PHENOTYPIC MARKERS IDENTIFICATION FOR POD SHATTERING RESISTANCE AND YIELD STABILITY STUDIES IN SOYBEAN (*Glycine max* [L.] Merril)

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ABSTRACT

Pod shattering and yield instability are among the challenges faced in soybean production in Nigeria. In view of the above, an experiment to identify phenotypic markers for pod shattering resistance and yield stability studies in twenty-six (26) soybean genotypes was conducted across three locations (Minna, Chinka and Awka) in Nigeria during 2019 and 2020 cropping seasons. In each of the locations, the experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data were collected on growth, yield and pod traits. Meteorological data were collected on rainfall, temperature and relative humidity. At harvest, pod shattering evaluation was done using the sun-dry method. Data on growth, yield and pod traits were analyzed using Analysis of Variance (ANOVA), Additive Main Effect and Multiplicative Interaction (AMMI) and Genotype plus Genotype × Environment Interaction (GGE) bi-plot analyses. The relationship between pod shattering and pod morphological traits was determined using Pearson correlation analysis model. The results indicated that, out of the 26 soybean genotypes, NCRI SOYAC78 with an average seed yield of 1.45 ton/ha in 2019 and 1.44 ton/ha in 2020, and NCRI SOYAC20 with an average seed yield of 1.34 ton/ha in 2019 and 1.21 ton/ha in 2020 were the only stable and high yielding genotype in both years of studies. Genotypes NCRI SOYAC22, NCRI SOYAC77, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC67, NCRI SOYAC29, NCRI SOYAC69 and NCRI SOYAC76 were stable and resistant to pod shattering in both years of studies. Therefore, none of the genotypes was stable in both yield and pod shattering resistance across environments and years. In individual environments, genotypes NCRI SOYAC18, NCRI SOYAC29, and NCRI SOYAC3 were stable in yield as well as pod shattering resistance in Minna and are recommended for this environment; NCRI SOYAC77, NCRI SOYAC78, NCRI SOYAC28, and NCRI SOYAC61 exhibited the same attribute in Chinka and are recommended; while in Awka, NCRI SOYAC25, NCRI SOYAC20, and NCRI SOYAC22 were stable for two parameters and are recommended for Awka. The pod shattering resistant genotypes are therefore recommended as donor parents in any breeding programme that focuses on pod shattering resistance in soybean. They could also be selected for large scale production as there will be minimal yield loss due to pod shattering even with delay in harvest. In terms of average performances of the genotypes in the three environments, they were high yielding in both years in only Chinka (1.30 ton/ha and 1.41 ton/ha, respectively). While in Minna, there were high yielding only in 2019 cropping season (1.54 ton/ha), their yield in Awka was very low in both years (1.04 ton/ha and 1.02 ton/ha, respectively). Therefore, Chinka is recommended for large scale soybean production. Some pod traits were associated with pod shattering resistance. Pod length, seed weight, seed weight/pod weight ratio, and pod wall weight/pod weight ratio appeared to be valuable phenotypic markers that could serve as selection indices for pod shattering resistance in any soybean breeding programme.

TABLE OF CONTENTS

Content **Page**

LIST OF TABLES

Table **Page**

LIST OF FIGURES

ABBREVIATIONS

AD: Anno Domini

AMMI: Additive Main Effects and Multiplicative Interaction

ANOVA: Analysis of Variance

ATP: Adenosine triphosphate

CGIAR: Consultative Group on International Agricultural Research

DMRT: Duncan Multiple Range Test

FAO: Food and Agricultural Organization

FCC: Fibre Cap Cells

G×E: Genotype by Environment

GEI: Genotype by Environment Interaction

GGE: Genotype plus Genotype by Environment Interaction

GLM: General Linear Model

IITA: International Institute of Tropical Agriculture

IPCA1: First Principal Component Scores of Interactions

MET: Multi-Environment Trials

NCRI: National Cereals Research Institute

NILs: Near-Isogenic Lines

NST1/2: NAC Secondary Wall Thickening Promoting Factor 1 and 2

PC: Principal Component

QTL: Quantitative Trait Locus

RCBD: Randomized Complete Block Design

RH: Relative Humidity

RIT: Random Impact Test

SAS: Statistical Analysis System

SHAT1-5: Shattering 1-5

SREG: Sites Regression

SS: Shattering Susceptible

SSP: Single Supper Phospate

TGX: Glycine Cross

UNRBDA: Upper Niger River Basin Development Authority

US: United States

USDA: United States Department of Agriculture

USSEC: United States Soybean Export Council

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Soybean (*Glycine max* (L) Merril) is an important crop in Nigerian agriculture. This is due to its high quality protein (Akande *et al*., 2009), and rich domestic oil (Ikeogu and Nwofia, 2013). Soybean cultivation in Nigeria has been due to mainly its adaptability and predominant utilization as a food crop for human, source of protein for animal nutrition; as medicinal and industrial crop. Data from several regions of the world revealed that consumption of food containing soybean and soybean products have been associated with reduction in cardiovascular disease risk factor, reduced osteoporosis, alleviation of menopausal symptoms, reduced risks of cancer, diabetes and serum cholesterol (Dixit *et al*., 2011).

Soybean as a grain 1egume grows in tropica1 and sub tropica1, as well as temperate climatic conditions. It has the genetic potential to yield up to 4 ton ha^{-1}, if improved varieties are used (Hailu and Kelemu, 2014). United States Department of Agriculture (USDA, 2021) reported that in 2019 and 2020 farming season, 122.64 million hectares of land worldwide were cultivated with soybean, with an average seed yield of 2.77 tons ha^{-1}. However, soybean production in Nigeria in the same period was on an average of 0.88 ton/ha, in farmers' field (USDA, 2021). This output is far below the genetic potential of the crop. Soybean is now cultivated in most countries of the world, though about 90 % of the production in recent years has been concentrated in few countries; the United States (33.06 %), Brazil (22 %), Argentina (16 %), China (10 %) and India (9

%) (Vlahović *et al*., 2013). In Nigeria, Soybean is largely produced in the middle belt. However, its production in recent years has extended beyond these traditional areas to cover other Northern and Southern regions of the country, which were otherwise considered to be unsuitable or marginal for its production (Ikeogu and Nwofia, 2013). Benue state is the leading soybean producer in Nigeria, accounting for about 30 % of total soybean production of the country (Sahel, 2017). Other producing states are Kaduna, Taraba, Plateau, Nasarawa, Niger, Kwara, Oyo, Kebbi, Jigawa, Borno, Bauchi, Sokoto, Lagos, Zamfara, and Abuja. The cultivation of this crop in Nigeria has been faced with some challenges including pod shattering and yield instability.

Pod shattering is the opening of mature pods along the dorsal or ventral sutures of the soybean pod and subsequent seed dispersal as the crop reaches maturity, as well as during harvest, resulting in seed loss (Bhor *et al*., 2014). In susceptible varieties, this can occur before harvest due to wind disturbances or during harvest as the harvesting implement move through the crop in dry weather conditions. Pod shattering in soybean may result to a yield loss that ranges from 34 % to 100 % (Tefera *et al*., 2009). It could be caused by the time of harvest after maturity, environmental conditions, chemical composition of the pod wall; anatomical structure of the pod, and genetic factor of the variety (Krisnawati and Adie, 2017). In the major soybean production areas of Nigeria, the crop reaches maturity at the end of October or early November. Coincidentally, this is the period of rainfall cessation and the beginning of dry harmattan wind, with low relative humidity and rising temperatures, creating a suitable condition for pod shattering.

Pod shattering occurs as a result of pod wall dehydration and separation of the cells in the dehiscence zone, located in sutures between the lignified pod wall edge and a replum containing vascular tissue (Bara *et al*., 2013). Generally in a pod, there is formation of abscission layers at the binding sites of the walls (valves) and accumulation of the force to dehisce pod walls upon drying during and after maturation (Funatsuki *et al*., 2014). When the dehiscing force becomes more than the binding strength of the pod walls, the pod dehisces, leading to seed loss.

Pod shattering behaviour of soybean varieties was found to be associated with its phenotypic traits (both agronomic and morphological characteristics) (Adeyeye *et al*., 2014; Krisnawati and Adie, 2017). The thickness and length of the bundle cap on the dorsal side of the soybean pod and thickness of the pod were negatively and significantly correlated with the degree of pod shattering (Zhang *et al*., 2018). Another study revealed that genotype with the small pod, less width and low volume/weight of seed was tolerant to pod shattering (Bara *et al*., 2013).

Another major constraint to effective soybean production in Nigeria is yield instability associated with the crop across environments (Ikeogu and Nwofia, 2013). Stability has been defined as the tendency of a crop to maintain similar performance across environments (Cucolotto *et al*., 2007). Good performance of stable genotypes is less dependent upon favourable environments, which makes their yield more predictable (Fasahat *et al*., 2015).

An ideal soybean genotype is one that has the potentials to achieve the greatest yield and pod shattering resistance across many environments regardless of environmental conditions (De Bruin and Pedersen, 2008). This type of genotype is believed to possess genes that control soybean productivity and pod shattering resistance, regardless of biotic and abiotic stresses, and could be integrated into breeding programmes for the development of high yielding stable genotypes (Tyagi *et al*., 2011).

1.2 Statement of the Research Problem

The demand for soybean and soybean products in Sub-Sahara Africa outweighs its production. This leads to increased importation of soybean from the major producing countries of the world like United States, Brazil and China. Despite being the second highest soybean producer in Africa after South Africa, Nigeria still imported over 120,000 metric tons of soybeans, including raw soybeans, flours and meals in 2015 (Sahel, 2017). According to United States Department of Agriculture (USDA, 2021), soybean production in Nigeria in 2019 and 2020 farming season was on an average of 0.88 ton/ha, in farmers' field. This yield is far below the genetic potential of the crop, which is up to 4 tons/ha (Hailu and Kelemu, 2014). Some genotypes grown in Nigeria have the potential for high yielding, but are highly unstable as they are vulnerable to environmental changes and/or very susceptible to pod shattering.

Nowadays, the problems associated with soybean cultivation in Nigeria are climate change and scarcity of labour. Shortage of labour could delay harvesting, leading to yield losses through pod shattering. Pod dehiscence (shattering) is a major production constraint in the soybean production areas of the warm tropics. Seed losses of 50–100% are often associated with pod shattering during dry weather conditions in susceptible genotypes when harvesting is delayed after maturity (Bara *et al*., 2013). This loss of seed not only has a drastic effect on yield, but also results in the emergence of the crop as a weed in the subsequent growing season. In addition, shattering losses reduces yield potential that has already been achieved, and also leads to the loss of valuable genetic materials.

1.3 Justification for the Study

Increasing yield per unit area in soybean has received great attention among soybean breeders over the years; yet yield recorded in farmers' field in Nigeria is still far below the world average. This could be as a result of the use of varieties that are not stable and/or susceptible to pod shattering before harvest.

Among the several methods of controlling shattering in soybean, genetic improvement is the most reliable and environmentally friendly method (Bhor *et al*. 2014). Information on the agronomic and morphological traits (phenotypic markers) responsible for pod shattering resistance will enhance breeding effort aimed at developing pod shattering resistant varieties that are acceptable to producers (Krisnawati and Adie, 2017).

In the hot tropics and areas where machines are used for harvesting, resistance to pod shattering is one of great economic benefits to farmers. A study involving soybean farmers in Benue State, Nigeria revealed that resistance to pod shattering was a prerequisite for the adoption of any variety by the farming communities (Krisnawati and Adie, 2017). Hence, there is need to develop improved genotypes with stable high yield and ability to stand in the field for relatively longer periods after maturity without shattering. The use of such genotypes is important for sustainable production of soybean in the tropics. Bara *et al*. (2013) and Krisnawati and Adie (2017) have carried out commendable researches to establish phenotypic markers for pod shattering resistance in soybean. However, none was able to establish environmental influence through multi environmental trials and stability studies. This study therefore seeks to address this gap.

Enhancement in shattering resistance may promote productivity, harvesting of uniformly ripe seeds, efficiency of seed recovery and improved oil extraction. It will also promote adjustment in the time of harvesting and threshing; reduce cost of production, problem of volunteer plants and longevity of seed (Bara *et al*., 2013).

Improved soybean varieties will lead to significant increase in our local production, and provide raw materials to both livestock industries and other soybean processors. Improved varieties could offer a higher grain yield in different ecological locations, as well as at research station and farmers' field (Chianu *et al*., 2008).

1.4 Aim and Objectives of the Study

The aim of the study was to identify phenotypic markers for pod shattering resistance and stable genotypes in yield and pod shattering resistance across environments.

The objectives of the study were to:

i. identify high yielding stable soybean genotypes that are resistant to pod shattering;

ii. identify phenotypic markers responsible for pod shattering resistance;

iii. determine the relationship between the markers and pod shattering resistance;

iv. determine the genotypic stability and pod shattering resistance within and across environments.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin of Soybean

The origin of the soybean plant is unclear, but many botanists believe it is derived from *Glycine ussuriensis*, which was a legume native to Central China. In the first century A.D., the distribution of soybean throughout China was probably done by trade missions and subsequently to other Asian countries. By the 16th and 17th centuries, there were a number of references to native soy foods in diaries of European visitors to China and Japan (Pratap and Kumar, 2011). In 1804, soybean was brought to the United States by a Yankee clipper ship from China, and in 1829, U.S farmers first grew the crop (USSEC, 2015). During the U.S civil war (1861-1865), when coffee was scarce, soldiers were able to use soybean as coffee berries to brew coffee. In the late 1880s, farmers began to grow soybean to serve as forage for cattle.

In 1908, in the city of Hull, Great Britain, soybean seeds were found to be suitable replacement for linseed and cotton. However, subsequent to Sino-Japanese war, Britain systematically tested the ability of soybeans to produce good yields in their African colonies (Kolapo, 2011). Incidentally, the five leading soybean producers in Africa as at year 2007 (namely; Nigeria, South Africa, Uganda, Zimbabwe and Egypt), all have strong historical ties to Great Britain (Shurtleff and Aoyagi, 2009). However, it should be noted that the introduction of soybean into Africa was faced with many challenges such as no or poor germination, crop failure after germination and low yields. For example, crop failure was recorded at Moor Plantation, Ibadan, Nigeria, when soybean was planted on 0.55 hectare in the year 1908 (Kolapo, 2011).

Later advances in scientific studies revealed that *Bradyrhizobium japonicum* populations required for effective nodulation of soybean are found to be non-endemic to soils in Africa (Jaiswal and Dakora, 2019). In 1970s also, there was a little interest and effort in Africa to grow and improve soybean as a result of low yields and seed viability, high shattering rate and limited postharvest uses. Interestingly, at present, Consultative Group on International Agricultural Research (CGIAR), based in sub-Saharan African, has recorded great progress in both crop improvement and postharvest processing and utilization. To avoid the need to inoculate soybean with *B. japonicum*, soybean breeders at the International Institute of Tropical Agriculture (IITA), Nigeria, developed new soybean genotypes for Africa, called Glycine cross (TGX), which are capable of nodulating with *Bradyrhizobium* species populations indigenous to soils in Africa (Yan *et al*., 2014). Also, since the 1970s, soybean breeders at IITA have been working successfully on developing improved varieties of soybean that can fix more nitrogen from the atmosphere without *Rhizobium* inoculation; yield high; store well and are resistant to pod shattering.

2.2 Ecology and Botany of Soybean

Soybean is cultivated in elevation of 0 to 2,200 m above sea level (masl), with optimum being from 300 to 1,600 masl and a rainfall of 300 to 1400 mm per annum (Mullen, 2003). Flowering may not occur at very high altitudes (above 2500 masl), and the crop remains vegetative. During growing period, water requirement for maximum productivity of the crop ranges from 450 – 700 mm, well distributed and the temperature must be of 25 - 30 ^{o}C range (FAO, 2002). Suitable soil pH for soybean production is 6 to 6.5. Soybean has the ability to improve soil fertility by sequestering atmospheric nitrogen. Improved promiscuous varieties fix from 44 to 103 kgN/ha annually, depending on the soil environment (Sanginga *et al*., 2003).

Soybean belongs to the family Fabaceae and sub-family Papilionoideae. It is an annual leguminous crop with fine brown or grey hairs, covering the stems, leaves and pods. Leaves are trifoliolate; leaflets are 2 to 7 cm broad and 6 to 15 cm in length. Flowers could be purple, pink or white in colour. The flowers are self-pollinated and are borne on axils of the crop. The pod develops in arrays of 3 to 5; one pod being 3 to 8 cm long containing usually 2 to 4 seeds. Soybean is well adapted to diverse environment and can grow as high as 120 cm depending on the genotype and environmental conditions.

Soybean development occurs in two phases; the vegetative and reproductive phases. The vegetative phase begins when the seed germinates and terminates at the time the first flower develops. The reproductive phase begins from the appearance of the flower and ends when the pods are ready for harvest. The transition from vegetative to reproductive phase is influenced by day length, altitude, and temperature (Mullen, 2003). The crop requires about 100 to 146 days to reach maturity from the day of germination. However, the actual number of days depends on the genotype, growth and environmental conditions (Mullen, 2003). Yields vary from 0.5 ton/ha in low input cropping systems in Africa, to 4.5 ton/ha under intensive system of farming. But according to Agnoro (2008), the yield potential of modern varieties is 3 ton/ha.

2.3 Mechanism of Pod Shattering

Pod shattering simply means the opening of matured pods along the dorsal or ventral sutures and subsequent dispersal of seed as the crop reaches maturity, as well as during harvesting. The extent of yield loss due to pod shattering in soybean may range from 34 to 100 percent depending upon delayed harvesting after maturity, the environmental conditions during harvesting and genotype of the crop (Tefera *et al*., 2009; Krisnawati and Adie, 2017). The pattern of pod shattering shows that the tissues are under tension. The morphological characteristics of the whole plant and raceme as well as those of single pods and how individual characters relate with each other, affect pod shattering behaviour of any soybean genotype. Within the crop canopy, before and during harvest, much pod shattering occurs due to the natural movement of the canopy, which results in pods knocking against each other or against the stems and branches. This problem of mechanical damage is likely to be much affected by other plant attributes such as pod angles, pod length and width (Mohammed, 2010). Together with other aspects of plant architecture such as height and stem stiffness, these attributes may affect the laxness of the plant and hence the degree and type of movement made by the canopy and of branches within it (Mohammed, 2010). With majority of agriculture operations depending on human labour, the untimely and delayed harvesting result in increased pod shattering.

Furthermore, Adeyeye *et al*. (2014) stated that pod shattering behaviour of soybean variety was found to associate with agronomical, morphological, and physiological characteristics. Zhang *et al*. (2018) reported that the thickness and length of the bundle cap on the dorsal side of the pod and pod thickness were negatively and significantly correlated with the degree of pod shattering. Another study by Bara *et al.* (2013) revealed that genotype that possesses small pod, less pod width and low volume/weight of seed was tolerant to pod shattering. They also stated that pod thickness as one of pod traits was more reliable for selection for improvement against pod shattering.

Krisnawati and Adie (2017) found shattering to range from 0 % to 100 %; meaning that resistant genotypes showed no shattered pods. This is in line with Tukamuhabwa *et al*. (2002), which identified three soybean genotypes (TGx 1448-2E, Duiker and Nam 2) as being shattering resistant by showing no seed loss due to pod shattering during the harvesting period; therefore recommended the use of resistant varieties as good source of resistance in breeding for shattering resistance and susceptible varieties should be avoided. Another study by Khan *et al*. (2013) showed that pod shattering percentage ranged from 8.7 % (Himsoy-1560) to 93.3 % (Punjab-1), and that no variety showed resistance to pod shattering. Similarly, shattering resistance screening conducted by Bara *et al*. (2013) revealed that shattering percentage ranged from 0.673 % (JSM 170) to 67.05 % (JSM 131). They also discovered that the rate at which pods shattered increased after 7 days and kept increasing as the pods get older.

Krisnawati and Adie (2017) reported that pod shattering behaviour of any soybean genotype is associated with other agronomic characteristics. In their research, they observed that 100 seed weight, pod width, and width at the mid part of the pod had no significant effect on a number of shattered pods per plant, showing that these parameters would not be useful as an index for pod shattering selection. Meanwhile, Bara *et al*. (2013) reported a significant and positive association of shattering percentage with pod width and width at mid part of the pod.

Furthermore, pod shattering was found to negatively correlate with number of pod per plant, pod thickness, and seed weight/pod weight ratio. It implied that a genotype with increase in the number of pod per plant, thicker pod, and higher seed weight/pod weight ratio will have a lower pod shattering. However, they observed that pod length and pod wall weight/pod weight ratio, were found to be significantly and positively correlated to pod shattering. This means that longer pod length and an increase in pod wall weight will result in a higher pod shattering percentage. This finding is in agreement with the works of Adeyeye *et al*. (2014), which recommended large seed and pod thickness as reliable index and indicator in selecting for shattering in soybean breeding programme. Similarly, a more recent study by Krisnawati and Adie (2017) revealed that pod length is one of the essential factors associated with pod shattering resistance, as well as pod wall thickness. However, this does not agree with the earlier report by Morgan *et al*. (1998), which stated that genotypes with small pod (with less width and weight of periphery region) and low volume/weight of seed have a low shattering percentage. The knowledge of correlation existing between traits is of great use in breeding programmes to easily identify those traits that may be used as selection indices (Adeyeye *et al*., 2014).

Krisnawati and Adie (2017) concluded that genotypes with thicker pod and larger seed size will possess lower pod shattering. Various studies of pod anatomy have been conducted, and certain anatomical structures of the soybean pod have been recognized as important for resistance to shattering. Examination of the dehiscence zone of soybean pod and the expression analysis of the soybean endo polygalacturonase transcript revealed that the endo polygalacturonase was primarily found in dehiscence-related tissue and was presumably involved in the breakdown of the middle lamella before dehiscence (Christiansen *et al*., 2002). A study by Dong *et al*. (2014) revealed that the excessively lignified fiber cap cells (FCC) with the abscission layer unchanged in the soybean pod ventral suture as the key cellular feature of the shattering-resistant trait. Meanwhile, Funatsuki *et al*. (2014) revealed two important aspects of pod shattering, namely, the dehiscing force and the associated regulatory gene.

2.4 Genetics of Pod Shattering Resistance

Certain studies carried out to understand and explain the genetics of pod shattering in soybean revealed different results. Caviness (1963) reported that four major genes govern susceptibility to pod shattering. Tsuchiya (1986) reported the presence of one to two genes responsible for shattering. Another researcher; Akpan (1988) reported two to twelve genes are involved in resistance to pod shattering. Bailey *et al*. (1997) reported that one important quantitative trait locus (QTL) and a few minor QTLs controlled soybean pod shattering. Tukamuhabwa *et al*. (2000) showed that two genes, which are partially dominant over resistance, controlled pod shattering.

The cultivated soybean [*Glycine max* Merr.(L.)] is more resistant than the wild soybean (*Glycine soja* Sieb. et Zucc.) to shattering. Genetic analysis using a mapping population derived from a cross between these two species has not identified any quantitative trait loci (QTLs) with large effects on shattering, suggesting that multiple genes with minor effects contribute to shattering resistance in the cultivated species (Liu *et al*., 2007). A gene responsible for domestication, SHAT1-5 on chromosome 16, has very recently been identified (Dong *et al*., 2014). This gene, which is homologous to NST1/2 of *A. thaliana*, activates secondary cell-wall biosynthesis and promotes the thickening of fibre-cap cells in pod sutures (Dong *et al*., 2014), the dehiscence site in soybean pods. SHAT1-5 also enhances pod-wall binding strength. Genetic variation in the degree of pod dehiscence is also present in cultivated soybean cultivars (Funatsuki *et al*., 2014).

Although shattering susceptible (SS) cultivars are more shattering-resistant than wild soybeans, such cultivars are not suitable for harvesting under dry conditions. In contrast to results obtained from interspecific genetic analysis, a major QTL for pod dehiscence has been identified in the cultivated species on chromosome 16 (Yamada *et al*., 2009). An anatomical analysis using near-isogenic lines (NILs) for this QTL, designated as qPDH1, has revealed no marked differences in suture morphology, including that of secondary cell-wall formation (Suzuki *et al*., 2009). Furthermore, qPDH1 mapping has delimited this QTL to a 134-kb genomic region lacking candidate genes homologous to the *Arabidopsis* genes associated with pod dehiscence (Suzuki *et al*., 2010). These facts suggest the involvement of, at least, a novel gene and mechanism in the regulation of pod dehiscence associated with qPDH1.

2.5 Molecular Marker Assisted Selection for Yield and Pod Shattering in Soybean

Molecular markers have been used in identification and selection of pod shattering resistant soybean genotypes. Among many various molecular markers, Kompetitive Allele-Specific PCR (KASP) and insertion/deletion (InDel) markers have been widely used because they are simple, stable, accurate, fast and cost effective. Seo *et al*. (2022) selected three genes (Glyma.16g141200, Glyma.16g141500 and Glyma.16g076600) for the development of both KASP and InDel markers for soybean pod shattering resistance and yield.

2.6 Distinction between Shattering and Non-shattering Regions in Soybean

Soybean pod is made up of a single carpel, which encloses the central cavity where the seeds are situated. Along the length of the pod are two sutures; the dorsal and ventral, where the pod opens when mature (Christiansen *et al*., 2002). Closer examination of the top of the bundle cap shows that the two halves of the structure do not meet where the suture begins, but are bordered by two different kinds of cells. Microscopic examination of cross sections of dorsal and ventral sutures of soybean pods at two different stages of maturity revealed that the dehiscence zone of soybean pods is functionally equivalent to the dehiscence zone known from crucifers (Christiansen *et al*., 2002).

Enzymatic assays demonstrated the presence of endo-1, 4-β-glucanases and endopolygalacturonase, the activity of which accumulated in the dehiscence zone that reaches peak at the time of maturation (Christiansen *et al*., 2002). Analysis of the soybean endopolygalacturonase transcription revealed that the endopolygalacturonase is primarily found in dehiscence-related tissue and is presumed to be involved in the breakdown of the middle lamella prior to dehiscence (Christiansen et al., 2002). Agrawal *et al*. (2002) reported on the activities of two hydrolytic enzymes (cellulase and polygalacturonase) and two oxidoreductase enzymes (peroxidase and polyphenol oxidase) at the shattering and non-shattering zones of two soybean varieties contrasting in pod shattering. The continuous increase of cellulase activity at the shattering zone of a susceptible variety indicates the involvement and role of this enzyme in the pod shattering process. The shift in the activity from the non-shattering zone to the shattering zone in susceptible variety and vice versa in resistant variety was also observed. Funatsuki *et al*. (2014) also reported that shattering resistant cultivars have high levels of synthesis of Heat Shock Protein (HSP72-73).

2.7 Role of Climate on Soybean Productivity and Pod Shattering

Soybean is highly sensitive to changes in climatic parameters (Dugje *et al.*, 2009). The main factor responsible for crop losses in soybean production is usually drought (Viana *et al.*, 2013). The two most critical periods for moisture stress are during seedling emergence to seedling establishment and the grain filling period. Both excess and shortage of moisture are harmful to the crop during the period of seedling emergency to establishment (Viana *et al.*, 2013). The soybean plant requires more water as it increases in growth and development. Maximum demand is reached at the time of flowering and early pod formation and remains high until physiological maturity.

An annual rainfall of 700-1200 mm that is well distributed during the soybean production cycle will meet the crops water needs (Mondine *et al.*, 2001). Mondine *et al.* (2001) also reported that soybean productivity could be optimum in a lower rainfall range of 500 to 700 mm if well distributed throughout the production cycle. Environmental factor like drought stress during pod maturation has been found to result in a weak pod structure, resulting in pod shattering. Delayed harvesting also increased the degree of shattering (Tukamuhabwa *et al.*, 2002). Other environmental factors that could cause pod shattering include low humidity, high temperature, rapid temperature changes, and alternating wetting and drying (Agrawal *et al.*, 2002). Rains followed by dry weather at harvest enhance pod shattering. Average temperatures essential for the best soybean development are between 20 and 35 ^oC. As reported by Viana *et al.* (2013), temperatures outside this range (20-35 ^oC) can lead to physiological disorders and poor growth. However, in addition to these factors, the genotypic characteristics play a key role in the overall expression of pod shattering (Bhor *et al.*, 2014).

Environmental relative humidity (RH) may also affect pod shattering through modifying pod moisture content (Zhang *et al.*, 2018). Romkaew *et al.* (2007) examined the relationship between pod shattering and pod position and moisture content in two soybean cultivars, and found that the pods at maturity did not shatter at any part of the stem due to the high moisture content of pods in both cultivars. After maturity, the frequency of pod shattering at the upper part of the stem increased as the moisture content of pods decreased. Thus the moisture content of pods may be considered as the main factor controlling pod shattering in *Glycine max.*

Romkaew *et al.* (2007) found that the moisture content of pods and the RH were closely correlated with the degree of pod shattering in *Glycine max*. They showed that keeping the RH at less than 25% enhances shattering while RH of above 50% inhibits pod shattering. The moisture content of unshattered pods was consistently higher than that of the shattered ones. Although dependent upon pod moisture and environmental conditions, when desiccants and plant growth regulators were used to manage vegetative growth, and seed shattering was reduced and seed yield was increased (García-Díaz and Steiner, 2000). Upon drying, soybean pod shatters via reduction of pod wall binding strength and increasing tension forces. The torsion force on dried pod walls serves as alternative driving force for shattering under low humidity, which prevails in dry climates (Funatsuki *et al*., 2014). Under such conditions, pod walls shrink and curl in a vertical plane perpendicular to the axis of the fiber direction. Dehydration over the threshold leads to pod shattering when sutures dig inward. Because the fiber and pod axes cross at an angle, this curling results in twisting or spiral coiling of pod walls after shattering (Funatsuki *et al*., 2014).

2.8 Soil Requirements for Soybean Production

2.8.1 Soil fertility

Nutrient availability in proper concentration in the soil influences soybean performances (Chiezey, 2013). Soybean cultivation is one of the best cost-effective ways to maintain soil fertility and yet reap other benefits associated with the crop (Njeru, *et al.*, 2013). The crop is among grain legumes that are capable of fixing high level of nitrogen, thus improving soil nitrogen content. Most soils in the tropics contain adequate strains of *Rhizobia* that can cause soybean to nodulate, particularly, promiscuous varieties. Therefore, N application rarely leads to an increase in seed yield of soybean (Chiezey, 2013).

Phosphorus plays a key role in soybean productivity. Phosphorus has been reported to influence some growth and yield parameters such as leaf area index, number of days to 50 % flowering, dry matter accumulation, and seed yield (Chiezey and Odunze, 2009; Chiezey, 2013). Phosphorus deficiency is one of the soil mineral stresses that limit crop growth and productivity. The ability to carry out nitrogen fixation makes phosphorus the most limiting element for soybean growth and yield. Phosphorus deficiency limits nodule growth relative to shoot growth in soybean. Also, number of days to 50 % flowering increased with phosphorus application, which increased dry matter accumulation and translocation for grain filling, and consequently, higher grain yield. Field experiments in the savanna have established that soybean grain yield could be doubled or tripled to 1750-2000 kg/ha with the use of single super phosphate. Thus, rates ranging from 20-30kgP/ha have been recommended for production of soybean (Chiezey, 2013). However, Dugje *et al.* (2009) recommended 40 kgP/ha.

Other mineral nutrients also exert significant influence on soybean growth and grain yield. For instance, potassium is essential for enzymatic activities for carbohydrate synthesis and breakdown of sugar. It also plays a role in water balance of the plant and in the production of high energy phosphate molecules like Adenosine triphosphate (ATP).

2.8.2 Soil pH and Texture

Soil pH influences growth and yield traits in soybean. Dugje *et al.* (2009) reported that soybean can be cultivated on a wide range of soils with pH ranging from 4.5 to 8.5.

However, Njeru *et al.* (2013) stated that a soil with a pH range of 5.5 to 7.5 is considered most suitable for soybean production. Uguru *et al.* (2012) reported that soil pH has a strong effect on soybean root growth as well as agronomic and yield traits. Their result showed that soybean growth and yield performance increased with increase in soil pH from 5.5 to 7.0. This could be attributed to the fact that at such pH, mineral nutrients like Ca, P and K are readily available (Costello *et al.*, 2003). Consequently, there is an increase in plant uptake of the nutrients.

The ideal soil texture for soybean production is a loose, well-drained loam. A loose, well-aerated soil allows air to get to the roots and improve nodulation. Heavy clay soils can cause difficulties in planting and seedling emergence due to crusting, but once emerged, soybean can adapt very well to the soil condition. However, soybean production is not to be done in sandy, gravelly, or shallow soils in order to avert drought stress (Dugje *et al*., 2009). Also, soils prone to water logging should be avoided.

2.9 Effect of Pod Shattering on Seed Yield

Pod shattering when crops are due for harvest in hot and dry conditions could result in serious seed yield losses (Adeyeye *et al*., 2014). Planting of soybean varieties that are highly susceptible to pod shattering could lead to zero harvest. Seed losses of 50-100 % are often associated with pod shattering in susceptible genotypes when harvesting is delayed after maturity in dry weather conditions (Bara *et al*., 2013). However Tefera *et al*. (2009) reported that a yield loss that ranges from 34 % to 100 % could be recorded in susceptible soybean varieties.

2.10 Management of Pod Shattering in Soybean

Pod shattering in soybean could be managed in diverse ways. Cultivation of shattering resistant or tolerant soybean varieties remains the best remedial approach for minimizing pod shattering in soybean (Adeyeye *et al*., 2014). Also, it has been found that proper application of plant growth regulators is capable of regulating some of the morphological and physiological processes of the plant especially in hot and dry conditions to slow rapid drying, which consequently reduce pod shattering (Leyla *et al*., 2006). Zhang and Bellaloui (2012) suggested that timing of seed maturity may be more important than the planting date with regards to soybean shattering pattern. Hence, it may be necessary for growers to aim at harvesting around the month of September, when climate does not favour pod shattering. Early harvesting of mature crops is another effective means of reducing pod shattering and subsequent yield loss. However, shortage of labour during harvest period could delay harvest, resulting to yield losses through pod shattering.

2.11 Techniques of Pod Shattering Assessment in Soybean

To assess the susceptibility of soybean lines to pod shattering, breeders had to rely mainly upon visual observations of the crop in the field or upon hand tests of pods (Bruce *et al*., 2002). However, a test procedure, which exposes pods to random impacts in a similar manner to those that occur in the crop canopy during harvest, has been developed (Bruce *et al*., 2002). This random impact test (RIT) enables the rapid comparison of susceptibility to shattering in samples of fully mature pods from individual plants. There are five types of assessment methods for pod shattering. These are;

i. Field-screening method, which relies on visual observation in the field (Tukamuhabwa *et al*., 2020). The naturally shatter-resistant lines are screened 2 to 4 weeks after the physiological dry pod maturity.

ii. The desiccator method, where pods containing two or more seeds are subjected to desiccation inside a desiccator at room temperature for 30 days (Romkaew and Umezaki, 2006). The degree of pod shattering is evaluated at 3, 5, 7, 14, 21, 28 and 35 days from the day of sample placement in the desiccators.

iii. The oven-dry method, where pods are subjected to oven-drying for a specified period (Tukamuhabwa *et al*, 2002). Usually, about 30 pods that serve as sample from each genotype are kept in an oven at 30 ^{o}C for three days, and then increased to 40 ^{o}C for one day, increased to 50 ^{o}C for another day and lastly to 60 ^{o}C for three days. The number of pods that shattered are then counted and converted in percentage.

iv. The sun-dry method, makes use of heat from the sun (Krisnawati and Adie, 2016; Krisnawati *et al*., 2020). The use of sun-dry method in pod shattering evaluation is a simulation of field conditions. It also provides information on the duration of delayed harvesting of a genotype to avoid losses due to pod shattering.

v. the mechanical cracking method, which is a laboratory procedure used to test individual pods for resistance to shattering and to evaluate the mechanical properties of the pod during shattering (Romkaew and Umezaki, 2006; Morgan *et al*., 2000; Timothy *et al*., 2003)

2.12 Yield Stability in Soybean

Yield stability is always considered as an important topic in plant breeding, especially with continuous variation in climatic conditions. Crop varieties may not show uniform performance across different environments due to G×E interactions (Fasahat *et al*., 2015). A stable soybean cultivar usually possesses a relatively small seed yield fluctuations across locations (Adie and Krisnawati, 2015). Crop yield varies due to suitability of genotypes to different growing seasons or environmental conditions. A particular genotype does not always express the same phenotypic traits under all environments and different genotypes respond differently to a particular environment (Tyagi and Khan, 2010). In order to attain high and stable yields, adequate choice of suitable soybean cultivar in a specific environment is of upmost importance (Popovic, 2010). According to Tyagi *et al.* (2011), high yielding soybean genotypes are more likely to have lower stability and *vice versa*, that is, low yielding genotypes tend to have high stability across locations. Gebeyehu and Assefa (2003) noted that selection based on the highest yielding genotypes appeared less stable than the average of all lines, and selection based solely on seed yield can result in many stable genotypes being discarded.

Soybean breeders have traditionally stressed wide adaptation instead of specific adaptation in their breeding programmes and as a result selected genotypes that perform well over a wide range of climatic conditions. Wide adaptation offers stability against the variability inherent in an ecosystem, but a significant yield advantage in specific environment may be provided by specific adaptations.

2.12.1 Static Stability

Static stability is stability in the biological sense. It is the ability of genotypes to maintain uniform production in different environments, with low variation between them (Sabaghnia *et al*., 2015). That is a stable genotype is the one possessing a constant performance irrespective of any changes in environmental conditions. This type of stability is rarely a favoured feature of crop genotypes, especially if genotypes with high phenotypic stability have low yield. As a result, this is not of interest to plant breeders to evaluate the phenotypic stability of the genotype performance, or other related random variables. Although, it is helpful to evaluate the phenotypic stability of the traits that should retain their levels such as stress characters like drought resistance, qualitative traits, or disease resistance (Fasahat *et al*., 2015).

2.12.2 Dynamic Stability

Dynamic stability refers to stability in the agronomic sense. This stability shows that the genotype positively responds to improvements in edaphic and climatic conditions of the environment and can perform above the mean in different environments (Sabaghnia *et al*., 2015). The concept of dynamic stability is useful for quantitative traits such as yield and is of great interest to both plant breeders and farmers.

2.12.3 Stability and G×E Analyses Techniques

Different techniques have been developed to reveal stability and G×E interaction patterns. These techniques include joint regression (Finlay and Wilkinson, 1963), sum of squared deviations from regression (Eberhart and Russel, 1966), and stability variance (Shukla, 1972). Alternatively, additive main effects and multiplicative interaction (AMMI) model has been used to get a clearer view of the complicated pattern of genotypic responses to the environment (Yan and Tinker, 2006; Ishaq *et al*., 2015). Yan *et al*. (2000) proposed another methodology called genotype plus genotype × environment interaction (GGE) biplot for graphical representation of GE interaction pattern of Multi-environment trial (MET) data.

Regression analysis is an approach originally proposed by Yates and Cochram (1938) and later modified by Finlay and Wilkinson (1963) and Eberhart and Russel (1966). It has been widely used in comparing and measuring genotypic performances of soybean (Ojo, 2002; Ojo *et al*., 2002). It is used to measure the sensitivity of genotypes to production environments. The regression coefficient (b-value) is the genotypic sensitivity to changes in the environmental conditions. Values of $b>1$ indicates genotypes with a higher than average sensitivity and less stable; $b=1$ means the genotypes are averagely stable, while $b<1$ means genotypes that are less sensitive and thus, more stable (Ishaq *et al*., 2015).

The variance across environments is used as a parameter to estimate the static stability of genotypes. A genotype with the sample estimate very close to zero is recognized to be stable, which means that environmental changes will not influence the genotype performance (Fasahat *et al*., 2015). Wricke's model is the simplest method to evaluate dynamic stability (Fasahat *et al*., 2015). Wricke suggested the ecovalence (W_i^2) concept as the ratio of the interaction sum of squares contributed by each genotype to the G×E interaction sum of squares. In other words, the ecovalence of the i^{th} genotype is its interaction with the environments, squared and summed across environments. Genotypes with a low W_i^2 value ($W_i^2<1$) have smaller deviations from the mean across environments and are therefore more stable. That is the lower the value of W_i^2 of a genotype, the greater the dynamic stability of such genotype.

AMMI analysis combines a univariate method for the additive effects of genotypes and environments, with a multivariate method for the multiplicative effect of G×E interaction (Cucolotto *et al.*, 2007). It partitions the sum of squares of GEI into several principal components (PC), of which the first two principal components usually capture greater percentage of the sum of squares of G×E interaction. The results of the AMMI model analysis is usually interpreted by a bi-plot between Principal Component (PC) Axis 1 versus PC Axis 2. In the AMMI bi-plot, genotypes or environments with large negative or positive PC2 scores have high interactions, while those with PC2 scores near zero (close to the horizontal line) have little interaction across the environments and are considered more stable than those further away from the line (Agyeman *et al.*, 2015). Yan and Rajcan (2002) defined an ideal test environment as one that has small PC2 scores, that is, more representative of the overall environment; and large PC1 scores, which represents power to discriminate. Also, the environmental vector in the bi-plot shows the discriminating ability of an environment for the genotypes tested. A long environment vector represents good discriminating ability for a given environment and *vice versa*. Discriminant test environments accurately resolve genotype differences, thereby providing the necessary information for selection by a breeder (Tukamuhabwa *et al*., 2012). Therefore, testing soybean genotypes for yield in an environment with high representative and discriminating ability only may suffice.

Another AMMI bi-plot makes use of the main effect and the First Principal Component Scores of Interactions (IPCA1) of both genotypes and environments. In the bi-plot, genotypes or environments that are located almost on the perpendicular line of the graph have similar seed yields and those that appear almost on the horizontal line have similar interaction (Ishaq *et al*., 2015). Genotypes or environments that are located at the right side of the midpoint of the perpendicular line have higher yields than those on the left side. According to Egesi and Asiedu (2002), genotypes or environments that have large negative or positive IPCA1 scores have high interactions, while the ones with scores close to zero (near the horizontal line) have little interaction across environments and are considered to be more stable than those that are further away from the line.

GGE biplot is a graphical tool that displays, interprets and explores two important sources of variation, namely genotype main effect and GE interaction of MET data (Fan *et al*., 2007). GGE biplot analysis considers that only the G and GE effects are important and that they need to be considered simultaneously when evaluating genotypes. Therefore, the GGE biplot has been used in crop variety trials to effectively identify the best-performing genotype across environments; identify the best genotypes for mega-environment delineation, whereby specific genotypes can be recommended to specific mega- environments and evaluate the yield and stability of genotypes (Yan and Tinker, 2006). Mega environments are test environments having different winning genotypes located at the vertex of the polygon (Tukamuhabwa *et al*., 2012). The versatility of the GGE biplot relative to other techniques, especially in mega-environment analysis and genotype selection, is worthy of being exploited for selection of genotypes for specific environments (Agyeman *et al.*, 2015). It would also assist in guiding the direction of varietal development for stable ecology based selections.

The polygon view of the GGE-biplot shows “which-won-where”; that is the best genotype in each environment and it summarizes the GEI pattern of a multi environment yield trial data. The polygon is formed by connecting the genotypes located further away from the origin of the biplot such that all other genotypes are contained within the polygon. A perpendicular line starting from the origin is drawn to each side of the polygon and extended beyond the polygon so that the biplot is divided into several sectors, and the different environments were separated into different sectors. The genotype at the vertices of each sector of each sector is the best performer at environment(s) included in that sector (Agyeman *et al.*, 2015).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Locations

The experiments were conducted in three locations for two cropping seasons (2019 and 2020) (Appendix A). The first location was at Upper Niger River Basin Development Authority (UNRBDA) farm (Latitude 9.6737°N, Longitude 6.5109°E) in Minna, Niger State; the second was at UNRBDA farm (Latitude 9.0535°N, Longitude 7.3026°E) in Chinka, Kaduna State; while the third location was at the Teaching and Research Farm of the Department of Crop Science and Horticulture (Latitude 6.3437°N, Longitude 7.0938°E), Nnnamdi Azikiwe University, Awka, Anambra State.

3.2 Soil Analysis

Soil samples were collected from each location using a steel auger into a bucket and mixed properly. They were air-dried at room temperature and passed through 2mm sieve before being analyzed in the laboratory for their physical and chemical properties. The soil pH was measured in a soil water ratio of 1:2 using glass electrode and pH meter. Particle size distribution was determined by the hydrometer (Ikeogu and Nwofia, 2013). Total soil Nitrogen was determined by the Kjeldahl method (Saez-Plaza *et al*., 2013), while available Phosphorus was by the Bray 1 method, and exchangeable Potassium by the use of a flame photometer (Ikeogu and Nwofia, 2013).

3.3 Experimental Design and Field Layout

The experiments were conducted using Randomized Complete Block Design (RCBD) with three (3) replications. The gross plot size was 3 m x 2 m = 6 m^2; giving 4 ridges of 2 m long each. The net plot size was 1.5 m x 2 m = 3 m^2; to give 2 ridges of 2 m long each. Along each replication, gross plots were separated by a distance of 0.5 m, while an alley of 1 m distance separated one replication from the other. The total experimental area was 65 m x 11 m = 715 m^2.

