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Comparative Performance of Pre-Commercial vs Existing Maize Hybrids in Zambia

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ABSTRACT: Maize production in Zambia has remained below the global average, with a national yield of 2,800 kg/ha compared to the world average of 5,000 kg/ha, as reported by FAO. This yield gap is mainly attributed to challenges such as pests, diseases, declining soil fertility and the use of low yielding varieties with limited resistance to pests and diseases, that are not suited to local Agro ecological conditions. To address these challenges, this study was conducted at Agri-Wind in Serenje District, Zambia, to evaluate and compare the performance of six pre-commercial maize hybrids against sixteen commercially available hybrids. A total of twenty-two maize hybrids were assessed, including six pre-commercial varieties (PV17, PV18, PV19, PV20, PV21, PV22) and sixteen commercial varieties (V1 - V16). The trial was arranged in a Randomized Complete Block Design (RCBD) with three replications. Performance evaluation focused on yield potential, insect and disease resistance, as well as distinctiveness, uniformity, and stability (DUS). Data were analyzed using ANOVA in Field Book (CIMMYT) at a 5% significance level (p = 0.05). Results indicated that V5 and PV19 were the highest-yielding hybrids, producing 5,850.70 kg/ha and 5,498.18 kg/ha, respectively. These varieties, along with PV18, showed strong resistance to Northern Leaf Blight (NLB) and Maize Streak Virus (MSV), making them promising candidates for commercial release. Although PV17 had a lower yield (3,781.05 kg/ha), it demonstrated the best resistance to NLB (score of 1.5), suggesting its potential for disease-prone areas. In contrast, PV21, which had lower yields and weaker disease resistance, was deemed less suitable for release. Generally, PV19, PV18, and PV17 emerged as the most promising pre-commercial hybrids, while V5 was recommended for high-yielding areas. In addition, the DUS analysis revealed superior characteristics in the pre-commercial hybrids, such as enhanced anthocyanin coloration and optimal growth duration, indicating their potential adaptability to local agroecological conditions.

KEYWORDS: Distinctiveness, Uniformity, Stability (DUS), pre-commercial, existing, maize hybrids, resistance, performance, Zambia

INTRODUCTION

Maize (Zea mays L.) is a significant cereal crop globally and is a member of the family Poaceae (Akbar et al., 2018). Maize is fast-growing, yield-high, and extremely versatile. Maize was first evolved in Mesoamerica, i.e., current-day Mexico and Central America, and was domesticated from teosinte about 9,000 years ago through selective breeding for useful traits such as increased kernel size and yield (Gerster & Mabhaudhi, 2020). Its cultivation was later carried over to the Americas, even to Canada and Chile, before it was eventually introduced to Africa. Maize is now the third most important cereal crop globally after rice and wheat, primarily due to its versatility and yields (Pandey et al., 2017).

It occurs in diverse agro-ecological areas and is of significant contribution to global food security (Janke, 2017). Maize is a major staple food in Africa and Zambia, and it is a key propeller of the economy. Maize has extensive use for human consumption, animal feed, and industry, such as food processing and paper manufacturing (Worku et al., 2020).

Nutritionally, maize is rich in carbohydrates, essential amino acids, and minerals such as iron, magnesium, and phosphorus and is therefore an essential food material for malnourished individuals and food-insecure individuals (Gerster & Mabhaudhi, 2020; Smith, 2011). In Zambia, agriculture sustains over 70% of the country's population and accounts for approximately 15% of the GDP, while maize is responsible for contributing to the supply of 60% of national calorific consumption (Worku et al., 2020; Kalinda et al., 2014; Sitko et al., 2011).

Although maize is highly significant, its production in Zambia has a number of challenges including low productivity due to dependence on local varieties and vulnerability to pests and diseases such as maize streak virus and leaf blight (Rahmarati et al., 2020; Pandey et al., 2017). Promoting high-yielding hybrid maize varieties is important in the context of productivity improvement and income for farmers.

