestock feed 4) other, specify ...
- 8.14. In your area, is cowpea a staple or co-staple food crop? 1. Staple, 2. Co-staple
- 8.15. In your village, out of 10 farmers how many of them do you think are engaged in cowpea production? \_\_\_\_\_
- 8.16. What is the most important crop other than cowpea and the average area of land under cultivation for each crop in your area?

### **9. Cowpea production and marketing calendar**

- 9.1. Do you sell cowpea for income generation? 1) yes 2.No
- 9.2. If the answer to Q 9.1 is 1 or if you sell cowpea tell us its current prices per kg (birr).in your area.
- 9.3. What are the cowpea growing seasons in your area? 1) belg 2) meher 3)both
- 9.4. Which type of planting method do you mostly use? 1. Broadcasting, 2. Row 3. Both
- 9.5. If you use the row method of planting, indicate the spacing? Between rows \_\_\_\_\_(cm)  
Between Plants \_\_\_\_\_(cm)
- 9.6. Do you use herbicide in cowpea? 1. Yes, 2. No
- 9.7. If no to code 9.6 is 2, how do you manage weeds? 1. Hoeing 2. Hand weeding 3. Both 4. Weeding is not required
- 9.8. Do you use fertilizer for cowpea? 1) yes 2)No
- 9.9. Do you apply pesticides to control insect pests and diseases? 1) Yes 2) No
- 9.10. Do you have disease and pests problems in cowpea production? 1. Yes, 2. No, 3. I do not know
- 9.11. If your answer to code 9.10 is yes, how did you diagnose the disease and pests? 1. Observation 2. Through experts, 3. Other, specify -----
- 9.12. If your answer to code 9.10 is yes, how did you control insect pests & diseases? 1) Traditional 2) chemical 3) No action.
- 9.13. Are there insect pests that affect cowpea production? 1. Yes, 2. No
- 9.14. If your answer to code 9.13 is yes describe them, \_\_\_\_\_
- 9.15. Which type of the variety is more susceptible to the pests of your answer in code 9.13? 1. Local 2. Improved 3. Both

### **10. Crop rotation**

- 10.1. Do you practice crop rotation? 1. Yes, 2. No.
- 10.2. If your answer to question 10.1. Yes, which crops do you consider for crop rotation with cowpea? \_\_\_\_\_

- 10.3. If your answer to question 10.1 is yes, after how many years do you crop rotate? (1) Every other year, (2) After 3 years, (3)After 4 years, (4) After 5 years
- 10.4. What is the type of cropping system you use? 1. Mono cropping 2. Intercropping 3. Others (please specify)

### **11. Intercropping**

- 11.1. Do you commonly practice intercropping when growing cowpea? 1. Yes, 2.No
- 11.2. If yes, to Q 11.1 is 1, explain the reason. 1. To increase yield/unit area, 2. To minimize risk through crop diversification, 3. To increase soil fertility, 4. For efficient utilization of resources, 5. cowpea gives reasonable yield under the shade
- 11.3. If your answer to question 11.1 is yes, which crops do you include in the intercropping program?  
1) Maize 2) cassava 3) sorghum 4) sole 5) others
- 11.4. If your answer to question 11.1 is No, it is because? 1. Cowpea cannot tolerate shade effect, 2. Most crops remain less productive when intercropped with cowpea, 3. Other, specify .....

### **12. Harvesting, storage, and post-harvest management**

- 12.1. At what age do you usually harvest cowpea (months)? \_\_\_\_\_ -
- 12.2. Do you harvest cowpea all at once or at a different time? 1. All at once 2. Picking at a different time (green harvest) 3. Depends on market conditions, 4. Other specify -----
- 12.3. How long can you keep cowpea in the traditional method without any deterioration (months)? \_\_\_\_\_
- 12.4. What type of traditional storage facilities have you used for cowpea 1. Gotera 2. Pit /Underground storage 3. Pile 4. Suck, 6. Other, specify .....
- 12.5. From Q 12.4 which type of storage duration do you think results in a better storage life?  
\_\_\_\_\_
- 12.6. What are the major postharvest problems for cowpea? 1. Lack of modern storage facility 2. The bulkiness of the produce, 3. Storage pest, 4. High cost of product transportation, 5. Lack of any form of value addition
- 12.7. Which management practice would you say consumes the most time when producing cowpea? 1. Land preparation 2. Planting 3. Weeding, 4. Harvesting 5. Transporting yield after harvest
- 12.8. Which part of cowpea do you use for meal preparations? 1. Seed 2. Leaves 3. both
- 12.9. Describe how you cook cowpea: 1. boiling using pots, 2. Eaten raw (Green), 3. Roasting 4. Other, specify .....