3.4 Experimental Material

Twenty-six (26) soybean genotypes were used for the experiments. The genotypes were obtained from National Cereals Research Institute (NCRI), Badeggi. The genotypes are:

NCRI SOY AC78, NCRI SOY AC18, NCRI SOY AC17, NCRI SOY AC69, NCRI SOY AC77, NCRI SOY AC73, NCRI SOY AC26, NCRI SOY AC29, NCRI SOY AC25, NCRI SOY AC28, NCRI SOY AC64, NCRI SOY AC65, NCRI SOY AC24, NCRI SOY AC3, NCRI SOY AC9, NCRI SOY AC7, NCRI SOY AC68, NCRI SOY AC20, NCRI SOY AC62, NCRI SOY AC63, NCRI SOY AC75, NCRI SOY AC10, NCRI SOY AC67, NCRI SOY AC76, NCRI SOY AC61, NCRI SOY AC22.

3.5 Cultural Practices

3.5.1 Land Preparation

The lands were cleared manually using cutlass, after which ridges were made manually by hoe.

3.5.2 Planting and Seed Rate

Three (3) soybean seeds were sown per hill and later thinned down to one plant per stand. The planting distance used was 75 cm × 20 cm between and within rows, respectively. This gave a plant population of 66, 667 plants per hectare. In each year, planting was done on 18th July in Minna; 25th July in Chinka and 26th August in Awka.

3.5.3 Weeding

Weeds were controlled manually using hoe, at 2 and 6 weeks after planting, as recommended by Dugje *et al.* (2009).

3.5.4 Fertilizer Application

Single Super Phosphate (SSP) was applied during seed planting at the rate of 40kg per hectare, as recommended by Dugje *et al.* (2009).

3.5.5 Harvest

Harvesting was done when 95% of the pods reached maturity; that is when pods were brown in colour.

3.6 Data Collection

3.6.1Meteorological Data

In each of the locations and the years, the following meteorological parameters were taken:

i. Amount of monthly rainfall and total rainfall for the years (mm).

ii. Mean monthly temperature during the growing years (^oC)

iii. Mean monthly relative humidity during the growing years (%)

The data were obtained from Nigerian Meteorological Agency (NiMet), National Weather Forecasting and Climate Research Centre, Nnamdi Azikiwe International Airport, Abuja.

3.6.2 Seedling Emergence, Plant Growth, Flowering and Maturity Data

The following seedling emergence, plant growth, flowering and maturity data were collected;

i. **Emergence (%):** the emergence percentage was calculated using the formula below, according to Baset Mia and Shamsuddin (2009):

$$\text{Emergence (\%)} = \frac{\text{number of emerged seedling} \times 100}{\text{Number of seeds planted}}$$

ii. **Plant height (cm):** this was measured from each of the tagged plants at flowering using measuring tape. It was measured from ground to the last leaf of the main shoot and average height of the five randomly selected plants was computed and recorded.

iii. **Branches per plant:** the number of branches from the tagged plants was counted manually and their average computed and recorded.

iv. **Days to 50 % flowering:** the days to 50% flowering was recorded when half of the plants in a net plot flowered. This was done through visual counting.

v. **Days to maturity:** this was counted from sowing date to the date when 95% of the plants in a net plot reached maturity.

3.6.3 Data on Pod Traits

i. **Pod length (cm)**: The length of 20 randomly selected pods was taken from base to the tip of the pods, using a measuring tape. The average length was taken and recorded.

ii. **Pod width (cm):** The width of the selected pods was taken at the upper part of the pod, using a measuring tape. The average width was taken and recorded

iii. **Length-width ratio (cm):** This was obtained by dividing the average length by the average width. The higher the value, the longer the length of the pod relative to its width.

iv. **Pod thickness (cm):** The thickness of the selected pods was measured at the middle of the pod, using a vernier calliper. The average pod thickness was obtained and recorded.

v. **Width at mid part of the pod (cm):** This was measured from the randomly sampled pods at the middle of the pod, using a measuring tape. The average was measured and recorded.

vi. **Seed weight from 20 pods (g):** Weight of seeds of 20 randomly sampled pods was obtained using a digital weighing balance.

vii. **Pod wall weight of 20 pods (g):** The pod walls were weighed also using a digital weighing balance.

viii. **Pod weight (g):** This was obtained by adding the seed weight and pod wall weight.

ix. **Seed weight and pod weight ratio:** This ratio is the value obtained by dividing seed weight by pod weight. Higher value indicates larger seeds.

x. **Pod wall weight and pod weight ratio:** This was obtained by the division of pod wall weight by pod weight. Similarly, higher value signifies larger pod walls.

3.6.4 Data on Plant Yield and Yield Components

i. **Number of pods per plant:** Was counted manually from 5 tagged plants during harvest and was recorded.

ii. **Number of seeds per pod:** Twenty (20) pods were randomly selected from each genotype; the number of seeds they contained were counted and their average recorded.

iii. **Above ground biomass (kg/plot):** This was taken by weighing the above-ground parts of all the plants in a net plot during harvest, using a weighing balance.

iv. **Seed yield (kg/plot):** The weight of seeds harvested per net plot was measured using a weighing balance and was recorded.

v. **100-seed weight (g):** One hundred (100) seeds of each genotype were randomly selected and their weight measured using a digital weighing balance and the value recorded.

vi. **Harvest index:** this was determined by using the formula described by Kemanian *et al*. (2007). This is given below:

Harvest index = seed yield
____

Above ground biomass

3.7 Pod Shattering Identification

Pod shattering identification was done using the sun-dry method, as described by Krisnawati and Adie (2016) and Krisnawati *et al*. (2020). Five plants were sampled per plot and four pods harvested from each plant; giving a total of 20 pods. The harvest was done when about 95 % of the pods turned brown. These pods were placed inside paper bags and sun-dried for seven days. On the 7th day the number of shattered pods was counted, and the genotypes were classified into different categories based on the percentage of shattered pods (Table 3.1).

Table 3.1: Pod shattering scoring rate

Score	Description	Category
1	No pod shattering	Very resistant
2	< 25% pod shattering	Resistant
3	25 - 50% pod shattering	Moderately Resistant
4	51 - 75% pod shattering	Highly susceptible
5	> 75% pod shattering	Very highly susceptible

Source: Krisnawati and Adie (2017)

3.8 Data Analyses

3.8.1 Analysis of Variance

Data collected were subjected to Analysis of Variance (ANOVA) using General Linear Model (GLM) procedure of SAS (SAS, 1997). Levels of significance were determined at 5%. Means were separated using Duncan Multiple Range Test at $p = 0.05$.

The ANOVA model is $Y_{ij.} = \mu + g_i + e_j + ge_{ij} + \varepsilon_{ij.}$

3.8.2 Genotypic Sensitivity

To determine genotypic sensitivity and stability the following linear regression model was used (Eberhart and Russell, 1966);

$$Y_{ij.} = \mu + b_i L_j + \delta_{ij} + \varepsilon_{ij.}$$

Where; $Y_{ij.}$ is the mean for the genotypes i at location j. μ; the general mean for genotype. b_i ; the regression coefficient for the ith genotype at a given location index which measures the response of a given genotype to varying location. L_j ; the environmental index, which is defined as the mean deviation for all genotypes at a given location from the overall mean. δ_{ij} ; the deviation from regression for the ith genotype at the jth location. $\varepsilon_{ij.}$; the mean for experimental error.

3.8.3 Relationship between Pod Shattering and Pod Morphological Traits

The relationship between pod shattering and pod morphological traits was determined using Pearson correlation analysis model:

$$r_{xy} = \frac{N\sum xy - (\sum x)(\sum y)}{\sqrt{[N\sum x^2 - (\sum x)^2][N\sum y^2 - (\sum y)^2]}}$$

Where:

r_{xy} = correlation coefficient of x and y

N = number of pairs of scores

$\sum xy$ = sum of the products of paired scores

$\sum x$ = sum of x scores

$\sum y$ = sum of y scores

$\sum x^2$ = sum of squared x scores

$\sum y^2$ = sum of squared y scores

3.8.4 Stability Pattern

Additive Main Effect and Multiplicative Interaction (AMMI) was used to determine the stability pattern of the genotypes across the locations according to Adie and Krisnawati (2015). The AMMI model is $Y_{ij.} = \mu + g_i + e_j + \sum \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij.}$

Where Y_{ij} is the mean of the ith line in the jth environment, μ is the grand mean, g_i is the genotype effect, e_j is the site effect, λ_k is the singular value for principal components k, α_{ik} is the eigenvector score for genotype i and component k, γ_{jk} is the eigenvector score for environment j and component k, and $\varepsilon_{ij.}$ is the error for genotype i and environment j. AMMI bi-plot makes use of the main effect and the First Principal Component Scores of Interactions (IPCA1) of both genotypes and environments.

To estimate the static stability of the genotypes, the following equation was used as recommended by Fasahat *et al*. (2015):

$$S^2_{xi} = \frac{\sum (X_{ij} - \bar{X}_{i.})^2}{E - 1}$$

Where S^2_{xi} is the variance across environments; X_{ij} is the performance of the i^{th} genotype in the j^{th} environment; $\bar{X}_i$ is the mean performance of the i^{th} genotype and E is the number of environments.

Wricke's ecovalence model was used to evaluate the dynamic stability and it is expressed as;

$$W^2{}_i = \sum(X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})^2$$

Where $W^2{}_i$ is Wricke's ecovalence; X_{ij} is the mean performance of the i^{th} genotype in the j^{th} environment; $X_{i.}$ and $X_{.j}$ are the genotype and environment mean deviations, respectively, and $X_{..}$ is the overall mean.

3.8.5 Best Genotypes in Mega Environments

Genotype plus genotype × environment interaction (GGE) bi-plot was used to identify the best-performing genotype across environments. The polygon view of the GGE-biplot was used to show "which-won-where"; that is the best genotype in each environment and it summarized the GEI pattern of a multi environment yield trial data. The GGE biplot used is based on the Sites Regression (SREG) linear-bilinear (multiplicative) model (Cornelius *et al*., 1996), which is given below:

$$\bar{y}_{ij} - \mu_j = \sum_{k=1}^{t} \lambda_k \, \alpha_{ik} \, \gamma_{jk} + \bar{\varepsilon}_{ij}$$

Where $\bar{y}_{ij}$ is the cell mean of genotype i in environment j; μj is the mean value in environment j; $i = 1, \cdots g$; $j = 1, \cdots e$, g and e being the numbers of cultivars and environments, respectively; and t is the number of principal components (PC) used or retained in the model, with $t \leq \min(e, g - 1)$. The model is subject to the constraint $\lambda_1 \geq \lambda_2 \geq \cdots \lambda_t \geq 0$ and to orthonormality constraints on the α_{ik} scores, with similar constraints on the γ_{jk} scores [defined by replacing symbols $(i,g,\vec{\alpha})$ with (j,e,γ)]. The ε_{ij} are assumed normally and independently distributed $(0, \sigma^2/r)$, where r is the number of replications within an environment.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Weather

4.1.1.1 Rainfall

The peak of rainfall in year 2019 in Minna was in the month of August, while in Chinka and Awka; it was in the month of September. However, while rainfall was fairly distributed during the developmental stages of the crop in Minna and Chinka, there were abrupt changes in Awka (Figure 4.1). In the year 2020, the peak of rainfall in Minna and Chinka was in the month of September; and in the month of July in Awka. Again, the rainfall pattern was more fairly distributed in Minna and Chinka than in Awka (Figure 4.2). The total annual rainfall for both year 2019 and 2020 in the three environments is presented in Figure 4.3. The highest annual rainfall in both years was recorded in Awka (3821.5 mm in 2019 and 2777 mm in 2020). The second highest in both years was recorded in Minna (1694.2 mm and 1763.57 mm, respectively); while the lowest annual rainfall in both years was recorded in Chinka (1140.2 mm and 1031.4 mm, respectively)

4.1.1.2 Temperature

The maximum monthly temperature during the field experiment in 2019 ranged from 29-34.6 ^{o}C in Minna; 29.8-33.8 ^{o}C in Chinka; and 30.4-34.4 ^{o}C in Awka (Figure 4.4). Both minimum and maximum temperatures of the environments in 2019 were fairly uniform during this period (Figure 4.4). Temperature was rising as the crop approached maturity and the hottest temperature in each environment during the field experiment was recorded in November, which was the month of harvest and pod shattering identification. Although similar result was recorded in the year 2020, maximum temperature ranged from 28.9-35.7 ^{o}C in Minna; 28.7-35.3 ^{o}C in Chinka; and 29.8-34.6 ^{o}C in Awka (Figure 4.5).

4.1.1.3 Relative Humidity

The relative humidity during the field experiment in 2019 ranged from 53-85 % in Minna; 53-87 % in Chinka; and 62-84 % in Awka (Figure 4.6). The relative humidity across the environments was fairly uniform, but there was an apparent decline as the crop was approaching harvest (October-November) (Figure 4.6). In 2020, the relative humidity ranged from 43-86 % in Minna; 43-85 % in Chinka; and 69-84 % in Awka (Figure 4.7). It also follow similar pattern as observed in 2019 across the environments. Furthermore, it is worthy of note that in both 2019 and 2020 there was a slight decline in the month of August in Awka (Figures 4.6 and 4.7).

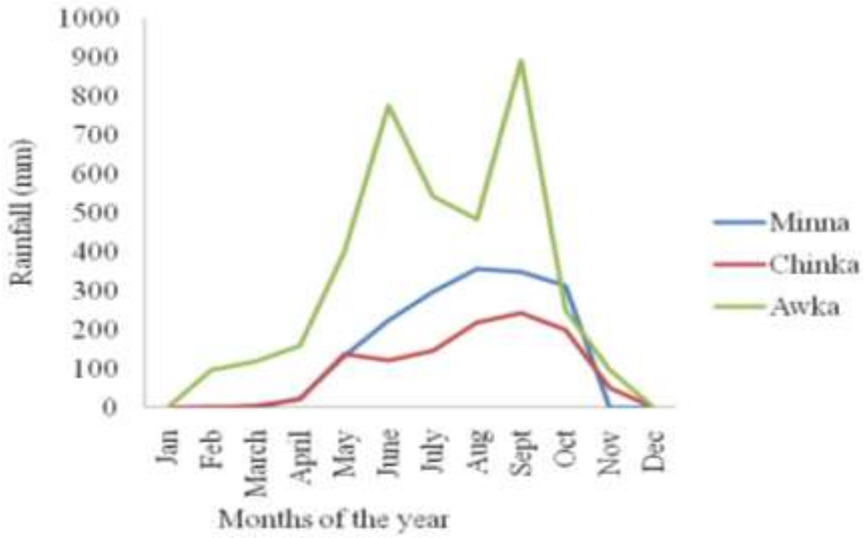

Figure 4.1: Total monthly rainfalls in the three environments in 2019
Source: Nigerian Meteorological Agency (NiMet), Abuja (2021)

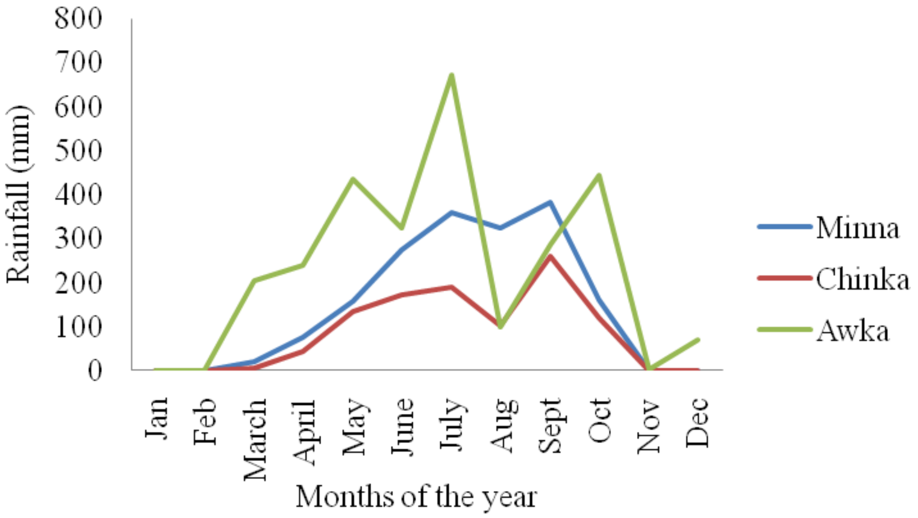

Figure 4.2: Total monthly rainfalls in the three environments in 2020
Source: Nigerian Meteorological Agency (NiMet), Abuja (2021)

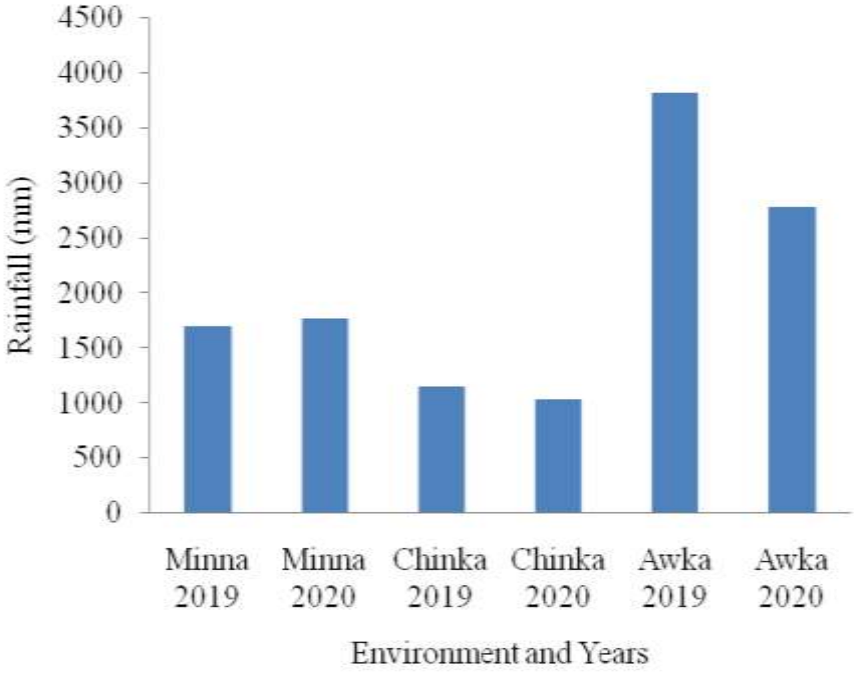

Figure 4.3: Total annual rainfall of the three environments in 2019 and 2020
Source: Nigerian Meteorological Agency (NiMet), Abuja (2021)

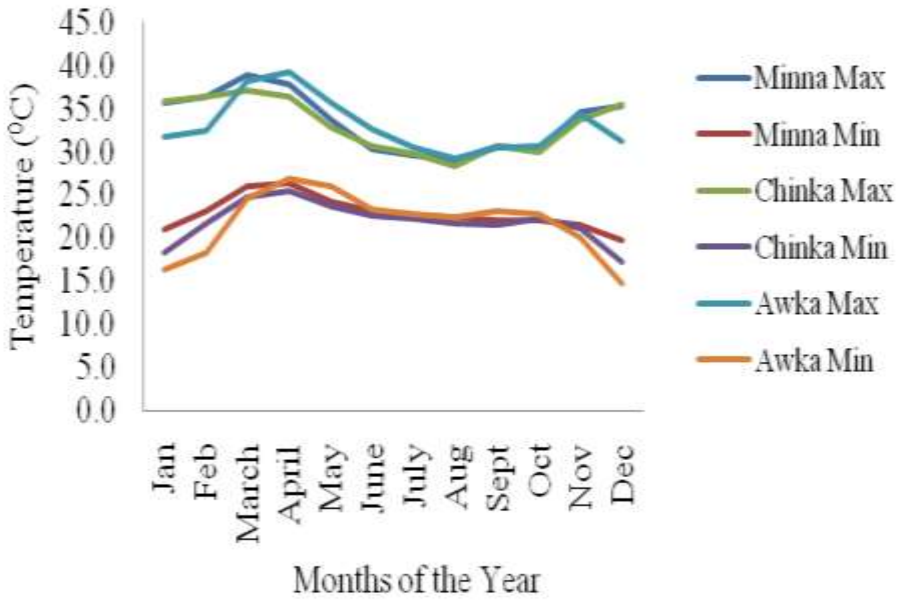

Figure 4.4: Monthly average minimum and maximum temperatures in the three environments in 2019
Source: Nigerian Meteorological Agency (NiMet), Abuja (2021)

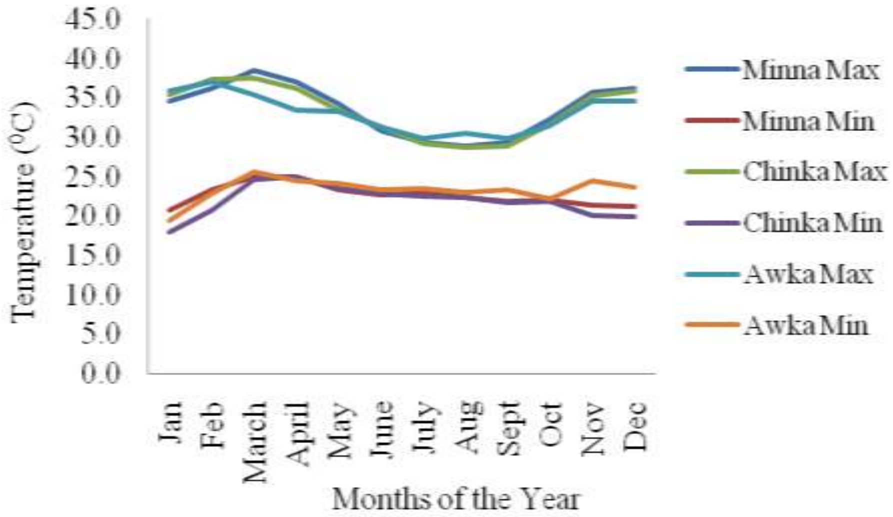

Figure 4.5: Monthly average minimum and maximum temperatures in the three environments in 2020
Source: Nigerian Meteorological Agency (NiMet), Abuja (2021)

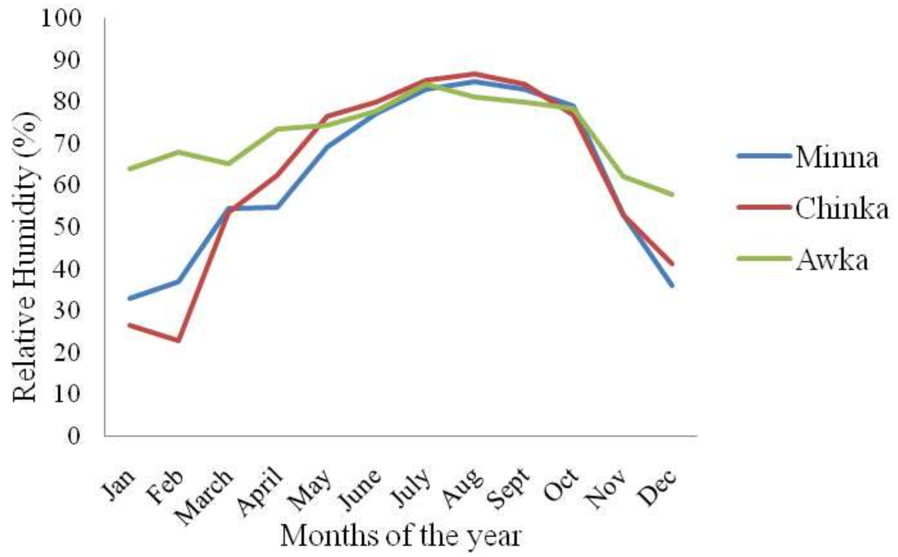

Figure 4.6: Monthly average relative humidity of the three environments in 2019
Source: Nigerian Meteorological Agency (NiMet), Abuja (2021)

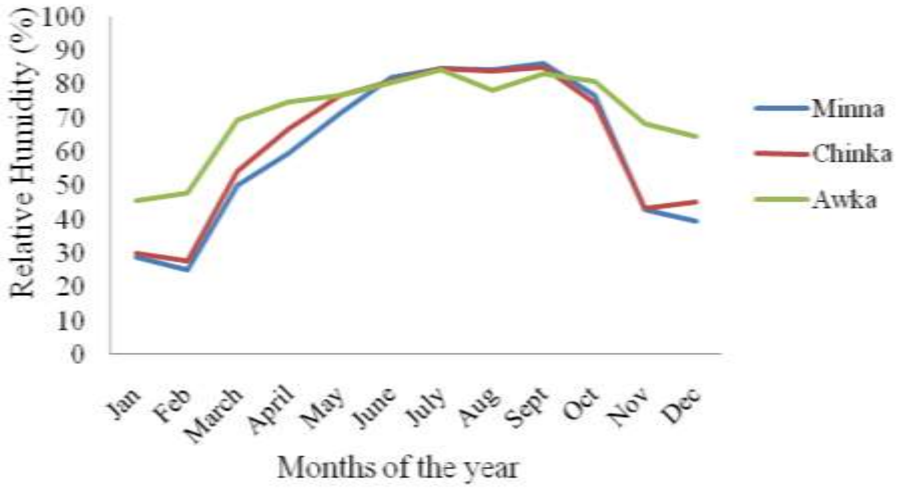

Figure 4.7: Monthly average relative humidity of the three environments in 2020
Source: Nigerian Meteorological Agency (NiMet), Abuja (2021)

4.1.2 Soil

The soil physical and chemical properties of the three environments in 2019 and 2020 are presented in Table 4.1. The results show the soil texture of all the experimental locations were sandy loam. In 2019, the soil pH ranged from 6.4 in Awka to 6.7 in Minna, while in 2020, it ranged 6.5 in Awka to 6.6 in Minna. Nitrogen was highest in Awka in both years; however, it was of the same level with Chinka in 2020; while Minna had the lowest soil nitrogen in both years (Table 4.1). Phosphorus and potassium were highest in Chinka and lowest in Awka in both years.

Table 4.1: Soil physical and chemical properties of the study environments

	Minna		Chinka		Awka	
Parameter	2019	2020	2019	2020	2019	2020
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Sand (g kg^{-1})	800	780	780	790	790	800
Silt (g kg^{-1})	130	130	120	110	100	100
Clay (g kg^{-1})	70	90	100	100	110	100
pH (H_2O)	6.7	6.6	6.5	6.5	6.4	6.5
Nitrogen (g kg^{-1})	1.0	1.1	1.2	1.4	1.4	1.4
Available Phosphorus (mg kg^{-1})	10.0	9.8	10.3	10.4	9.5	9.4
Potassium (cmolkg^{-1})	0.06	0.05	0.08	0.08	0.05	0.04

4.1.3 Mean Square for Plant Growth and Yield Traits of Soybean Genotypes across Environments and Years

The Genotype (G) effect was significant for all the growth and yield traits except pods per plant (Table 4.2). Environment (E) effect was significant for all the growth and yield traits except days to 50 % flowering. Year (Y) effect was significant for all the growth and yield traits except pod per plant and above ground biomass. G×E interaction was significant for days to 50 % flowering, plant height, days to maturity, seed yield, one hundred seed weight and harvest index. G×Y interaction was significant for emergence percentage, days to 50 % flowering; plant height, days to maturity, and one hundred seed weight. E×Y interaction was significant for all the traits except seeds per pod. Finally, G×E×Y interaction was significant for only days to maturity, branches per plant, and harvest index.

4.1.4 Mean Square for Pod Traits of Soybean Genotypes across Environments and Years

The Genotype, Environment and E×Y interaction effects were significant for all the pod traits evaluated (Table 4.3). Year effect was significant for all the pod traits except seed weight/pod weight ratio, pod wall weight/pod weight ratio, and pod shattering. G×E interaction was significant for pod length, pod width, pod thickness, pod mid width, seed weight and pod weight. G×Y interaction was significant for pod length and seed weight only; while G×E×Y interaction was significant for all the traits except pod wall weight, seed weight/pod weight ratio, pod wall weight/pod weight ratio, and pod shattering.

Table 4.2: Mean square for growth and yield traits of soybean genotypes across three environments during 2019 and 2020

Parameter	Genotype	Environment	Year	G×E	G×Y	E×Y	G×E×Y
Emergence (%)	707.41**	7588.51**	10388.94**	132.58ns	816.27**	6427.43**	144.49ns
D50%F	41.03**	4.85ns	109.14**	12.41**	10.47**	1176.00**	3.32ns
PH (cm)	136.08**	3766.26**	10455.01**	68.23**	103.75**	3970.32**	49.01ns
DM	42.30**	1682.44**	23.11**	13.72**	10.84**	1439.46**	11.87**
B/P	4.63**	6.49**	60.31**	1.16ns	1.25ns	171.78**	1.67*
P/P	1107.84ns	22661.57**	2450.94ns	1188.53ns	759.60ns	57913.62**	1454.81ns
S/P	0.20**	0.47**	0.500**	0.05ns	0.07ns	0.02ns	0.08ns
AGB (ton/ha)	1.07*	17.30**	0.18ns	0.97ns	0.72ns	48.36**	0.82ns
SY (ton/ha)	0.20*	4.62**	2.19**	0.20*	0.15ns	4.07**	0.16ns
100SW (g)	23.33**	191.08**	73.92**	2.59**	5.17**	32.35**	2.02ns
HI	0.01**	0.09**	0.14**	0.01**	0.00ns	0.08**	0.01**

D50%F = Days to 50% Flowering; PH = Plant Height; DM = Days to Maturity, B/P = Branches per Plant; P/P = Pods per Plant; S/P = Seeds per Pod; AGB = Above Ground Biomass, SY = Seed Yield; 100SW = one hundred seed weight; HI = Harvest Index; G×E = Genotype/Environment interaction; G×Y = Genotype/Year interaction ; E×Y = Environment/Year interaction; G×E×Y = Genotype/Environment/Year interaction; * = Significant at P≤0.05; ** = Significant at P≤0.01; ns = Non Significant.

Table 4.3: Mean square for pod traits of soybean genotypes across three environments during 2019 and 2020

Parameter	Genotype	Environment	Year	G×E	G×Y	E×Y	G×E×Y
Pod length (cm)	0.43**	2.02**	2.96**	0.10**	0.12**	1.77**	0.08*
Pod width (cm)	0.01**	0.72**	0.85**	0.01*	0.00ns	0.32**	0.01**
LW Ratio	0.49**	44.48**	56.58**	0.24ns	0.26ns	24.33**	0.31**
Pod thickness (cm)	0.01**	0.08**	0.05**	0.00**	0.00ns	0.01**	0.00**
Pod mid width (cm)	0.01**	0.13**	0.05**	0.01**	0.00ns	0.05**	0.01**
Seed weight (g)	3.49**	92.06**	13.34**	1.00**	0.57*	29.16**	0.67**
Pod wall weight (g)	0.47**	5.04**	1.56**	0.23ns	0.19ns	3.35**	0.26ns
Pod weight (g)	5.72**	138.83**	24.46**	1.88**	1.08ns	51.60**	1.43**
SWPW Ratio	0.00**	0.04**	0.00ns	0.00ns	0.00ns	0.00*	0.00ns
PWWPW Ratio	0.00**	0.04**	0.00ns	0.00ns	0.00ns	0.00*	0.00ns
Pod Sht (%)	4350.29**	1218.64**	65.44ns	112.93ns	103.79ns	662.55*	144.31ns

L/W Ratio = Pod Length/Pod Width Ratio; SWPW Ratio = Seed weight/Pod weight Ratio; PWWPW Ratio = Pod wall weight/Pod weight Ratio; Pod Sht = Pod shattering percentage; G×E = Genotype/Environment interaction; G×Y = Genotype/Year interaction; E×Y = Environment/Year interaction; G×E×Y = Genotype/Environment/Year interaction; * = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$; ns = Non Significant.

4.1.5 Performance of the Soybean Genotypes for Growth and Yield Traits in Individual Environments

4.1.5.1 Plant Growth Traits of the Soybean Genotypes in Minna

The performances of the soybean genotypes on growth traits in Minna are presented in Table 4.4. The genotypes differed significantly in all the traits in both 2019 and 2020. In 2019, the highest emergence percentage (68 %) was observed in NCRI SOYAC26. It was significantly different from NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC76, and NCRI SOYAC22. In 2020, NCRI SOYAC73 had the highest seedling emergence percentage (89 %), which was significantly different from other genotypes except NCRI SOYAC17, NCRI SOYAC26, and NCRI SOYAC22. The lowest emergence percentage in both years (26 % and 62 %, respectively) was observed in NCRI SOYAC65, although not significantly different from some genotypes in each year as shown in Table 4.4. The highest number of days to 50 % flowering was recorded in NCRI SOYAC7 in both 2019 and 2020 (56.33 days and 54.67 days, respectively), which did not differ significantly with NCRI SOYAC17, NCRI SOYAC77 and NCRI SOYAC76 in 2019 but differed significantly from all other genotypes in 2020. The shortest number of days to achieve 50 % flowering among the genotypes was recorded in NCRI SOYAC29, NCRI SOYAC24, and NCRI SOYAC9 in 2019 (47.33 days each); and in NCRI SOYAC29 in 2020 (43.67 days).

The tallest plant in 2019 was NCRI SOYAC78 (30.67 cm), which was not significantly different from NCRI SOYAC17, NCRI SOYAC73, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC62, NCRI SOYAC67, NCRI SOYAC61, NCRI SOYAC22. Meanwhile, in 2020, NCRI

SOYAC76 was the tallest with an average plant height of 47.33 cm that was not significantly different from NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC68, and NCRI SOYAC22. The shortest plant height was observed in NCRI SOYAC10 in 2019 (20.33 cm); and NCRI SOYAC63 in 2020 (28.67 cm). However, these two genotypes did not differ significantly from each other in the two years of study. In terms of number of days to reach maturity in 2019, it took NCRI SOYAC7 approximately 121 days to reach maturity; the highest recorded among the genotypes, which differed significantly from every other genotype. In 2020, NCRI SOYAC18 was the last to reach maturity (119 days), but was not significantly different from NCRI SOYAC69, NCRI SOYAC3, NCRI SOYAC7, and NCRI SOYAC76. On other hand, in 2019, it took three genotypes (NCRI SOYAC64, NCRI SOYAC65, and NCRI SOYAC24) 114 days to reach maturity; the lowest recorded among the genotypes. But in 2020, a record of 111.67 days was gotten from NCRI SOYAC9 (the lowest for the year). However, the earlier maturing genotypes in 2019 and that of 2020 did not differ significantly from each other in any of the years.

The highest average number of branches observed in a plant in 2019 was in NCRI SOYAC73 (7 branches), which differed significantly from NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC9, and NCRI SOYAC63 only. NCRI SOYAC7 had the highest average number of branches per plant (5.33 branches) in 2020. This differed differently from NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC68, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, and NCRI SOYAC22. The least number of branches per plant in 2019 was recorded in NCRI SOYAC9, which was significantly different from only NCRI SOYAC73 and NCRI

SOYAC76. Similarly, in 2020 NCRI SOYAC9 along with NCRI SOYAC75 had the least number of branches per plant.

4.1.5.2 Yield Traits of the Soybean Genotypes in Minna

The performances of the genotypes on yield traits in Minna are as presented in Table 4.5. For average number of pods produced by a plant, NCRI SOYAC3 had 92 pods per plant in 2019. This was the highest for the year and was significantly different from NCRI SOYAC17, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC63, NCRI SOYAC75, and NCRI SOYAC10. Conversely, in 2020, NCRI SOYAC17 had the highest average number of pods per plant (80.33 pods), which differed significantly from four genotypes viz: NCRI SOYAC73, NCRI SOYAC25, NCRI SOYAC9, and NCRI SOYAC67. NCRI SOYAC24 had the lowest average number of pods per plant in 2019 (48 pods), while NCRI SOYAC25 produced the least average number of pods per plant in 2020 (34.33 pods). The genotype with the highest average number of seed per pod in 2019 was NCRI SOYAC7 (2.83 seeds), which was significantly different from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC63, and NCRI SOYAC10. In 2020, the genotype NCRI SOYAC25 had the pods with highest average number of seeds (2.7 seeds), which differed significantly from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC73, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC63, NCRI SOYAC10, NCRI SOYAC67, and NCRI SOYAC61. The genotype that produced pods with the least number of seeds in 2019 was NCRI SOYAC3 (2.2 seeds) and in 2020 it was NCRI SOYAC64 (2.2 seeds).

The above ground biomass of NCRI SOYAC77 (5.33 tons/ha) was the highest for the year 2019. It differed significantly from NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC10, and NCRI SOYAC67. In 2020, the genotype NCRI SOYAC17 had the highest above ground biomass (3.3 tons/ha) that differed significantly from NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC9, NCRI SOYAC16, NCRI SOYAC67, and NCRI SOYAC22. The genotype with the least above ground biomass in 2019 was NCRI SOYAC63 (2.43 tons/ha), but genotype NCRI SOYAC25 produced the least in 2020 (1.5 tons/ha).

The mean seed yield of NCRI SOYAC77 (2.37 tons/ha) became the highest produced among the genotypes for the year 2019. But it was not significantly different from some genotypes like NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC3, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC22. In 2020, NCRI SOYAC78 had the highest yield (1.53 tons/ha), which differed significantly from only NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC9, NCRI SOYAC68, and NCRI SOYAC67. The poorest in yield among the genotypes in 2019 was NCRI SOYAC65 (1 ton/ha), but it was significantly different from only NCRI SOYAC77, NCRI SOYAC73, and NCRI SOYAC28. The year 2020 had NCRI SOYAC25 as the lowest in yield (0.67 ton/ha). However, it differed significantly from only four genotypes namely; NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, and NCRI SOYAC29.

The genotype that produced the largest seeds in 2019 and 2020 was NCRI SOYAC77, as indicated by its significantly high one hundred seeds weight (19 g and 16 g, respectively). This differed significantly from all other genotypes in 2019 and all genotypes except NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC20, NCRI SOYAC62, and NCRI SOYAC22 in 2020. The lowest in seed weight in 2019 and 2020 among the genotypes was NCRI SOYAC7 (11.33 g and 10 g, respectively). It differed significantly from all other genotypes in 2019 expect NCRI SOYAC78, NCRI SOYAC64, NCRI SOYAC63, and NCRI SOYAC75; and NCRI SOYAC18, NCRI SOYAC69, NCRI SOYAC73, NCRI SOYAC28, and NCRI SOYAC63 in 2020. The highest harvest index in 2019 (0.51) was recorded in NCRI SOYAC67, which significantly differed from NCRI SOYAC18, NCRI SOYAC73, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC10, and NCRI SOYAC76. In 2020, NCRI SOYAC22 had the highest harvest index (0.5) that differed significantly from only NCRI SOYAC77 and NCRI SOYAC9. The lowest harvest index in 2019 (0.34) was recorded in NCRI SOYAC65; and that of 2020 (0.38) was recorded in NCRI SOYAC9.

Table 4.4: Performances of the soybean genotypes on growth traits in Minna

Genotype	Emergence (%)		D50%F		PH (cm)		DM		B/P	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	60.33abcd	64.00hi	52.00bcd	48.00c	30.67a	34.00fghij	116.33bcdef	116.33bcde	6.33abc	4.67abc
NCRI SOYAC18	51.00abcdef	71.33bcdefghi	50.67defg	48.00c	23.33cdef	38.67bcdefgh	118.33b	119.00a	6.00abc	4.67abc
NCRI SOYAC17	44.67defg	80.00abcd	54.33ab	51.67b	25.00abcdef	44.33abc	118.00bc	116.33bcde	5.33abc	4.00bcde
NCRI SOYAC69	47.00cdefg	74.67bcdefgh	51.33cde	45.67defg	22.33def	41.00abcdefg	118.00bc	117.33abc	5.67abc	4.67abc
NCRI SOYAC77	37.67fgh	71.67bcdefghi	53.67abc	47.00cde	21.67ef	35.67defghi	118.00bc	116.00bcdef	6.00abc	3.33de
NCRI SOYAC73	54.33abcdef	89.00a	52.33bcd	47.33cd	28.33abcd	38.00cdefgh	117.67bcd	115.67bcdefg	7.00a	3.33de
NCRI SOYAC26	68.00a	82.00ab	51.00cdef	45.33defg	23.00def	44.00abc	117.33bcd	113.67fghij	6.00abc	4.67abc
NCRI SOYAC29	64.33abc	74..33bcdefgh	47.33h	43.67g	23.33cdef	43.33abcd	117.33bcd	114.67defgh	5.33abc	4.00bcde
NCRI SOYAC25	39.67efgh	77.00bcde	51.00cdef	45.33defg	30.00ab	44.00abc	115.00efg	113.00hij	6.33abc	4.00bcde
NCRI SOYAC28	57.00abcde	72.67bcdefghi	50.67defg	45.00efg	25.67abcdef	42.00abcdef	117.33bcd	114.67defgh	6.00abc	4.33abcd
NCRI SOYAC64	53.67abcdef	78.00bcd	49.00efgh	45.00efg	23.00def	34.00fghij	114.00g	113.00hij	5.00bc	4.33abcd
NCRI SOYAC65	26.00h	62.00i	49.00efgh	45.67defg	23.33cdef	39.33abcdefgh	114.00g	112.00ij	5.00bc	3.33de
NCRI SOYAC24	45.33defg	67.00efghi	47.33h	44.67fg	26.00abcdef	39.00bcdefgh	114.00g	113.67fghij	6.00abc	3.67cde
NCRI SOYAC3	31.67gh	77.00bcde	50.33defg	46.67cdef	26.67abcde	43.00abcde	117.00bcde	117.00abcd	6.33abc	4.67abc
NCRI SOYAC9	49.33bcdefg	71.00cdefghi	47.33h	44.67fg	29.33abc	41.67abcdefg	114.33fg	111.67j	4.67c	3.00e
NCRI SOYAC7	47.00cdefg	75.33bcdefg	56.33a	54.67a	24.33bcdef	35.67defghij	121.33a	118.00ab	6.00abc	5.33a
NCRI SOYAC68	56.67abcde	74.00bcdefgh	50.67defg	45.67defg	24.33bcdef	40.00abcdefg	117.33bcd	114.33efghi	5.67abc	4.00bcde
NCRI SOYAC20	51.00abcdef	65.67fghi	48.33fgh	45.00efg	24.00bcdef	37.33cdefghi	115.00efg	112.67hij	5.67abc	4.33abcd
NCRI SOYAC62	62.67abcd	64.00hi	51.00cdef	47.00cde	24.67abcdef	35.00efghij	116.67bcde	114.00efghij	6.33abc	4.67abc
NCRI SOYAC63	67.00ab	65.00ghi	52.33bcd	44.00g	21.00ef	28.67j	116.00cdefg	113.33hij	5.00bc	5.00ab
NCRI SOYAC75	58.33abcd	70.33defghi	51.00cdef	45.00efg	24.33bcdef	31.33hij	116.33bcdef	113.67fghij	5.33abc	3.00e
NCRI SOYAC10	65.33ab	69.33defghi	48.00gh	43.67g	20.33f	29.33ij	115.67defg	115.00cdefgh	6.00abc	3.67cde
NCRI SOYAC67	58.67abcd	72.67bcdefghi	49.67defgh	45.67defg	26.33abcdef	33.67ghij	114.33fg	114.00efghi	5.67abc	3.33de
NCRI SOYAC76	37.67fgh	75.bcdefg	54.67ab	52.33b	22.67def	47.33a	118.00bc	117.33abcd	6.67ab	5.00ab
NCRI SOYAC61	56.67abcde	76.00bcdef	51.33cde	47.33cd	26.00abcdef	36.67cdefghij	117.00bcde	116.00bcdef	6.00abc	4.33abcd
NCRI SOYAC22	47.00cdefg	81.67abc	50.33defg	45.00efg	26.33abcdef	46.67ab	117.00bcde	114.33efghi	6.33abc	4.00bcde
Mean	51.46	73.13	50.81	46.00	24.85	38.62	116.59	114.87	5.83	4.13
Range (Min-Max)	26.00-68.00	62.00-89.00	47.33-56.33	43.67-54.67	21.00-30.67	28.67-47.33	114.00-121.33	111.67-119.00	4.67-7.00	3.00-5.33
±SE	6.40	3.85	0.95	0.77	2.17	2.91	0.82	0.83	0.60	0.47
CV	21.54	9.12	3.23	2.87	15.12	13.05	1.22	1.25	17.83	19.54

Means followed by the same letter(s) within a column are not significantly different at P≤0.05 using DMRT; D50%F = Days to 50% Flowering; PH = Plant Height; DM = Days to Maturity, B/P = Branches per Plant; ±SE = Standard error of the mean; CV = Coefficient of Variation.