Nutritionally, maize is rich in carbohydrates, essential amino acids, and minerals such as iron, magnesium, and phosphorus, and as a result, it is a valuable food source for food-insecure and malnourished populations (Gerster & Mabhaudhi, 2020; Smith, 2011). In Zambia, agriculture supports over 70% of the population and contributes around 15% of the GDP, with maize contributing 60% of national caloric intake (Worku et al., 2020; Kalinda et al., 2014; Sitko et al., 2011).

Despite being important, Zambia's maize production is faced with some issues like low productivity due to reliance on local varieties and vulnerability to pests and diseases like maize streak virus and leaf blight (Rahmarati et al., 2020; Pandey et al., 2017). also, climatic conditions like rainfall availability, temperature, light and soil conditions affect maize productivity. The adoption of hybrid maize varieties with high yield potential must be encouraged to increase productivity and farmers' income.

factors for maize yield play a vital role in the estimation of maize productivity and quality determination and also bearing a pivotal role in determining farmers' decision, scientists and their effectiveness. Those factors are comprised of ear quantity, ears/plant, rows per cob, seeds per row, weight per 1000 kernels, weight per grain, field weight, harvest index, cob length e.t.c.

Ear population is defined as the number of ears that can be harvested per unit area, usually measured in units of square meters. Ear population is one of the determinants of maize production per unit area. The farmer in Zambia wants high ear population and ensures this by using highest planting density and spacing in a way that he gets high output. Luapula farmers have reported ear populations of 25,000 to 30,000 per hectare (Mulako et al., 2019). FOA (2020) nonetheless suggests the optimum ear population as 50, 000 to 60, 000/ ha depending on area, fertility of the soil and weather conditions.

100 kernel weight is the weight of 100 maize kernels and is used as an indicator of grain yield (Manda et al., 2018). It is a measurement of seed quality and size. FAO standard 100 kernel weight is between 25 and 40 grams. Grain weight is an essential component of maize yield as it reflects the true amount of harvest maize. In Zambia, a significant improvement in grain weight enhancement has been recorded through the dissemination of resistant and high-yielding maize varieties. As the ultimate measure of maize yield, grain weight is influenced by a number of agronomic practices. For instance, Dasho maize can produce a heavy tonnage of grain and has found widespread acceptance among farmers across the nation (Setimela et al., 2009).

Percentage shelling of maize or the proportion of kernel to whole ear weight after removal of the cob and husk is an important factor of yield in maize production because it directly impacts the amount of grain that can be processed and utilized (Smith et al., 2018). Percentage shelling varies with the variety of maize, environmental factors and management. It is usually between 75% to 85%, i.e., from every 100 kg of harvested maize ears, 75 to 85 kg of maize kernels can be obtained after removal of the cob and husk (FAO, 2020).

Also, different abiotic or environmental factors affect maize production. Abiotic components are the non-living components of the environment that affect living organisms and ecosystems and can change the growth, survival, and distribution of plants and animals. One of the most important is temperature. Mean temperature over the last 10 years (2010–2019) was at its highest globally, and in coming years, it is also expected to increase because of rising greenhouse gas (GHG) emissions (World Meteorological Organization, 2019; Tembo & Sarjanov, 2013). Temperature decrease can retard growth, and a decrease of 1°C can result in a yield loss of 31 kg/ha. Maize is extremely sensitive to heat stress at the multiplicative stage. Research has shown that a one-degree daily temperature increases above 30 ◦C reduces the final maize yield by 1% under good growing conditions and 1.7% under drought-stressed conditions (Lobell et al., 2009). High temperatures during sensitive growth phases can reduce maize plant height by around 10 to 30 % which can, in turn, translate to low yields. The optimum temperature for maize is 20 to 30 degrees Celsius, and the extreme temperatures influence pollination and grain filling.

Rain-fed farming is very prevalent in developing countries like Zambia and is most vulnerable to climate risk. It has been noted through a study that 95% of cultivated land in sub-Saharan Africa relies on rainfall (Kihara et al., 2020). The optimum rainfall for peak maize productivity is found to be 600 to 800 mm (FAO, 2011). Drought is a severe abiotic stress that affects rain fed maize production globally. Water-induced plant stress during the asexual and sexual phases of maize is reported to lower yields by 39.3%.