**13. Labour**

- 13.1. Kind of labor used in cowpea production )Family2) hired3) labor exchanges(Dubbo) 4) family and hired
- 13.2. Is there any specific farm operation traditionally set to men and women in cowpea production? 1. Yes, 2. No
- 13.3. If yes to code 13.2 is yes, specify farm operations exclusively performed by men  
1) Land preparation, 2) Selection of varieties 3) Planting, 4) Weeding/cultivation, 5) Harvesting, 6) Processing 7) Marketing
- 13.4. If yes to code 13.2 is yes, specify farm operations exclusively performed by women  
1) Land preparation, 2) Selection of varieties 3) Planting, 4) Weeding/cultivation, 5) Harvesting, 6) Processing 7) Marketing
- 13.5. Who does perform the major work in cowpea production? 1. Husband 2. Wife 3. Both participate equally, 4. Children 5. All family members equally
- 13.6. Who decides on what type of variety to plant and when to plant? 1. The husband, 2. The wife, 3. Both

**14. Institutional services**

- 14.1. Do you have access to market, credit, and extension services 1. Yes, 2 No;
- 14.2. If yes, please indicate in the table

Sources	Tick if used	Frequency of use(1= Never used; 2=Rarely; 3= Frequently)	Distance (km)	Perception on effectiveness(1=Very good; 2=Good ; 3= poor)
Neighbor/Friend/relative				
Extension office				
Mass media (radio/TV)				
Farmers Union				
Market place				
Micro-finance office				
Banks				
Other (specify.....)				

**15. Farmers' general perception of cowpea**

No	Characteristics	A	B	C	D	E
1	According to you, cowpea improves soil productivity					
2	According to you, cowpea help improvement in nutrition					
3	According to you, cowpea contributes to an increase in farm income					
4	According to you, help to attain household food security					
5	According to you, cowpea is very safe for human consumption					
6	According to you, cowpea is very easy for cooking					
7	According to you, cowpea generally is compatible with our farming system					
8	According to you, workload related to cowpea farm operations is not difficult					

A. Strongly agree B. Agree. C. Indifference D. Disagree E. Strongly disagree

No	Crop Characteristics	A	B	C	D	E	F	G	H	I	J	Sum
1	Disease and pest resistance (A)											
2	Suitability for intercropping (B)											
3	Early maturity (C)											
4	Taste (D)											
5	Leaf shedding (manuring) I											
6	Seed size (F)											
7	Yield (G)											
8	Seed color (H)											
9	Cooking time (I)											
10	Marketability (J)											
11	Other (specify)											

**16. Farmers' selection criteria for cowpea (Pair-wise ranking)**

16.1. Would you like to plant improved cowpea cultivars? 1)Yes 2)No

16.2. What improved qualities would you like in such cultivars?

17. What challenges do you encounter in cowpea production/Please List also opportunities in cowpea production and marketing?

.....  
 .....

18. In your opinion, what should be the focus of the current cowpea research efforts in order of priority?

\_\_\_\_\_

**Thank you!!**

## **BIOGRAPHICAL SCACHE**



The author was born in a small rural Kebele called Wogera, in Damot Gale district of Wolayita zone in Southern Nations Nationalities and People's Region (SNNPR) on July 3, 1968. He attended elementary and secondary education in Boditi Primary and Junior Schools from 1976 to 1984. He then attended his senior secondary education at Boditi High School from 1985 to 1988. After completion of secondary school, he joined Arbaminch Teachers Training Institute (TTI) from October 1988 to July 1989. From 1990 up to 1996 he has served in the Ministry of Education as an elementary teacher for seven years. To upgrade his academic stand, he joined the then Alemaya University of Agriculture, now Haromaya University in 1997 and graduated with a Bachelor of Sciences degree in plant science in July 2000. Then after graduation, he was employed in the bureau of agriculture and served for one year.

After graduation, he joined South Agricultural Research Institute (SARI) at Areka Agricultural Research Center (AARC) as a pulse crops breeder (researcher) from June 2001 to August 2005. He also left for further study at Hawassa University to pursue his MSc and graduated with Agronomy on July 7, 2007. After graduation, he joined the SARI and served at AARC to present as assistant researcher II, researcher I, Researcher-II, and Center director during different times until he joined the School of Plant and Horticultural Sciences of Awassa College of Agriculture, Hawassa University in October 2015 to pursue his PhD study.