Table 4.5: Performances of the genotypes on yield traits in Minna

Genotype	P/P		S/P		AGB (ton/ha)		SY (ton/ha)		100SW (g)		HI	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	78.67abc	72.33abc	2.40cdefgh	2.40bcde	3.57abcd	3.03ab	1.70abc	1.53a	13.33efgh	12.67bcd	0.48abcd	0.50a
NCRI SOYAC18	66.33abc	71.67abc	2.63abcd	2.53abcd	4.30abcd	2.87abc	1.70abc	1.37abcd	14.33cdefg	12.00de	0.39de	0.48ab
NCRI SOYAC17	58.00bc	80.33a	2.43bcdefgh	2.40bcde	4.07abcd	3.30a	1.53bc	1.47ab	14.00defg	13.00bcd	0.41abcde	0.44ab
NCRI SOYAC69	67.33abc	65.00abcd	2.33efgh	2.27de	3.67abcd	2.73abcd	1.50bc	1.20abcde	16.33bc	12.00de	0.41abcde	0.44ab
NCRI SOYAC77	74.67acb	56.33abcd	2.50bcdefg	2.53abcd	5.33a	3.03ab	2.37a	1.23abcde	19.00a	16.00a	0.46abcd	0.41b
NCRI SOYAC73	84.00ab	40.33bcd	2.67abc	2.40bcde	5.03ab	1.53cd	1.87ab	0.73de	14.33cdefg	12.00de	0.38de	0.48ab
NCRI SOYAC26	71.33abc	44.00abcd	2.47bcdefgh	2.60abc	3.80abcd	1.70bcd	1.67abc	0.83bcde	15.00bcdef	13.00bcd	0.45abcd	0.49a
NCRI SOYAC29	69.67abc	75.33ab	2.60abcde	2.60abc	3.87abcd	3.00ab	1.63abc	1.40abc	13.67defg	13.00bcd	0.44abcd	0.46ab
NCRI SOYAC25	71.67abc	34.33d	2.63abcd	2.7a	3.73abcd	1.50d	1.70abc	0.67e	15.33bcde	13.00bcd	0.46abcd	0.45ab
NCRI SOYAC28	76.00abc	45.33abcd	2.63abcd	2.67ab	3.83abcd	1.80bcd	1.83ab	0.80cde	15.00bcdef	12.00de	0.48abcd	0.47ab
NCRI SOYAC64	63.33abc	52.33abcd	2.70ab	2.20e	2.67cd	1.77bcd	1.27bc	0.87cde	13.00fgh	14.00abcd	0.48abcd	0.49a
NCRI SOYAC65	54.33bc	54.00abcd	2.33efgh	2.53abcd	2.93cd	2.30abcd	1.00c	1.00abcde	15.33bcde	13.67bcd	0.34e	0.45ab
NCRI SOYAC24	48.00c	58.00abcd	2.30fgh	2.40bcde	2.97cd	2.20abcd	1.17bc	1.00abcde	16.33bc	14.33abc	0.42abcde	0.46ab
NCRI SOYAC3	92.00a	60.33abcd	2.20h	2.27de	4.03abcd	2.30abcd	1.60abc	1.10abcde	14.00defg	13.67bcd	0.40bcde	0.47ab
NCRI SOYAC9	59.33bc	36.67cd	2.43bcdefgh	2.47abcde	3.00cd	1.93bcd	1.50bc	0.77cde	14.67bcdef	13.33bcd	0.49ab	0.38b
NCRI SOYAC7	59.33bc	51.67abcd	2.83a	2.67ab	3.30bcd	2.23abcd	1.57bc	0.97abcde	11.33h	10.00e	0.49ab	0.43ab
NCRI SOYAC68	69.33abc	54.67abcd	2.70ab	2.40bcde	3.20bcd	1.87bcd	1.47bc	0.87bcde	14.33cdefg	12.67bcd	0.46abcd	0.46ab
NCRI SOYAC20	65.00abc	68.00abcd	2.27gh	2.40bcde	3.20bcd	2.67abcd	1.50bc	1.20abcde	16.67b	14.67ab	0.47abcd	0.45ab
NCRI SOYAC62	63.67abc	49.33abcd	2.60abcde	2.47abcde	3.20bcd	2.03abcd	1.47bc	0.93abcde	15.00bcdef	14.33abc	0.46abcd	0.45ab
NCRI SOYAC63	55.67bc	75.33ab	2.37defgh	2.33cde	2.43d	2.90ab	1.20bc	1.27abcde	12.33gh	10.00e	0.49ab	0.44ab
NCRI SOYAC75	53.00c	61.67abcd	2.60abcde	2.67ab	3.03bcd	2.37abcd	1.33bc	1.10abcde	12.33gh	12.33cd	0.44abcd	0.47ab
NCRI SOYAC10	58.00bc	44.67abcd	2.50bcdefg	2.40bcde	3.30bcd	2.10abcd	1.27bc	0.93abcde	14.67bcdef	13.00bcd	0.39cde	0.46ab
NCRI SOYAC67	55.67ab	39.67bcd	2.67abc	2.40bcde	2.60cd	1.73bcd	1.33bc	0.83bcde	13.67defg	13.33bcd	0.51a	0.48ab
NCRI SOYAC76	76.67abc	54.67abcd	2.63abcd	2.67ab	4.5abc	2.67abcd	1.70abc	1.00abcde	15.67bcd	13.00bcd	0.38de	0.44ab
NCRI SOYAC61	74.67abc	66.33abcd	2.57abcdef	2.33cde	3.70abcd	2.23abcd	1.60abc	1.03abcde	14.33cdefg	12.33cd	0.43abcde	0.46ab
NCRI SOYAC22	71.67abc	52.00abcd	2.63abcd	2.46abcde	3.93abcd	1.90bcd	1.67abc	0.97abcde	15.00bcdef	14.00abcd	0.42abcde	0.50a
Mean	66.82	56.32	2.52	2.47	3.58	2.28	1.54	1.04	14.58	12.97	0.44	0.46
Range (Min-Max)	48.00-92.00	34.33-80.33	2.20-2.83	2.20-2.70	2.43-5.33	1.50-3.30	1.00-2.37	0.67-1.53	11.33-19.00	12.00-16.00	0.34-0.51	0.41-0.50
±SE	10.85	12.76	0.1	0.1	0.71	0.47	0.28	0.23	0.72	0.71	0.04	0.03
CV	28.11	39.23	6.8	7.12	34.21	35.78	31.23	38.47	8.58	9.44	14.29	12.45

Means followed by the same letter(s) within a column are not significantly different at P≤0.05 using DMRT; P/P = Pods per Plant; S/P = Seeds per Pod; AGB = Above Ground Biomass, SY = Seed Yield; 100SW = one hundred seed weight; HI = Harvest Index; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.5.3 Plant Growth Traits of the Soybean Genotypes in Chinka

The genotypes' performances on growth traits in Chinka are as presented in Table 4.6. The genotypes were significantly different in all the traits in both 2019 and 2020. In 2019, the highest emergence percentage of 77.33 % was observed in NCRI SOYAC62. It was significantly different from NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC3, and NCRI SOYAC76. In 2020, NCRI SOYAC73 had the highest seedling emergence percentage (92.67 %), which was significantly different from other genotypes except NCRI SOYAC17, and NCRI SOYAC22. The lowest percentage of seedling emergence in 2019 (44.67 %) was observed in NCRI SOYAC25, which was significantly different from NCRI SOYAC78, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, and NCRI SOYAC10. The lowest in 2020 was recorded in NCRI SOYAC 65 (61 %), which significantly differed from NCRI SOYAC17, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC76 and NCRI SOYAC22.

The highest number of days to attain 50 % flowering was recorded in NCRI SOYAC7 in both 2019 and 2020 (55.33 days and 53 days, respectively), which did not differ significantly from NCRI SOYAC17 and NCRI SOYAC77 in 2019 but differed significantly from all other genotypes in 2020. The shortest number of days to achieve 50 % flowering among the genotypes was recorded in NCRI SOYAC9 in 2019 (46.33 days); and in NCRI SOYAC29 in 2020 (43 days).

The average tallest plant in 2019 was recorded in genotype NCRI SOYAC26 (28.33 cm), which was significantly different from NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC76, and NCRI SOYAC22. Meanwhile, in 2020, NCRI SOYAC22 produced the tallest plants with an average plant height of 49.67 cm. But it was not significantly different from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC62, NCRI SOYAC67, NCRI SOYAC76 and NCRI SOYAC22. The shortest plant height was observed in NCRI SOYAC76 in 2019 (16.67 cm); and NCRI SOYAC63 in 2020 (26 cm). For number of days to reach maturity in 2019, it took NCRI SOYAC7 approximately 116 days to reach maturity, which the highest recorded among the genotypes that differed significantly from every other genotype. In 2020, NCRI SOYAC18 was the last to reach maturity (120 days), but was not significantly different from NCRI SOYAC3, NCRI SOYAC7, and NCRI SOYAC76. Conversely, in 2019, it took NCRI SOYAC63 approximately 105 days to reach maturity; the lowest recorded among the genotypes. But in 2020, a record of 111.67 days was gotten from NCRI SOYAC65 and NCRI SOYAC9 (the lowest for the year). Interestingly, the earlier maturing genotype of 2019 and those of 2020 did not differ significantly from each other in any of the years.

The highest average number of branches recorded in a plant in 2019 was in NCRI SOYAC73 and NCRI SOYAC 26 (5.67 branches), which differed significantly from NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC75, NCRI SOYAC67 and NCRI SOYAC22. In 2020, NCRI SOYAC7 had the highest average number of branches per plant (7.67 branches). This differed differently from other genotypes except NCRI SOYAC25 and NCRI SOYAC3 only. On the other hand, in 2019 the least number of branches per plant was recorded in NCRI SOYAC65, NCRI SOYAC24 and NCRI SOYAC67. Similarly, in 2020 NCRI

SOYAC9 along with NCRI SOYAC64 and NCRI SOYAC20 had the least number of branches per plant.

Table 4.6: Performances of the genotypes on growth traits in Chinka

Genotype	Emergence (%)		D50%F		PH (cm)		DM		B/P	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	72.33ab	65.00ef	51.33bc	48.33def	26.33ab	41.33abcdef	107.00ghi	117.00bcde	4.67abcd	6.33cde
NCRI SOYAC18	62.00abcde	71.00cdefg	50.00bcde	49.33cd	23.00abcd	36.33defgh	110.67bcde	120.00a	4.67abcd	5.67efg
NCRI SOYAC17	50.67bcde	81.00abc	54.33a	50.33bc	24.00abcd	44.00abcde	112.00bc	116.00defg	2.67de	6.00def
NCRI SOYAC69	61.33abcde	73.00bcdefg	51.33bc	46.00gh	22.00bcde	45.67ab	108.00fgh	117.67bcd	3.67abcde	6.33cde
NCRI SOYAC77	50.67bcde	72.33bcdefg	54.00a	47.00fg	21.33bcde	35.67efgh	106.33hij	116.67bcde	3.00cde	5.33fg
NCRI SOYAC73	64.33abcde	92.67a	51.67b	47.00fg	25.00abc	40.33bcdef	109.00efg	116.33cdef	5.67a	6.00def
NCRI SOYAC26	68.67abcd	79.00bcd	51.00bc	45.00hij	28.33a	45.00abc	109.67def	113.67hij	5.67a	6.67bcd
NCRI SOYAC29	77.00a	75.00bcdef	47.00hi	43.00l	23.33abcde	40.33bcdef	109.00efg	115.33efgh	4.00abcde	5.33fg
NCRI SOYAC25	44.67e	78.00bcde	49.00defg	45.00hij	24.67abcd	42.00abcdef	105.00ij	112.33ij	3.67abcde	7.33ab
NCRI SOYAC28	64.00abcde	72.33bcdefg	50.67bcd	44.33ijkl	24.67abcd	40.67bcdef	110.33bcde	114.33fghi	3.33bcde	6.33cde
NCRI SOYAC64	65.00abcde	73.67bcdefg	49.67cdef	44.33ijkl	24.67abcd	34.67fgh	105.00ij	112.67ij	4.67abcd	4.33h
NCRI SOYAC65	47.33de	61.00g	50.00bcde	45.33hi	23.67abcd	41.67abcdef	105.67ij	111.67j	2.00e	6.00def
NCRI SOYAC24	58.00abcde	70.00cdefg	47.67ghi	45.00hij	22.00bcde	45.00abc	105.33ij	114.33fghi	2.00e	5.67efg
NCRI SOYAC3	45.67de	78.00bcde	51.00bc	49.00cde	20.00cde	40.67bcdef	111.33bcd	118.00abcd	3.67abcde	7.00abc
NCRI SOYAC9	73.33ab	68.33cdefg	46.33i	45.00hij	23.67abcd	43.33abcde	105.67ij	111.67j	4.00abcde	6.00def
NCRI SOYAC7	61.33abcde	71.33cdefg	55.33a	53.00a	19.33cde	37.00cdefg	115.67a	118.33abc	5.00abc	7.67a
NCRI SOYAC68	66.67abcde	74.67bcdef	50.00bcde	46.00gh	23.00abcd	37.33bcdefg	111.00bcde	115.00efgh	4.33abcd	5.67efg
NCRI SOYAC20	71.33abc	65.67efg	48.33efgh	44.33ijkl	25.33abc	34.33fghi	108.00fgh	112.33ij	4.67abcd	4.33h
NCRI SOYAC62	77.33a	70.00cdefg	51.00bc	48.00def	24.00abcd	43.67abcde	111.00bcde	113.67hij	5.00abc	6.33cde
NCRI SOYAC63	68.33abcd	66.00defg	51.33bc	44.00ijkl	18.67de	26.00i	104.67j	113.67hij	4.33abcd	5.67efg
NCRI SOYAC75	61.33abcde	70.67cdefg	51.00bc	44.67hijk	20.67bcde	31.67ghi	110.67bcde	114.00ghi	2.67de	5.67efg
NCRI SOYAC10	68.67abcd	63.67fg	47.33ghi	43.33kl	20.00cde	28.33hi	110.33bcde	114.00ghi	5.33ab	5.00gh
NCRI SOYAC67	63.67abcde	73.00bcdefg	49.00defg	44.33ijkl	26.33ab	44.67abcd	106.67hij	114.00ghi	2.00e	5.67efg
NCRI SOYAC76	49.00cde	74.67bcdef	48.00fghi	51.33b	16.67e	44.00abcde	112.33b	118.67ab	4.67abcd	6.33cde
NCRI SOYAC61	66.00abcde	72.67bcdefg	49.67cdef	47.67ef	23.00abcd	35.67efgh	111.00bcde	116.00defg		5.33fg
NCRI SOYAC22	64.67abcde	84.67ab	51.33bc	43.67jkl	22.00bcde	49.67a	110.00cdef	114.33fghi	3.00cde	6.33cde
Mean	62.44	72.97	50.28	46.32	22.91	39.58	108.9	115.06	3.97	5.94
Range (Min-Max)	44.67-77.33	61.00-92.67	46.33-55.33	43.00-53.00	16.67-28.33	26.00-49.67	104.67-115.67	111.67-120	2.00-5.67	4.33-7.67
±SE	8.20	4.63	0.7	0.58	2.18	3.01	0.82	0.82	0.79	0.31
CV	22.76	10.99	2.41	2.16	16.45	13.17	1.31	1.23	34.31	9.04

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; D50%F = Days to 50% Flowering; PH = Plant Height; DM = Days to Maturity, B/P = Branches per Plant; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.5.4 Yield Traits of the Soybean Genotypes in Chinka

The performances of the genotypes on yield traits in Chinka are as presented in Table 4.7. For average number of pods on a plant, NCRI SOYAC26 had 88.67 pods per plant in 2019. This was the highest for the year, and was significantly different from NCRI SOYAC17, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, NCRI SOYAC76, and NCRI SOYAC22. In 2020, NCRI SOYAC25 had the highest average number of pods per plant (117.67 pods), which differed significantly from NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC63, NCRI SOYAC75 and NCRI SOYAC10. NCRI SOYAC65 had the lowest average number of pods per plant in 2019 (38 pods), while NCRI SOYAC29 produced the least average number of pods per plant in 2020 (66.33 pods).

Two genotypes (NCRI SOYAC75 and NCRI SOYAC67) were with the highest average number of seeds per pod in 2019 (2.73 each), which was significantly different from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC20, and NCRI SOYAC63. In 2020, genotypes NCRI SOYAC73 and NCRI SOYAC67 had the pods with highest average number of seeds (2.73 seeds), which differed significantly from NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC20, NCRI SOYAC63, NCRI SOYAC10, NCRI SOYAC76, and NCRI SOYAC61. The genotype that produced pods with the least number of seeds in 2019 was NCRI SOYAC69 (2.3 seeds) and in 2020, three genotypes (NCRI SOYAC20, NCRI SOYAC63 and NCRI SOYAC10) had pods with the least number of seeds (2.2 seeds).

The above ground biomass of NCRI SOYAC77 (3.70 tons/ha) was the highest gotten for the year 2019. It differed significantly from NCRI SOYAC17, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, and NCRI SOYAC67. In 2020, the genotype NCRI SOYAC62 had the highest above ground biomass (4.87 tons/ha) that differed significantly from NCRI SOYAC18, NCRI SOYAC29, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, and NCRI SOYAC10. The genotype with the least above ground biomass in 2019 was NCRI SOYAC65 (2 tons/ha), but genotype NCRI SOYAC29 produced the least in 2020 (2.47 tons/ha).

The mean seed yield produced by NCRI SOYAC77 (1.73 tons/ha) was the highest produced among the genotypes for the year 2019. But it was not significantly different from the yield of NCRI SOYAC17, NCRI SOYAC18, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC10, NCRI SOYAC67, and NCRI SOYAC22. In 2020, NCRI SOYAC9 had the highest average seed yield (1.97 tons/ha), which differed significantly from only NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC10, and NCRI SOYAC22. The lowest in yield among the genotypes in 2019 was NCRI SOYAC65 (0.9 ton/ha), which was significantly different from NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC20, NCRI SOYAC63 and NCRI SOYAC61. The year 2020 had NCRI

SOYAC18 as the least in average seed yield (0.9 ton/ha) and it differed significantly from NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC62, NCRI SOYAC75, and NCRI SOYAC76.

The genotype NCRI SOYAC77, having an average one hundred seeds weight of 16.33 g produced the heaviest seeds in 2019, which differed significantly from all other genotypes in 2019. In 2020, NCRI SOYAC9 had the heaviest seeds (15.33), although not significantly different from NCRI SOYAC77, NCRI SOYAC65, and NCRI SOYAC20. The lowest in seed weight in 2019 and 2020 among the genotypes was NCRI SOYAC7 (8 g and 9.33 g, respectively). The highest harvest index in 2019 (0.503) was recorded in NCRI SOYAC26, which significantly differed from NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC73, NCRI SOYAC25, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, and NCRI SOYAC76. In 2020, NCRI SOYAC20 had the highest harvest index (0.49) that differed significantly from other genotypes except NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC63, NCRI SOYAC75 and NCRI SOYAC10. The lowest harvest index in 2019 (0.4) was recorded in NCRI SOYAC73; and that of 2020 (0.33) was recorded in NCRI SOYAC62.

Table 4.7: Performances of the genotypes on yield traits in Chinka

Genotype	P/P		S/P		AGB (ton/ha)		SY (ton/ha)		100SW (g)		HI	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	56.00abc	102.33abcdef	2.40efg	2.60abc	3.03abcd	3.90abcdef	1.37abcdef	1.47abcdef	11.00fgh	11.67defghi	0.46abcd	0.38cdef
NCRI SOYAC18	58.33abc	78.33efgh	2.63abcd	2.67ab	2.83abcde	2.60ef	1.23bcdef	0.90f	11.00fgh	10.33ghij	0.43cdef	0.34def
NCRI SOYAC17	43.67bc	97.00abcdef	2.50bcdefg	2.60abc	2.50cde	4.27abcd	1.10def	1.67abc	10.33gh	12.33cdefg	0.44cdef	0.40bcdef
NCRI SOYAC69	72.00ab	102.00abcdef	2.30g	2.40bcde	3.20abcd	4.53ab	1.50abcd	1.70abc	11.67defg	12.67cdef	0.47abcd	0.38cdef
NCRI SOYAC77	60.00abc	79.00efgh	2.50bcdefg	2.33cde	3.70a	3.23abcdef	1.73a	1.33bcdef	16.33a	15.00ab	0.46abcd	0.41bcd
NCRI SOYAC73	71.67ab	99.00abcdef	2.60abcde	2.73a	3.43abc	3.60abcdef	1.37abcdef	1.20cdef	11.00fgh	9.67ij	0.40f	0.33f
NCRI SOYAC26	88.67a	103.67abcde	2.57abcde	2.47abcde	3.23abcd	4.50abc	1.63ab	1.83ab	12.67bcde	11.33defghij	0.50a	0.41bcd
NCRI SOYAC29	53.00bc	66.33h	2.57abcde	2.53abcd	2.80abcde	2.47f	1.33abcdef	0.97ef	11.67defg	11.33defghij	0.47abcd	0.41bcd
NCRI SOYAC25	40.33bc	117.67a	2.60abcde	2.60abc	2.37de	4.17abcde	1.00ef	1.53abcde	11.67defg	11.33defghij	0.42def	0.37cdef
NCRI SOYAC28	65.33abc	94.00abcdef	2.60abcde	2.47abcde	2.77abcde	3.83abcdef	1.40abcde	1.40abcdef	11.33efgh	12.00defgh	0.49ab	0.37cdef
NCRI SOYAC64	66.00abc	81.00defgh	2.63abcd	2.40bcde	3.03abcd	2.87cdef	1.40abcde	1.03def	10.00hi	10.00hij	0.46abcde	0.36cdef
NCRI SOYAC65	38.00c	105.00abcd	2.33fg	2.60abc	2.00e	4.00abcdef	0.90f	1.57abcd	12.00cdef	14.33abc	0.45bcdef	0.39bcdef
NCRI SOYAC24	42.33bc	113.33ab	2.43defg	2.27de	2.43de	4.33abcd	1.13cdef	1.87ab	13.67b	12.67cdef	0.46abcd	0.42abc
NCRI SOYAC3	43.00bc	90.00bcdefgh	2.33fg	2.60abc	2.57bcde	2.80def	1.10def	0.97ef	11.00fgh	10.67fghij	0.43cdef	0.35cdef
NCRI SOYAC9	49.67bc	101.67abcdef	2.47cdefg	2.60abc	2.80abcde	4.33abcd	1.30abcdef	1.97a	12.00cdef	15.33a	0.46abcd	0.46ab
NCRI SOYAC7	70.67abc	93.00abcdefg	2.70ab	2.53abcd	3.07abcd	3.13bcdef	1.27abcdef	1.17cdef	8.00j	9.33j	0.41ef	0.37cdef
NCRI SOYAC68	51.33bc	82.33cdefgh	2.67abc	2.67ab	2.67bcde	3.20bcdef	1.20bcdef	1.20cdef	8.67ij	11.00efghij	0.45bcde	0.38cdef
NCRI SOYAC20	62.33abc	67.67gh	2.40efg	2.20e	3.13abcd	2.70def	1.43abcde	1.30bcdef	12.67bcde	13.33abcd	0.45bcde	0.49a
NCRI SOYAC62	54.00bc	108.00abc	2.63abcd	2.53abcd	2.80abcde	4.87a	1.30abcdef	1.57abcd	12.00cdef	11.67defghi	0.46abcd	0.33f
NCRI SOYAC63	57.67abc	84.00cdefgh	2.40efg	2.20e	3.07abcd	3.33abcdef	1.43abcde	1.47abcdef	10.67fgh	12.00defgh	0.47abcd	0.46ab
NCRI SOYAC75	46.33bc	89.00bcdefgh	2.73a	2.60abc	2.67bcde	3.90abcdef	1.27abcdef	1.63abc	11.67defg	11.33defghij	0.48abc	0.42abc
NCRI SOYAC10	46.00bc	77.33fgh	2.53abcdef	2.20e	2.63bcde	2.87cdef	1.23bcdef	1.20cdef	13.00bcd	13.00bcde	0.46abcd	0.42abc
NCRI SOYAC67	50.33bc	93.67abcdef	2.73a	2.73a	2.33de	3.63abcdef	1.10def	1.40abcdef	11.67defg	11.00efghij	0.47abcd	0.37cdef
NCRI SOYAC76	51.67bc	95.00abcdef	2.60abcde	2.40bcde	3.00abcd	3.90abcdef	1.37abcdef	1.60abcd	13.33bc	11.33defghij	0.45bcde	0.41bcd
NCRI SOYAC61	71.67ab	101.67abcdef	2.70ab	2.40bcde	3.47ab	3.73abcdef	1.60abc	1.47abcdef	11.33efgh	10.00hij	0.46abcde	0.40bcdef
NCRI SOYAC22	54.67bc	93.67abcdef	2.67abc	2.60abc	2.43ed	3.90abcdef	1.20bcdef	1.33bcdef	11.67defg	12.33cdefg	0.49ab	0.36cdef
Mean	56.33	92.91	2.55	2.50	2.84	3.64	1.30	1.41	11.62	11.81	0.46	0.39
Range (Min-Max)	38.00-88.67	66.33-117.67	2.30-2.73	2.20-2.73	2.00-3.70	2.47-4.87	0.90-1.73	0.90-1.97	8.00-16.33	9.33-15.33	0.40-0.50	0.33-0.49
±SE	11.73	9.08	0.07	0.1	0.34	0.58	0.17	0.21	0.58	0.74	0.02	0.03
CV	36.07	16.93	5.06	6.71	20.59	27.7	22.78	25.25	8.58	10.84	6.44	11.42

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; P/P = Pods per Plant; S/P = Seeds per Pod; AGB = Above Ground Biomass, SY = Seed Yield; 100SW = one hundred seed weight; HI = Harvest Index; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.5.5 Plant Growth Traits of the Soybean Genotypes in Awka

The performances of the genotypes on growth traits in Awka are presented in Table 4.8. The genotypes differed significantly in all the traits in both years of study. In 2019, the highest emergence percentage of 80 % was observed in genotypes NCRI SOYAC26 and NCRI SOYAC61. They were significantly different from NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC76, and NCRI SOYAC22. In 2020, the highest seedling emergence percentage (78 %) was obtained in NCRI SOYAC61, which was significantly different from other genotypes except NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC 29, NCRI SOYAC 3, NCRI SOYAC 75, NCRI SOYAC 67, NCRI SOYAC76, and NCRI SOYAC22. The lowest emergence percentage in 2019 (26.67 %) was recorded in NCRI SOYAC77, but was not significantly different from NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC76, and NCRI SOYAC22. The year 2020 had NCRI SOYAC 24 as the lowest in seedling emergence percentage (29 %), which did not differ significantly from NCRI SOYAC69, NCRI SOYAC65, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC63, and NCRI SOYAC10.

The last genotype in 2019 to achieve 50 % flowering was NCRI SOYAC67 (49 days), which differed significantly from NCRI SOYAC17, NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, and NCRI SOYAC75. The last genotype in 2020 was NCRI SOYAC76 (53.33 days) that differed significantly from NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC62, NCRI

SOYAC63, NCRI SOYAC75, and NCRI SOYAC22. The first genotype to achieve 50 % flowering among the genotypes in 2019 was recorded in NCRI SOYAC9 (42.67 days); and NCRI SOYAC25 in 2020 (48.67 days).

The genotype with the tallest plant in 2019 was NCRI SOYAC7 (55 cm), which was not significantly different from NCRI SOYAC24, NCRI SOYAC20, NCRI SOYAC63, and NCRI SOYAC75. Meanwhile, in 2020, NCRI SOYAC9 was the tallest with an average plant height of 47.33 cm, which was not significantly different from NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC67, NCRI SOYAC76 and NCRI SOYAC61. The shortest plants in 2019 were observed in NCRI SOYAC77 (25.33 cm); and NCRI SOYAC10 in 2020 (30.67 cm).

In terms maturity duration in 2019, the last genotype to reach maturity was NCRI SOYAC65 (approximately 120 days); the highest recorded among the genotypes, which differed significantly from every other genotype except NCRI SOYAC7 and NCRI SOYAC22. In 2020, NCRI SOYAC69 was the last to reach maturity (109.33 days), it was significantly different from NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC7, NCRI SOYAC75 and NCRI SOYAC67. On other hand, in 2019, genotypes NCRI SOYAC62 and NCRI SOYAC75 were the first to reach maturity (107 days); the lowest recorded among the genotypes. But in 2020, a record of 102.67 days was gotten from NCRI SOYAC29, which was the lowest for the year; making the genotype the first to reach maturity in Awka in 2020.

The highest average number of branches borne on a plant in 2019 was in NCRI SOYAC9 (5 branches), which differed significantly from NCRI SOYAC69 and NCRI

SOYAC67 only. Two genotypes (NCRI SOYAC26 and NCRI SOYAC25) had the highest average number of branches per plant (7.33 branches) in 2020. This differed differently from NCRI SOYAC17, NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC68, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC10, and NCRI SOYAC67. The least number of branches per plant in 2019 was obtained from NCRI SOYAC69 and NCRI SOYAC67, which were significantly different from only NCRI SOYAC9. Similarly, in 2020 NCRI SOYAC65 had the least number of branches per plant.

4.1.5.6 Yield Traits of the Soybean Genotypes in Awka

The performances of the genotypes on yield traits in Awka are as presented in Table 4.9. For average number of pods borne by a plant, in 2019, NCRI SOYAC7 had highest (182.67 pods), which was significantly different from NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC68, NCRI SOYAC67, and NCRI SOYAC76. In 2020, NCRI SOYAC61 had the highest average number of pods per plant (77.67 pods), which differed significantly from NCRI SOYAC65, and NCRI SOYAC63 only. Conversely, NCRI SOYAC77 had the lowest average number of pods per plant in 2019 (16 pods), while NCRI SOYAC63 produced the least average number of pods per plant in 2020 (51 pods). The genotypes with the highest average number of seed per pod in 2019 were NCRI SOYAC7 and NCRI SOYAC9 (3 seeds each), which was significantly different from NCRI SOYAC77, NCRI SOYAC24, NCRI SOYAC3, and NCRI SOYAC63. In 2020, the genotype NCRI SOYAC75 had the pods with highest average number of seeds (2.6 seeds), which differed significantly from NCRI SOYAC67 only. The genotypes that produced pods with the least number of seeds in 2019 were NCRI

SOYAC77, NCRI SOYAC3, NCRI SOYAC24, and NCRI SOYAC63 (2 seeds each) and in 2020 it was NCRI SOYAC67 (2.2 seeds).

The above ground biomass of NCRI SOYAC9 (3.23 tons/ha) was the highest gotten for the year 2019 in this location. It differed significantly from NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC62, and NCRI SOYAC75. In 2020, the genotype NCRI SOYAC25 had the highest above ground biomass (3.57 tons/ha) that differed significantly from NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC10, and NCRI SOYAC67. The genotype with the least above ground biomass in 2019 was NCRI SOYAC77 (1.37 tons/ha), but genotype NCRI SOYAC63 produced the least in 2020 (2 tons/ha).

The mean seed yield of NCRI SOYAC18 and NCRI SOYAC64 (1.5 tons/ha each) was the highest produced among the genotypes for the year 2019. They were significantly different from some genotypes like NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC68, NCRI SOYAC62, and NCRI SOYAC75. In 2020, NCRI SOYAC61 had the highest yield (1.4 tons/ha), which differed significantly from only NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC10 and NCRI SOYAC67. The poorest in yield among the genotypes in 2019 was NCRI SOYAC77 (0.23 ton/ha), but it was significantly different from other genotypes except NCRI SOYAC65, and NCRI SOYAC75 only. The year 2020 had NCRI SOYAC63 as the lowest in yield (0.7 ton/ha). However, it differed significantly from only five genotypes namely; NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC25, NCRI SOYAC9, and NCRI SOYAC61.

The genotype that produced the heaviest seeds in 2019 was NCRI SOYAC77, as shown by its high one hundred seeds weight (17.67 g) that was significantly higher than seeds of other genotypes. In 2020, NCRI SOYAC 20 was the genotype with the heaviest seeds (14.67 g). However, it was not significantly different from NCRI SOYAC 77 and others like NCRI SOYAC29, NCRI SOYAC64, NCRI SOYAC7, NCRI SOYAC61 and NCRI SOYAC22. The lowest in seed weight in 2019 among the genotypes was NCRI SOYAC63 (10 g); and in 2020 it was NCRI SOYAC67 and NCRI SOYAC67 (10 g each). The highest harvest index in 2019 (0.49) was recorded in NCRI SOYAC18 and NCRI SOYAC25, which significantly differed from NCRI SOYAC17, NCRI SOYAC77, and NCRI SOYAC73 only. In 2020, NCRI SOYAC63 had the highest harvest index (0.44) that differed significantly from only NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC75 and NCRI SOYAC22. The lowest harvest index in 2019 (0.33) was recorded in NCRI SOYAC17; and that of 2020 (0.31) was recorded in NCRI SOYAC26 and NCRI SOYAC24.

Table 4.8: Performances of the genotypes on growth traits in Awka

Genotype	Emergence (%)		D50%F		PH (cm)		DM		B/P	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	51.67bcdefg	55.33bcdefgh	46.67abcde	52.00abcd	42.33defg	39.00abcdef	115.67bcd	105.67abcdef	3.67ab	5.67abcde
NCRI SOYAC18	43.33defgh	55.67bcdefgh	46.67abcde	51.33abcde	47.67bcd	39.00abcdef	111.67efghijk	104.00def	4.00ab	5.00cdef
NCRI SOYAC17	38.33efgh	58.00abcdef	45.67bcdefg	51.33abcde	42.33defg	36.33cdef	114.67bcdef	104.67bcdef	3.67ab	4.67def
NCRI SOYAC69	31.67gh	33.00ij	46.33abcdef	51.00abcde	30.00jkl	33.33def	113.33cdefgh	109.33a	2.67b	6.00abcde
NCRI SOYAC77	26.67h	58.00abcdef	46.00abcdef	52.00abcd	25.33l	36.33cdef	115.33bcde	104.33cdef	3.00ab	5.00cdef
NCRI SOYAC73	63.33abcd	55.67bcdefgh	46.33abcdef	51.33abcde	42.00defg	35.00cdef	115.00bcde	106.33abcdef	3.00ab	5.33bcdef
NCRI SOYAC26	80.00a	53.33bcdefghi	44.33defg	51.67abcde	46.67cde	43.67abc	109.67hijklm	106.67abcde	4.67ab	7.33a
NCRI SOYAC29	70.00abc	62.00abcde	47.33abcd	49.33de	34.00hij	42.00abcd	111.67efghijk	102.67f	3.00ab	5.33bcdef
NCRI SOYAC25	60.00abcde	53.00bcdefghi	47.67abc	48.67e	45.67cdef	42.67abc	110.33ghijklm	103.67ef	4.00ab	7.33a
NCRI SOYAC28	46.67cdefgh	55.67bcdefgh	45.00bcdefg	49.67cde	35.33ghij	38.67abcdef	109.00ijklm	108.33ab	3.67ab	5.67abcde
NCRI SOYAC64	53.33bcdefg	53.33bcdefghi	46.67abcde	51.33abcde	40.33efgh	40.33abcde	112.00defghij	106.00abcdef	4.67ab	6.67abc
NCRI SOYAC65	33.33fgh	35.33hij	44.67cdefg	51.33abcde	40.33efgh	33.33def	119.67a	108.33ab	3.00ab	3.67f
NCRI SOYAC24	65.00abcd	29.00j	46.00abcdef	53.00ab	51.33abc	33.00ef	114.00cdefg	108.33ab	3.67ab	4.67def
NCRI SOYAC3	31.67gh	57.67abcdefg	46.00abcdef	51.00abcde	39.33fghi	43.67abc	109.67hijklm	106.67abcde	3.67ab	5.33bcdef
NCRI SOYAC9	63.33abcd	40.00fghij	42.67g	51.33abcde	47.67bcd	47.33a	109.67hijklm	106.00abcdef	5.00a	5.33bcdef
NCRI SOYAC7	60.00abcde	39.67fghij	44.00efg	51.00abcde	55.00a	39.67abcde	118.00ab	104.67bcdef	4.00ab	5.00cdef
NCRI SOYAC68	56.67abcdef	42.33efghij	43.33fg	52.00abcd	31.00jkl	40.33abcde	114.00cdefg	107.67abcd	3.67ab	5.00cdef
NCRI SOYAC20	63.33abcd	46.33defghij	45.67bcdefg	52.33abcd	52.67abc	42.00abcd	108.33jklm	105.67abcdef	4.33ab	6.33abcd
NCRI SOYAC62	65.00abcd	51.33cdefghi	44.00efg	50.00bcde	34.67hij	37.33bcdef	107.00m	107.33abcde	3.00ab	6.00abcde
NCRI SOYAC63	75.00ab	37.00ghij	44.33defg	49.67cde	49.67abc	35.33cdef	107.33lm	108.33ab	3.33ab	5.33bcdef
NCRI SOYAC75	58.33abcde	57.67abcdefg	44.67cdefg	49.67cde	54.33ab	35.00cdef	107.00m	104.67bcdef	3.00ab	4.33ef
NCRI SOYAC10	78.33a	33.33ij	46.00abcdef	51.33abcde	32.67ijk	30.67f	108.00klm	108.00abc	3.67ab	4.67def
NCRI SOYAC67	61.67abcde	64.33abcd	49.00a	52.00abcd	26.00kl	41.67abcde	112.67cdefghi	103.67ef	2.67b	5.00cdef
NCRI SOYAC76	48.33cdefgh	73.33ab	47.00abcde	53.33a	39.33fghi	43.33abc	113.00cdefgh	108.33ab	4.33ab	7.00ab
NCRI SOYAC61	80.00a	78.00a	46.67abcde	52.67abc	40.00efgh	45.33ab	111.00fghijkl	108.00abc	4.00ab	6.33abcd
NCRI SOYAC22	46.67cdefgh	71.00abc	48.00ab	50.00bcde	41.00defgh	38.33bcdef	116.33abc	106.33abcdef	4.00ab	6.67abc
Mean	55.83	51.9	45.79	51.17	41.03	38.95	112.08	106.29	3.67	5.56
Range (Min-Max)	26.67-78.33	29.00-78.00	42.67-49.00	48.67-53.33	25.33-55.00	30.67-47.33	107.00-119.67	102.67-109.33	2.67-5.00	3.67-7.33
±SE	8.24	7.28	1.09	1.15	2.47	3.14	1.3	1.38	0.72	0.67
CV	25.58	24.31	4.14	3.91	10.43	13.94	2.02	2.24	33.9	20.97

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; D50%F = Days to 50% Flowering; PH = Plant Height; DM = Days to Maturity, B/P = Branches per Plant: ±SE = Standard error of the mean: CV = Coefficient of Variation.

Table 4.9: Performances of the genotypes on yield traits in Awka

Genotype	P/P		S/P		AGB (ton/ha)		SY (ton/ha)		100SW (g)		HI	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	76.00abcd	76.00ab	2.33ab	2.27ab	2.57abcdef	3.23abc	1.27abc	1.33ab	11.00efg	11.00cd	0.46ab	0.41ab
NCRI SOYAC18	154.33ab	76.33ab	2.33ab	2.33ab	3.17abc	3.27abc	1.5a	1.17abc	12.00cdefg	11.00cd	0.49a	0.36abc
NCRI SOYAC17	130.67abc	69.00abc	2.67ab	2.40ab	2.83abcd	2.97abcd	0.97abcde	1.07abcd	11.67defg	11.67bcd	0.33c	0.36abc
NCRI SOYAC69	129.33abc	63.00abc	2.67ab	2.20b	2.10cdefg	2.90abcde	0.97abcde	1.13abcd	14.00bc	10.00d	0.46ab	0.40abc
NCRI SOYAC77	16.00d	58.00abc	2.00b	2.47ab	1.37g	2.63bcdef	0.23f	0.97abcd	17.67a	13.00abc	0.17d	0.37abc
NCRI SOYAC73	89.67abcd	72.00abc	2.33ab	2.27ab	2.07defg	2.80abcdef	0.83cde	1.03abcd	12.00cdefg	11.33bcd	0.39bc	0.37abc
NCRI SOYAC26	69.00bcd	62.33abc	2.67ab	2.40ab	3.20ab	2.77abcdef	1.40ab	0.87cd	12.67bcdef	11.33bcd	0.44ab	0.31c
NCRI SOYAC29	138.67ab	60.67abc	2.67ab	2.47ab	2.30abcdefg	2.47cdef	1.07abcde	0.87cd	11.67defg	12.33abcd	0.46ab	0.36abc
NCRI SOYAC25	124.33abc	75.67ab	2.33ab	2.27ab	2.23abcdefg	3.57a	1.10abcde	1.37a	13.67bcd	10.33cd	0.49a	0.38abc
NCRI SOYAC28	103.33abcd	61.00abc	2.67ab	2.40ab	2.53abcdef	2.70bcdef	1.17abcde	0.90bcd	13.00bcde	11.00cd	0.46ab	0.33bc
NCRI SOYAC64	88.00abcd	61.67abc	2.33ab	2.47ab	3.20ab	3.00abcd	1.5a	1.03abcd	11.00efg	14.00ab	0.47ab	0.34bc
NCRI SOYAC65	102.33abcd	55.00bc	2.67ab	2.27ab	1.53fg	2.10ef	0.67ef	0.80cd	13.00bcde	11.00cd	0.43ab	0.39abc
NCRI SOYAC24	152.33ab	59.00abc	2.00b	2.47ab	2.13bcdefg	2.63bcdef	0.93bcde	0.83cd	14.00bc	11.33bcd	0.42abc	0.31c
NCRI SOYAC3	76.00abcd	70.33abc	2.00b	2.27ab	2.03defg	2.70bcdef	0.97abcde	1.00abcd	12.00cdefg	11.00cd	0.47ab	0.37abc
NCRI SOYAC9	162.33ab	74.00ab	3.00a	2.33ab	3.23a	3.30abc	1.46ab	1.20abc	12.33bcdef	11.67bcd	0.45ab	0.36abc
NCRI SOYAC7	182.67a	59.67abc	3.00a	2.33ab	2.67abcde	2.50cdef	1.10abcde	1.00abcd	10.67fg	12.00abcd	0.40abc	0.40abc
NCRI SOYAC68	25.67cd	60.00abc	2.67ab	2.47ab	1.87defg	2.73abcdef	0.83cde	1.13abcd	12.00cdefg	11.33bcd	0.44ab	0.42ab
NCRI SOYAC20	89.67abcd	67.33abc	2.33ab	2.27ab	2.47abcdef	2.90abcde	1.10abcde	1.13abcd	14.33b	14.67a	0.45ab	0.39abc
NCRI SOYAC62	81.00abcd	69.67abc	2.33ab	2.40ab	1.80defg	2.47cdef	0.80cde	0.87cd	13.00bcde	11.67bcd	0.44ab	0.35abc
NCRI SOYAC63	173.67ab	51.00c	2.00b	2.40ab	2.43abcdefg	2.00f	1.10abcde	0.70d	10.00g	11.67bcd	0.45ab	0.44a
NCRI SOYAC75	131.33abc	58.67abc	2.33ab	2.60a	1.63efg	2.27def	0.70def	0.77cd	10.67fg	10.67cd	0.42abc	0.33bc
NCRI SOYAC10	98.67abcd	60.67abc	2.67ab	2.33ab	2.83abcd	2.33def	1.23abcd	0.90bcd	12.33bcdef	10.67cd	0.43ab	0.39abc
NCRI SOYAC67	66.67bcd	59.33abc	2.67ab	2.40ab	2.50abcdef	2.27def	1.07abcde	0.90bcd	11.67defg	10.00d	0.42abc	0.40abc
NCRI SOYAC76	73.33bcd	75.33ab	2.67ab	2.33ab	2.20abcdefg	2.93abcde	1.00abcde	1.13abcd	14.33b	11.00cd	0.46ab	0.39abc
NCRI SOYAC61	95.00abcd	77.67a	2.33ab	2.47ab	2.37abcdefg	3.37ab	0.97abcde	1.40a	12.33bcdef	12.00abcd	0.41abc	0.41ab
NCRI SOYAC22	114.33abcd	76.00ab	2.33ab	2.40ab	2.60abcdef	3.30abc	1.13abcde	1.13abcd	13.00bcde	13.00abc	0.43ab	0.34bc
Mean	105.55	65.74	2.46	2.37	2.38	2.77	1.04	1.02	12.54	11.56	0.43	0.37
Range (Min-Max)	16.00-182.67	51.00-77.67	2.00-3.00	2.20-2.60	1.37-3.23	2.00-3.57	0.23-1.50	0.70-1.37	10.00-17.67	1.00-14.67	0.33-0.49	0.31-0.44
±SE	37.87	7.62	0.29	0.13	0.38	0.3	0.19	0.15	0.77	0.94	0.03	0.03
CV	62.15	20.07	20.43	9.57	27.83	18.53	32.75	26.02	10.69	14.07	13.32	15.72

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; P/P = Pods per Plant; S/P = Seeds per Pod; AGB = Above Ground Biomass, SY = Seed Yield; 100SW = one hundred seed weight; HI = Harvest Index; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.6 Performance of the Soybean Genotypes for Pod Traits in Minna, 2019 and 2020

The performances of the genotypes for pod traits in Minna are contained in Table 4.10. The genotypes differed significantly in all the pod traits studied. For pod length, the longest pods in 2019 and 2020 were obtained from NCRI SOYAC77 (4.17 cm and 3.97 cm, respectively), but they were not significantly different from the pods of NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC24, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC67, NCRI SOYAC76, and NCRI SOYAC22 in 2019. In 2020, it was not significantly different from the pods of NCRI SOYAC17, NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC10, NCRI SOYAC67, and NCRI SOYAC76. Conversely, the shortest pods in both years were observed in NCRI SOYAC64 (3.27 cm and 3.1 cm, respectively), which in 2019 did not differ significantly from the pods of NCRI SOYAC18, NCRI SOYAC69, NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC62, NCRI SOYAC75, and NCRI SOYAC61. In 2020, it did not differ significantly from the pods of NCRI SOYAC73, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC62, and NCRI SOYAC61. In terms of pod width in 2019, six genotypes (NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC24, NCRI SOYAC20, and NCRI SOYAC76) had pods with average widths of 1 cm. This was the widest obtained for the year, which differed significantly from pods of only five genotypes namely; NCRI SOYAC77, NCRI SOYAC65, NCRI SOYAC7, NCRI SOYAC63, and NCRI SOYAC22. In 2020, genotype NCRI SOYAC10 had the widest pods (average pod width of 1.03 cm) that were not significantly different from NCRI

SOYAC78, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC63, NCRI SOYAC76, and NCRI SOYAC61. The smallest pod width was observed in pods of NCRI SOYAC7 in 2019 (0.8 cm) and in pods of NCRI SOYAC64 in 2020 (0.87 cm).

The genotypes' performances in length/width ratio, which expresses the length of a pod relative to its width, shows that pods of genotype NCRI SOYAC7 had the highest in 2019 and 2020, along with NCRI SOYAC26 (5.09 and 4.1, respectively). In 2019, they were significantly different from the pods of other genotypes except NCRI SOYAC77, NCRI SOYAC65, and NCRI SOYAC22 only. While in 2020, they were significantly different from NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC10, and NCRI SOYAC61. The lowest length/width ratio in 2019 was recorded in NCRI SOYAC3 (3.51); and NCRI SOYAC61 in 2020.

The genotype with pods that were the widest at the mid part in 2019 was NCRI SOYAC68, with average width at mid part of 0.97 cm. This was significantly higher than those of NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC63, and NCRI SOYAC22. Meanwhile, in 2020, two genotypes (NCRI SOYAC17 and NCRI SOYAC77) had pods with significantly wider width at mid part (0.9 cm each). This significantly differed from NCRI SOYAC18, NCRI SOYAC69, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC75, and NCRI SOYAC61. The shortest widths at the mid parts of pod in 2019 were recorded in pods of NCRI SOYAC77 and NCRI SOYAC7 (0.77 cm each). In 2020, the shortest were in the pods of NCRI SOYAC73 and NCRI SOYAC64.

The thickest pods in 2019 were obtained from genotype NCRI SOYAC77 (0.65 cm), which were significantly thicker than pods of other genotypes except NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC20, and NCRI SOYAC76. Two genotypes in 2020 (NCRI SOYAC73 and NCRI SOYAC20) produced the thickest pods (0.9 cm) that were significantly thicker than pods of NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC67, and NCRI SOYAC22. On the other hand, in 2019, genotypes NCRI SOYAC78, NCRI SOYAC62, and NCRI SOYAC67 produced pods with the lowest thickness (0.52 cm each). Whereas, genotype NCRI SOYAC29 produced pods that were the lowest in thickness (0.52 cm) in 2020.

The weight of seeds from randomly selected 20 pods shows that in 2019, genotype NCRI SOYAC77 having a seed weight of 8.33 g was the highest among the genotypes in that year, being significantly different from others. In 2020, the same genotype (NCRI SOYAC77) with NCRI SOYAC65 had the highest seed weight for the year (7.33 g each); and they significantly differed from others except NCRI SOYAC28, NCRI SOYAC9, NCRI SOYAC10, NCRI SOYAC67, and NCRI SOYAC76. The lowest seed weight in both 2019 and 2020 was recorded in NCRI SOYAC63 (5 g and 4.67 g, respectively). In terms of pod wall weight, genotype NCRI SOYAC77 had the highest in 2019 (3.33 g), which was not significantly different from other genotypes except NCRI SOYAC64, NCRI SOYAC3, and NCRI SOYAC7. In 2020, the same genotype (NCRI SOYAC77) along with NCRI SOYAC18, NCRI SOYAC26, NCRI SOYAC65, and NCRI SOYAC10 had the highest pod wall weight (3 g each); but were significantly different from only NCRI SOYAC73. Conversely, the lowest pod wall weight in 2019 was obtained from NCRI SOYAC64, NCRI SOYAC3, and NCRI SOYAC7 (2.33 g each). While in 2020 the lowest was obtained from NCRI SOYAC73.

The genotype with the heaviest pods in 2019 was NCRI SOYAC77 (11.67 g) and it differed significantly from other genotypes except NCRI SOYAC28. In 2020, NCRI SOYAC77 and NCRI SOYAC65 produced the heaviest pods (10.33 g), which differed significantly from other genotypes except NCRI SOYAC18, NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC9, NCRI SOYAC10, NCRI SOYAC67, and NCRI SOYAC76. The lowest genotypes in pod weight in 2019 were NCRI SOYAC7 and NCRI SOYAC63 (7.67 g each), while 2020 had NCRI SOYAC73, NCRI SOYAC3, NCRI SOYAC63, and NCRI SOYAC61 as the genotypes with the lowest pod weight (7.33 g).

The genotypes' performances in seed weight/pod weight ratio, which is an expression of the weight of seeds relative to weight of pod, shows that in 2019, six genotypes (NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC64, NCRI SOYAC68, NCRI SOYAC76, and NCRI SOYAC22) had seed weight/pod weight ratio of 0.72, which was the highest obtained in that year. They differed significantly from only NCRI SOYAC63. In 2020, three genotypes (NCRI SOYAC78, NCRI SOYAC73, and NCRI SOYAC68) had the highest (0.72); and they differed significantly from only NCRI SOYAC64 and NCRI SOYAC63. The lowest ratio in both 2019 and 2020 was obtained from NCRI SOYAC63 (0.66 and 0.64, respectively).

Pod wall weight/pod weight ratio, which shows the weight of pod walls in relation to the weight of pod; was observed to be highest in NCRI SOYAC63 in both 2019 and 2020 (0.34 and 0.36, respectively). In 2019, it differed significantly from NCRI

SOYAC18, NCRI SOYAC77, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC76, and NCRI SOYAC22; while in 2020, it differed significantly from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC67, NCRI SOYAC76, and NCRI SOYAC22. The lowest ratio in 2019 (0.28) was obtained from NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC64, NCRI SOYAC68, NCRI SOYAC76, and NCRI SOYAC22, whereas the lowest in 2020 (0.28) was obtain from NCRI SOYAC78, NCRI SOYAC73, and NCRI SOYAC68.

The highest pod shattering percentage in both years of study was recorded in NCRI SOYAC63 (90 % in 2019 and 98.33 % in 2020), and was significantly different from other genotypes in both years. In 2019, genotypes NCRI SOYAC77 and NCRI SOYAC76 had no pod shattering (0 %). However, in 2020, it was genotypes NCRI SOYAC78 and NCRI SOYAC7 that had the lowest pod shattering percentage (5 %).

Table 4.10: Performances of 26 genotypes of soybean for pod traits in Minna in 2019 and 2020 cropping season

Genotype	Pod Length (cm)		Pod Width (cm)		LW Ratio		Pod Thickness (cm)		Pod Mid Width (cm)		Seed Weight (g)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	3.73bcdef	3.50bcdef	0.93abc	0.97abc	4.01def	3.63def	0.52d	0.53ghi	0.90ab	0.83abc	6.33cde	6.00bcd
NCRI SOYAC18	3.47efg	3.47cdef	0.90abcd	0.93bcd	3.70def	3.73bcdef	0.56bcd	0.57abcdefghi	0.93ab	0.80bcd	6.67bcd	6.00bcd
NCRI SOYAC17	3.73bcdef	3.67abcd	0.97ab	1.00ab	3.87def	3.67cdefg	0.58bcd	0.53ghi	0.90ab	0.90a	6.33cde	5.67bcde
NCRI SOYAC69	3.50efg	3.60bcde	0.93abc	0.90cd	3.80def	4.00abc	0.57bcd	0.57abcdefghi	0.83bc	0.77cd	6.00def	5.67bcde
NCRI SOYAC77	4.17a	3.97a	0.87bcd	1.00ab	4.82abc	3.97abcd	0.65a	0.59abcdef	0.77c	0.90a	8.33a	7.33a
NCRI SOYAC73	3.63defg	3.37defg	1.00a	0.90cd	3.63ef	3.77abcdef	0.57bcd	0.63a	0.87abc	0.73d	7.00bc	5.33cde
NCRI SOYAC26	3.87abcde	3.70abcd	0.93abc	0.90cd	4.16bcdef	4.10a	0.53d	0.58abcdefgh	0.87abc	0.80bcd	7.00bc	6.00bcd
NCRI SOYAC29	3.67cdefg	3.53bcdef	1.00a	0.93bcd	3.67ef	3.80abcde	0.57bcd	0.52i	0.87abc	0.83abc	6.33cde	6.00bcd
NCRI SOYAC25	4.03abcd	3.53bcdef	1.00a	0.90cd	4.03def	3.93abcde	0.56bcd	0.55defghi	0.87abc	0.83abc	7.00bc	6.00bcd
NCRI SOYAC28	3.87abcde	3.73abc	0.93abc	0.93bcd	4.31bcde	4.00abc	0.57bcd	0.59abcdef	0.9ab	0.83abc	7.33b	6.33abc
NCRI SOYAC64	3.27g	3.10g	0.90abcd	0.87d	3.63ef	3.60efg	0.56bcd	0.58abcdefgh	0.83bc	0.73d	6.00def	5.00de
NCRI SOYAC65	3.63defg	3.57bcde	0.83cd	0.93bcd	4.42abcd	3.83abcde	0.62ab	0.62abc	0.87abc	0.77cd	7.00bc	7.33a
NCRI SOYAC24	3.80abcdef	3.77abc	1.00a	0.93bcd	3.8def	4.03ab	0.60abc	0.61abcd	0.87abc	0.77cd	7.00bc	5.67bcde
NCRI SOYAC3	3.40fg	3.30efg	0.97ab	0.97abc	3.51f	3.43fg	0.57bcd	0.55defghi	0.83bc	0.80bcd	5.67efg	5.00de
NCRI SOYAC9	3.67cdefg	3.63abcde	0.97ab	1.00ab	3.81def	3.63defg	0.61abc	0.62abc	0.83bc	0.87ab	7.00bc	6.67ab
NCRI SOYAC7	4.07abc	3.70abcd	0.80d	0.90cd	5.09a	4.10a	0.54cd	0.54fghi	0.77c	0.87ab	5.33fg	5.33cde
NCRI SOYAC68	3.77abcdef	3.43cdefg	0.93abc	0.93bcd	4.04def	3.70bcdef	0.54cd	0.61abcd	0.97a	0.80bcd	6.67bcd	6.00bcd
NCRI SOYAC20	3.87abcde	3.83ab	1.00a	0.97abc	3.87def	3.97abcd	0.62ab	0.63a	0.90ab	0.80bcd	7.00bc	5.67bcde
NCRI SOYAC62	3.60defg	3.43cdefg	0.90abcd	0.93bcd	4.01def	3.70bcdef	0.52d	0.59abcdef	0.90ab	0.80bcd	7.33b	6.00bcd
NCRI SOYAC63	3.73bcdef	3.53bcdef	0.87bcd	0.97abc	4.32bcde	3.67cdefg	0.57bcd	0.56cdefghi	0.83bc	0.77cd	5.00g	4.67e
NCRI SOYAC75	3.47efg	3.50bcdef	0.90abcd	0.90cd	3.85def	3.90abcde	0.55bcd	0.55defghi	0.87abc	0.80bcd	5.67efg	5.67bcde
NCRI SOYAC10	3.70bcdef	3.73abc	0.93abc	1.03a	3.98def	3.60efg	0.55bcd	0.59abcdef	0.93ab	0.87ab	6.67bcd	6.33abc
NCRI SOYAC67	3.83abcde	3.67abcd	0.93abc	0.93bcd	4.15cdef	3.93abcde	0.52d	0.55defghi	0.93ab	0.83abc	5.67efg	6.33abc
NCRI SOYAC76	4.03abcd	3.77abc	1.00a	1.00ab	4.03def	3.77abcdef	0.61abc	0.60abcde	0.87abc	0.83abc	6.67bcd	6.33abc
NCRI SOYAC61	3.60efg	3.20fg	0.97ab	0.97abc	3.78def	3.33g	0.55bcd	0.58abcdefgh	0.90ab	0.80bcd	6.00def	5.00de
NCRI SOYAC22	4.1ab	3.57bcde	0.87bcd	0.93bcd	4.88ab	3.83abcde	0.58bcd	0.56cdefghi	0.83bc	0.87ab	6.67bcd	5.33cde
Mean	3.74	3.57	0.93	0.94	4.05	3.79	0.57	0.58	0.87	0.82	6.52	5.87
Range (Min-Max)	3.27-4.17	3.10-3.97	0.80-1.00	0.87-1.03	3.51-5.09	3.33-4.10	0.52-0.65	0.52-0.63	0.77-0.97	0.73-0.90	5.00-8.33	4.67-7.33
±SE	0.14	0.12	0.04	0.03	0.26	0.12	0.02	0.02	0.04	0.03	0.34	0.39
CV	6.61	5.76	7.72	4.96	11.05	5.64	7.45	5.66	7.82	5.64	9.21	11.38

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; L/W Ratio = Pod Length/Pod Width Ratio; ±SE = Standard error of the mean; CV = Coefficient of Variation.

Table 4.10 Continued: Performances of 26 genotypes of soybean for pod traits in Minna in 2019 and 2020 cropping season

Genotype	Pod Wall Weight (g)		Pod Weight (g)		SWPW Ratio		PWWPW Ratio		Pod Sht (%)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	3.00ab	2.33ab	9.33bcde	8.33bcd	0.68ab	0.72a	0.32ab	0.28c	23.33bcdef	5.00g
NCRI SOYAC18	2.67ab	3.00a	9.33bcde	9.00abc	0.72a	0.67abc	0.28b	0.33abc	36.67bc	31.67b
NCRI SOYAC17	3.00ab	2.33ab	9.33bcde	8.00bcd	0.68ab	0.71ab	0.32ab	0.29bc	17.00bcdef	6.67fg
NCRI SOYAC69	2.67ab	2.33ab	8.67cdef	8.00bcd	0.70ab	0.71ab	0.30ab	0.29bc	27.67bcde	13.33defg
NCRI SOYAC77	3.33a	3.00a	11.67a	10.33a	0.72a	0.71ab	0.28b	0.29bc	0.00f	10.00defg
NCRI SOYAC73	3.00ab	2.00b	10.00bc	7.33d	0.70ab	0.72a	0.30ab	0.28c	16.67bcdef	6.67fg
NCRI SOYAC26	3.00ab	3.00a	10.00bc	9.00abc	0.70ab	0.67abc	0.30ab	0.33abc	16.67bcdef	25.00bcd
NCRI SOYAC29	3.00ab	2.67ab	9.33bcde	8.67bcd	0.68ab	0.69abc	0.32ab	0.31abc	11.67cdef	8.33efg
NCRI SOYAC25	3.00ab	2.67ab	10.00bc	8.67bcd	0.70ab	0.70abc	0.30ab	0.30bc	20.33bcdef	21.67bcdef
NCRI SOYAC28	3.00ab	2.67ab	10.33ab	9.00abc	0.71a	0.71ab	0.29b	0.29bc	32.00bcd	11.67defg
NCRI SOYAC64	2.33b	2.67ab	8.33def	7.67cd	0.72a	0.66bc	0.28b	0.34ab	30.00bcd	30.00bc
NCRI SOYAC65	3.00ab	3.00a	10.00bc	10.33a	0.70ab	0.71ab	0.30ab	0.29bc	39.00b	20.00bcdefg
NCRI SOYAC24	3.00ab	2.67ab	10.00bc	8.33bcd	0.70ab	0.68abc	0.30ab	0.32abc	26.67bcde	11.67defg
NCRI SOYAC3	2.33b	2.33ab	8.00ef	7.33d	0.71a	0.68abc	0.29b	0.32abc	13.33bcdef	18.33bcdefg
NCRI SOYAC9	3.00ab	2.67ab	10.00bc	9.33ab	0.70ab	0.71ab	0.30ab	0.29bc	23.33bcdef	11.67defg
NCRI SOYAC7	2.33b	2.33ab	7.67f	7.67cd	0.70ab	0.70abc	0.30ab	0.30bc	8.33def	5.00g
NCRI SOYAC68	2.67ab	2.33ab	9.33bcde	8.33bcd	0.72a	0.72a	0.28b	0.28c	26.67bcde	10.00defg
NCRI SOYAC20	3.00ab	2.67ab	10.00bc	8.33bcd	0.70ab	0.68abc	0.30ab	0.32abc	21.67bcdef	10.00defg
NCRI SOYAC62	3.00ab	2.67ab	10.00bc	8.67bcd	0.71a	0.70abc	0.29b	0.30bc	28.33bcde	23.33bcde
NCRI SOYAC63	2.67ab	2.67ab	7.67f	7.33d	0.66b	0.64c	0.34a	0.36a	90.00a	98.33a
NCRI SOYAC75	2.67ab	2.67ab	8.33def	8.33bcd	0.68ab	0.68abc	0.32ab	0.32abc	28.33bcde	13.33defg
NCRI SOYAC10	3.00ab	3.00a	9.67bcd	9.33ab	0.69ab	0.68abc	0.31ab	0.32abc	25.67bcdef	18.33bcdefg
NCRI SOYAC67	2.67ab	2.67ab	8.33def	9.00abc	0.68ab	0.71ab	0.32ab	0.29bc	25.00bcdef	16.67bcdefg
NCRI SOYAC76	2.67ab	2.67ab	9.33bcde	9.00abc	0.72a	0.70abc	0.28b	0.30bc	0.00f	11.67defg
NCRI SOYAC61	2.67ab	2.33ab	8.67cdef	7.33d	0.69ab	0.68abc	0.31ab	0.32abc	28.33bcde	31.67b
NCRI SOYAC22	2.67ab	2.33ab	9.33bcde	7.67cd	0.72a	0.70abc	0.28b	0.30bc	3.33ef	15.00cdefg
Mean	2.82	2.6	9.33	8.47	0.7	0.69	0.3	0.31	23.85	18.65
Range (Min-Max)	2.33-3.33	2.00-3.00	7.67-11.67	7.33-10.33	0.66-0.71	0.64-0.72	0.28-0.34	0.28-0.36	0.00-90.00	5.00-98.33
±SE	0.24	0.28	0.5	0.56	0.02	0.02	0.02	0.02	9.06	5.57
CV	14.47	18.82	9.35	11.42	3.96	5.39	9.19	12.22	65.81	51.68

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; SWPW Ratio = Seed weight/Pod weight Ratio; PWWPW Ratio = Pod wall weight/Pod weight Ratio; Pod Sht = Pod shattering percentage; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.7 Performance of the Soybean Genotypes for Pod Traits in Chinka, 2019 and 2020

The performances of the genotypes for pod traits in Chinka are as presented in Table 4.11. The genotypes differed significantly in all the pod traits studied. For pod length, the longest pods in 2019 were obtained from NCRI SOYAC26 (4.2 cm), but they were not significantly different from the pods of NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC75, and NCRI SOYAC22. In 2020, the longest pods were obtained from NCRI SOYAC67 (4.27 cm) and they were significantly different from the pods of other genotypes. Conversely, the shortest pods in 2019 were observed in NCRI SOYAC65 (3.3 cm), but did not differ significantly from the pods of NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC63, NCRI SOYAC10, NCRI SOYAC67 and NCRI SOYAC61. In 2020, the shortest pods were obtained from NCRI SOYAC64 (3.5) and they did not differ significantly from the pods of NCRI SOYAC18, NCRI SOYAC29, NCRI SOYAC28, NCRI SOYAC63, NCRI SOYAC75 and NCRI SOYAC61.

In terms of pod width in 2019, two genotypes (NCRI SOYAC77 and NCRI SOYAC10) had pods with average widths of 0.97 cm, which was the widest for the year, and they differed significantly from pods of other genotypes except NCRI SOYAC17, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC20, and NCRI SOYAC79. In 2020, NCRI SOYAC10 had the widest pods (average pod width of 1.03 cm) that were significantly different from pods of other genotypes except NCRI SOYAC77. The smallest pod width in 2019 was observed in pods of NCRI SOYAC65 (0.73 cm) and in pods of NCRI SOYAC64 in 2020 (0.87 cm).

The genotypes' performances in length/width ratio shows that pods of NCRI SOYAC26 had the highest ratio in 2019 (5.08); and these pods were significantly different from the pods of NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC10 and NCRI SOYAC61. While in 2020, NCRI SOYAC 67 had pods with the highest ratio (4.43) that were significantly different from pods of NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC7, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC76 and NCRI SOYAC61. The lowest length/width ratio in 2019 was recorded in pods of NCRI SOYAC18 (3.66); and pods of NCRI SOYAC75 in 2020 (3.73).

Pods of NCRI SOYAC76 were the widest at the mid part in 2019 (0.9 cm). This was significantly higher than pods of other genotypes except NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC10, and NCRI SOYAC67. Meanwhile, in 2020, NCRI SOYAC67 had pods with significantly wider width at mid part (0.9 cm). This significantly differed from pods of other genotypes except NCRI SOYAC17, NCRI SOYAC77, and NCRI SOYAC22. The shortest width at the mid parts of pod in 2019 was recorded in pods of NCRI SOYAC78, NCRI SOYAC73 and NCRI SOYAC64 (0.7 cm each). In 2020, the shortest was in the pods of NCRI SOYAC24 (0.7 cm).

The thickest pods in 2019 were obtained from NCRI SOYAC75 (0.64 cm), which were significantly thicker than pods of other genotypes except NCRI SOYAC77, NCRI

SOYAC26, NCRI SOYAC65, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC76 and NCRI SOYAC22. In 2020, NCRI SOYAC65 produced the thickest pods (0.65 cm) that were significantly thicker than pods of other genotypes except NCRI SOYAC3 and NCRI SOYAC10. Conversely, in 2019, NCRI SOYAC67 produced pods with the lowest thickness (0.42 cm). Whereas, genotype NCRI SOYAC78 produced pods that were the lowest in thickness (0.49 cm) in 2020.

The weight of seeds from randomly selected 20 pods in Chinka, shows that in 2019, NCRI SOYAC77 having an average seed weight of 5.67 g was the highest of the year in this location. It was significantly different from other genotypes except NCRI SOYAC9, NCRI SOYAC62, and NCRI SOYAC75. In 2020, NCRI SOYAC65 had the highest seed weight for the year (7.33 g); and it significantly differed from others except NCRI SOYAC77 and NCRI SOYAC9. The lowest seed weight in 2019 was recorded in NCRI SOYAC7 (3 g), while the lowest in 2020 was recorded in NCRI SOYAC63 (4 g). The heaviest pods walls in 2019 were recorded in NCRI SOYAC77, NCRI SOYAC62, and NCRI SOYAC63 (3 g each), and they differed significantly from other genotypes except NCRI SOYAC9 only. In 2020, NCRI SOYAC65 had the highest pod wall weight (3.33 g), which was significantly different from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC64, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC10, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC22. A pod wall weight of 2 g, which was the lowest in 2019, was obtained from eighteen genotypes (Table 4.11). Similarly in 2020, 2 g was also the lowest and was obtained from NCRI SOYAC78, NCRI SOYAC73, NCRI SOYAC7, NCRI SOYAC76, and NCRI SOYAC61.

The genotype with the heaviest pods in 2019 was NCRI SOYAC77 (8.67 g) and it differed significantly from other genotypes except NCRI SOYAC9 and NCRI SOYAC62. In 2020, NCRI SOYAC65 produced the heaviest pods (10.67 g), which differed significantly from other genotypes except NCRI SOYAC77 and NCRI SOYAC9. Pod weight in 2019 was observed to be lowest in NCRI SOYAC7 (5 g), while 2020 had NCRI SOYAC73, NCRI SOYAC63, and NCRI SOYAC61 as the genotypes with the lowest pod weight (6.33 g).

The genotypes' performances in seed weight/pod weight ratio, shows that in 2019, NCRI SOYAC75 had the highest ratio (0.71) that differed significantly from only NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC67, and NCRI SOYAC76. In 2020, two genotypes (NCRI SOYAC78 and NCRI SOYAC10) had the highest ratio (0.72); and they differed significantly from NCRI SOYAC18, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC63, NCRI SOYAC75, and NCRI SOYAC67. The lowest ratio in 2019 was obtained from NCRI SOYAC63 (0.59); while in 2020, the lowest ratio was obtained from NCRI SOYAC3.

Pod wall weight/pod weight ratio in 2019 was observed to be highest in NCRI SOYAC63 (0.41) and it differed significantly from other genotypes except NCRI SOYAC7. In 2020, the highest ratio was recorded in NCRI SOYAC3 and it differed significantly from other genotypes except NCRI SOYAC18, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC63, NCRI SOYAC75, and NCRI SOYAC67. The lowest ratio in 2019 (0.29) was obtained from NCRI SOYAC75, whereas the lowest in 2020 (0.28) was obtain from NCRI SOYAC78 and NCRI SOYAC10.

The highest pod shattering percentage in both years of study was recorded in NCRI SOYAC63 (90 % in 2019 and 80 % in 2020), and was significantly different from other genotypes in both years. In 2019, the lowest pod shattering percentage was recorded in NCRI SOYAC7 (1.67 %). However, in 2020, it was NCRI SOYAC28 that had the lowest pod shattering percentage (3.33 %).

Table 4.11: Performances of 26 genotypes of soybean for pod traits in Chinka in 2019 and 2020 cropping season

Genotype	Pod Length (cm)		Pod Width (cm)		LW Ratio		Pod Thickness (cm)		Pod Mid Width (cm)		Seed Weight (g)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	3.60bcde	3.80bcdef	0.87bcd	0.90de	4.18bcde	4.20abcd	0.49fg	0.49g	0.70e	0.83bc	4.00de	5.33cde
NCRI SOYAC18	3.33de	3.70defghi	0.83cd	0.93cd	3.66e	3.97cdefgh	0.52cdef	0.59bc	0.73de	0.80bc	3.67ef	4.67def
NCRI SOYAC17	3.80abcde	3.93bc	0.93ab	0.97bc	4.19bcde	4.07bcdefg	0.49fg	0.57cdef	0.83abc	0.87ab	4.33cde	5.33cde
NCRI SOYAC69	3.73abcde	3.80bcdef	0.87bcd	0.90de	4.34abcde	4.20abcd	0.51def	0.55cdefg	0.77cde	0.80bc	4.00de	5.67bcd
NCRI SOYAC77	3.83abcd	3.83bcde	0.97a	1.00ab	3.98cde	3.83fgh	0.60abc	0.59bc	0.87ab	0.87ab	5.67a	6.67ab
NCRI SOYAC73	3.87abc	3.80bcdef	0.80de	0.90de	4.83ab	4.20abcd	0.54bcdef	0.55cdefg	0.70e	0.80bc	4.00de	4.33ef
NCRI SOYAC26	4.20a	3.87bcde	0.83cd	0.90de	5.08a	4.27abc	0.58abcd	0.58bcde	0.80bcd	0.83bc	4.00de	5.33cde
NCRI SOYAC29	3.57bcde	3.53hi	0.90abc	0.90de	3.96cde	3.93defgh	0.50def	0.52defg	0.77cde	0.77cd	4.33cde	4.67def
NCRI SOYAC25	3.63bcde	3.87bcde	0.90abc	0.90de	4.04bcde	4.27abc	0.55bcdef	0.55cdefg	0.73de	0.80bc	4.33cde	5.67bcd
NCRI SOYAC28	3.63bcde	3.67efghi	0.87bcd	0.90de	4.22bcde	4.07bcdefg	0.54bcdef	0.55cdefg	0.80bcd	0.77cd	4.00de	5.67bcd
NCRI SOYAC64	3.33de	3.50i	0.83cd	0.87e	4.01cde	4.07bcdefg	0.51def	0.52defg	0.70e	0.80bc	4.00de	4.33ef
NCRI SOYAC65	3.30e	3.83bcde	0.73e	0.93cd	4.51abcd	4.10bcdef	0.58abcd	0.65a	0.80bcd	0.77cd	4.33cde	7.33a
NCRI SOYAC24	3.83abcd	3.80bcdef	0.83cd	0.90de	4.63abc	4.20abcd	0.53cdef	0.55cdefg	0.73de	0.70e	4.33cde	5.67bcd
NCRI SOYAC3	3.47cde	3.73cdefgh	0.87bcd	0.90de	4.02cde	4.13abcdef	0.55bcdef	0.58abcd	0.83abc	0.80bc	4.00de	4.67def
NCRI SOYAC9	3.97abc	3.97b	0.87bcd	0.93cd	4.60abc	4.23abcd	0.62ab	0.59bc	0.77cde	0.80bc	5.00abc	6.67ab
NCRI SOYAC7	3.87abc	3.77bcdefg	0.83cd	0.93cd	4.66abc	4.03bcdefgh	0.42g	0.52defg	0.83abc	0.77cd	3.00f	4.67def
NCRI SOYAC68	3.47cde	3.77bcdefg	0.83cd	0.90de	4.19bcde	4.17abcde	0.51def	0.54cdefg	0.73de	0.80bc	4.00de	4.33ef
NCRI SOYAC20	4.07ab	3.77bcdefg	0.90abc	0.90de	4.52abcd	4.17abcde	0.60abc	0.54cdefg	0.73de	0.73de	4.33cde	4.33ef
NCRI SOYAC62	3.97abc	3.87bcde	0.87bcd	0.90de	4.60abc	4.30ab	0.62ab	0.54cdefg	0.80bcd	0.77cd	5.33ab	5.00cdef
NCRI SOYAC63	3.73abcde	3.57ghi	0.87bcd	0.90de	4.32abcde	3.97cdefgh	0.57abcde	0.56cdefg	0.77cde	0.73de	4.33cde	4.00f
NCRI SOYAC75	3.97abc	3.60fghi	0.87bcd	0.97bc	4.59abc	3.73h	0.64a	0.59bc	0.80bcd	0.80bc	5.00abc	5.67bcd
NCRI SOYAC10	3.60bcde	3.87bcde	0.97a	1.03a	3.73de	3.77gh	0.54bcdef	0.64ab	0.83abc	0.83bc	4.67bcd	6.00bc
NCRI SOYAC67	3.63bcde	4.27a	0.83cd	0.97bc	4.36abcde	4.43a	0.51def	0.50fg	0.87ab	0.90a	3.67ef	5.00cdef
NCRI SOYAC76	3.93abc	3.80bcdef	0.90abc	0.97bc	4.38abcde	3.93defgh	0.61ab	0.54cdefg	0.90a	0.80bc	4.33cde	4.67def
NCRI SOYAC61	3.50cde	3.60fghi	0.87bcd	0.93cd	4.04bcde	3.87efgh	0.49efg	0.52defg	0.77cde	0.80bc	4.00de	4.33ef
NCRI SOYAC22	4.03ab	3.90bcd	0.87bcd	0.90de	4.60abc	4.30ab	0.58abcd	0.57cdef	0.77cde	0.87ab	4.33cde	5.33cde
Mean	3.73	3.78	0.87	0.92	4.32	4.09	0.55	0.56	0.78	0.80	4.27	5.21
Range (Min-Max)	3.30-4.20	3.50-4.27	0.73-0.97	0.87-1.00	3.66-5.08	3.37-4.43	0.42-0.64	0.49-0.65	0.70-0.90	0.70-0.90	3.00-5.67	4.00-7.33
±SE	0.19	0.08	0.03	0.02	0.28	0.11	0.03	0.02	0.03	0.02	0.31	0.4
CV	8.66	3.66	6.69	3.91	11.41	4.81	8.75	7.29	6.86	5.13	12.74	13.19

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; L/W Ratio = Pod Length/Pod Width Ratio; ±SE = Standard error of the mean; CV = Coefficient of Variation.

Table 4.11 Continued: Performances of 26 genotypes of soybean for pod traits in Chinka in 2019 and 2020 cropping season

Genotype	Pod Wall Weight (g)		Pod Weight (g)		SWPW Ratio		PWWPW Ratio		Pod Sht (%)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	2.00c	2.00c	6.00efg	7.33cde	0.67ab	0.72a	0.33bc	0.28e	15.00bcde	6.67fg
NCRI SOYAC18	2.00c	2.67abc	5.67fg	7.33cde	0.65b	0.64bcde	0.35b	0.36abcd	23.33bc	48.33b
NCRI SOYAC17	2.00c	2.33bc	6.33def	7.67cde	0.68ab	0.70ab	0.32bc	0.30de	11.67bcde	6.67fg
NCRI SOYAC69	2.00c	2.67abc	6.00efg	8.33bcd	0.67ab	0.68abcd	0.33bc	0.32bcde	16.67bcde	31.67bcd
NCRI SOYAC77	3.00a	3.00ab	8.67a	9.67ab	0.65b	0.69abc	0.35b	0.31cde	15.00bcde	8.33efg
NCRI SOYAC73	2.00c	2.00c	6.00efg	6.33e	0.66b	0.68abcd	0.34b	0.32bcde	3.33de	6.67fg
NCRI SOYAC26	2.00c	2.33bc	6.00efg	7.67cde	0.67ab	0.70ab	0.33bc	0.30de	21.67bc	6.67fg
NCRI SOYAC29	2.00c	2.33bc	6.33def	7.00de	0.68ab	0.67abcd	0.32bc	0.33bcde	3.33de	13.33defg
NCRI SOYAC25	2.00c	3.00ab	6.33def	8.67bc	0.68ab	0.66bcde	0.32bc	0.34abcd	16.67bcde	11.67defg
NCRI SOYAC28	2.00c	2.67abc	6.00efg	8.33bcd	0.67ab	0.68abcd	0.33bc	0.32bcde	18.33bcd	3.33g
NCRI SOYAC64	2.00c	2.33bc	6.00efg	6.67e	0.67ab	0.66bcde	0.33bc	0.34abcd	10.00bcde	20.00cdefg
NCRI SOYAC65	2.00c	3.33a	6.33def	10.67a	0.68ab	0.69abc	0.32bc	0.31cde	21.67bc	30.00bcd
NCRI SOYAC24	2.33bc	3.00ab	6.67cdef	8.67bc	0.66b	0.66bcde	0.34b	0.34abcd	8.33cde	16.67cdefg
NCRI SOYAC3	2.00c	3.00ab	6.00efg	7.67cde	0.67ab	0.61e	0.33bc	0.39a	15.00bcde	35.00bc
NCRI SOYAC9	2.67ab	3.00ab	7.67abc	9.67ab	0.66b	0.69abc	0.34b	0.31cde	21.67bc	18.33cdefg
NCRI SOYAC7	2.00c	2.00c	5.00g	6.67e	0.60c	0.69abc	0.40a	0.31cde	1.67e	18.33cdefg
NCRI SOYAC68	2.00c	2.33bc	6.00efg	6.67e	0.67ab	0.65bcde	0.33bc	0.35abcd	3.33de	11.67defg
NCRI SOYAC20	2.33bc	2.67abc	6.67cdef	7.00de	0.66b	0.62de	0.34b	0.38ab	10.00bcde	13.33defg
NCRI SOYAC62	3.00a	2.33bc	8.33ab	7.33cde	0.64b	0.68abcd	0.36b	0.32bcde	11.67bcde	15.00cdefg
NCRI SOYAC63	3.00a	2.33bc	7.33bcd	6.33e	0.59c	0.63cde	0.41a	0.37abc	90.00a	80.00a
NCRI SOYAC75	2.00c	3.00ab	7.00cde	8.67bc	0.71a	0.66bcde	0.29c	0.34abcd	5.00de	26.67cdef
NCRI SOYAC10	2.33bc	2.33bc	7.00cde	8.33bcd	0.67ab	0.72a	0.33bc	0.28e	5.00de	8.33efg
NCRI SOYAC67	2.00c	2.67abc	5.67fg	7.67cde	0.65b	0.66bcde	0.35b	0.34abcd	25.00b	28.33bcde
NCRI SOYAC76	2.33bc	2.00c	6.67cdef	6.67e	0.66b	0.70ab	0.34b	0.30de	5.00de	6.67fg
NCRI SOYAC61	2.00c	2.00c	6.00efg	6.33e	0.67ab	0.68abcd	0.33bc	0.32bcde	21.67bc	21.67cdefg
NCRI SOYAC22	2.00c	2.33bc	6.33def	7.67cde	0.68ab	0.70ab	0.32bc	0.30de	21.67bc	50.00g
Mean	2.19	2.53	6.46	7.73	0.66	0.67	0.34	0.33	16.22	19.17
Range (Min-Max)	2.00-3.00	2.00-3.33	5.00-8.67	6.33-10.67	0.59-0.71	0.61-0.72	0.29-0.41	0.28-0.39	1.67-90.00	3.33-80.00
±SE	0.15	0.26	0.4	0.55	0.01	0.02	0.01	0.02	5.29	7.06
CV	11.64	17.55	10.8	12.4	3.82	5.58	7.61	11.53	56.5	63.84

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; SWPW Ratio = Seed weight/Pod weight Ratio; PWWPW Ratio = Pod wall weight/Pod weight Ratio; Pod Sht = Pod shattering percentage; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.8 Performance of the Soybean Genotypes for Pod Traits in Awka, 2019 and 2020

The performances of the genotypes for pod traits in Awka are presented in Table 4.12. The genotypes were significantly different in all the pod traits studied. For pod length, the longest pods in 2019 were obtained from NCRI SOYAC25 and NCRI SOYAC20 (4.67 cm, each), but they were not significantly different from the pods of NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC7, NCRI SOYAC10, NCRI SOYAC76, and NCRI SOYAC22. In 2020, the longest pods were obtained from NCRI SOYAC76 (4 cm), which was not significantly different from the pods of NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC67 and NCRI SOYAC22. Conversely, the shortest pods in 2019 were observed in NCRI SOYAC3 (3.37 cm), which did not differ significantly from the pods of NCRI SOYAC77, NCRI SOYAC63, and NCRI SOYAC67. The shortest pods in 2020 were from NCRI SOYAC64 and they did not differ significantly from the pods of NCRI SOYAC69, NCRI SOYAC3, and NCRI SOYAC75.

In terms of pod width in 2019, the widest pods were obtained from NCRI SOYAC67 (0.8 cm), and they differed significantly from the pods of NCRI SOYAC73, NCRI SOYAC3, NCRI SOYAC63, and NCRI SOYAC61. In 2020, two genotypes (NCRI SOYAC25 and NCRI SOYAC76) had pods with average widths of 1 cm. This was the widest obtained for the year, which differed significantly from pods of NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC7, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC67, and NCRI SOYAC61. The smallest pod width was observed in pods of NCRI SOYAC3 in 2019 (0.6 cm) and in pods of NCRI SOYAC65 in 2020 (0.77 cm).

The highest length/width ratio in 2019 was obtained from the pods of NCRI SOYAC25 (6.38), and they were significantly different from the pods of NCRI SOYAC18, NCRI SOYAC77, and NCRI SOYAC67. While in 2020, the highest ratio was recorded in the pods of NCRI SOYAC65 (4.83) and they were significantly different from the pods of NCRI SOYAC69, NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC76 and NCRI SOYAC22. The lowest length/width ratio in 2019 was recorded in the pods of NCRI SOYAC67 (4.6); and in the pods of NCRI SOYAC64 (3.7) in 2020.

NCRI SOYAC17 was the genotype with pods that were the widest at the mid part in 2019. They had an average width at mid part of 0.89 cm. They were significantly wider than pods of NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC61 and NCRI SOYAC22. Meanwhile, in 2020, two genotypes (NCRI SOYAC25 and NCRI SOYAC76) had pods with significantly wider width at mid part (0.87 cm each). This significantly differed from NCRI SOYAC18, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC7, NCRI SOYAC63, and NCRI SOYAC67. The shortest widths at the mid parts of pod in 2019 were recorded in pods of NCRI SOYAC77 and NCRI SOYAC65 (0.69 cm each). In 2020, the shortest were in the pods of NCRI SOYAC64.

The thickest pods in 2019 were obtained from genotype NCRI SOYAC10 (0.63 cm), which were significantly thicker than pods of other genotypes except NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC9, NCRI SOYAC63 and NCRI SOYAC76. In 2020 NCRI SOYAC77 produced the thickest pods (0.63 cm) that were significantly thicker than pods of other genotypes except NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC20, and NCRI SOYAC76. On the other hand, in 2019, NCRI SOYAC77 pods with the lowest thickness (0.42). Whereas in 2020, NCRI SOYAC67 produced pods that were lowest in thickness (0.49).

In the case of weight of seeds from randomly selected 20 pods in 2019, two genotypes (NCRI SOYAC29 and NCRI SOYAC10) having average seed weight of 5.33 g were the highest among the genotypes in that year, and were significantly different from NCRI SOYAC18, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC22. In 2020, NCRI SOYAC77 and NCRI SOYAC65 had the highest seed weight for the year (6.33 g each); and they significantly differed from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC67 and NCRI SOYAC61. The lowest seed weight in 2019 was recorded in NCRI SOYAC63 (3.67 g), while the lowest in 2020 was recorded in NCRI SOYAC75.

In terms of pod wall weight, genotype NCRI SOYAC25, having an average pod wall weight of 3 g in 2019 was the highest for that year; and was significantly different from NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC65, NCRI SOYAC3, NCRI

SOYAC62 and NCRI SOYAC76. In 2020, NCRI SOYAC18, NCRI SOYAC26 and NCRI SOYAC62 had the highest pod wall weight (3 g each); but were significantly different from only NCRI SOYAC3 and NCRI SOYAC75. Conversely, the lowest pod wall weight in 2019 was obtained from NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC62 and NCRI SOYAC76 (2 g each). While in 2020 the lowest was obtained from NCRI SOYAC3 and NCRI SOYAC75.

The genotypes with the heaviest pods in 2019 were NCRI SOYAC29, NCRI SOYAC25, and NCRI SOYAC10 (8 g each) and they differed significantly from NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC76, NCRI SOYAC61, NCRI SOYAC22. In 2020, NCRI SOYAC62 produced the heaviest pods (9.33 g), which differed significantly from NCRI SOYAC69, NCRI SOYAC28, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC67 and NCRI SOYAC61. The lowest genotypes in pod weight in 2019 were NCRI SOYAC77, NCRI SOYAC65, NCRI SOYAC3 and NCRI SOYAC63 (6 g each), while 2020 had NCRI SOYAC63 as the genotype with the lowest pod weight (6.33 g).

The genotype, NCRI SOYAC17 had the highest seed weight/pod weight ratio in 2019 (0.71), which differed significantly from NCRI SOYAC25, NCRI SOYAC20, and NCRI SOYAC63. In 2020, two genotypes (NCRI SOYAC77 and NCRI SOYAC7) had the highest (0.71); and they differed significantly from NCRI SOYAC69 and NCRI SOYAC63. The lowest ratio in both 2019 and 2020 was obtained from NCRI SOYAC63 (0.61 and 0.63, respectively).

The highest pod wall weight/pod weight ratio was recorded in NCRI SOYAC63; both 2019 and 2020 (0.39 and 0.37, respectively). In 2019, it differed significantly from

NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC10, NCRI SOYAC67 and NCRI SOYAC76; while in 2020, it differed significantly from NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC7, and NCRI SOYAC75. The lowest ratio in 2019 (0.29) was obtained from NCRI SOYAC17, whereas the lowest in 2020 (0.29) was obtain from NCRI SOYAC77 and NCRI SOYAC7.

The highest pod shattering percentage in both 2019 and 2020 was recorded in NCRI SOYAC63 (88.33 % and 90 %, respectively), and was significantly different from other genotypes in both years. In 2019, NCRI SOYAC76 had lowest pod shattering (5 %). However, in 2020, it was NCRI SOYAC22 that had the lowest pod shattering percentage (1.67 %), though not significantly different from NCRI SOYAC76 that had 10 % pod shattering.

Table 4.12: Performances of 26 genotypes of soybean for pod traits in Awka in 2019 and 2020 cropping season

Genotype	Pod Length (cm)		Pod Width (cm)		LW Ratio		Pod Thickness (cm)		Pod Mid Width (cm)		Seed Weight (g)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	3.83efg	3.87abc	0.70abcd	0.87bcd	5.79abc	4.47abcd	0.48defg	0.50de	0.83abcdef	0.77abc	5.00ab	5.33bcd
NCRI SOYAC18	3.83efg	3.77abcd	0.73abc	0.83cd	5.25bcd	4.53abc	0.49defg	0.54bcde	0.79cdef	0.73bc	4.67bc	5.67abc
NCRI SOYAC17	4.03bcdef	3.83abc	0.70abcd	0.90abc	5.76abc	4.30abcde	0.53bcdef	0.56bcd	0.89a	0.80abc	5.00ab	5.33bcd
NCRI SOYAC69	4.03bcdef	3.47de	0.73abc	0.87bcd	5.51abcd	4.07bcde	0.46efg	0.54bcde	0.85abcde	0.80abc	4.33cd	4.67de
NCRI SOYAC77	3.57gh	3.97ab	0.70abcd	0.83cd	5.10cd	4.80a	0.42g	0.63a	0.69g	0.77abc	4.00de	6.33a
NCRI SOYAC73	4.20bcde	3.63bcd	0.67bcd	0.93abc	6.32a	3.90cde	0.49defg	0.55bcde	0.75fg	0.83ab	4.33cd	5.67abc
NCRI SOYAC26	4.37abcd	3.80abcd	0.70abcd	0.90abc	6.24ab	4.20abcde	0.57abcd	0.51de	0.80bcdef	0.77abc	5.00ab	5.67abc
NCRI SOYAC29	4.47ab	3.60cd	0.73abc	0.97ab	6.28ab	3.73e	0.59abc	0.55bcde	0.86abcd	0.80abc	5.33a	6.00ab
NCRI SOYAC25	4.67a	3.87abc	0.73abc	1.00a	6.38a	3.87de	0.55abcde	0.54bcde	0.88ab	0.87a	5.00ab	5.67abc
NCRI SOYAC28	4.03bcdef	3.80abcd	0.70abcd	0.87bcd	5.76abc	4.40abcd	0.51bcdefg	0.55bcde	0.76fg	0.77abc	5.00ab	5.00cd
NCRI SOYAC64	4.07bcdef	3.20e	0.73abc	0.87bcd	5.58abcd	3.70e	0.60ab	0.54bcde	0.78def	0.70c	5.00ab	5.33bcd
NCRI SOYAC65	4.07bcdef	3.70abcd	0.73abc	0.77d	5.55abcd	4.83a	0.49defg	0.60ab	0.69g	0.73bc	4.00de	5.33bcd
NCRI SOYAC24	4.03bcdef	3.63bcd	0.70abcd	0.90abc	5.84abc	3.97cde	0.51bcdefg	0.58abc	0.83abcdef	0.80abc	4.67bc	6.00ab
NCRI SOYAC3	3.37h	3.47de	0.60d	0.90abc	5.75abc	3.90cde	0.45fg	0.55bcde	0.79cdef	0.80abc	4.00de	4.67de
NCRI SOYAC9	4.00cdefg	3.63bcd	0.73abc	0.90abc	5.48abcd	4.03cde	0.54abcde	0.59abc	0.81abcdef	0.77abc	5.00ab	5.00cd
NCRI SOYAC7	4.40abc	3.90abc	0.77ab	0.83cd	5.76abc	4.70ab	0.49defg	0.52cde	0.87abc	0.73bc	5.00ab	5.67abc
NCRI SOYAC68	3.93defg	3.73abcd	0.73abc	0.97ab	5.38abcd	3.87de	0.48defg	0.52cde	0.78def	0.83ab	5.00ab	5.67abc
NCRI SOYAC20	4.67a	3.80abcd	0.77ab	0.97ab	6.10abc	3.93cde	0.51bcdefg	0.60ab	0.83abcdef	0.80abc	4.67bc	5.67abc
NCRI SOYAC62	3.93defg	3.57cd	0.70abcd	0.93abc	5.62abcd	3.87de	0.51bcdefg	0.50de	0.77efg	0.83ab	4.67bc	6.33a
NCRI SOYAC63	3.73fgh	3.63bcd	0.63cd	0.87bcd	5.90abc	4.20abcde	0.54abcde	0.55bcde	0.78def	0.73bc	3.67e	4.67de
NCRI SOYAC75	3.97cdefg	3.47de	0.70abcd	0.87bcd	5.67abcd	4.03cde	0.49defg	0.53bcde	0.81abcdef	0.77abc	5.00ab	4.00e
NCRI SOYAC10	4.27abcde	3.60cd	0.77ab	0.90abc	5.57abcd	4.00cde	0.63a	0.53bcde	0.84abcde	0.77abc	5.33a	5.67abc
NCRI SOYAC67	3.67fgh	3.70abcd	0.80a	0.87bcd	4.60d	4.33abcde	0.46efg	0.49e	0.88ab	0.73bc	5.00ab	4.67de
NCRI SOYAC76	4.27abcde	4.00a	0.70abcd	1.00a	6.10abc	4.00cde	0.57abcd	0.59abc	0.82abcdef	0.87a	4.67bc	6.00ab
NCRI SOYAC61	3.97cdefg	3.60cd	0.63cd	0.87bcd	6.28ab	4.23abcde	0.45fg	0.53bcde	0.78def	0.77abc	4.33cd	5.00cd
NCRI SOYAC22	4.30abcd	3.90abc	0.70abcd	0.97ab	6.14abc	4.03cde	0.43g	0.55bcde	0.78def	0.80abc	4.33cd	6.00ab
Mean	4.06	3.7	0.71	0.9	5.76	4.15	0.51	0.55	0.81	0.78	4.69	5.42
Range (Min-Max)	3.37-4.67	3.20-4.00	0.60-0.80	0.77-1.00	4.60-6.38	3.70-4.83	0.42-0.63	0.49-0.63	0.69-0.89	0.70-0.87	3.67-5.33	4.00-6.33
±SE	0.16	0.12	0.04	0.04	0.38	0.23	0.03	0.02	0.03	0.04	0.22	0.31
CV	6.95	5.6	8.98	7.84	11.34	9.68	11.48	7.76	6.43	8.8	8.23	9.94

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; L/W Ratio = Pod Length/Pod Width Ratio; ±SE = Standard error of the mean; CV = Coefficient of Variation.

Table 4.12 Continued: Performances of 26 genotypes of soybean for pod traits in Awka in 2019 and 2020 cropping season

Genotype	Pod Wall Weight (g)		Pod Weight (g)		SWPW Ratio		PWWPW Ratio		Pod Sht (%)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	2.33ab	2.67ab	7.33ab	8.00abcde	0.68abc	0.67abc	0.32bcd	0.33abc	16.67bc	21.67bcde
NCRI SOYAC18	2.33ab	3.00a	7.00abc	8.67abc	0.67abc	0.66abc	0.33bcd	0.34abc	28.33bc	36.67bc
NCRI SOYAC17	2.00b	2.67ab	7.00abc	8.00abcde	0.71a	0.67abc	0.29d	0.33abc	18.33bc	18.33bcde
NCRI SOYAC69	2.33ab	2.67ab	6.67bc	7.33cdef	0.66abcd	0.64bc	0.34abcd	0.36ab	16.67bc	25.00bcd
NCRI SOYAC77	2.00b	2.67ab	6.00c	9.00ab	0.67abc	0.71a	0.33bcd	0.29c	11.67bc	3.33e
NCRI SOYAC73	2.33ab	2.67ab	6.67bc	8.33abcd	0.66abcd	0.68abc	0.34abcd	0.32abc	15.00bc	16.67cde
NCRI SOYAC26	2.67ab	3.00a	7.67ab	8.67abc	0.66abcd	0.66abc	0.34abcd	0.34abc	21.67bc	18.33bcde
NCRI SOYAC29	2.67ab	2.67ab	8.00a	8.67abc	0.67abc	0.70ab	0.33bcd	0.30bc	10.00bc	10.00de
NCRI SOYAC25	3.00a	2.67ab	8.00a	8.33abcd	0.63cd	0.68abc	0.37ab	0.32abc	23.33bc	18.33bcde
NCRI SOYAC28	2.33ab	2.33ab	7.33ab	7.33cdef	0.68abc	0.68abc	0.32bcd	0.32abc	30.00bc	25.00bcd
NCRI SOYAC64	2.33ab	2.67ab	7.33ab	8.00abcde	0.68abc	0.67abc	0.32bcd	0.33abc	26.67bc	25.00bcd
NCRI SOYAC65	2.00b	2.67ab	6.00c	8.00abcde	0.67abc	0.67abc	0.33bcd	0.33abc	31.67b	38.33b
NCRI SOYAC24	2.33ab	2.67ab	7.00abc	8.67abc	0.67abc	0.70ab	0.33bcd	0.30bc	23.33bc	26.67bcd
NCRI SOYAC3	2.00b	2.00b	6.00c	6.67ef	0.67abc	0.70ab	0.33bcd	0.30bc	18.33bc	11.67de
NCRI SOYAC9	2.67ab	2.33ab	7.67ab	7.33cdef	0.66abcd	0.68abc	0.34abcd	0.32abc	23.33bc	21.67bcde
NCRI SOYAC7	2.33ab	2.33ab	7.33ab	8.00abcde	0.68abc	0.71a	0.32bcd	0.29c	10.00bc	8.33de
NCRI SOYAC68	2.33ab	2.67ab	7.33ab	8.33abcd	0.68abc	0.68abc	0.32bcd	0.32abc	25.00bc	28.33bcd
NCRI SOYAC20	2.67ab	2.67ab	7.33ab	8.33abcd	0.64bcd	0.68abc	0.36abc	0.32abc	21.67bc	20.00bcde
NCRI SOYAC62	2.00b	3.00a	6.67bc	9.33a	0.70ab	0.68abc	0.30cd	0.32abc	28.33bc	25.00bcd
NCRI SOYAC63	2.33ab	2.33ab	6.00c	6.33f	0.61d	0.63c	0.39a	0.37a	88.33a	90.00a
NCRI SOYAC75	2.67ab	2.00b	7.67ab	6.67ef	0.66abcd	0.70ab	0.34abcd	0.30bc	21.67bc	25.00bcd
NCRI SOYAC10	2.67ab	2.67ab	8.00a	8.33abcd	0.67abc	0.68abc	0.33bcd	0.32abc	21.67bc	25.00bcd
NCRI SOYAC67	2.33ab	2.33ab	7.33ab	7.00def	0.68abc	0.67abc	0.32bcd	0.33abc	21.67bc	26.67bcd
NCRI SOYAC76	2.00b	2.67ab	6.67bc	8.67abc	0.70ab	0.69abc	0.30cd	0.31abc	5.00c	10.00de
NCRI SOYAC61	2.33ab	2.67ab	6.67bc	7.67bcdef	0.66abcd	0.66abc	0.34abcd	0.34abc	28.33bc	26.67bcd
NCRI SOYAC22	2.33ab	2.67ab	6.67bc	8.67abc	0.66abcd	0.70ab	0.34abcd	0.30bc	16.67bc	1.67e
Mean	2.36	2.59	7.05	8.01	0.67	0.68	0.33	0.32	23.21	23.21
Range (Min-Max)	2.00-3.00	2.00-3.00	6.00-8.00	6.33-9.33	0.61-0.71	0.63-0.71	0.29-0.39	0.29-0.37	5.00-88.33	1.67-90.00
±SE	0.27	0.31	0.42	0.55	0.02	0.02	0.02	0.02	9.18	7.16
CV	19.56	20.41	10.28	11.88	5.02	5.14	10.11	10.88	68.49	53.45

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; SWPW Ratio = Seed weight/Pod weight Ratio; PWWPW Ratio = Pod wall weight/Pod weight Ratio; Pod Sht = Pod shattering percentage; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.9 Combined Performance of the Genotypes for Seed Yield and Pod Shattering

4.1.9.1 Seed Yield

After combined analysis of yield data that involved genotypes' yields across locations and years, the highest seed yield was obtained from NCRI SOYAC78 (1.44 ton/ha) (Table 4.13). This differed significantly from NCRI SOYAC73, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC75, NCRI SOYAC10, and NCRI SOYAC67. The poorest in seed yield among the genotypes in combined analysis was NCRI SOYAC65 (0.99 ton/ha) but it did not differ significantly from NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC10, and NCRI SOYAC67.

4.1.9.2 Pod Shattering

The combined performance of the genotypes on pod shattering is a result of combined data analysis of genotypes' pod shattering percentages across locations and years. This is also contained in Table 4.13. Among the genotypes, the genotype with the most shattered pods was NCRI SOYAC63 (89.44 %), which differed significantly from the rest of genotypes. Conversely, the genotype with least shattered pods was NCRI SOYAC76 (6.39 %) but was not significantly different from NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC7, and NCRI SOYAC22.

Table 4.13: Combined Analysis Results of the Genotypes on Seed Yield and Pod Shattering

Genotype	Seed Yield	Pod Shattering
NCRI SOYAC78	1.44a	14.72efghijkl
NCRI SOYAC18	1.31abcd	34.17b
NCRI SOYAC17	1.30abcd	13.11fghijkl
NCRI SOYAC69	1.33abcd	21.83cdef
NCRI SOYAC77	1.31abcd	8.06kl
NCRI SOYAC73	1.17bcde	10.83ghijkl
NCRI SOYAC26	1.37ab	18.33defghi
NCRI SOYAC29	1.21abcde	9.44ijkl
NCRI SOYAC25	1.23abcde	18.67defgh
NCRI SOYAC28	1.25abcd	20.06def
NCRI SOYAC64	1.18bcde	23.61cde
NCRI SOYAC65	0.99e	30.11bc
NCRI SOYAC24	1.16bcde	18.89defgh
NCRI SOYAC3	1.12cde	18.61defghi
NCRI SOYAC9	1.36abcd	20.00defg
NCRI SOYAC7	1.18bcde	8.61jkl
NCRI SOYAC68	1.12cde	17.50defghij
NCRI SOYAC20	1.28abcd	16.11efghijk
NCRI SOYAC62	1.16bcde	21.94cdef
NCRI SOYAC63	1.19abcde	89.44a
NCRI SOYAC75	1.13bcde	20.00defg
NCRI SOYAC10	1.13bcde	17.33defghij
NCRI SOYAC67	1.11de	23.89cde
NCRI SOYAC76	1.30abcd	6.39l
NCRI SOYAC61	1.34abcd	26.39bcd
NCRI SOYAC22	1.24abcd	10.56hijkl
Mean	1.23	20.72
±SE	0.09	3.24
CV	12.41	27.07

Means followed by the same letter(s) within a column are not significantly different at P=0.05 using DMRT; ±SE = Standard error of the mean; CV = Coefficient of Variation.

4.1.10 Stability Studies of the Genotypes for Seed Yield and Pod Shattering

4.1.10.1 Genotypes' Stability for Seed Yield in 2019

The seed yield of the 26 soybean genotypes across the three locations in 2019 ranged from 0.86 to 1.57 tons/ha (Table 4.14). Sixteen genotypes gave higher seed yield than the grand mean (1.30 tons/ha). The environments' seed yield ranged from 1.04 tons/ha in Awka to 1.54 tons/ha in Minna (Table 4.14).

The regression coefficient (b) and the mean values for seed yield, for the 26 soybean genotypes over three environments are presented in Table 4.15. The b value is the genotypic sensitivity to changes in the environmental conditions. Values of $b>1$ means genotypes with a higher than average sensitivity and less stable, while $b<1$ means genotypes that are less sensitive and more stable.

Table 4.15 shows that the genotype with the least sensitivity to changes in environment was NCRI SOYAC64, as it had the lowest b value (-0.450). This genotype also had mean seed yield of 1.39 ton/ha, which is greater than grand mean (1.30 ton/ha). Similarly, six other genotypes (NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC26, NCRI SOYAC9, NCRI SOYAC7, and NCRI SOYAC20), had low sensitivity to changes in the environments ($b<1$) with above average seed yield. All the high yielding and low sensitive genotypes also produced high static and dynamic (Wricke's Ecovalence) stabilities (Table 4.15).

In the AMMI bi-plot (Figure 4.8), the difference among genotypes in terms of direction and magnitude along the X-axis (yield) and Y-axis (IPCA 1 scores) are provided. It makes use of the main effect and the First Principal Component Scores of Interactions (IPCA1) of both genotypes and environments. In the bi-plot, genotypes or environments that are located almost on the perpendicular line of the graph have similar seed yields and those that appear almost on the horizontal line have similar interaction (Ishaq *et al*., 2015). Genotypes or environments that are located at the right side of the midpoint of the perpendicular line have higher yields than those on the left side. The genotypes NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC76, NCRI SOYAC61, NCRI SOYAC22 recorded high yields. In contrast, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC67, NCRI SOYAC63, NCRI SOYAC10, NCRI SOYAC17, NCRI SOYAC25, NCRI SOYAC3, NCRI SOYAC75, NCRI SOYAC68, and NCRI SOYAC62 were low yielding.

According to Egesi and Asiedu (2002), genotypes or environments that have large negative or positive IPCA1 scores have high interactions, while the ones with scores close to zero (near the horizontal line) have little interaction across environments and are considered to be more stable than those that are further away from the line. In the bi-plot, NCRI SOYAC20, NCRI SOYAC22, NCRI SOYAC7, NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC69, and NCRI SOYAC28 are very close to the horizontal line near the zero point on IPCA1 (Figure 4.8). Since these genotypes are located on the right side of the midpoint of the perpendicular line, they produced high and stable yield. Genotypes NCRI SOYAC26, NCRI SOYAC18, NCRI SOYAC9, NCRI SOYAC64, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC73 were a little far away from the horizontal line, meaning that the genotypes were high yielding but relatively unstable. Genotypes NCRI SOYAC17, NCRI SOYAC3 and NCRI SOYAC25 were also stable but low yielding (located at the left side). The most unstable genotype was

NCRI SOYAC77; while the poorest in yield was NCRI SOYAC65. In terms of environment, Chinka was the most stable, as it produced the least interaction score, while Minna and Akwa in that order were relatively unstable, producing highest interaction scores.

The polygon view of the GGE bi-plot (Figure 4.9) identifies two environments; with Minna and Chinka grouped as one environment, having NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC61, NCRI SOYAC76 and NCRI SOYAC69 as the best genotypes (winning genotypes) in this environment. The best genotypes for the second environment (Awka) were NCRI SOYAC9, NCRI SOYAC64, NCRI SOYAC10, and NCRI SOYAC25. The remaining sectors have no environment within them, thus the genotypes they contain were not the highest yielding at any environment.

4.1.10.2 Genotypes' Stability for Seed Yield in 2020

The seed yield of the soybean genotypes across the three locations in 2020 is also contained in Table 4.14, and it ranged from 0.98 to 1.44 tons/ha. Twelve genotypes gave higher seed yield than the grand mean (1.16 tons/ha). The environments' seed yield ranged from 1.02 tons/ha in Awka to 1.41 tons/ha in Igabi.

The regression coefficient (b) and the mean values for seed yield, for the 26 soybean genotypes over three environments are presented in Table 4.15. The Table shows that the genotype with the least environmental sensitivity was NCRI SOYAC18, as it had the lowest b value (-0.992). This genotype had mean seed yield of 1.15 tons/ha, which is below grand mean (1.16 ton/ha). Interestingly, five genotypes (NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC20, and NCRI SOYAC61), had low sensitivity to changes in the environments ($b<1$) with above average seed yield. All the high yielding and low sensitive genotypes also produced high static and dynamic (Wricke's Ecovalence) stabilities (Table 4.15).

In the AMMI bi-plot (Figure 4.10), twelve genotypes are located at the right side of the midpoint of the perpendicular line and thus have higher yields than those on the left side. The genotypes are NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC75, NCRI SOYAC76, NCRI SOYAC61. The only high yielding environment for this year was Chinka, as it is the only one on the right side of the midpoint of the perpendicular line.

In the bi-plot also, NCRI SOYAC17, NCRI SOYAC61, NCRI SOYAC63, NCRI SOYAC22, and NCRI SOYAC73 are very close to the horizontal line near the zero point on IPCA1 and are considered more stable than other genotypes. However, only NCRI SOYAC17 and NCRI SOYAC61 are high yielding (located at the right side). The most unstable genotype for the year was NCRI SOYAC9, while the poorest in yield was NCRI SOYAC64. In terms of environment, Awka was the most stable, as it produced the least interaction score, while Minna and Chinka were relatively unstable, producing high interaction scores.

In the GGE bi-plot (Figure 4.11), three environments were identified; Minna, Chinka and Awka. The best genotypes in Minna were NCRI SOYAC78 and NCRI SOYAC77; the best in Chinka were NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC26, NCRI SOYAC62, NCRI SOYAC65, NCRI SOYAC61 and NCRI SOYAC76, while NCRI SOYAC18, NCRI SOYAC29, NCRI SOYAC3, and NCRI SOYAC20 were the best in Awka. The remaining sectors have no environment within them, thus the genotypes they contain were not the highest yielding at any environment.

Table 4.14: Mean seed yield of the genotypes in the three environments and two years (ton/ha)

	Minna		Chinka		Awka		Mean	
Genotype	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	1.70	1.53	1.37	1.47	1.27	1.33	1.45	1.44
NCRI SOYAC18	1.70	1.37	1.23	0.90	1.50	1.17	1.48	1.15
NCRI SOYAC17	1.53	1.47	1.10	1.67	0.97	1.07	1.20	1.40
NCRI SOYAC69	1.50	1.20	1.50	1.70	0.97	1.13	1.32	1.34
NCRI SOYAC77	2.37	1.23	1.73	1.33	0.23	0.97	1.44	1.18
NCRI SOYAC73	1.87	0.73	1.37	1.20	0.83	1.03	1.36	0.99
NCRI SOYAC26	1.67	0.83	1.63	1.83	1.40	0.87	1.57	1.18
NCRI SOYAC29	1.63	1.40	1.33	0.97	1.07	0.87	1.34	1.08
NCRI SOYAC25	1.70	0.67	1.00	1.53	1.10	1.37	1.27	1.19
NCRI SOYAC28	1.83	0.80	1.40	1.40	1.17	0.90	1.47	1.03
NCRI SOYAC64	1.27	0.87	1.40	1.03	1.50	1.03	1.39	0.98
NCRI SOYAC65	1.00	1.00	0.90	1.57	0.67	0.80	0.86	1.12
NCRI SOYAC24	1.17	1.00	1.13	1.87	0.93	0.83	1.08	1.23
NCRI SOYAC3	1.60	1.10	1.10	0.97	0.97	1.00	1.22	1.02
NCRI SOYAC9	1.50	0.77	1.30	1.97	1.46	1.20	1.42	1.31
NCRI SOYAC7	1.57	0.97	1.27	1.17	1.10	1.00	1.31	1.05
NCRI SOYAC68	1.47	0.87	1.20	1.20	0.83	1.13	1.17	1.07
NCRI SOYAC20	1.50	1.20	1.43	1.30	1.10	1.13	1.34	1.21
NCRI SOYAC62	1.47	0.93	1.30	1.57	0.80	0.87	1.19	1.12
NCRI SOYAC63	1.20	1.27	1.43	1.47	1.10	0.70	1.24	1.15
NCRI SOYAC75	1.33	1.10	1.27	1.63	0.70	0.77	1.10	1.17
NCRI SOYAC10	1.27	0.93	1.23	1.20	1.23	0.90	1.24	1.01
NCRI SOYAC67	1.33	0.83	1.10	1.40	1.07	0.90	1.17	1.04
NCRI SOYAC76	1.70	1.00	1.37	1.60	1.00	1.13	1.36	1.24
NCRI SOYAC61	1.60	1.03	1.60	1.47	0.97	1.40	1.39	1.30
NCRI SOYAC22	1.67	0.97	1.20	1.33	1.13	1.13	1.33	1.14
Mean	1.54	1.04	1.30	1.41	1.04	1.02	1.30	1.16

Table 4.15: Sensitivity and stability coefficients for seed yield of the genotypes across three environments and two years

Genotype	Sensitivity (b-value)		Static Stability		Wricke's Ecovalence		Mean square Deviation	
	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	0.82	0.08	0.05	0.01	0.02	0.09	0.02	0.02
NCRI SOYAC18	0.30	-0.99	0.06	0.06	0.14	0.39	0.10	0.02
NCRI SOYAC17	1.07	0.99	0.09	0.09	0.02	0.07	0.03	0.09
NCRI SOYAC69	1.11	1.39	0.09	0.10	0.04	0.02	0.03	0.02
NCRI SOYAC77	4.32	0.57	1.21	0.04	1.45	0.05	0.04	0.04
NCRI SOYAC73	2.05	0.87	0.27	0.06	0.14	0.05	0.01	0.04
NCRI SOYAC26	0.56	2.57	0.02	0.32	0.03	0.24	0.01	0.00
NCRI SOYAC29	1.10	-0.50	0.08	0.08	0.01	0.33	0.01	0.13
NCRI SOYAC25	1.09	1.44	0.14	0.21	0.12	0.27	0.14	0.22
NCRI SOYAC28	1.28	1.45	0.11	0.10	0.02	0.03	0.02	0.00
NCRI SOYAC64	-0.45	0.23	0.01	0.01	0.27	0.08	0.00	0.01
NCRI SOYAC65	0.67	1.73	0.03	0.16	0.02	0.07	0.00	0.03
NCRI SOYAC24	0.49	2.47	0.02	0.31	0.04	0.23	0.01	0.03
NCRI SOYAC3	1.20	-0.22	0.11	0.01	0.03	0.15	0.04	0.01
NCRI SOYAC9	0.04	2.63	0.01	0.37	0.13	0.34	0.02	0.07
NCRI SOYAC7	0.91	0.49	0.06	0.01	0.01	0.03	0.01	0.00
NCRI SOYAC68	1.27	0.56	0.10	0.03	0.01	0.06	0.00	0.03
NCRI SOYAC20	0.82	0.34	0.05	0.01	0.02	0.04	0.01	0.01
NCRI SOYAC62	1.36	1.74	0.12	0.15	0.03	0.06	0.01	0.01
NCRI SOYAC63	0.27	1.20	0.03	0.16	0.13	0.16	0.05	0.18
NCRI SOYAC75	1.30	1.77	0.12	0.19	0.05	0.12	0.03	0.07
NCRI SOYAC10	0.07	0.74	0.01	0.03	0.11	0.01	0.00	0.00
NCRI SOYAC67	0.49	1.40	0.02	0.10	0.04	0.02	0.01	0.00
NCRI SOYAC76	1.38	1.41	0.12	0.10	0.02	0.03	0.00	0.01
NCRI SOYAC61	1.32	0.71	0.13	0.06	0.07	0.09	0.04	0.06
NCRI SOYAC22	1.02	0.75	0.086	0.03	0.03	0.02	0.04	0.01

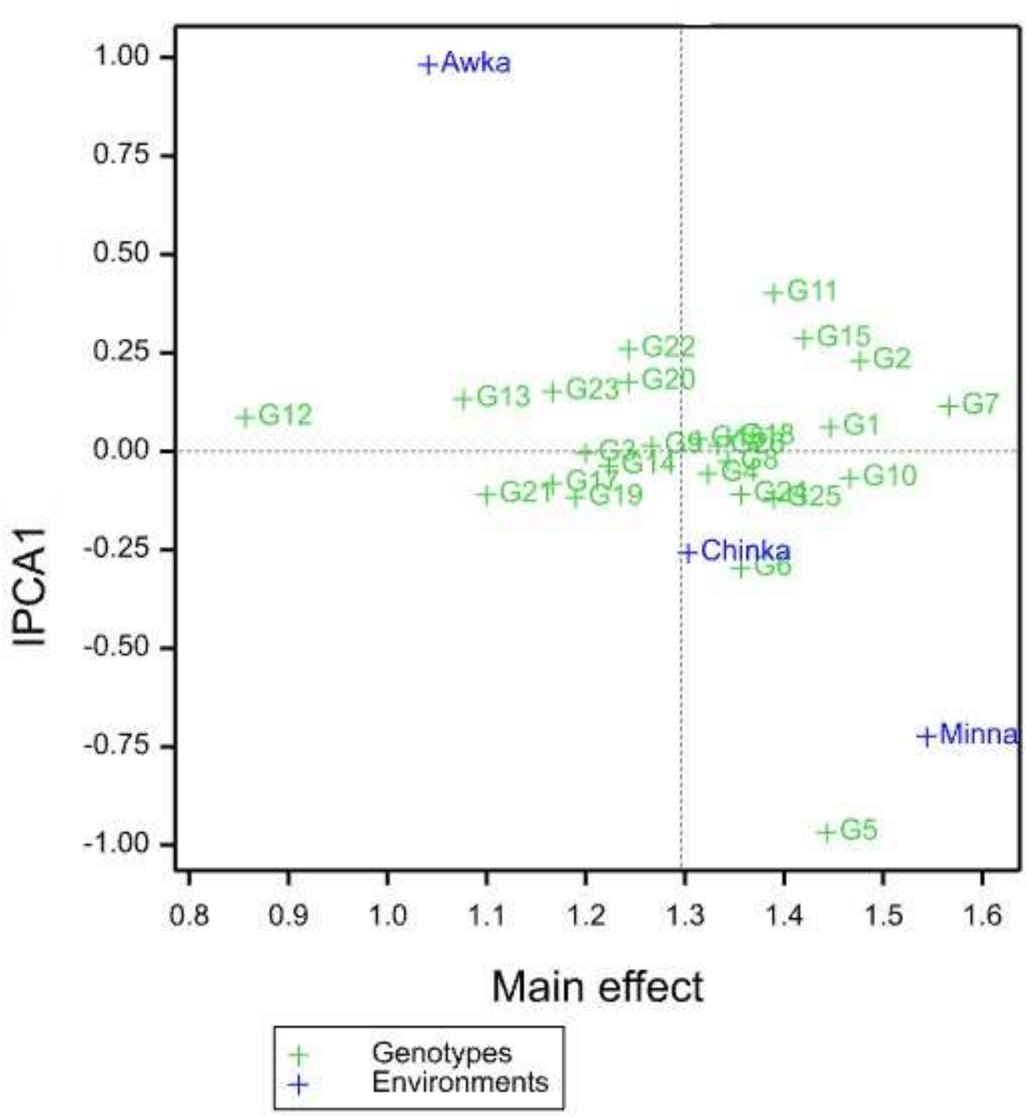

Figure 4.8: AMMI Bi-plot of seed yield for the 26 soybean genotypes across three environments in 2019

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

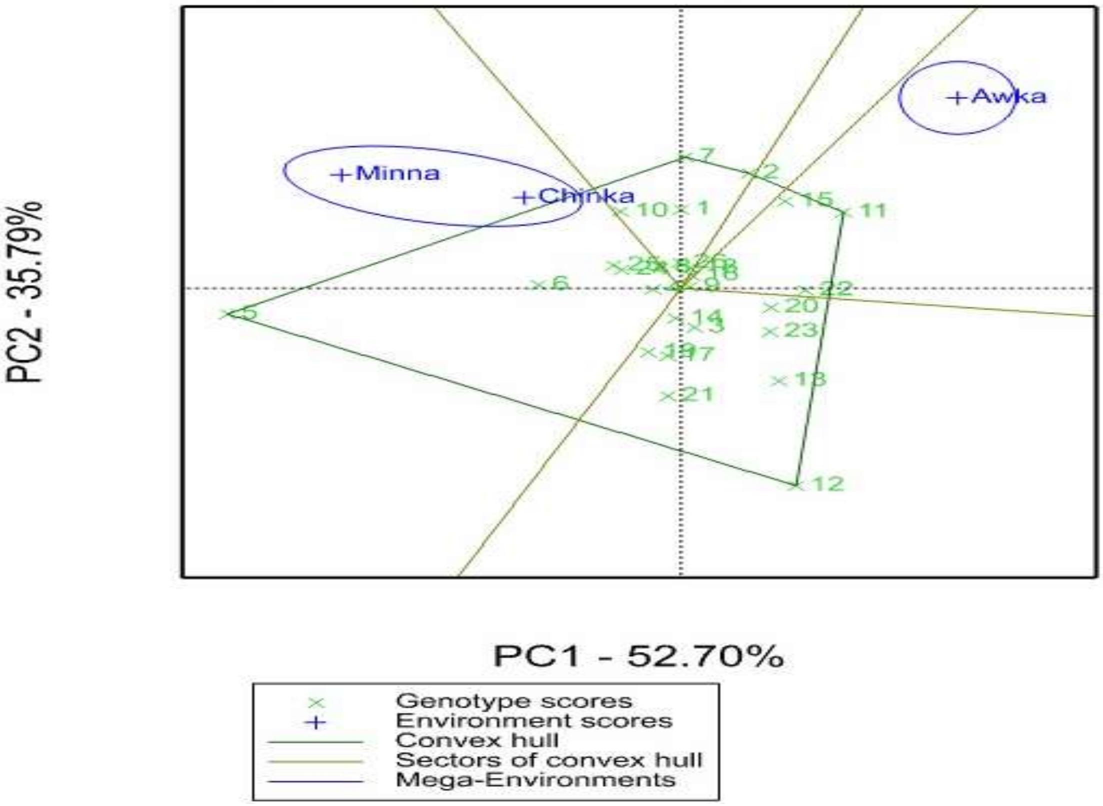

Figure 4.9: GGE biplot for best genotypes in different environments for seed yield in 2019

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

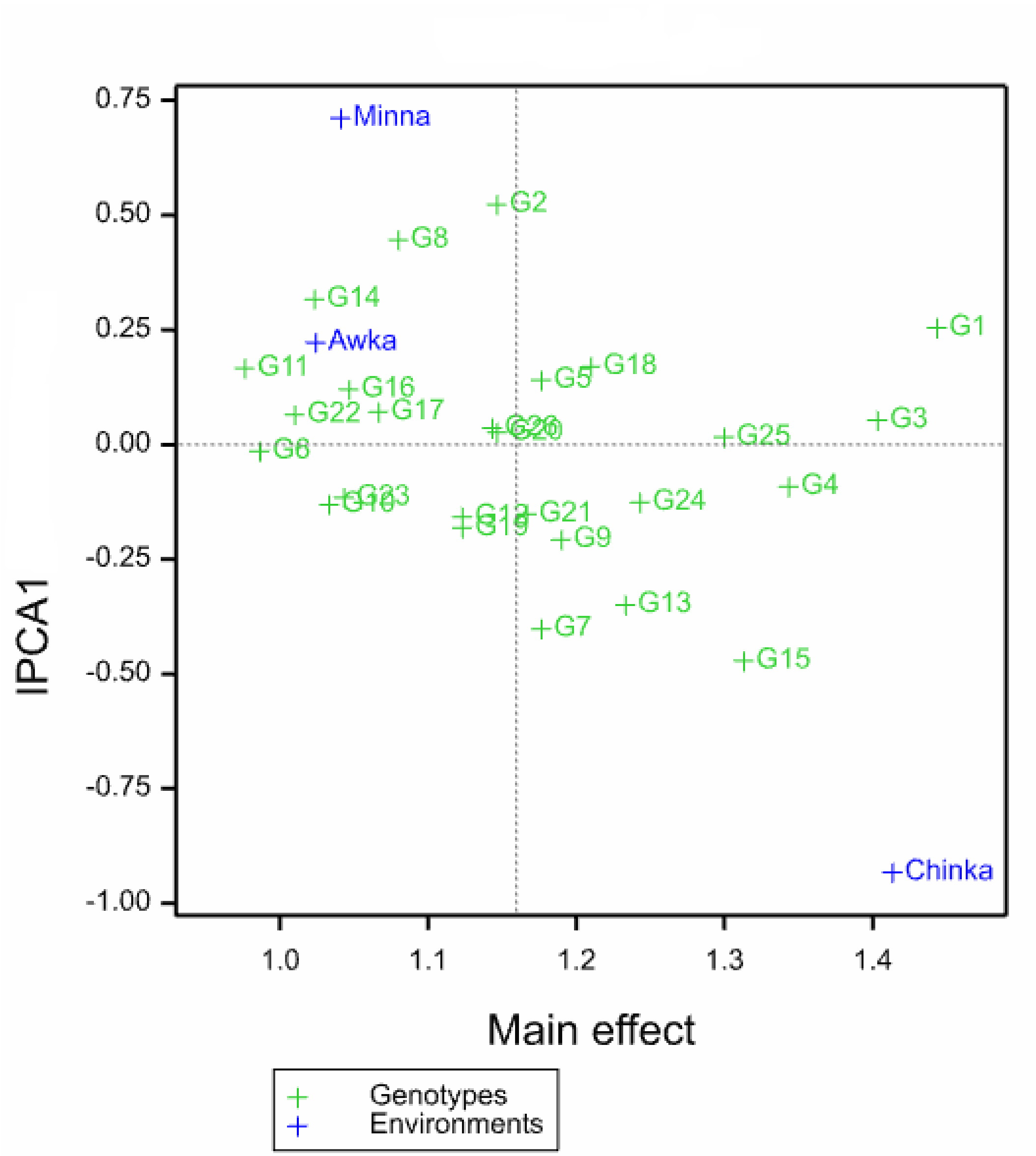

Figure 4.10: AMMI Bi-plot of seed yield for the 26 soybean genotypes across three environments in 2020

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

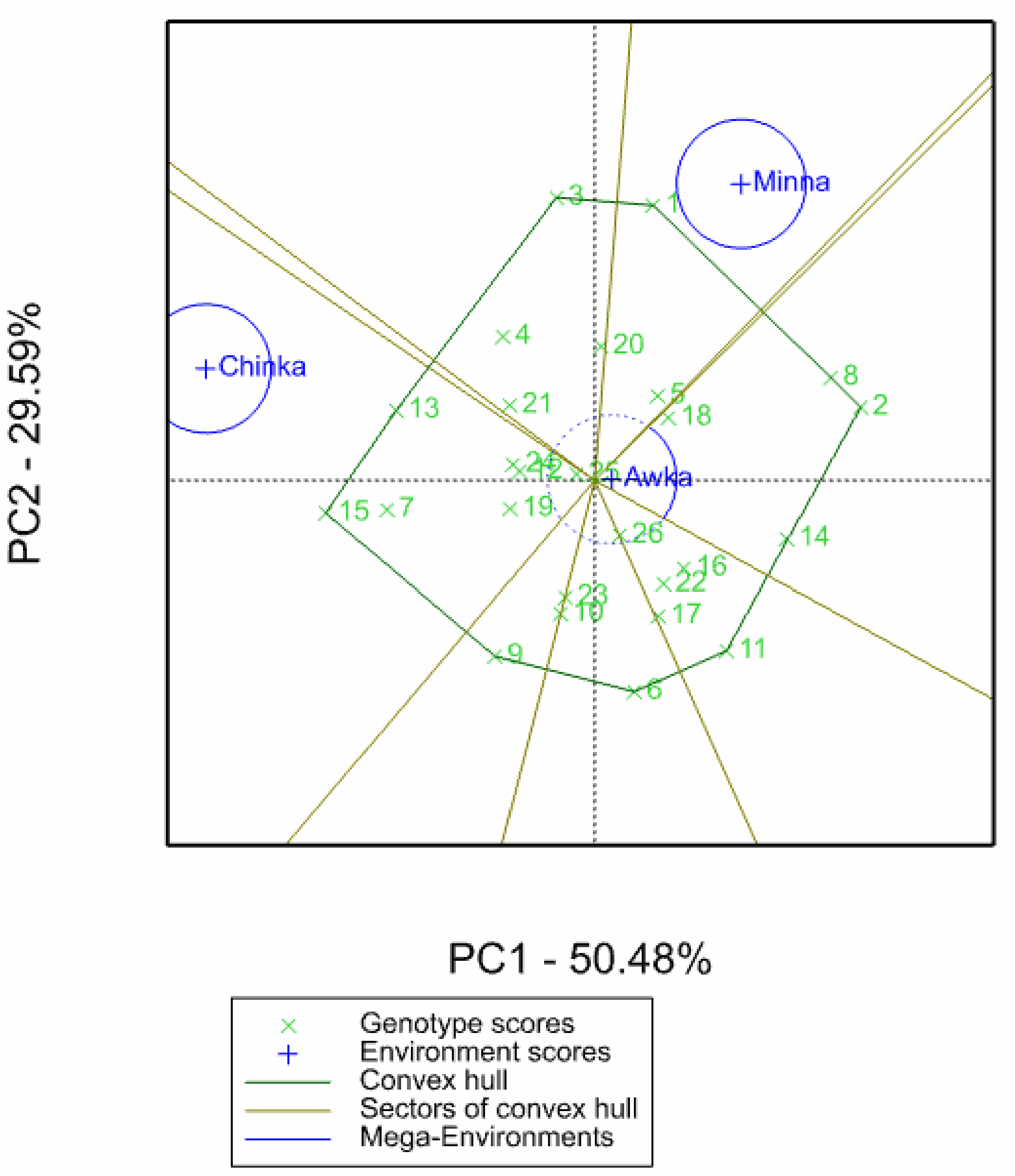

Figure 4.11: GGE biplot for best genotypes in different environments for seed yield in 2020

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

4.1.10.3 Genotypes' Stability across the Environments for Pod Shattering in 2019

The pod shattering rates of the 26 soybean genotypes across the three locations in 2019 ranged from 3.33 % to 89.44 % (Table 4.16). The environments' mean ranged from 16.22 % in Chinka to 23.85 % in Minna.

The regression coefficient (b) and the mean values for pod shattering percentage of the soybean genotypes over three environments are presented in Table 4.17. The Table shows that NCRI SOYAC22, having a b-value of -1.92 was the most stable. This genotype was also resistant to pod shattering (Table 4.18). Other resistant and stable genotypes were NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC67, and NCRI SOYAC76. However, only NCRI SOYAC9 had high static stability, while none had high dynamic (Wricke's Ecovalence) stability (Table 4.17).

The AMMI bi-plot for pod shattering (Figure 4.12) shows the stable genotypes in terms of pod shattering across the three environments. In the bi-plot, the environments are located almost on the perpendicular line of the graph and thus have similar influence on pod shattering behaviour of the genotypes. Genotypes NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC7, NCRI SOYAC61, NCRI SOYAC17, and NCRI SOYAC69 were located very close to the horizontal line of the bi-plot and are termed stable. Five of these stable genotypes (NCRI SOYAC78, NCRI SOYAC29, NCRI SOYAC7, NCRI SOYAC17, and NCRI SOYAC69) were resistant to pod shattering while one (NCRI SOYAC61) was moderately resistant. Genotype NCRI SOYAC63 was both unstable and very highly susceptible to pod shattering.

The GGE bi-plot (Figure 4.13) grouped the three environments into one environment, with NCRI SOYAC63, NCRI SOYAC18, NCRI SOYAC61, NCRI SOYAC28 and NCRI SOYAC65 as the genotypes with the highest pod shattering percentage.

4.1.10.4 Genotypes' Stability across the Environments for Pod Shattering in 2020

The pod shattering rates of the genotypes across the three locations in 2020 ranged from 7.22 % to 89.44 % (Table 4.16). The environments' mean ranged from 18.65 % in Minna to 23.21 % in Awka.

The Table of regression coefficient (b) and mean values for pod shattering percentage of the soybean genotypes (Table 4.17), shows that NCRI SOYAC3, having a b-value of -4.672 was the most stable. This genotype was also resistant to pod shattering (Table 4.19). Other resistant and stable genotypes were NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC75, NCRI SOYAC67, NCRI SOYAC76, and NCRI SOYAC22. However, none of the genotypes had high static and dynamic (Wricke's Ecovalence) stabilities (Table 4.17).

The AMMI bi-plot for pod shattering (Figure 4.14) shows that the environments are located almost on the perpendicular line of the graph and thus have similar influence on pod shattering behaviour of the genotypes. Genotypes NCRI SOYAC77, NCRI SOYAC20, and NCRI SOYAC24 were located very close to the horizontal line of the bi-plot and are termed stable, and were resistant to pod shattering (Table 4.20). Genotype NCRI SOYAC63 was both unstable and very highly susceptible to pod shattering.

The GGE bi-plot (Figure 4.15) grouped the three environments into one environment, with NCRI SOYAC63, NCRI SOYAC64, NCRI SOYAC61, and NCRI SOYAC65 as the genotypes with the highest pod shattering percentage.

Table 4.16: Mean pod shattering percentage of the genotypes in the three environments and two years

Genotype	Minna		Chinka		Awka		Mean	
	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	23.33	5.00	15.00	6.67	16.67	21.67	18.33	11.11
NCRI SOYAC18	36.67	31.67	23.33	48.33	28.33	36.67	29.44	38.89
NCRI SOYAC17	17.00	6.67	11.67	6.67	18.33	18.33	15.67	10.56
NCRI SOYAC69	27.67	13.33	16.67	31.67	16.67	25.00	20.34	23.33
NCRI SOYAC77	0.00	10.00	15.00	8.33	11.67	3.33	8.89	7.22
NCRI SOYAC73	16.67	6.67	3.33	6.67	15.00	16.67	11.67	10.00
NCRI SOYAC26	16.67	25.00	21.67	6.67	21.67	18.33	20.00	16.67
NCRI SOYAC29	11.67	8.33	3.33	13.33	10.00	10.00	8.33	10.55
NCRI SOYAC25	20.33	21.67	16.67	11.67	23.33	18.33	20.11	17.22
NCRI SOYAC28	32.00	11.67	18.33	3.33	30.00	25.00	26.78	13.33
NCRI SOYAC64	30.00	30.00	10.00	20.00	26.67	25.00	22.22	25.00
NCRI SOYAC65	39.00	20.00	21.67	30.00	31.67	38.33	30.78	29.44
NCRI SOYAC24	26.67	11.67	8.33	16.67	23.33	26.67	19.44	18.34
NCRI SOYAC3	13.33	18.33	15.00	35.00	18.33	11.67	15.55	21.67
NCRI SOYAC9	23.33	11.67	21.67	18.33	23.33	21.67	22.78	17.22
NCRI SOYAC7	8.33	5.00	1.67	18.33	10.00	8.33	6.67	10.55
NCRI SOYAC68	26.67	10.00	3.33	11.67	25.00	28.33	18.33	16.67
NCRI SOYAC20	21.67	10.00	10.00	13.33	21.67	20.00	17.78	14.44
NCRI SOYAC62	28.33	23.33	11.67	15.00	28.33	25.00	22.78	21.11
NCRI SOYAC63	90.00	98.33	90.00	80.00	88.33	90.00	89.44	89.44
NCRI SOYAC75	28.33	13.33	5.00	26.67	21.67	25.00	18.33	21.67
NCRI SOYAC10	25.67	18.33	5.00	8.33	21.67	25.00	17.45	17.22
NCRI SOYAC67	25.00	16.67	25.00	28.33	21.67	26.67	23.89	23.89
NCRI SOYAC76	0.00	11.67	5.00	6.67	5.00	10.00	3.33	9.45
NCRI SOYAC61	28.33	31.67	21.67	21.67	28.33	26.67	26.11	26.67
NCRI SOYAC22	3.33	15.00	21.67	50.00	16.67	1.67	13.89	7.22
Mean	23.85	18.65	16.22	19.17	23.21	23.21	21.09	20.35

Table 4.17: Sensitivity and stability coefficients for pod shattering percentage of the genotypes across three environments and two years

	Sensitivity (b-value)		Static Stability		Wricke's Ecovalence		Mean square Deviation	
Genotype	2019	2020	2019	2020	2019	2020	2019	2020
NCRI SOYAC78	0.85	2.03	19.42	84.28	21.66	89.45	12.17	114.71
NCRI SOYAC18	1.44	–2.99	45.42	73.09	31.95	169.13	14.07	29.39
NCRI SOYAC17	0.74	1.68	12.42	45.32	3.09	36.30	4.75	53.75
NCRI SOYAC69	1.05	–2.40	40.33	86.17	55.83	161.05	40.27	96.92
NCRI SOYAC77	-1.54	–0.59	62.05	12.05	256.67	70.79	36.31	19.56
NCRI SOYAC73	1.68	1.44	52.82	33.33	18.54	21.83	2.28	39.54
NCRI SOYAC26	-0.48	3.12	8.33	86.07	80.03	179.68	8.32	44.88
NCRI SOYAC29	1.03	–0.87	19.47	6.48	0.56	27.58	0.20	3.00
NCRI SOYAC25	0.58	1.75	11.13	25.92	9.70	59.89	9.88	12.02
NCRI SOYAC28	1.71	3.78	54.51	119.50	20.10	155.44	1.74	52.45
NCRI SOYAC64	2.48	1.51	114.83	25.00	84.69	67.56	2.60	20.35
NCRI SOYAC65	1.99	0.41	75.68	84.23	49.32	99.43	4.45	166.22
NCRI SOYAC24	2.27	1.05	95.42	58.33	62.08	54.95	1.57	102.32
NCRI SOYAC3	-0.04	–4.67	6.48	144.4	43.88	378.59	12.89	3.65
NCRI SOYAC9	0.22	–0.04	0.92	25.92	21.47	22.66	0.12	51.81
NCRI SOYAC7	0.92	–2.49	19.42	48.13	2.69	120.95	7.45	15.33
NCRI SOYAC68	2.98	2.27	169.52	102.70	154.51	116.83	13.18	138.16
NCRI SOYAC20	1.52	0.70	45.40	25.93	12.89	14.85	6.12	45.47
NCRI SOYAC62	2.17	2.10	92.52	28.70	58.52	40.68	12.47	0.01
NCRI SOYAC63	-0.06	2.88	0.93	84.23	44.73	185.50	1.74	59.95
NCRI SOYAC75	2.80	–1.29	144.42	52.82	125.52	82.60	0.10	83.93
NCRI SOYAC10	2.55	3.19	120.19	70.40	91.72	91.52	1.50	7.99
NCRI SOYAC67	-0.12	–1.16	3.70	39.79	57.28	62.14	6.90	62.12
NCRI SOYAC76	-0.48	0.87	8.33	6.48	80.03	23.20	8.32	3.00
NCRI SOYAC61	0.87	1.51	14.79	25.00	0.48	67.56	1.99	20.35
NCRI SOYAC22	-1.92	0.31	89.89	48.13	337.82	161.52	44.03	95.03

Table 4.18: Genotype grouping based on mean pod shattering percentage across three environments in 2019

Score	Description	Category	Genotypes
1	No pod shattering	Very resistant	Nil
2	< 25% pod shattering	Resistant	NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, NCRI SOYAC76, NCRI SOYAC22
3	25 - 50% pod shattering	Moderately Resistant	NCRI SOYAC18, NCRI SOYAC28, NCRI SOYAC65, NCRI SOYAC61
4	51 - 75% pod shattering	Highly susceptible	Nil
5	> 75% pod shattering	Very highly susceptible	NCRI SOYAC63

Table 4.19: Genotype grouping based on mean pod shattering percentage across three environments in 2020

Score	Description	Category	Genotypes
1	No pod shattering	Very resistant	Nil
2	< 25% pod shattering	Resistant	NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, NCRI SOYAC76, NCRI SOYAC22
3	25 - 50% pod shattering	Moderately Resistant	NCRI SOYAC18, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC61
4	51 - 75% pod shattering	Highly susceptible	Nil
5	> 75% pod shattering	Very highly susceptible	NCRI SOYAC63

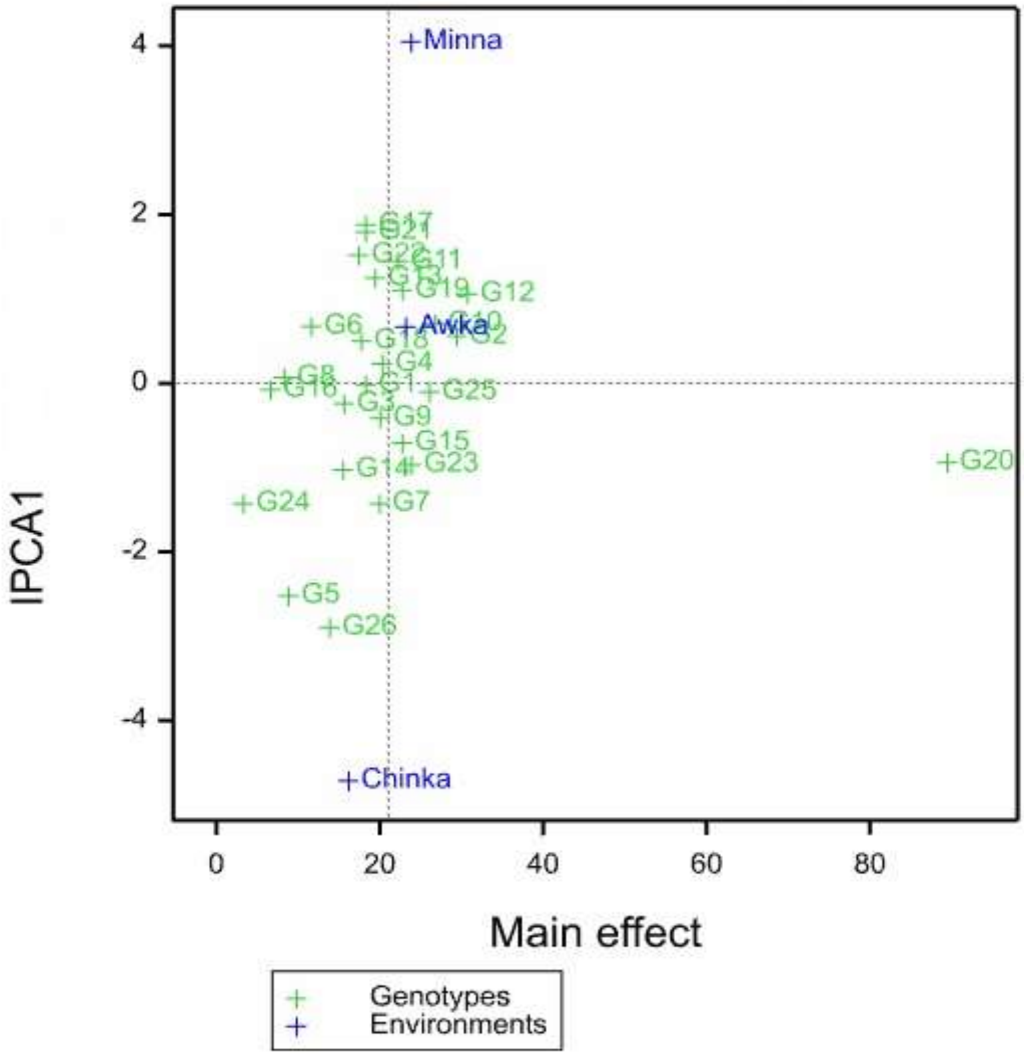

Figure 4.12: AMMI Bi-plot for pod shattering percentage of the soybean genotypes across three locations in 2019

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

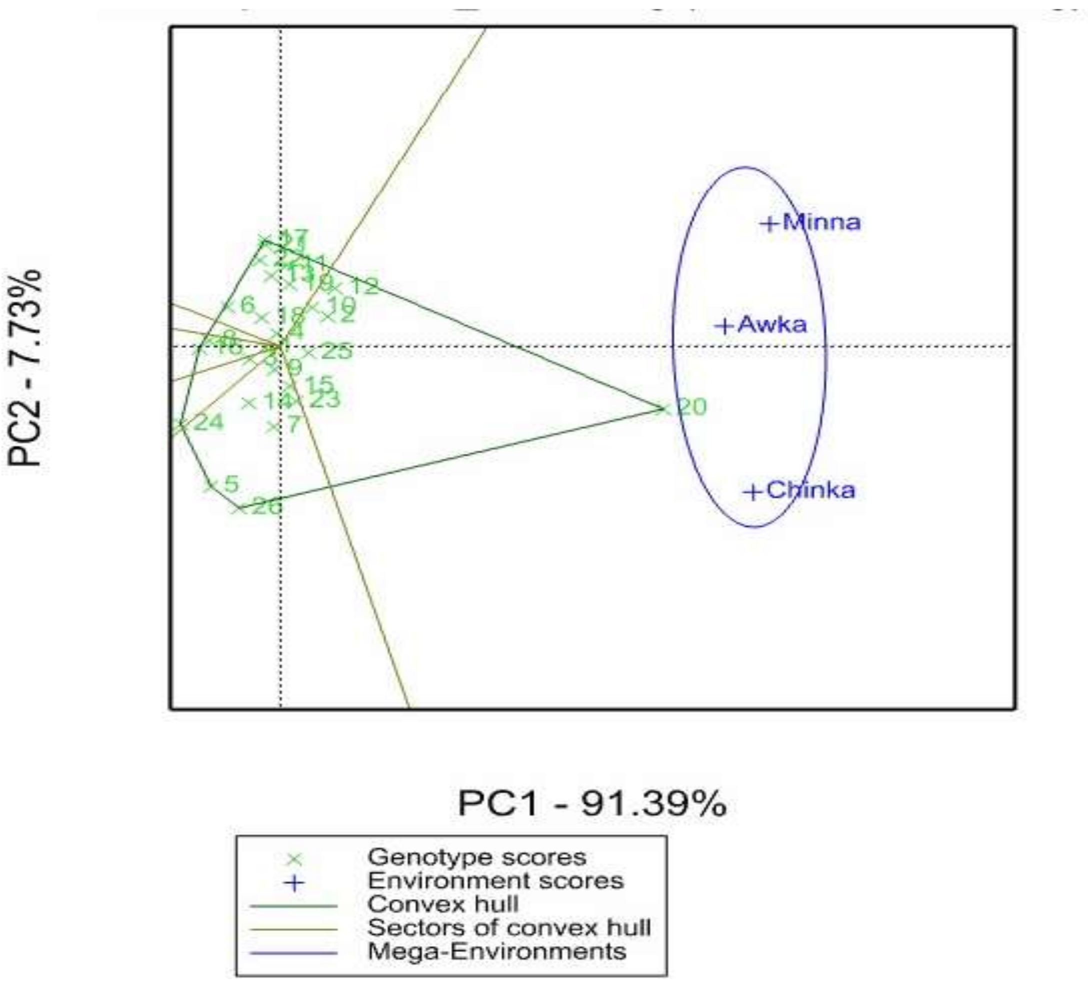

Figure 4.13: GGE bi-plot for pod shattering in different environments in 2019

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

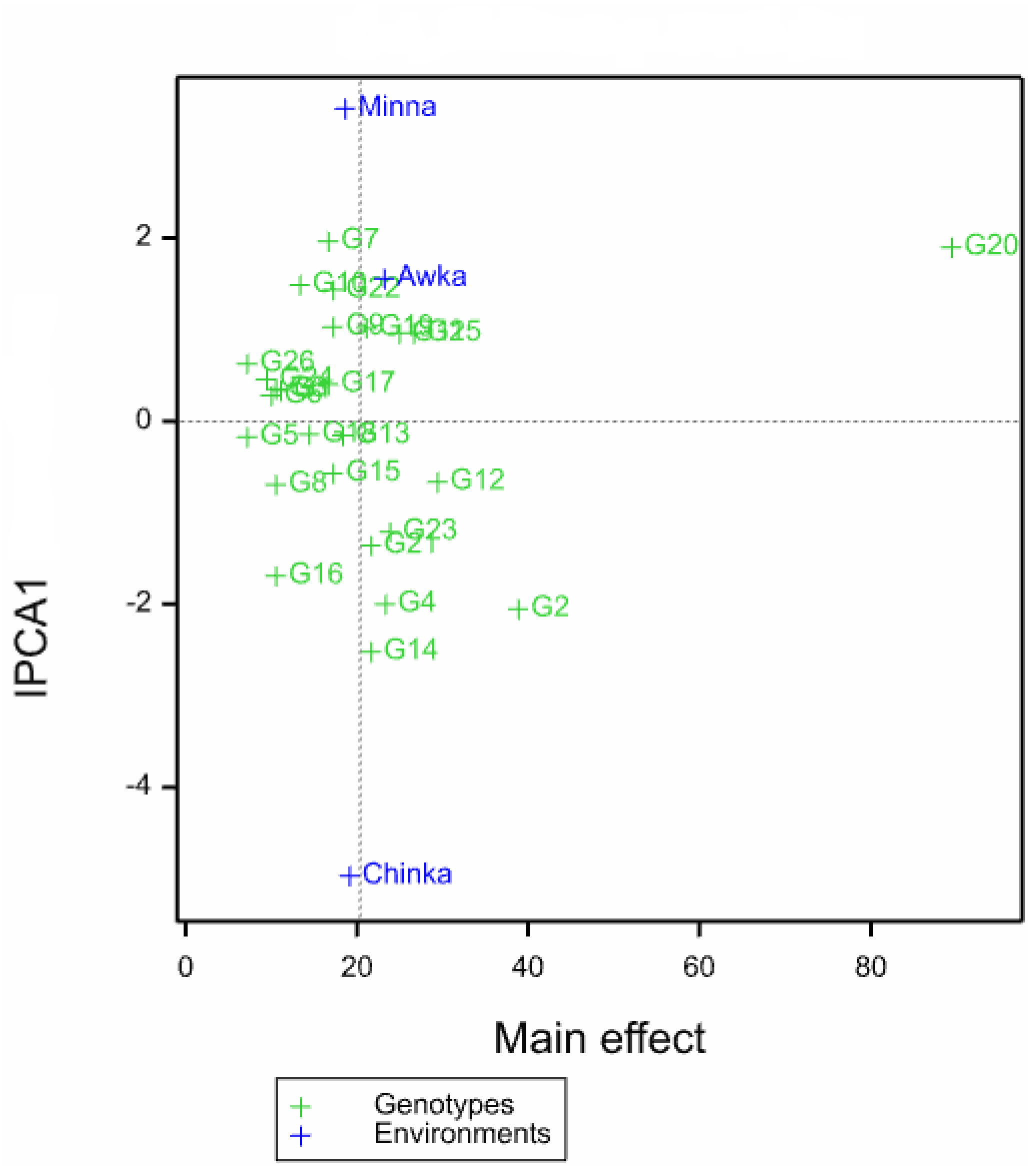

Figure 4.14: AMMI Bi-plot for pod shattering percentage of the soybean genotypes across three locations in 2020

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

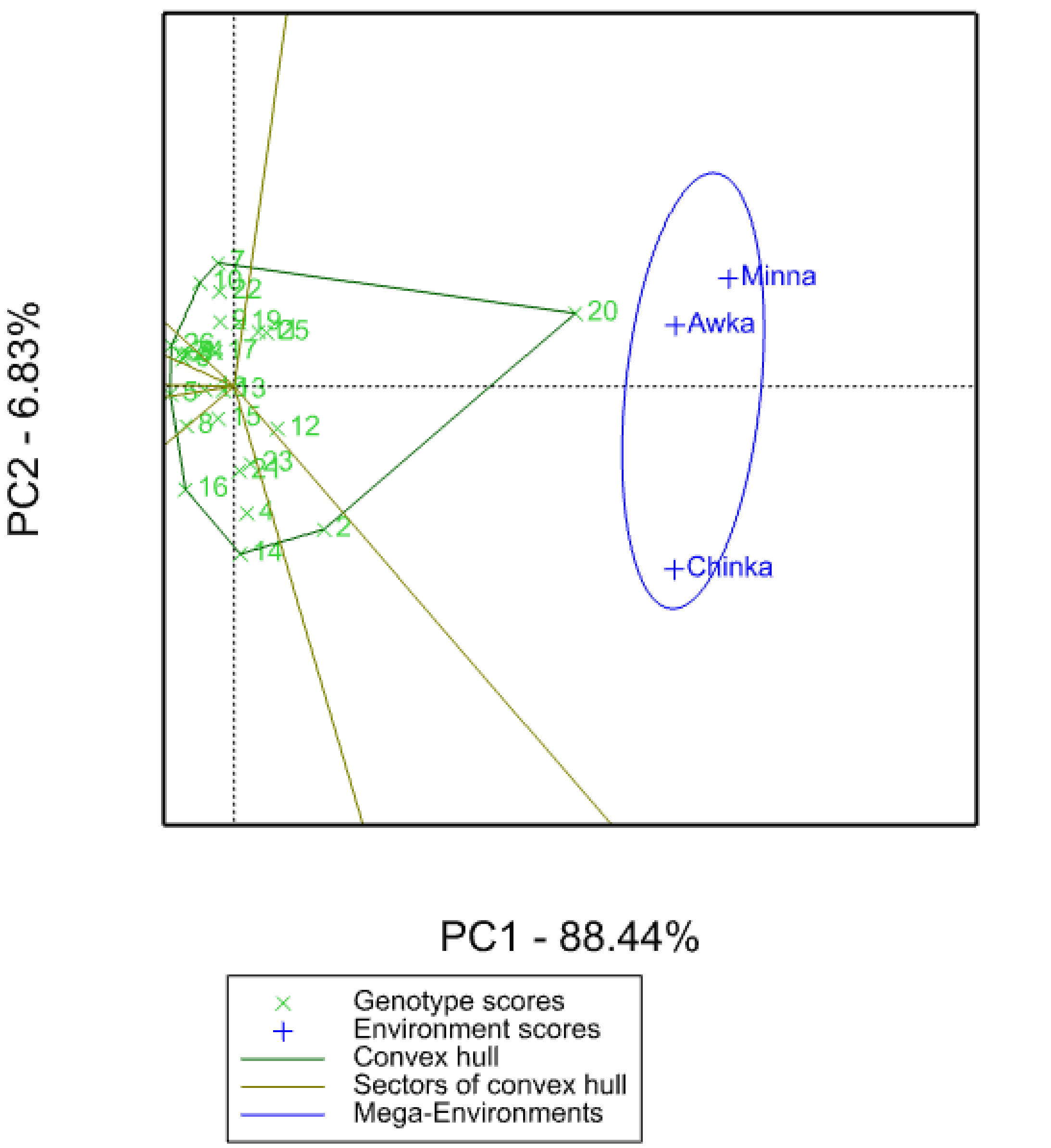

Figure 4.15: GGE bi-plot for pod shattering in different environments in 2020

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

4.1.10.5 Genotypes' Stability for Seed Yield in Minna Environment

The mean seed yields of the soybean genotypes in Minna in the two years of studies are presented in Table 4.20, and it ranged from 1 to 1.8 tons/ha. Sixteen genotypes gave higher seed yield than the grand mean (1.23 tons/ha).

NCRI SOYAC63 was the least sensitive and most stable genotype, as it had the lowest b value (-0.14). This genotype had mean seed yield (1.24 tons/ha) above grand mean (1.23 ton/ha). Furthermore, seven other genotypes (NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC29, NCRI SOYAC3 and NCRI SOYAC20), had low sensitivity to changes in the environments ($b<1$) with above average seed yield. All the high yielding and low sensitive genotypes also produced high static and dynamic (Wricke's Ecovalence) stabilities (Table 4.20).

In the AMMI bi-plot (Figure 4.16), thirteen genotypes are located at the right side of the midpoint of the perpendicular line and thus have higher yields than those on the left side. The genotypes are NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC29, NCRI SOYAC28, NCRI SOYAC3, NCRI SOYAC20, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC22.

In the bi-plot also, NCRI SOYAC3, NCRI SOYAC67, and NCRI SOYAC62 are very close to the horizontal line near the zero point on IPCA1 and are considered more stable than other genotypes. However, only NCRI SOYAC3 was high yielding (located at the right side). The most unstable genotypes in Minna were NCRI SOYAC73 and NCRI SOYAC77, while the poorest in yield was NCRI SOYAC65.

In the GGE bi-plot (Figure 4.17), the best genotypes in Minna in year 2019 were NCRI SOYAC77, NCRI SOYAC3, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC22; whereas NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC29, and NCRI SOYAC20 were the best in 2020. The remaining sectors have no environment within them, thus the genotypes they contain were not the highest yielding in neither 2019 nor 2020.

4.1.10.6 Genotypes' Stability for Seed Yield in Chinka Environment

The mean seed yields of the soybean genotypes in Chinka in the two years of studies are also presented in Table 4.20. The mean ranged from 1.04 to 1.73 tons/ha. Fourteen genotypes gave higher seed yield than the grand mean (1.36 tons/ha).

The least sensitive and most stable genotype was NCRI SOYAC77, as it had the lowest b value (-3.64). This genotype had mean seed yield (1.53 tons/ha) greater than the grand mean (1.36 ton/ha). Furthermore, five other genotypes (NCRI SOYAC78, NCRI SOYAC28, NCRI SOYAC20, NCRI SOYAC63 and NCRI SOYAC61), expressed low sensitivity to changes in the environments ($b<1$) with above average seed yield. All the high yielding and low sensitive genotypes also produced high static and dynamic (Wricke's Ecovalence) stabilities in this environment (Table 4.20).

In the AMMI bi-plot (Figure 4.18), fourteen genotypes are located at the right side of the midpoint of the perpendicular line and are categorized as high yielding genotypes. The genotypes are NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC63, NCRI SOYAC75, NCRI SOYAC76 and NCRI SOYAC61.

Also in the bi-plot, NCRI SOYAC78 and NCRI SOYAC22 are very close to the horizontal line near the zero point on IPCA1 and are considered more stable than other genotypes. However, only NCRI SOYAC78 was high yielding (located at the right side). The most unstable genotypes in this environment were NCRI SOYAC65 and NCRI SOYAC24 , while the poorest in yield was NCRI SOYAC3.

In the GGE bi-plot (Figure 4.19), the best genotypes in Chinka in the year 2019 were NCRI SOYAC77, NCRI SOYAC28, NCRI SOYAC20, NCRI SOYAC63 and NCRI SOYAC61; while NCRI SOYAC9, NCRI SOYAC62, and NCRI SOYAC75 were the best in 2020. The remaining sectors have no environment within them; therefore the genotypes they contain were not the highest yielding in any of the years of studies.

4.1.10.7 Genotypes' Stability for Seed Yield in Awka Environment

Table 4.20 also contains the mean seed yields of the soybean genotypes in Chinka in the two years of studies. The means ranged from 0.6 to 1.34 tons/ha. Thirteen genotypes gave higher seed yield than the grand mean (1.04 tons/ha).

NCRI SOYAC77, which had the lowest b value (-43.73) was the least sensitive and most stable genotype. However, this genotype had the lowest mean seed yield (0.6 tons/ha). Seven genotypes (NCRI SOYAC78, NCRI SOYAC69, NCRI SOYAC25, NCRI SOYAC20, NCRI SOYAC76, NCRI SOYAC61 and NCRI SOYAC22), expressed low sensitivity to changes in the environments ($b<1$) with above average seed yield. All the high yielding and low sensitive genotypes also produced high static and dynamic (Wricke's Ecovalence) stabilities in Awka (Table 4.20).

In the AMMI bi-plot (Figure 4.20), fourteen genotypes are located at the right side of the midpoint of the perpendicular line and are categorized as high yielding genotypes.

The genotypes are NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC69, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC10, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC22.

Also in the bi-plot, NCRI SOYAC3, NCRI SOYAC20 and NCRI SOYAC22 are very close to the horizontal line near the zero point on IPCA1 and are considered more stable than other genotypes. However, only NCRI SOYAC20 and NCRI SOYAC22 were high yielding (located at the right side). The most unstable genotype in this environment was NCRI SOYAC26; while the poorest in yield was NCRI SOYAC77.

In the GGE bi-plot (Figure 4.21), the best genotypes in Awka in the year 2019 were NCRI SOYAC18 and NCRI SOYAC9; while NCRI SOYAC78, NCRI SOYAC25, NCRI SOYAC61, NCRI SOYAC69, NCRI SOYAC76, NCRI SOYAC20, and NCRI SOYAC22 were the best in 2020 in this environment. The remaining sectors have no environment within them; therefore the genotypes they contain were not the highest yielding in any of the years of studies.

Table 4.20: Mean Seed Yield, Sensitivity and stability coefficients of the genotypes in the individual environments

Genotype	Sensitivity			Mean			Static Stability			Wricke's Ecovalence		
	Minna	Chinka	Awka	Minna	Chinka	Awka	Minna	Chinka	Awka	Minna	Chinka	Awka
NCRI SOYAC78	0.34	0.91	–3.55	1.62	1.42	1.30	0.01	0.00	0.00	0.06	0.00	0.00
NCRI SOYAC18	0.66	–3.00	19.50	1.54	1.07	1.34	0.05	0.06	0.06	0.02	0.10	0.05
NCRI SOYAC17	0.12	5.18	–5.91	1.50	1.39	1.02	0.00	0.16	0.01	0.09	0.11	0.01
NCRI SOYAC69	0.60	1.82	–9.45	1.35	1.60	1.05	0.05	0.02	0.01	0.02	0.00	0.02
NCRI SOYAC77	2.27	–3.64	–43.73	1.80	1.53	0.60	0.65	0.08	0.27	0.20	0.13	0.29
NCRI SOYAC73	2.27	–1.55	–11.82	1.30	1.29	0.93	0.65	0.02	0.02	0.20	0.04	0.02
NCRI SOYAC26	1.67	1.82	31.32	1.25	1.73	1.14	0.35	0.02	0.14	0.06	0.00	0.13
NCRI SOYAC29	0.46	–3.27	11.82	1.52	1.15	0.97	0.03	0.07	0.02	0.04	0.11	0.02
NCRI SOYAC25	2.05	4.82	–15.95	1.19	1.27	1.24	0.53	0.14	0.04	0.14	0.09	0.04
NCRI SOYAC28	2.05	0.00	15.95	1.32	1.40	1.04	0.53	0.00	0.04	0.18	0.01	0.03
NCRI SOYAC64	0.80	–3.36	27.77	1.07	1.22	1.27	0.08	0.07	0.11	0.01	0.12	0.10
NCRI SOYAC65	0.00	6.09	–7.68	1.00	1.24	0.74	0.00	0.23	0.01	0.13	0.16	0.01
NCRI SOYAC24	0.34	6.73	5.91	1.09	1.50	0.88	0.01	0.27	0.01	0.06	0.20	0.00
NCRI SOYAC3	0.99	–1.18	–1.77	1.35	1.04	0.99	0.13	0.01	0.00	0.00	0.03	0.00
NCRI SOYAC9	1.45	6.09	15.36	1.14	1.64	1.33	0.27	0.23	0.03	0.03	0.16	0.03
NCRI SOYAC7	1.19	–0.91	5.91	1.27	1.22	1.05	0.18	0.01	0.01	0.01	0.02	0.00
NCRI SOYAC68	1.19	0.00	–17.73	1.17	1.20	0.98	0.18	0.00	0.05	0.01	0.01	0.05
NCRI SOYAC20	0.60	–1.18	–1.77	1.35	1.37	1.12	0.05	0.01	0.00	0.02	0.03	0.00
NCRI SOYAC62	1.07	2.46	–4.14	1.20	1.44	0.84	0.15	0.04	0.00	0.00	0.01	0.00
NCRI SOYAC63	–0.14	0.36	23.64	1.24	1.45	0.90	0.00	0.00	0.08	0.16	0.00	0.07
NCRI SOYAC75	0.46	3.27	–4.14	1.22	1.45	0.74	0.03	0.07	0.00	0.04	0.03	0.00
NCRI SOYAC10	0.68	–0.27	19.50	1.10	1.22	1.07	0.06	0.00	0.06	0.01	0.01	0.05
NCRI SOYAC67	0.99	2.73	10.05	1.08	1.25	0.99	0.13	0.05	0.02	0.00	0.02	0.01
NCRI SOYAC76	1.39	2.09	–7.68	1.35	1.49	1.07	0.25	0.03	0.01	0.02	0.01	0.01
NCRI SOYAC61	1.13	–1.18	–25.41	1.32	1.54	1.19	0.17	0.01	0.09	0.00	0.03	0.10
NCRI SOYAC22	1.39	1.18	0.00	1.32	1.27	1.13	0.25	0.01	0.00	0.02	0.00	0.00
Grand Mean				**1.23**	**1.36**	**1.04**						

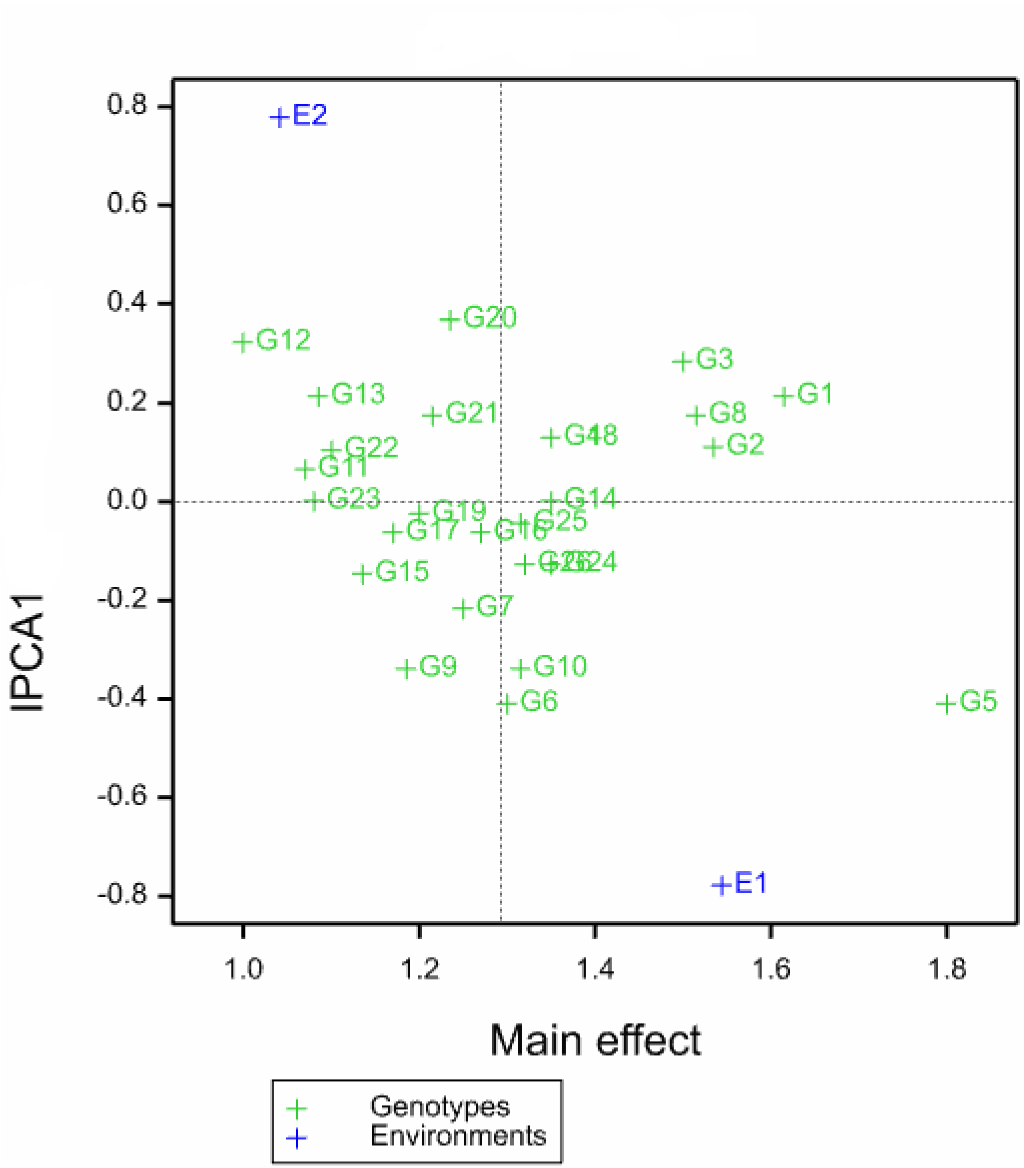

Figure 4.16: AMMI Bi-plot of seed yield for the 26 soybean genotypes in Minna

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

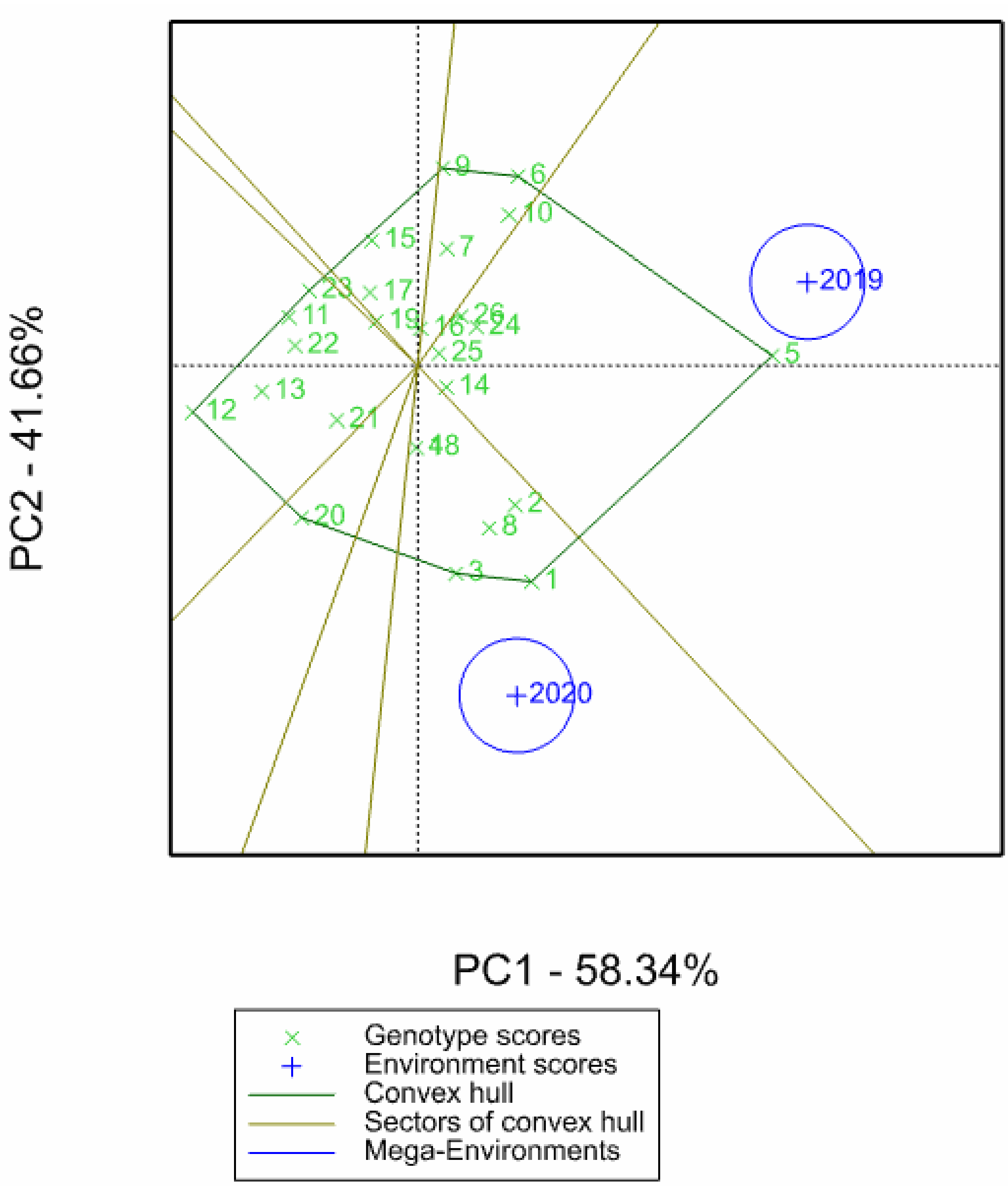

Figure 4.17: GGE biplot for best genotypes in different years for seed yield in Minna

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

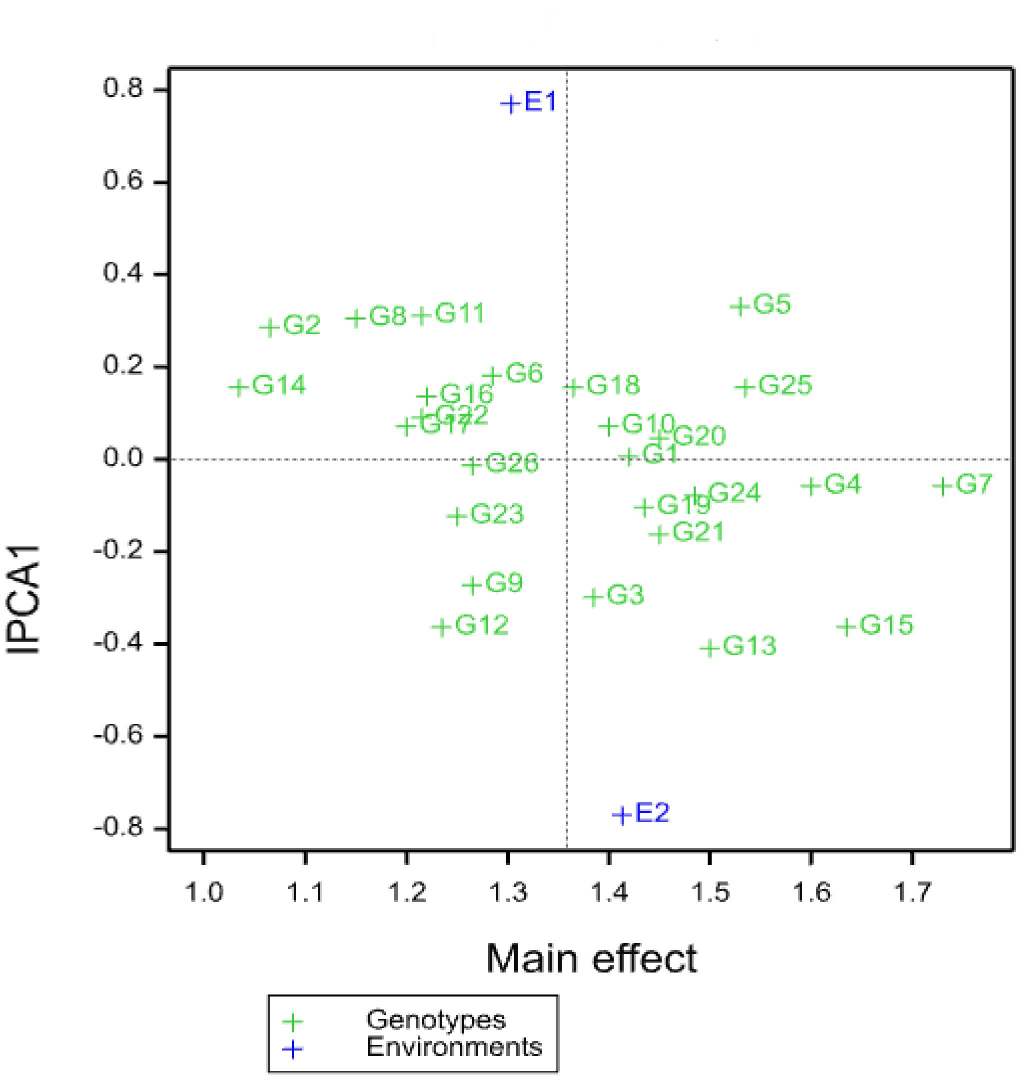

Figure 4.18: AMMI Bi-plot of seed yield for the 26 soybean genotypes in Chinka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

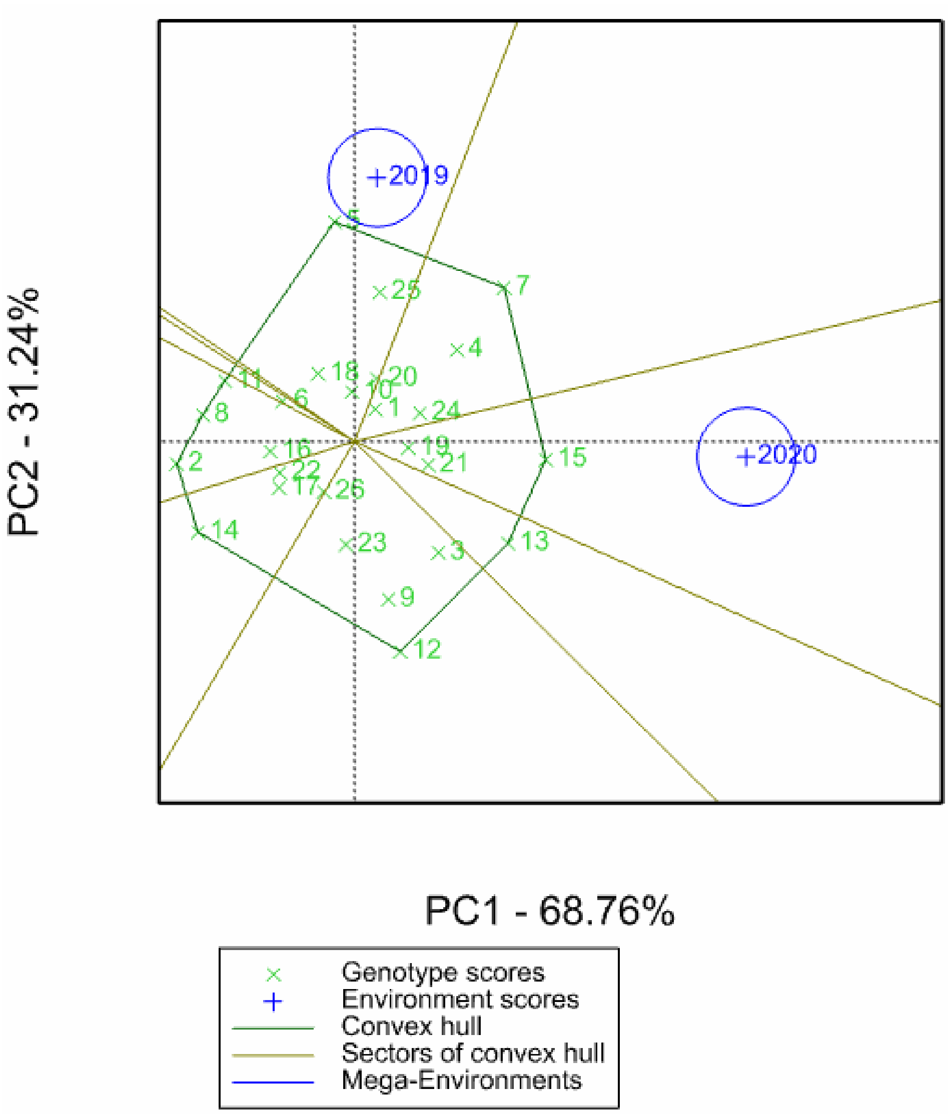

Figure 4.19: GGE biplot for best genotypes in different years for seed yield in Chinka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

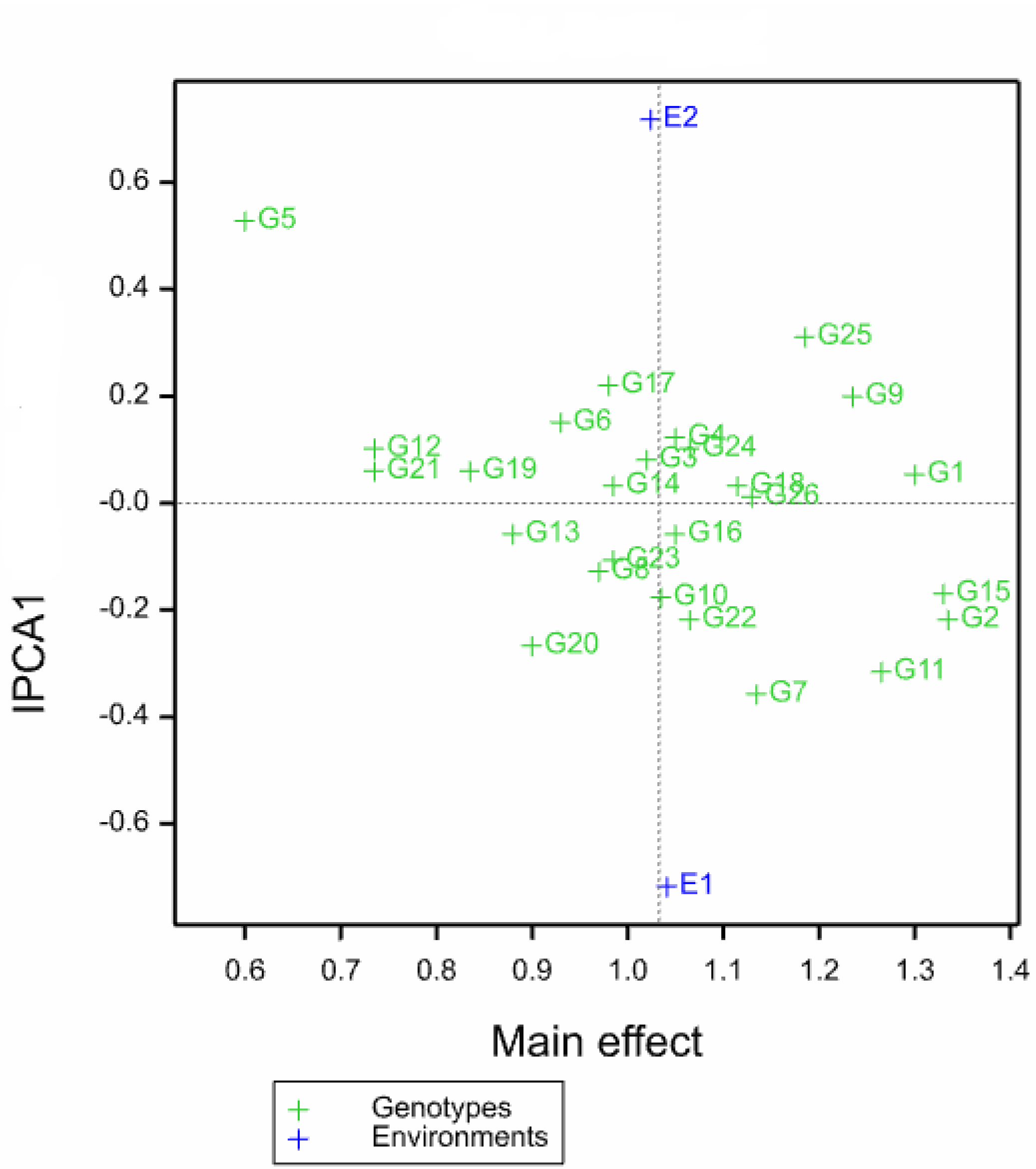

Figure 4.20: AMMI Bi-plot of seed yield for the 26 soybean genotypes in Awka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

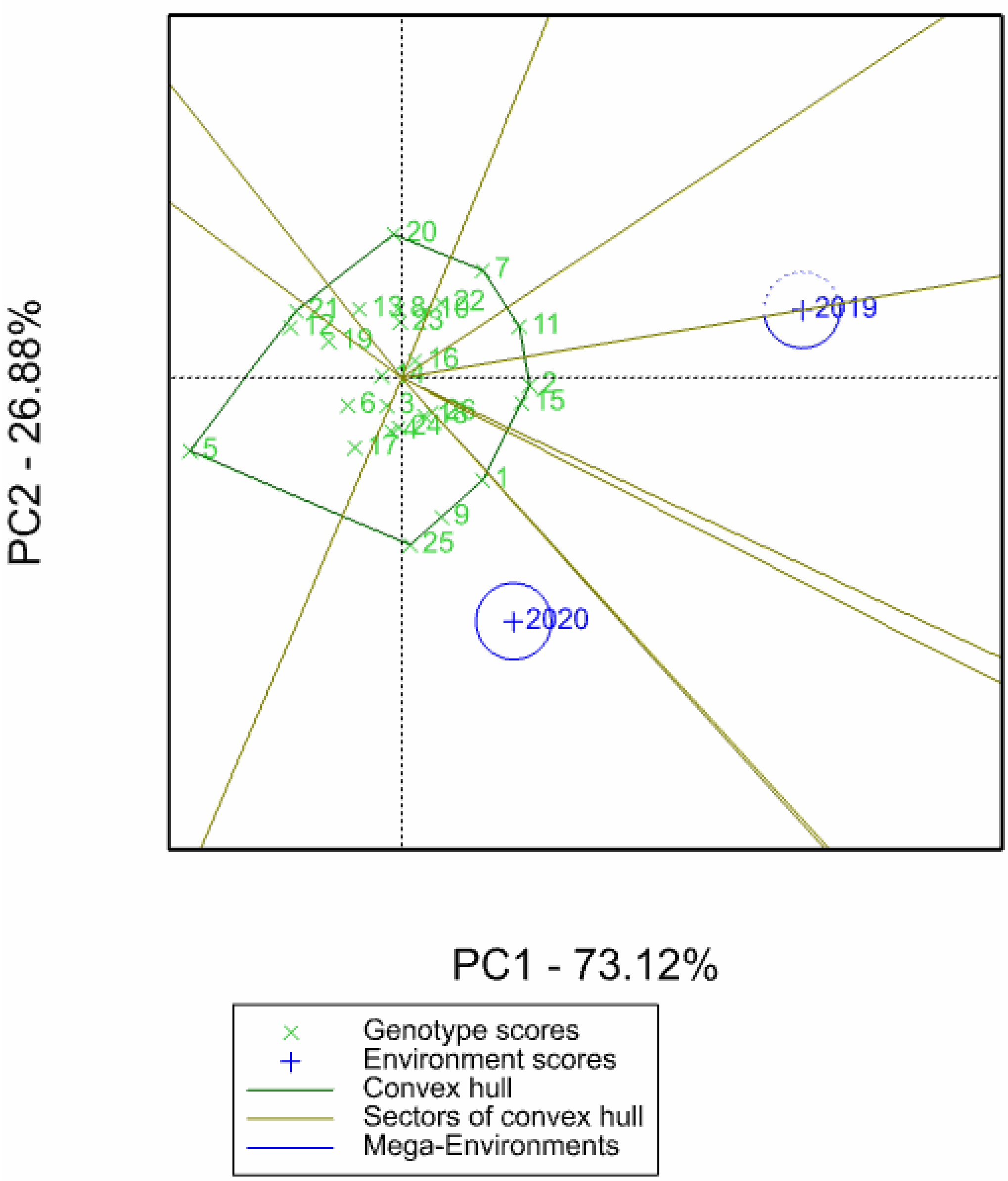

Figure 4.21: GGE biplot for best genotypes in different years for seed yield in Awka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

4.1.10.8 Genotypes' Stability for Pod Shattering in Minna Environment

The average pod shattering rates of the genotypes in Minna in two years ranged from 5 % to 94.17 % (Table 4.21). From Table 4.22, no genotype was very resistant to pod shattering, twenty were resistant and five were moderately resistant; none was highly susceptible, while one was very highly susceptible.

The Table of regression coefficient (b) and mean values for pod shattering percentage of the soybean genotypes (Table 4.21), shows that NCRI SOYAC76 and NCRI SOYAC22, having a b-value of -2.25 each were the most stable. These genotypes were also resistant to pod shattering (Table 4.22). Other resistant and stable genotypes were NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC3, and NCRI SOYAC7. However, only NCRI SOYAC25 had high static stability and NCRI SOYAC18 dynamic (Wricke's Ecovalence) stability (Table 4.21).

The AMMI bi-plot for pod shattering (Figure 4.22), genotypes NCRI SOYAC18, NCRI SOYAC62, NCRI SOYAC29, and NCRI SOYAC7 were located very close to the horizontal line of the bi-plot and are termed stable. However, only NCRI SOYAC29 and NCRI SOYAC7 were resistant to pod shattering, as they had pod shattering percentage below 25 % (Table 4.22). Genotype NCRI SOYAC63 was both unstable and very highly susceptible to pod shattering.

The GGE bi-plot (Figure 4.23) grouped two years into one, with NCRI SOYAC63, NCRI SOYAC64, NCRI SOYAC61, NCRI SOYAC62, and NCRI SOYAC18 as the genotypes with the highest pod shattering percentage.

4.1.10.9 Genotypes' Stability for Pod Shattering in Chinka Environment

The average pod shattering rates of the genotypes in Chinka in two years ranged from 5 % to 85 % (Table 4.21). From the Table that categorized the genotypes according to pod shattering percentage in this environment (Table 4.23), no genotype was very resistant to pod shattering, twenty-one were resistant and four were moderately resistant; none was highly susceptible, while one was very highly susceptible.

The Table of regression coefficient (b) and mean values for pod shattering percentage of the soybean genotypes (Table 4.21), shows that NCRI SOYAC22, having a b-value of -5.65 was the most stable. This genotype was also resistant to pod shattering (Table 4.23). Other resistant and stable genotypes were NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC9, NCRI SOYAC76 and NCRI SOYAC61. However, only NCRI SOYAC61 had high static stability and NCRI SOYAC76 had dynamic stability (Table 4.21).

The AMMI bi-plot for pod shattering (Figure 4.24) shows that genotypes NCRI SOYAC67, NCRI SOYAC62, NCRI SOYAC20, NCRI SOYAC10, NCRI SOYAC76, and NCRI SOYAC73 were located very close to the horizontal line of the bi-plot and are termed stable; and NCRI SOYAC62, NCRI SOYAC20, NCRI SOYAC10, NCRI SOYAC76 and NCRI SOYAC73 were resistant to pod shattering, as they had pod shattering percentage below 25 % (Table 4.23). Genotype NCRI SOYAC63 was both unstable and very highly susceptible to pod shattering.

The GGE bi-plot (Figure 4.25) grouped two years into one, with NCRI SOYAC63, NCRI SOYAC65, NCRI SOYAC61, NCRI SOYAC67, and NCRI SOYAC9 as the genotypes with the highest pod shattering percentage.

4.1.10.10 Genotypes' Stability for Pod Shattering in Awka Environment

The genotypes' average pod shattering rates in Awka in two years ranged from 7.5 % to 89.17 % (Table 4.21). From Table 4.24, none of the genotypes was very resistant to pod shattering, seventeen were resistant and eight were moderately resistant; none was highly susceptible, while one was very highly susceptible.

The Table of regression coefficient of the soybean genotypes (Table 4.21) shows that three genotypes (NCRI SOYAC64, NCRI SOYAC7 and NCRI SOYAC20), having b-values of -8.86 each were the least sensitive and thus, the most stable. But only NCRI SOYAC7 and NCRI SOYAC20 were resistant to pod shattering (Table 4.24). Other resistant and stable genotypes were NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC3, and NCRI SOYAC22. However, none of the genotypes had high static and dynamic stabilities (Table 4.21).

The AMMI bi-plot for pod shattering (Figure 4.26) shows that genotypes NCRI SOYAC29 and NCRI SOYAC17 were located on the horizontal line of the bi-plot, while NCRI SOYAC73, NCRI SOYAC7 and NCRI SOYAC63 were located very close to the horizontal line and are termed stable. However, only NCRI SOYAC29 and NCRI SOYAC17, NCRI SOYAC73, and NCRI SOYAC7 were resistant to pod shattering, as they had pod shattering percentage below 25 % (Table 4.24). Genotype NCRI SOYAC63 was very highly susceptible to pod shattering.

The GGE bi-plot (Figure 4.27) grouped the two years into one, with NCRI SOYAC63, NCRI SOYAC65, and NCRI SOYAC62 as the genotypes with the highest pod shattering percentage.

Table 4.21: Mean pod shattering percentage, sensitivity and stability coefficients of the genotypes in the individual environments

	Sensitivity			Mean			Static Stability			Wricke's Ecovalence		
Genotype	Minna	Chinka	Awka	Minna	Chinka	Awka	Minna	Chinka	Awka	Minna	Chinka	Awka
NCRI SOYAC78	3.53	–2.83	2.65	14.16	10.83	19.17	167.99	s34.69	12.50	86.30	63.60	12.50
NCRI SOYAC18	0.96	8.48	4.42	34.17	35.83	32.50	12.50	312.50	34.78	0.02	243.14	34.78
NCRI SOYAC17	1.99	–1.70	5.03	11.84	9.17	18.33	53.35	12.50	0.00	13.20	31.59	0.00
NCRI SOYAC69	1.99	5.09	4.42	20.50	24.17	20.84	102.82	112.50	34.69	41.84	72.62	34.69
NCRI SOYAC77	–1.93	–2.26	–4.42	5.00	11.66	7.50	50.00	22.24	34.78	115.40	46.26	34.78
NCRI SOYAC73	1.93	1.13	8.86	11.67	5.00	15.83	50.00	5.58	1.39	11.56	0.08	1.39
NCRI SOYAC26	–1.60	–5.09	–1.77	20.83	14.17	20.00	34.69	112.50	5.58	91.42	161.07	5.58
NCRI SOYAC29	0.64	3.39	5.07	10.00	8.33	10.00	5.58	50.00	0.00	1.71	24.86	0.00
NCRI SOYAC25	–0.26	–1.70	–2.65	21.00	14.17	20.83	0.90	12.50	12.50	21.33	31.59	12.5
NCRI SOYAC28	3.92	–5.09	–2.65	21.83	10.83	27.50	206.65	112.50	12.50	114.58	161.07	12.5
NCRI SOYAC64	0.00	3.39	–8.86	30.00	15.00	25.84	0.00	50.00	1.39	13.48	24.86	1.39
NCRI SOYAC65	3.66	2.83	3.53	29.50	25.84	35.00	180.50	34.69	22.18	95.33	14.48	22.18
NCRI SOYAC24	2.89	2.83	1.77	19.17	12.50	25.00	112.50	34.78	5.58	48.10	14.53	5.58
NCRI SOYAC3	–0.96	6.78	–3.53	15.83	25.00	15.00	12.50	200.00	22.18	51.94	145.38	22.18
NCRI SOYAC9	2.25	–1.13	–8.80	17.50	20.00	22.50	67.98	5.58	1.38	20.92	19.77	1.38
NCRI SOYAC7	0.64	5.65	–8.86	6.67	10.00	9.16	5.54	138.78	1.39	1.73	94.00	1.39
NCRI SOYAC68	3.21	2.83	1.77	18.33	7.50	26.67	138.94	34.78	5.54	65.87	14.53	5.54
NCRI SOYAC20	2.25	1.13	–8.86	15.83	11.66	20.84	68.09	5.54	1.39	20.98	0.07	1.39
NCRI SOYAC62	0.96	1.13	–1.77	25.83	13.33	26.67	12.50	5.54	5.54	0.02	0.07	5.54
NCRI SOYAC63	–1.60	–3.39	8.86	94.17	85.00	89.17	34.69	50.00	1.39	91.42	83.83	1.39
NCRI SOYAC75	2.89	7.35	1.77	20.83	15.83	23.34	112.50	234.79	5.54	48.10	175.25	5.54
NCRI SOYAC10	1.41	1.13	1.77	22.00	6.66	23.34	26.94	5.54	5.54	2.310	0.07	5.54
NCRI SOYAC67	1.60	1.13	2.65	20.84	26.67	24.17	34.69	5.54	12.50	4.92	0.07	12.50
NCRI SOYAC76	–2.25	0.57	2.65	5.84	5.83	7.50	68.09	1.39	12.50	142.16	0.82	12.50
NCRI SOYAC61	–0.64	0.00	–8.80	30.00	21.67	27.50	5.58	0.00	1.38	36.40	4.35	1.38
NCRI SOYAC22	–2.25	–5.65	–7.96	9.17	13.34	9.17	68.09	138.94	112.50	142.16	192.44	112.50

Table 4.22: Genotype grouping based on mean pod shattering percentage of 2019 and 2020 in Minna

Score	Description	Category	Genotypes
1	No pod shattering	Very resistant	Nil
2	< 25% pod shattering	Resistant	NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28 NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, NCRI SOYAC76, NCRI SOYAC22
3	25 - 50% pod shattering	Moderately Resistant	NCRI SOYAC18, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC62 NCRI SOYAC61
4	51 - 75% pod shattering	Highly susceptible	Nil
5	> 75% pod shattering	Very highly susceptible	NCRI SOYAC63

Table 4.23: Genotype grouping based on mean pod shattering percentage of 2019 and 2020 in Chinka

Score	Description	Category	Genotypes
1	No pod shattering	Very resistant	Nil
2	< 25% pod shattering	Resistant	NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC28 NCRI SOYAC64 NCRI SOYAC24, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62 NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC76, NCRI SOYAC61 NCRI SOYAC22
3	25 - 50% pod shattering	Moderately Resistant	NCRI SOYAC18, NCRI SOYAC65, NCRI SOYAC3, NCRI SOYAC67
4	51 - 75% pod shattering	Highly susceptible	Nil
5	> 75% pod shattering	Very highly susceptible	NCRI SOYAC63

Table 4.24: Genotype grouping based on mean pod shattering percentage of 2019 and 2020 in Awka

Score	Description	Category	Genotypes
1	No pod shattering	Very resistant	Nil
2	< 25% pod shattering	Resistant	NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, NCRI SOYAC76, NCRI SOYAC22
3	25 - 50% pod shattering	Moderately Resistant	NCRI SOYAC18, NCRI SOYAC28, NCRI SOYAC64, NCRI SOYAC65, NCRI SOYAC24, NCRI SOYAC68, NCRI SOYAC62, NCRI SOYAC61
4	51 - 75% pod shattering	Highly susceptible	Nil
5	> 75% pod shattering	Very highly susceptible	NCRI SOYAC63

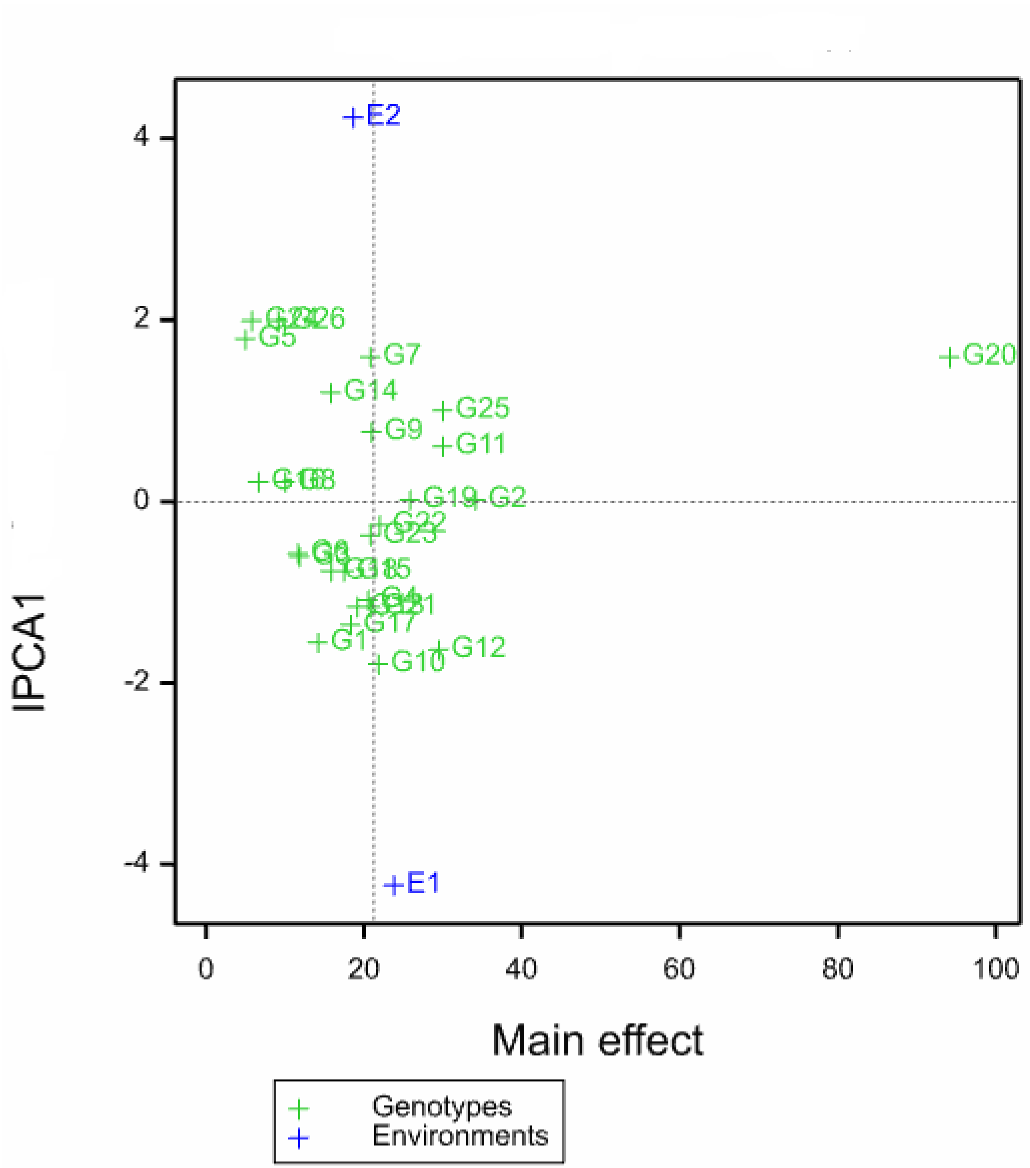

Figure 4.22: AMMI Bi-plot for pod shattering percentage of the soybean genotypes in Minna

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

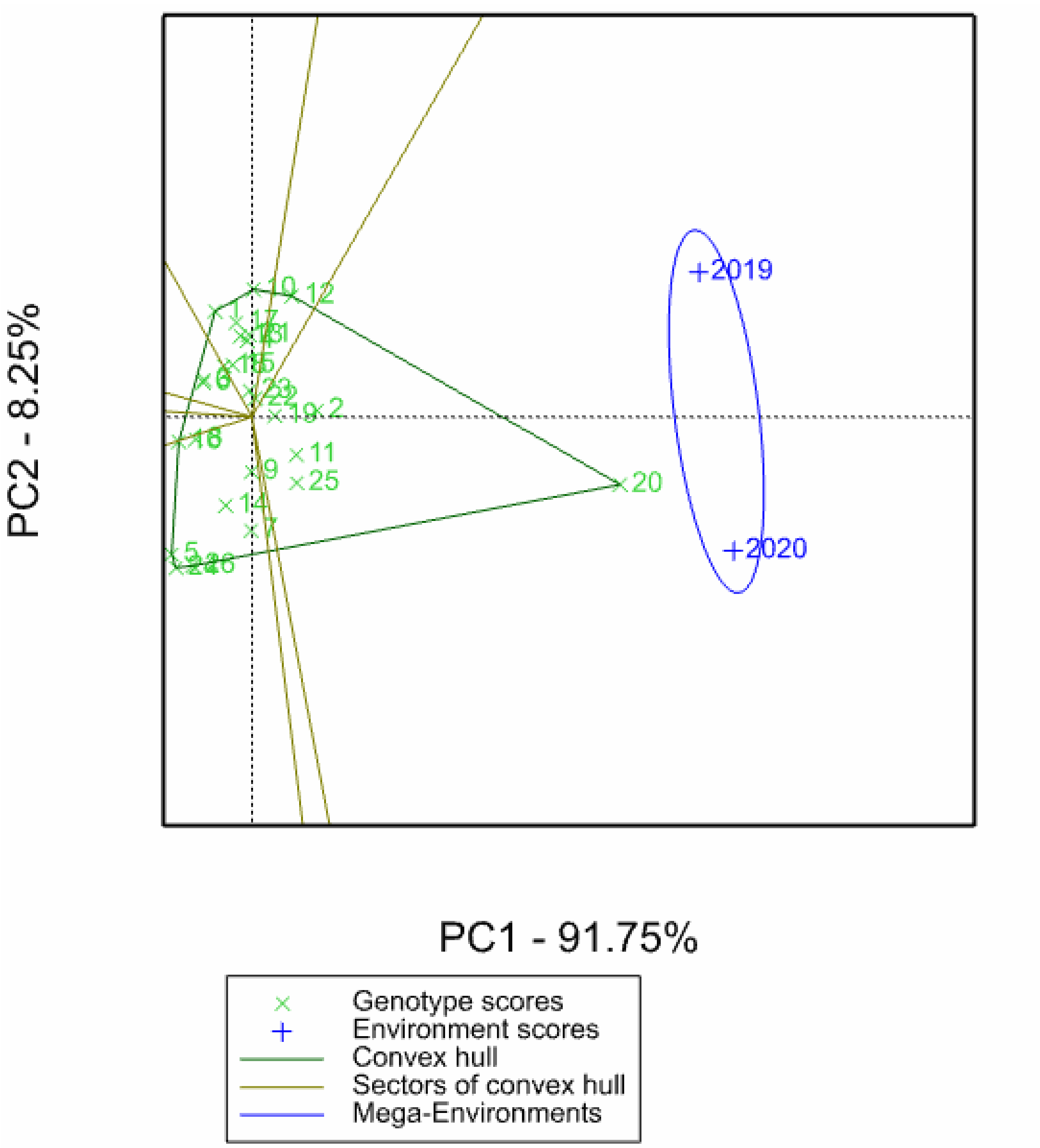

Figure 4.23: GGE bi-plot for pod shattering in different years in Minna

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

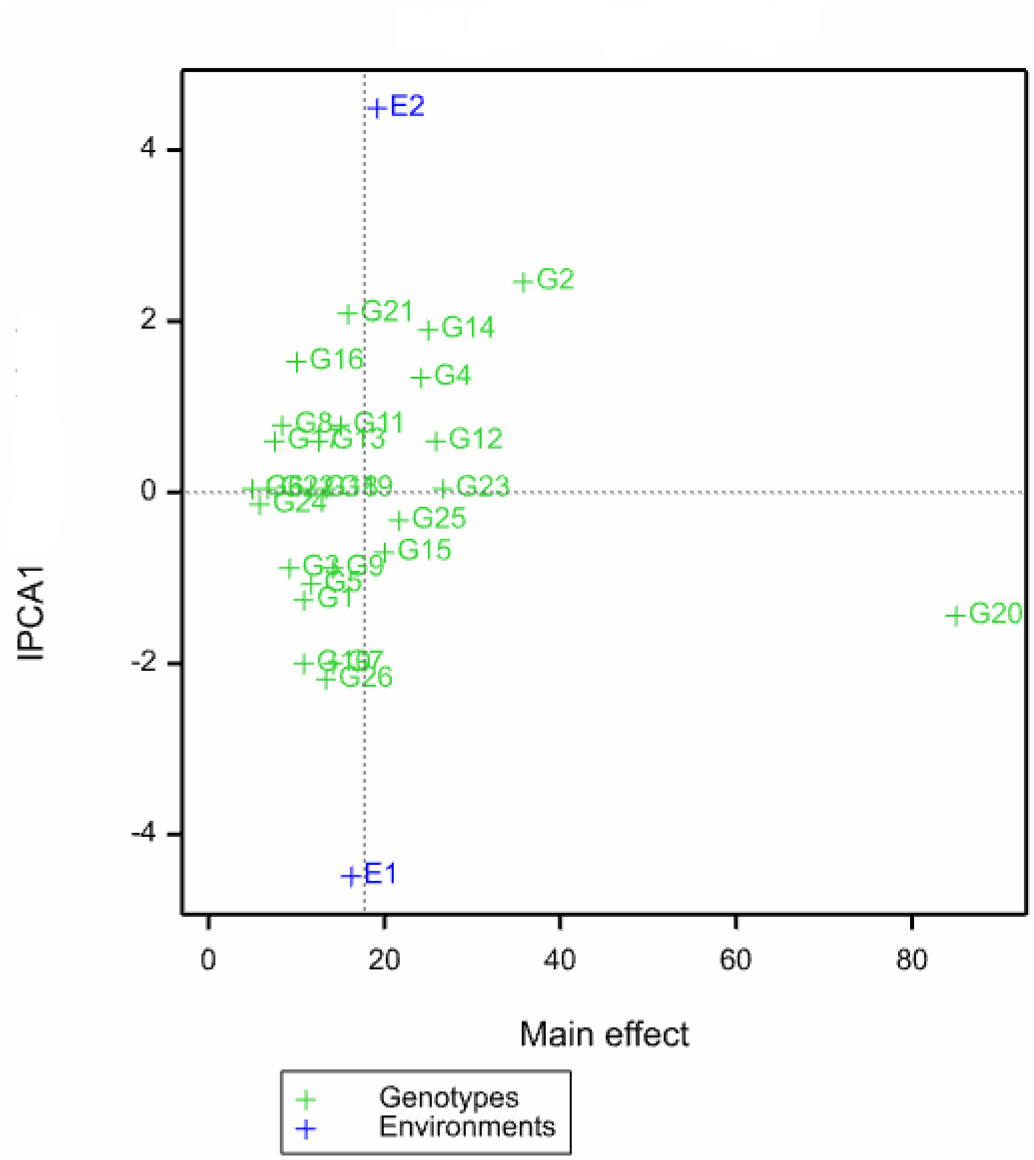

Figure 4.24: AMMI Bi-plot for pod shattering percentage of the soybean genotypes in Chinka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

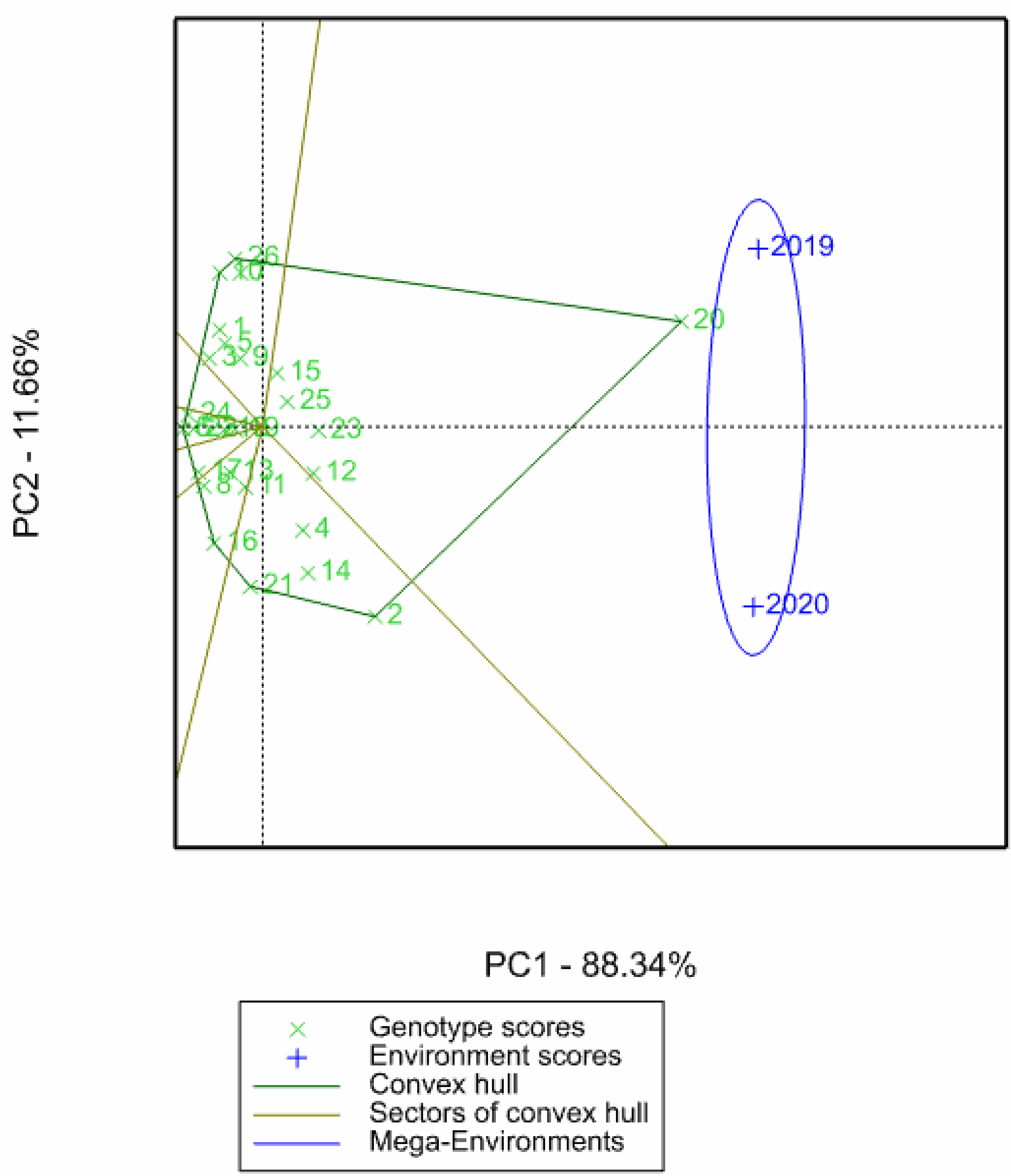

Figure 4.25: GGE bi-plot for pod shattering in different years in Chinka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

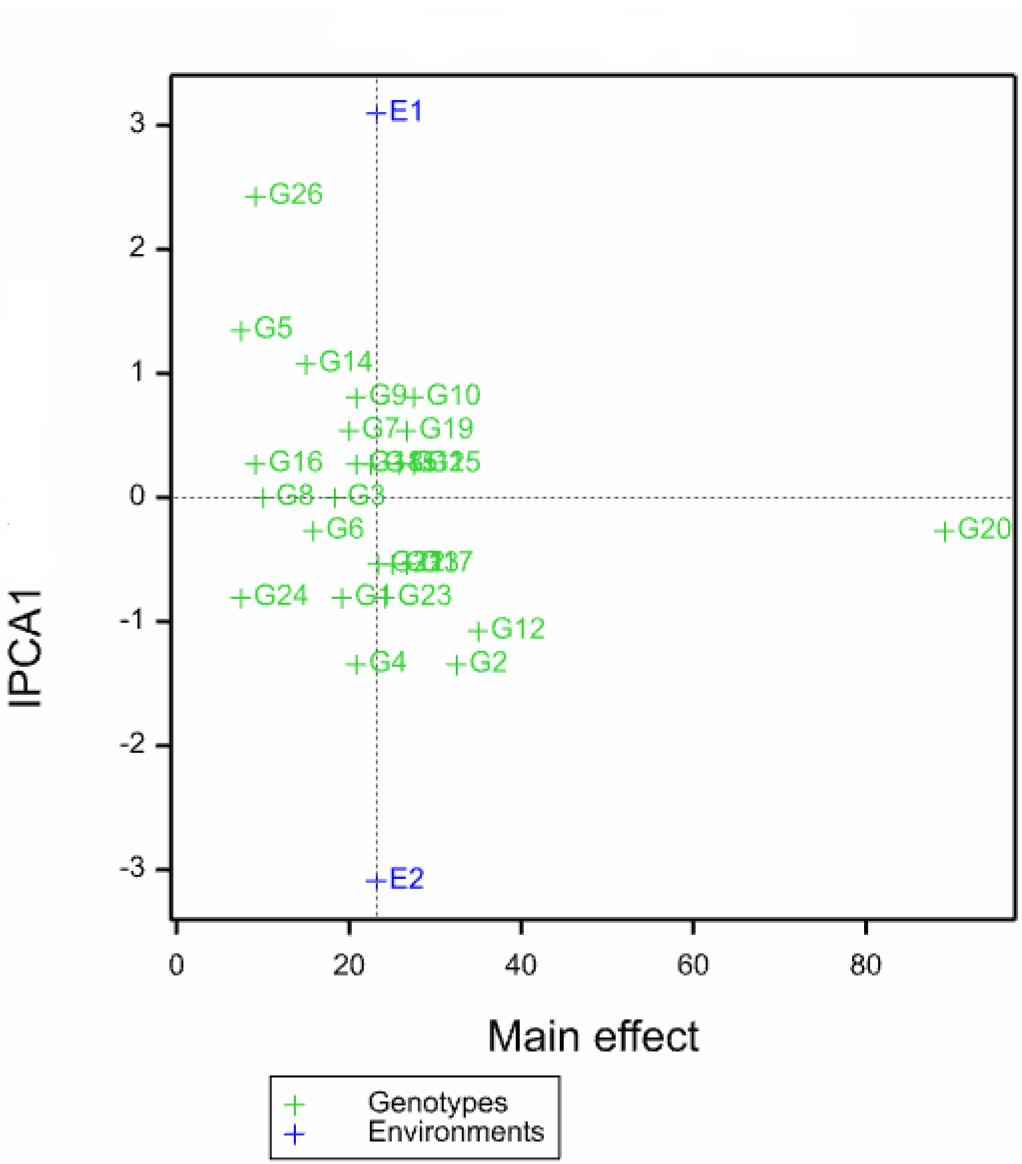

Figure 4.26: AMMI Bi-plot for pod shattering percentage of the soybean genotypes in Awka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC 22

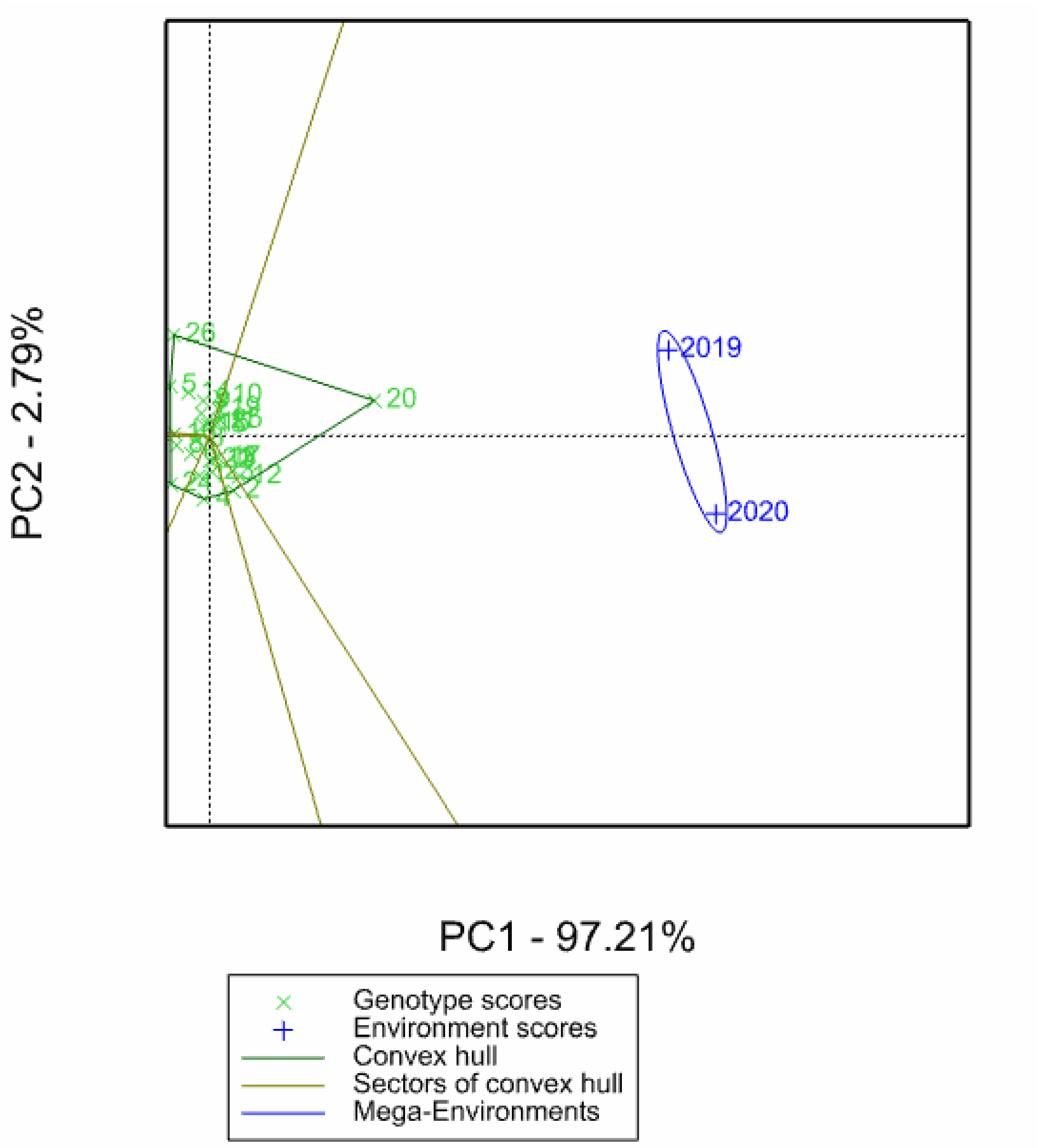

Figure 4.27: GGE bi-plot for pod shattering in different years in Awka

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

4.1.10.11 Combined Analysis for Genotypes' Stability across the Environments for Yield

The combined seed yield of the 26 soybean genotypes across the three locations ranged from 0.99 to 1.44 tons/ha (Table 4.25). Twelve genotypes gave higher seed yield than the grand mean (1.23 tons/ha). The environments' seed yield ranged from 1.03 tons/ha in Awka to 1.36 tons/ha in Chinka.

Table 4.26 shows that the genotype with the least sensitivity to changes in environment was NCRI SOYAC18, as it had the lowest b value (-0.352). This genotype also had mean seed yield (1.31 ton/ha) greater than grand mean (1.23 ton/ha). However, NCRI SOYAC78, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC61, and NCRI SOYAC22 also had low sensitivity to changes in the environments, with above average seed yield. All the high yielding and low sensitive genotypes also produced high static and dynamic stabilities (Table 4.26).

In the AMMI bi-plot (Figure 4.28), The genotypes NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC28, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC76, NCRI SOYAC61, and NCRI SOYAC22 recorded high yields, as they were located at the right side of the perpendicular line. Therefore, the genotypes located at the left side of the line were low yielding.

Also in the bi-plot, NCRI SOYAC20, NCRI SOYAC26, NCRI SOYAC78, NCRI SOYAC28, NCRI SOYAC76 and NCRI SOYAC61 are very close to the horizontal line near the zero point on IPCA1. Since these genotypes are located on the right side of the midpoint of the perpendicular line, they produced high and stable yield. The most unstable genotype was NCRI SOYAC77, while the poorest in yield was NCRI SOYAC65.

The polygon view of the GGE bi-plot (Figure 4.29) shows that two environments were identified; with Minna and Chinka grouped as one environment, having NCRI SOYAC77, NCRI SOYAC17, NCRI SOYAC76, NCRI SOYAC29, NCRI SOYAC26, NCRI SOYAC28 and NCRI SOYAC69 as the best genotypes (winning genotypes). The best genotypes for the second environment (Awka) were NCRI SOYAC9, NCRI SOYAC22, and NCRI SOYAC9. The remaining sectors have no environment within them, meaning that the genotypes they contain were not the highest yielding at any environment.

Table 4.25: Combined seed yield of the genotypes across the three environments (ton/ha)

Genotype	Minna	Chinka	Awka	Mean
NCRI SOYAC78	1.62	1.42	1.30	1.44
NCRI SOYAC18	1.54	1.07	1.34	1.31
NCRI SOYAC17	1.50	1.39	1.02	1.30
NCRI SOYAC69	1.35	1.60	1.05	1.33
NCRI SOYAC77	1.80	1.53	0.60	1.31
NCRI SOYAC73	1.30	1.29	0.93	1.17
NCRI SOYAC26	1.25	1.73	1.14	1.37
NCRI SOYAC29	1.52	1.15	0.97	1.21
NCRI SOYAC25	1.19	1.27	1.24	1.23
NCRI SOYAC28	1.32	1.40	1.04	1.25
NCRI SOYAC64	1.07	1.22	1.27	1.18
NCRI SOYAC65	1.00	1.24	0.74	0.99
NCRI SOYAC24	1.09	1.50	0.88	1.16
NCRI SOYAC3	1.35	1.04	0.99	1.12
NCRI SOYAC9	1.14	1.64	1.33	1.36
NCRI SOYAC7	1.27	1.22	1.05	1.18
NCRI SOYAC68	1.17	1.20	0.98	1.12
NCRI SOYAC20	1.35	1.37	1.12	1.28
NCRI SOYAC62	1.20	1.44	0.84	1.16
NCRI SOYAC63	1.24	1.45	0.90	1.19
NCRI SOYAC75	1.22	1.45	0.74	1.13
NCRI SOYAC10	1.10	1.23	1.07	1.13
NCRI SOYAC67	1.08	1.25	0.99	1.11
NCRI SOYAC76	1.35	1.49	1.07	1.30
NCRI SOYAC61	1.32	1.54	1.19	1.34
NCRI SOYAC22	1.32	1.27	1.13	1.24
Mean	1.29	1.36	1.03	1.23

Table 4.26: Combined sensitivity and stability coefficients for seed yield of the genotypes across three environments

Genotype	Sensitivity	Static Stability	Wricke's Ecovalence	Mean square Deviation
NCRI SOYAC78	0.62	0.03	0.04	0.03
NCRI SOYAC18	–0.35	0.06	0.22	0.10
NCRI SOYAC17	1.34	0.06	0.03	0.02
NCRI SOYAC69	1.53	0.08	0.03	0.01
NCRI SOYAC77	3.38	0.40	0.45	0.11
NCRI SOYAC73	1.19	0.04	0.01	0.00
NCRI SOYAC26	1.41	0.09	0.09	0.08
NCRI SOYAC29	1.01	0.08	0.10	0.09
NCRI SOYAC25	0.01	0.01	0.06	0.00
NCRI SOYAC28	1.12	0.04	0.00	0.00
NCRI SOYAC64	–0.33	0.01	0.12	0.01
NCRI SOYAC65	1.38	0.06	0.02	0.01
NCRI SOYAC24	1.57	0.10	0.07	0.05
NCRI SOYAC3	0.53	0.04	0.08	0.06
NCRI SOYAC9	0.43	0.06	0.13	0.12
NCRI SOYAC7	0.62	0.01	0.01	0.00
NCRI SOYAC68	0.69	0.02	0.01	0.00
NCRI SOYAC20	0.81	0.02	0.00	0.00
NCRI SOYAC62	1.71	0.09	0.04	0.01
NCRI SOYAC63	1.57	0.08	0.03	0.01
NCRI SOYAC75	2.09	0.13	0.08	0.01
NCRI SOYAC10	0.36	0.01	0.03	0.00
NCRI SOYAC67	0.68	0.02	0.01	0.01
NCRI SOYAC76	1.23	0.05	0.00	0.00
NCRI SOYAC61	0.90	0.03	0.01	0.01
NCRI SOYAC22	0.51	0.01	0.02	0.00

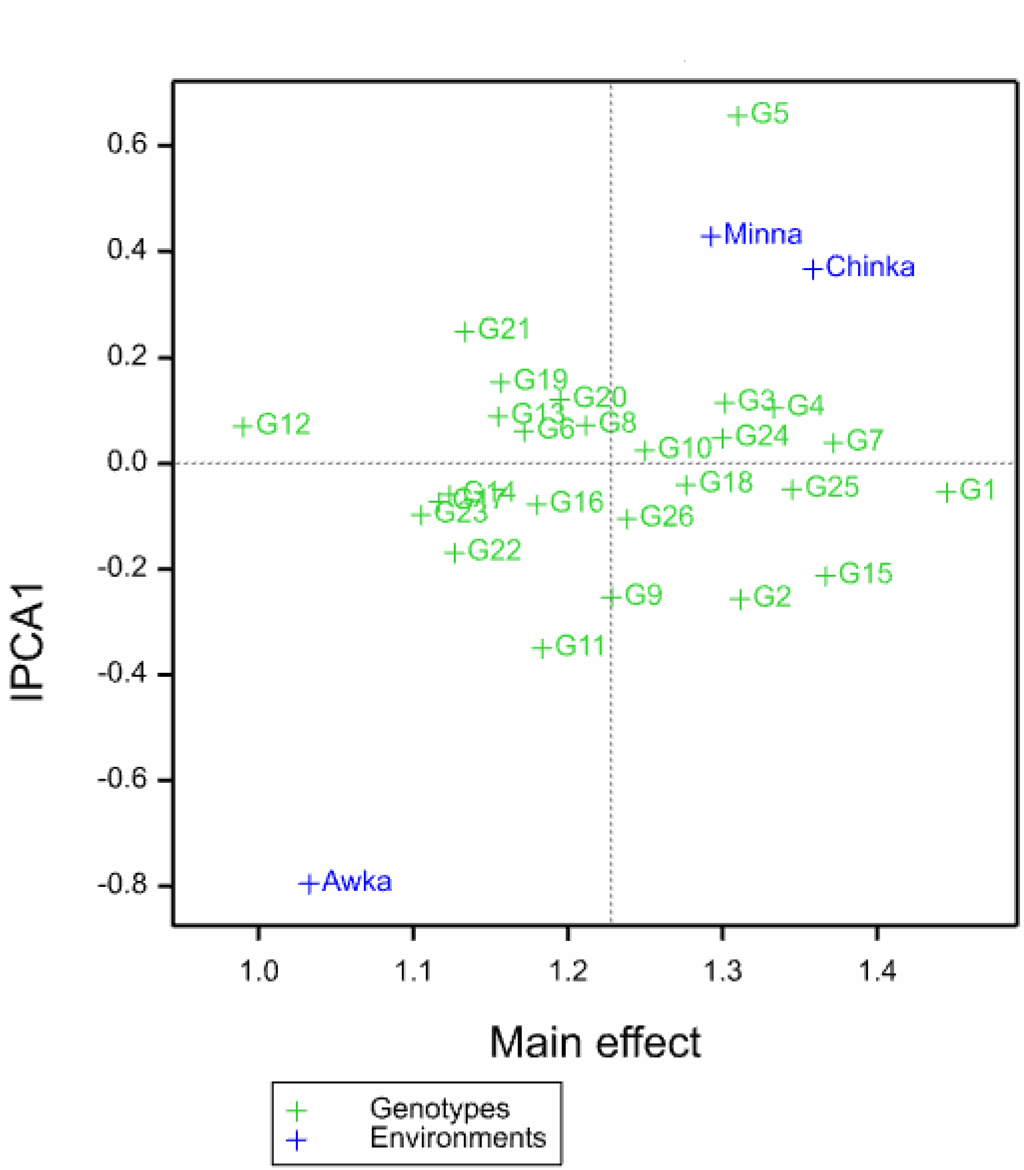

Figure 4.28: AMMI Bi-plot for combined seed yield of the soybean genotypes in different environments

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

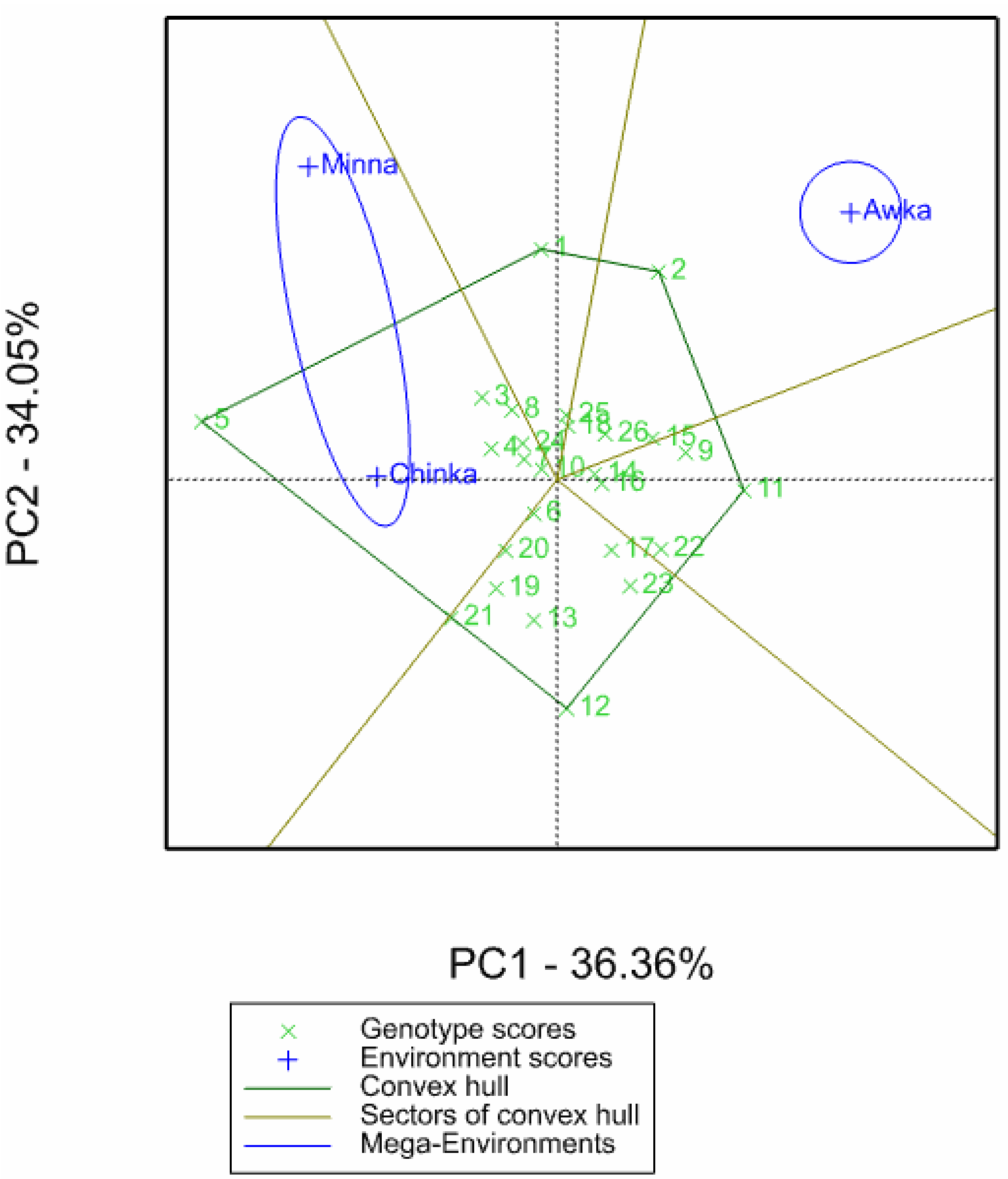

Figure 4.29: GGE bi-plot for combined seed yield in different environments

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

4.1.10.12 Combined Analysis for Genotypes' Stability across the Environments for Pod Shattering

The combined pod shattering rates of the genotypes across the three locations ranged from 6.39 % to 89.44 % (Table 4.27). The environments' mean ranged from 17.69 % in Chinka to 23.21 % in Minna.

The table of regression coefficient (b) shows that NCRI SOYAC3, having a b-value of -1.951 was the most stable. This genotype was also resistant to pod shattering (Table 4.28). Other resistant and stable genotypes were NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC67, NCRI SOYAC76, and NCRI SOYAC22. Two genotypes (NCRI SOYAC29 and NCRI SOYAC76) had high static stability, while none had high dynamic stability (Table 4.28).

The AMMI bi-plot for pod shattering (Figure 4.30) shows the stable genotypes in terms of pod shattering across the three environments. In the bi-plot, the environments are located almost on the perpendicular line of the graph and thus have similar influence on pod shattering behaviour of the genotypes. Therefore, genotypes provided greater variability than environmental differences. Genotypes NCRI SOYAC63, NCRI SOYAC65, NCRI SOYAC61, NCRI SOYAC75, NCRI SOYAC25 and NCRI SOYAC17 were relatively stable, as they were located closer to the horizontal line of the bi-plot than other genotypes. Three of these stable genotypes (NCRI SOYAC75, NCRI SOYAC25, and NCRI SOYAC17) were resistant to pod shattering while two (NCRI SOYAC61 and NCRI SOYAC65) were moderately resistant. Genotype NCRI SOYAC63 was very highly susceptible to pod shattering (Table 4.29).

The GGE bi-plot (Figure 4.31) grouped the three environments into one environment, with NCRI SOYAC63, NCRI SOYAC18, NCRI SOYAC61, and NCRI SOYAC65 as the genotypes with the highest pod shattering percentage.

Table 4.27: Combined pod shattering percentage of the genotypes across the three environments

Genotype	Minna	Chinka	Awka	Mean
NCRI SOYAC78	14.17	10.84	19.17	14.72
NCRI SOYAC18	34.17	35.83	32.50	34.17
NCRI SOYAC17	11.84	9.17	18.33	13.11
NCRI SOYAC69	20.50	24.17	20.84	21.83
NCRI SOYAC77	5.00	11.67	7.50	8.06
NCRI SOYAC73	11.67	5.00	15.84	10.83
NCRI SOYAC26	20.84	14.17	20.00	18.33
NCRI SOYAC29	10.00	8.33	10.00	9.44
NCRI SOYAC25	21.00	14.17	20.83	18.67
NCRI SOYAC28	21.84	10.83	27.50	20.06
NCRI SOYAC64	30.00	15.00	25.84	23.61
NCRI SOYAC65	29.50	25.84	35.00	30.11
NCRI SOYAC24	19.17	12.50	25.00	18.89
NCRI SOYAC3	15.83	25.00	15.00	18.61
NCRI SOYAC9	17.50	20.00	22.50	20.00
NCRI SOYAC7	6.67	10.00	9.17	8.61
NCRI SOYAC68	18.30	7.50	26.67	17.50
NCRI SOYAC20	15.84	11.67	20.84	16.11
NCRI SOYAC62	25.83	13.34	26.67	21.94
NCRI SOYAC63	94.17	85.00	89.17	89.44
NCRI SOYAC75	20.83	15.84	23.34	20.00
NCRI SOYAC10	22.00	6.67	23.34	17.33
NCRI SOYAC67	20.84	26.67	24.17	23.89
NCRI SOYAC76	5.84	5.84	7.50	6.39
NCRI SOYAC61	30.00	21.67	27.50	26.39
NCRI SOYAC22	9.17	13.34	9.17	10.56
Mean	21.25	17.69	23.21	20.72

Table 4.28: Sensitivity and stability coefficients for pod shattering percentage of the genotypes across three environments and two years

Genotype	Sensitivity	Static Stability	Wricke's Ecovalence	Mean square Deviation
NCRI SOYAC78	1.345	17.60	5.77	6.40
NCRI SOYAC18	–0.559	2.77	39.52	0.57
NCRI SOYAC17	1.413	22.20	11.57	12.60
NCRI SOYAC69	–0.691	4.12	44.38	0.63
NCRI SOYAC77	–0.999	11.34	66.15	6.79
NCRI SOYAC73	1.901	29.87	14.30	2.18
NCRI SOYAC26	1.224	13.18	5.85	2.51
NCRI SOYAC29	0.335	0.93	7.38	0.07
NCRI SOYAC25	1.347	15.17	5.51	1.45
NCRI SOYAC28	2.973	71.85	64.57	2.88
NCRI SOYAC64	2.445	59.96	65.57	24.68
NCRI SOYAC65	1.479	21.28	8.64	7.73
NCRI SOYAC24	2.126	39.12	24.51	6.24
NCRI SOYAC3	–1.951	30.80	136.8	0.94
NCRI SOYAC9	0.175	6.25	18.35	12.04
NCRI SOYAC7	–0.331	3.01	29.37	4.28
NCRI SOYAC68	3.299	92.35	93.33	11.28
NCRI SOYAC20	1.512	21.08	7.67	5.72
NCRI SOYAC62	2.619	55.75	47.41	2.25
NCRI SOYAC63	1.162	21.06	27.21	20.61
NCRI SOYAC75	1.340	14.58	2.11	0.53
NCRI SOYAC10	3.256	85.81	87.86	2.73
NCRI SOYAC67	–0.718	8.56	51.38	8.90
NCRI SOYAC76	0.225	0.92	9.18	1.04
NCRI SOYAC61	1.333	18.27	14.24	8.26
NCRI SOYAC22	–0.836	5.79	52.39	0.46

Table 4.29: Genotype grouping based on combined pod shattering percentage across three environments

Score	Description	Category	Genotypes
1	No pod shattering	Very resistant	Nil
2	< 25% pod shattering	Resistant	NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC73, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC64, NCRI SOYAC24, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC68, NCRI SOYAC20, NCRI SOYAC62, NCRI SOYAC28, NCRI SOYAC75, NCRI SOYAC10, NCRI SOYAC67, NCRI SOYAC76, NCRI SOYAC22
3	25 - 50% pod shattering	Moderately Resistant	NCRI SOYAC18, NCRI SOYAC65, NCRI SOYAC61
4	51 - 75% pod shattering	Highly susceptible	Nil
5	> 75% pod shattering	Very highly susceptible	NCRI SOYAC63

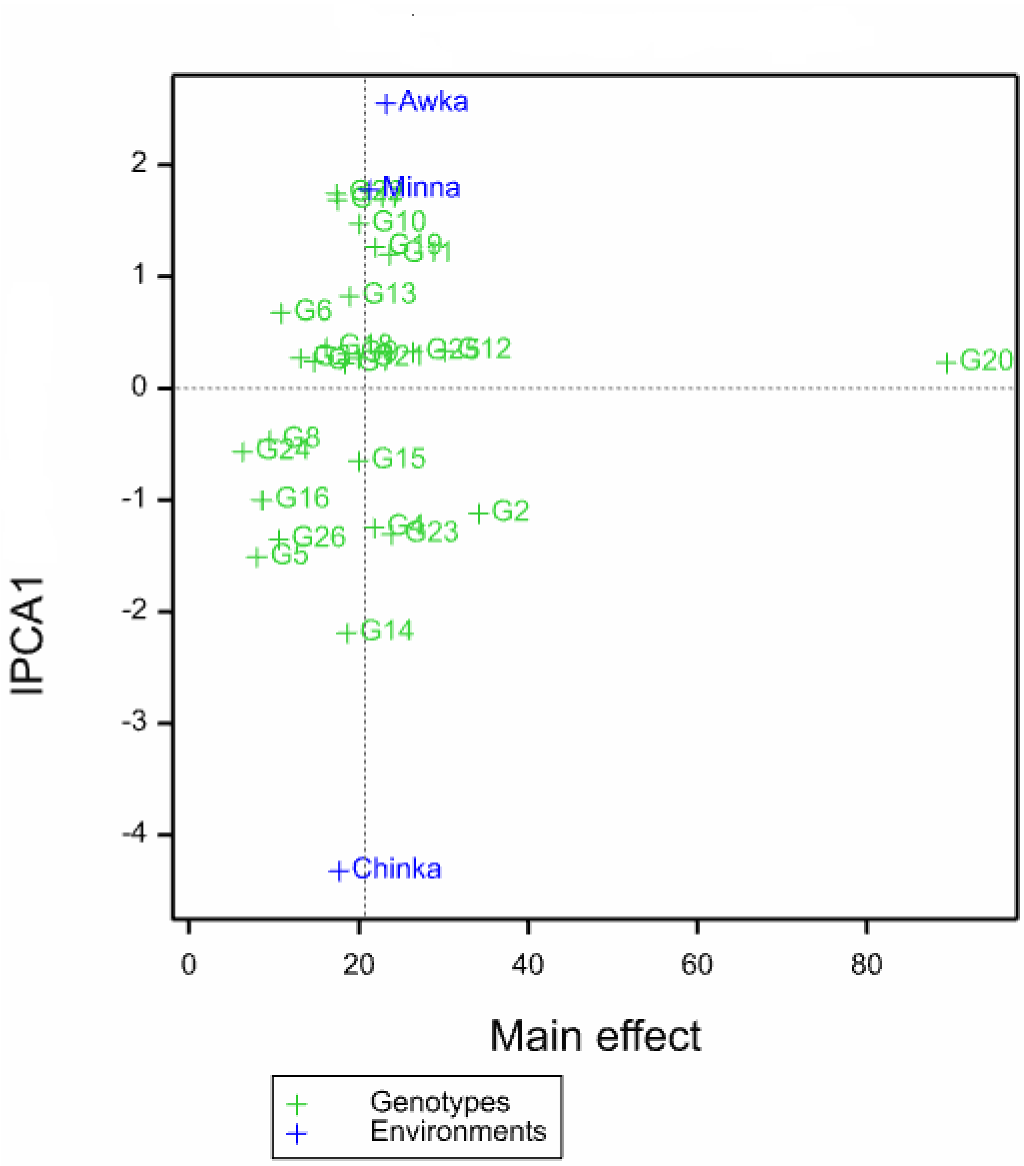

Figure 4.30: AMMI Bi-plot for combined pod shattering percentage of the soybean genotypes in different environments

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

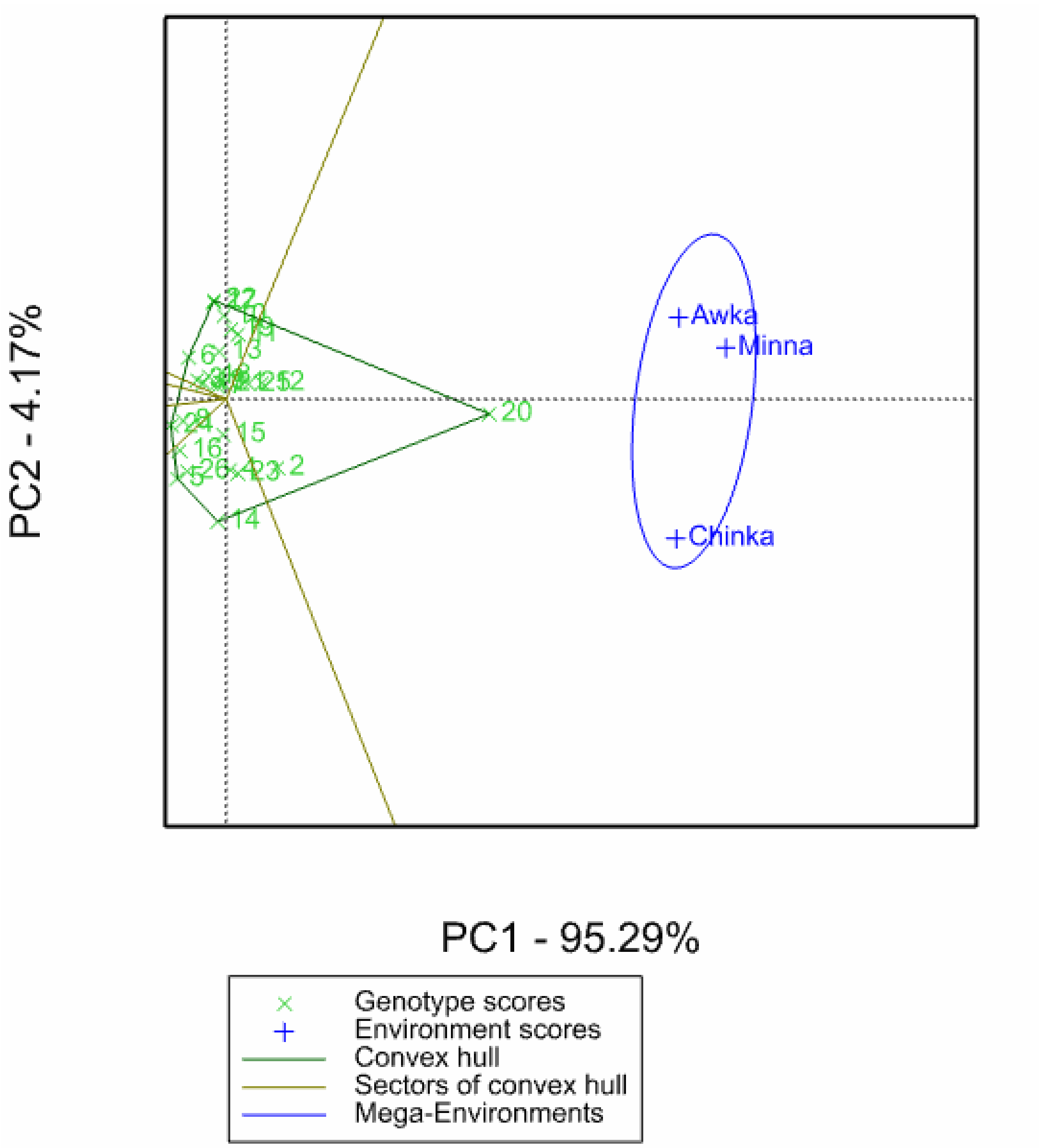

Figure 4.31: GGE bi-plot for combined pod shattering in different environments

1 = NCRI SOYAC78; 2 = NCRI SOYAC18; 3 = NCRI SOYAC17; 4 = NCRI SOYAC69; 5 = NCRI SOYAC77; 6 = NCRI SOYAC73; 7 = NCRI SOYAC26; 8 = NCRI SOYAC29; 9 = NCRI SOYAC25; 10 = NCRI SOYAC28; 11 = NCRI SOYAC64; 12 = NCRI SOYAC65; 13 = NCRI SOYAC24; 14 = NCRI SOYAC3; 15 = NCRI SOYAC9; 16 = NCRI SOYAC7; 17 = NCRI SOYAC68; 18 = NCRI SOYAC20; 19 = NCRI SOYAC62; 20 = NCRI SOYAC63; 21 = NCRI SOYAC75, 22 = NCRI SOYAC10, 23 = NCRI SOYAC67; 24 = NCRI SOYAC76; 25 = NCRI SOYAC61; 26 = NCRI SOYAC22

4.1.11 Phenotypic Markers Identification

4.1.11.1 Relationship between Pod Shattering and days to 50% flowering, days to maturity and other pod traits across the Environments and Years

The correlation coefficients contained in Table 4.30 represent the relationship between days to 50% flowering, days to maturity and other pod traits measured with pod shattering of the genotypes across the three environments and two years of studies. From the Table, the correlations between pod shattering and pod width, pod length/pod width ratio and pod thickness were not significant in all the environments and years. There was a negative correlation between pod shattering and pod length, which was only significant in Minna in 2019. The correlation between pod shattering and width at the mid part of the pod was negative in all the environments and years except Minna in 2019, which was positive. However, only the negative correlation in Awka in 2020 was significant. Similar correlation was observed in seed weight, where there were negative correlations in all environments and years except Chinka in 2019; and there were significant in Minna and Awka in both years. In the correlation between pod shattering and pod wall weight, only a positive correlation observed in Chinka in 2019 was significant, while only a negative correlation observed in Awka in 2020 was significant in the correlation between pod shattering and pod weight.

Pod shattering negatively and significantly correlated with seed weight/pod weight ratio in all the environments and years. Similarly, there were significant and positive correlations between pod shattering and pod wall weight/pod weight ratio in all the environments and years. The negative correlation mostly observed between pod shattering and days to 50 % flowering was not significant, while a significantly negative correlation existed between pod shattering and days to maturity in Chinka and Awka (both in 2019 only).

4.1.11.2 Combined Analysis of the Relationships among Pod Traits

The average values of all the pod traits were analysed to establish the relationships among them. The results of their relationships represented by correlation coefficients are presented in Table 4.31.

The following relationships were positive and significant: pod length and pod width; pod length and pod length/pod width ratio; pod length and width at the mid part of the pod; pod length and seed weight; pod length and pod weight; pod width and width at the mid part of the pod; pod thickness and seed weight; pod thickness and pod wall weight; pod thickness and pod weight; width at the mid part of the pod and seed weight/pod weight ratio; seed weight and pod wall weight; seed weight and pod weight; seed weight and seed weight/pod weight ratio; pod wall weight and pod weight; pod weight and seed weight/pod weight ratio; and pod wall weight/pod weight ratio and pod shattering.

Finally, the following relationships were negative and significant: pod weight and pod shattering, width at the mid part of the pod and pod wall weight/pod weight ratio; width at the mid part of the pod and pod shattering; seed weight and pod wall weight/pod weight ratio; seed weight and pod shattering; pod weight and pod wall weight/pod weight ratio; seed weight/pod weight ratio and pod wall weight/pod weight ratio; and seed weight/pod weight ratio and pod shattering.

Table 4.30: Correlation between pod shattering and days to 50% flowering, days to maturity and other pod traits across the three environments and years

Parameter	Environment	Year	PL (cm)	PW (cm)	LW Ratio	PT (cm)	WMP(cm)	SW (g)	PWW (g)	PWt (g)	SWPW Ratio	PWWPW Ratio	D50%F	DM
PS (%)	Minna	2019	-0.39*	-0.23ns	-0.13ns	-0.17ns	0.18ns	-0.39*	-0.11ns	-0.34ns	-0.49**	0.49**	-0.18ns	-0.33ns
		2020	-0.26ns	0.03ns	-0.26ns	-0.07ns	-0.33ns	-0.40*	0.22ns	-0.24ns	-0.72*	0.68*	-0.28ns	-0.19ns
	Chinka	2019	-0.05ns	-0.07ns	-0.01ns	0.14ns	-0.02ns	0.01ns	0.42*	0.18ns	-0.52**	0.52**	0.07ns	-0.42*
		2020	-0.27ns	-0.12ns	-0.14ns	0.13ns	-0.31ns	-0.23ns	0.21ns	-0.10ns	-0.58*	0.58*	-0.15ns	0.03ns
	Awka	2019	-0.26ns	-0.33ns	-0.03ns	0.10ns	-0.22ns	-0.42*	0.02ns	-0.29ns	-0.57**	0.57**	-0.29ns	-0.38*
		2020	-0.28ns	-0.31ns	0.08ns	-0.11ns	-0.39*	-0.41*	-0.09ns	-0.47*	-0.72*	0.72*	-0.15ns	0.35ns

* = significant at 5 %; ** = significant at 1 %; ns = not significant PL = Pod Length; PW = Pod Width; LW Ratio = Pod length/Pod width Ratio; PT = Pod Thickness; WMP = Width at the Mid Part of the Pod; SW = Seed Weight; PWW = Pod Wall Weight; PWt = Pod Weight; SWPW Ratio = Seed Weight/Pod Weight Ratio; PWWPW Ratio = Pod Wall Weight/Pod Weight Ratio; PS = Pod Shattering; D50%F = Days to 50% Flowering; DM = Days to Maturity.

Table 4.31: Correlation matrixes of the relationships among pod traits, days to 50% flowering and days to maturity during the 2019 and 2020 cropping seasons across environments

Parameter	PL (cm)	PW (cm)	LW Ratio	PT (cm)	MWL(cm)	SW (g)	PWW (g)	PWt (g)	SWPW Ratio	PWWPW Ratio	D50%F	DM	PS (%)
PL (cm)	-												
PW (cm)	0.45*	-											
LW Ratio	0.69**	-0.30ns	-										
PT (cm)	0.21ns	0.27ns	-0.01ns	-									
MWL(cm)	0.46**	0.71**	-0.07ns	-0.16ns	-								
SW (g)	0.43*	0.34ns	0.14ns	0.54**	0.23ns	-							
PWW (g)	0.29ns	0.24ns	0.04ns	0.63**	-0.06ns	0.72**	-						
PWt (g)	0.42*	0.33ns	0.11ns	0.60**	0.17ns	0.98**	0.83**	-					
SWPW Ratio	0.26ns	0.24ns	0.10ns	0.04ns	0.44*	0.60**	-0.09ns	0.47**	-				
PWWPW Ratio	-0.26ns	-0.23ns	-0.10ns	-0.04ns	-0.41*	-0.61**	0.08ns	-0.48**	-0.99**	-			
D50%F	0.16ns	-0.09ns	0.27ns	-0.38*	0.26ns	-0.20ns	-0.52**	-0.30ns	0.23ns	-0.21ns	-		
DM	0.06ns	-0.13ns	0.18ns	-0.38*	0.19ns	-0.19ns	-0.60**	-0.31ns	0.35ns	-0.34ns	0.79**		
PS (%)	-0.37ns	-0.37*	-0.11ns	0.04ns	-0.44*	-0.45*	0.13ns	-0.34ns	-0.86**	0.86**	-0.25ns	-0.34ns	-

* = significant at 5 %; ** = significant at 1 %; ns = not significant PL = Pod Length; PW = Pod Width; LW Ratio = Pod length/Pod width Ratio; PT = Pod Thickness; WMP = Width at the Mid Part of the Pod; SW = Seed Weight; PWW = Pod Wall Weight; PWt = Pod Weight; SWPW Ratio = Seed Weight/Pod Weight Ratio; PWWPW Ratio = Pod Wall Weight/Pod Weight Ratio; PS = Pod Shattering; D50%F = Days to 50% Flowering; DM = Days to Maturity.

4.2 Discussion

The higher seedling emergence in 2020 in Minna as compared to 2019 suggests that the seeds used in the second year were more viable and/or the environment was more favourable in 2020. The significantly high performances in pod yield per plant and above ground biomass by the high yielding genotypes across the three environments is an indication that a good pod yield and biomass accumulation could lead to high seed yield in soybean even with varying degrees of performance in other growth and yield parameters. This is in agreement with the work of Hao *et al*. (2012), which reported that number of pods and biomass are good selection indices for soybean yield. The non-significant pods per plant for the genotypes suggests that genotypes had similar pattern of pod formation, while non-significant days to 50 % flowering for the environment shows the environmental differences did not influence the time of flowering of the genotypes.

In terms of pod shattering resistance of the genotypes, the higher seed weight-pod weight ratio and lower pod wall weight-pod weight ratio observed in pod shattering resistant genotypes suggests that soybean genotypes with larger seeds are more likely to resist pod shattering than genotypes with smaller seeds. Similar result was reported by Krisnawati and Adie (2017), where genotypes with heavier seeds resisted pod shattering more than genotypes with lighter seeds.

In 2019, although NCRI SOYAC18 and NCRI SOYAC26 performed better than NCRI SOYAC78 in the mean seed yield, NCRI SOYAC78 is superior to both NCRI SOYAC18 and NCRI SOYAC26 in more favourable environments. This is due to the fact that NCRI SOYAC78 has a better adaption to improved environmental conditions, which is reflected in its higher genotypic sensitivity. Similar result was obtained by Ishaq *et al*. (2015), where TGx1989-40F did better than TGx1990- 55F in the average yield performance, but TGx1990-55F was superior to TGx1989-40F in more favourable environments due to its ability to utilize improved environmental conditions, which was reflected in its higher genotypic sensitivity. All the high yielding and low sensitive genotypes also produced high static and dynamic stabilities. According to Sabaghnia *et al*. (2015) high static stability points at the ability of the genotypes to give same performances across environments; and high dynamic stability shows that the genotypes positively responded to improvements in edaphic and climatic conditions of the environment and can perform above the mean in different environments. The concept of dynamic stability is useful for quantitative traits such as yield and is of great interest to both plant breeders and farmers.

The high yield recorded in Chinka in both years could be a reflection of adequate rainfall pattern and favourable level of soil nutrient elements. The poor yield in Awka on the other hand could be due its rainfall pattern. This is because, among the environments, Awka had an irregular rainfall pattern in both years and annual rainfall far higher than the recommended range of 700-1200 mm (Mondine *et al.*, 2001). This according to Dugje *et al.* (2009) could affect soybean productivity; meaning that rainfall and soil phosphorus level could be responsible for the comparatively poor yield obtained in Awka. This further explains why Sahel Capital Partners and Advisory Limited (SAHEL, 2017) ranked Kaduna State higher than Niger and Anambra States in soybean production in Nigeria.

Both AMMI and GGE bi-plots revealed similar interactions among the environments in pod shattering of the genotypes. They suggest that environment had little or no influence on the pod shattering pattern of the resistant genotypes. This could be as a result of similar temperature and relative humidity levels observed across the environments since pod shattering behaviour of a soybean genotype is greatly influenced by these two climatic parameters (Zhang *et al*., 2018). Therefore, genotypes provided greater variability than environmental differences.

Furthermore, grouping of the three environments into one environment by GGE bi-plot for pod shattering in both years is another proof to suggest that environment contributed a little or nothing to the variability observed in the pod shattering pattern of the genotypes in this study. That is irrespective of environment and year; some soybean genotypes can still exhibit the same level of resistance or susceptibility to pod shattering. This is in agreement with the findings of Bhor *et al*. (2014), which reported that the genotypic characteristics of any genotype play a major role in the overall expression of pod shattering of that genotype.

In the yield stability in individual environments, the years were not similar; thus, year had greater contribution to observed variability than genotype differences. However, for pod shattering, the years were similar; therefore, genotypes provided greater variability in individual environment than years' differences. The grouping of the two years into one by GGE bi-plot is another indication that in the individual environments, the years had similar influence on pod shattering behaviour of the genotypes.

The negative correlation between pod shattering and pod length in all the environments and years, as well as in combined analysis, although significant in one environment and one year only; points out that pod length could serve as a phenotypic marker for pod shattering resistance; where longer pods tend to resist shattering more than shorter pods. However, this result is not in agreement with works of Bara *et al*. (2013) (India) and Krisnawati and Adie (2017) (Indonesia); that reported that shorter pods tend to resist pod shattering more than longer pods. This therefore suggest that pod length as an important trait in selecting soybean genotypes for pod shattering resistance could be influenced by geographical locations.

Similarly, the negative correlation observed between pod shattering and seed weight suggests that genotypes with larger seeds were more resistant to pod shattering than those with smaller seeds, which is in agreement with the report of Krisnawati and Adie (2017). However, the varying result obtained in Chinka in 2019 and 2020 suggests that location and year could have a slight influence on how seed weight affects pod shattering behaviour of a soybean genotype.

The significant correlation of seed weight-pod weight ratio (negative) and pod wall weight-pod weight ratio (positive) with pod shattering further elucidates the earlier suggestion that genotypes with larger seeds could be more resistant to pod shattering than those of smaller seeds. Therefore seed weight-pod weight ratio and pod wall weight-pod weight ratio could be considered as phenotypic markers for pod shattering resistance. In any soybean germplasm therefore, high seed weight-pod weight ratio signifies low pod shattering ability and vice versa, whereas high pod wall weight-pod weight ratio means high pod shattering ability. This is in agreement with the findings of Krisnawati and Adie (2017), which stated that soybean genotypes with high seed weight-pod weight ratio and low pod wall weight-pod weight ratio were more resistant to pod shattering.

Some relationships exist among these markers that further establish their impact and connectivity in soybean pod shattering resistance. Pod length had a significantly positive correlation with seed weight; seed weight had a significantly positive correlation with seed weight-pod weight ratio and negative correlation with pod wall weight-pod weight ratio; while seed weight-pod weight ratio had a significantly negative correlation with pod wall weight-pod weight ratio. The above relationships imply that longer pods will give larger seeds; larger seeds will result in higher seed weight-pod weight ratio and lower pod wall weight-pod weight ratio; and finally higher seed weight-pod weight ratio or lower pod wall weight-pod weight ratio confers pod shattering resistance to any soybean genotype.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The genotypes exhibited some level of variability in seed yield and pod shattering when stressed. It was observed in all AMMI analyses in this study that environments provided greater variability in yield of the genotypes than genotype differences, while differences observed in the rate of pod shattering was a function of genotype differences, as environments had little influence on the way the genotypes shattered. Genotype NCRI SOYAC78 and NCRI SOYAC20 were the only stable and high yielding genotype in both years of studies, among all the genotypes. Genotypes NCRI SOYAC22, NCRI SOYAC77, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC67, NCRI SOYAC29, NCRI SOYAC69 and NCRI SOYAC76 were stable and resistant to pod shattering in both years of studies. In terms of environment, only Chinka was high yielding in both years. While Minna was high yielding in only 2019, Awka was not high yielding in any of the years.

In combined analysis of genotypes' stabilities for seed yield across environments and years, genotypes NCRI SOYAC18, NCRI SOYAC78, NCRI SOYAC9, NCRI SOYAC20, NCRI SOYAC61, NCRI SOYAC22, NCRI SOYAC26, NCRI SOYAC28 and NCRI SOYAC76 were identified as high yielding stable genotypes. The combined analysis of genotypes' stabilities for pod shattering resistance across environments and years identified twelve genotypes with stable pod shattering resistance. These were NCRI SOYAC3, NCRI SOYAC69, NCRI SOYAC77, NCRI SOYAC29, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC67, NCRI SOYAC76, NCRI SOYAC22, NCRI SOYAC75, NCRI SOYAC25, and NCRI SOYAC17.

In Minna, NCRI SOYAC63, NCRI SOYAC78, NCRI SOYAC18, NCRI SOYAC17, NCRI SOYAC69, NCRI SOYAC29, NCRI SOYAC3 and NCRI SOYAC20 were stable and high yielding. For pod shattering in this environment, NCRI SOYAC76, NCRI SOYAC22, NCRI SOYAC18, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC29, NCRI SOYAC25, NCRI SOYAC3, and NCRI SOYAC7 were stable and resistant to pod shattering.

Chinka had NCRI SOYAC77, NCRI SOYAC78, NCRI SOYAC28, NCRI SOYAC20, NCRI SOYAC63 and NCRI SOYAC61 as genotypes with stable high seed yields. In terms of pod shattering in this environment, NCRI SOYAC22, NCRI SOYAC78, NCRI SOYAC17, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC28, NCRI SOYAC9, NCRI SOYAC76, NCRI SOYAC61, NCRI SOYAC62, NCRI SOYAC20, NCRI SOYAC10, and NCRI SOYAC73 were resistant and stable.

In Awka, Seven genotypes (NCRI SOYAC78, NCRI SOYAC69, NCRI SOYAC25, NCRI SOYAC20, NCRI SOYAC76, NCRI SOYAC61 and NCRI SOYAC22), had high and stable seed yield. In the area of pod shattering of the genotypes in this environment, NCRI SOYAC7, NCRI SOYAC20, NCRI SOYAC77, NCRI SOYAC26, NCRI SOYAC25, NCRI SOYAC3, NCRI SOYAC22, NCRI SOYAC29, NCRI SOYAC17, and NCRI SOYAC73 as stable and resistant to pod shattering.

Pod shattering behaviour of the soybean genotypes used in this study was found to be associated with some of their pod phenotypic traits. The relationships that existed between pod shattering and some pod traits like pod length, seed weight, seed weight-pod weight ratio, and pod wall weight-pod weight ratio shows that these traits could be valuable selection indices for pod shattering resistance in any soybean breeding or production programme.

5.2 Recommendations

Based on the findings of this study, the following are recommended:

Genotypes NCRI SOYAC78 and NCRI SOYAC20 being able to produce high and stable seed yield in both years of studies and in combined stability analysis (NCRI SOYAC78; 1.45 ton/ha in 2019 and 1.44 ton/ha in 2020 and combined; NCRI SOYAC20; 1.34 ton/ha in 2019, 1.21 ton/ha in 2020, and 1.28 ton/ha in combined); are recommended for selection as a valuable genotypes in breeding of high yielding and stable soybean varieties; as well as in large scale soybean production. This is due to the fact that they perform better than the 0.88 ton/ha reported as an average soybean yield in Nigeria in 2019 and 2020 farming season by USDA (2021).

Genotypes NCRI SOYAC22, NCRI SOYAC77, NCRI SOYAC3, NCRI SOYAC9, NCRI SOYAC7, NCRI SOYAC67, NCRI SOYAC29, NCRI SOYAC69 and NCRI SOYAC76 showed resistance to pod shattering in both years and in combined analysis as well. These genotypes are therefore recommended as donor parents in any breeding programme that focuses on pod shattering resistance in soybean. They could also be selected for large scale production as there will be minimal yield loss due to pod shattering even with delay in harvest.

Although none of the genotypes proofed to be stable in high yield and pod shattering resistance across the environments and years, some genotypes could be recommended in specific environments for both stabilities in high yield and pod shattering resistance due to their performances in the two years of studies. For instance, genotypes NCRI SOYAC18, NCRI SOYAC29, and NCRI SOYAC3 are recommended in Minna; NCRI SOYAC77, NCRI SOYAC78, NCRI SOYAC28, and NCRI SOYAC61 are recommended in Chinka; while in Awka, NCRI SOYAC25, NCRI SOYAC20, and NCRI SOYAC22 are recommended.

Chinka proofed to be the highest in yield and as such among the three environments, Chinka is recommended for large scale soybean production.

Pod traits like pod length, seed weight, seed weight-pod weight ratio, and pod wall weight-pod weight ratio are recommended as phenotypic markers for selection of pod shattering resistant soybean genotypes. However, there is need to carry out more studies on the influence of pod traits and environmental differences on pod shattering behaviour of soybean genotypes, especially in the area of pod length and seed weight.

5.3 Contributions to Knowledge

This research brought out additional information, which are valuable contributions to knowledge in this field of research. It was determined that phenotypic makers for pod shattering resistance like pod length and seed weight could be influenced by the environment, but seed weight-pod weight ratio, and pod wall weight-pod weight ratio are independent of environmental changes. Furthermore, environments provided greater variability in yield than genotype differences, while differences observed in the rate of pod shattering was a function of genotype differences, as environments had little influence on pod shattering of the genotypes.

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APPENDIX

Appendix A Work Plan

S/N	Activities	May - Jun 2019	Jun - Jul 2019	July - Aug 2019	Aug - Oct 2019	Oct - Nov 2019	Dec 2019 - Jan 2020	May - Jun 2020	Jun - Jul 2020	July - Aug 2020	Aug - Oct 2020	Oct - Nov 2020	Dec 2020 - Jan 2021	Feb - Sept 2021
1	Literature review													
2	Site selection													
3	soil analysis													
4	Land preparation													
5	Planting													
6	Thinning													
7	First visit for data collection and weeding													
8	second weeding and data collection													
9	Harvesting, pod shattering evaluation and data collection													
10	Data analysis													
11	Thesis writing and defence													