Barron in 2003 investigated the frequency of dry spells in semi-arid regions in Kenya and Tanzania and reported that dry spells of less than10 days occurred in 70% of seasons during the flowering stage of the maize crop, which is extremely sensitive to water stress. Maize plants under drought stress also experience reduced growth rate and plant height and this is due to the fact that limited water supply affects photosynthesis, nutrient uptake and overall plant metabolism, resulting in shorter overall plant height at the close of the growing season. The typical maize plant height ranges from 1.8 to 3.7 meters but water shortage during drought reduces this by 10 to 50% or more depending on the intensity and duration of the drought stress. Literature shows that reduced height is likely to be associated with lower yield potential as well as lower kernel quality.

Maize is among the most vital staple foods of Zambia people, which consumes most of the population. But the yield of maize crops is typically influenced by a number of insect pests that, if not managed properly, could ultimately lead to serious damage (Rahmarati et al. 2020). The following discuss in detail five common insect pests of maize crops in Zambia, which are Amy worms, Stem borers, Cut worms, Grain borers, and Weevils. In all of them, we will outline their habits, life cycle, and potential control measures

Army worms are highly damaging pests having a potential to cause extensive damage in maize crops (up to 20-30%). Native to the Americas, they were first reported in Zambia in 2016 and soon spread in the whole country and caused significant yield loss up to 20% (Georgen et al., 2016). Pest larvae are nearly phytophagous in nature and consume aerial parts of the maize crop, causing high yield loss. These worms are specifically fond of maize crops and feed extensively on leaves, causing defoliation and decreased photosynthetic activity. Their high reproductive rate and capacity to move quickly make them hard to manage. Proper management involves the utilization of resistant maize varieties, early detection, and the use of suitable insecticides

Stem borers are another serious insect pest of maize production in Zambia. The principal pests include *Chilo partellus*, *Busseola fusca*, and *Sesamia calamistis*. The larvae of the insects tunnel within the stalks of maize, damaging the plants and inhibiting nutrient uptake. Infestation often leads to stunted plant growth, low yields, and susceptibility to secondary diseases. Stem borers may be managed using Integrated Pest Management (IPM) techniques like the use of pheromone traps, application of biological control agents, and planting of resistant varieties of maize. Also, proper sanitation, such as the removal of

Cut worms are soil-dwelling caterpillars that feed on young maize seedlings, typically cutting them at or slightly above the ground level. Night insects are most active during the early growth stages of maize, causing widespread damages to vulnerable crops (Rogers et al, 2013). Wilting and yellowing of the affected maize plants may be the first signs of infestation. Cultural practices such as proper land preparation, rotation of crops, and proper planting time can minimize cut worm populations (Rogers et al, 2013). Insecticide application targeted to infested areas or by using biological control agents can also effectively manage cut worms

Diseases such as leaf blight, which is a disease caused by the fungal pathogen *Setosphaeria turcica* formerly known as *Helminthosporium turcucum*, is a key disease in maize. Symptoms are large, irregular brown spots with a yellow halo, appearing initially on lower leaves and progressing upward. Fungus from one plant to another is spread by spores on the wind and rain. NCLB is largely observed under hot and humid weather in the growth period especially in the Northern and eastern provinces of 26 Zambia and can cause up to 50% loss in yield under severe conditions. Fungicides such as mancozeb and chlorothalonil are likely to control the disease. Resistant maize varieties and crop rotation can be used to control the leaf blight. Researchers have also found resistant maize hybrids that can be employed to reduce the impact of NCLB. For instance, the Varuna hybrid has shown high resistance to NCLB and is recommended for cultivation in areas prone to this disease. The use of resistant hybrids like Varuna can reduce yield loss due to NCLB (Welze and Geiger, 2000).

Maize streak virus, which is caused by leafhopper vectors, is a viral disease that infects maize crops in Zambia. The symptoms and signs include yellowing and chlorosis of leaves, dwarfing of the plant, and transparent streaks on leaves. It is widespread in sub-Saharan Africa, particularly in countries like South Africa, Zimbabwe and Kenya (Karavina, 2014). Its presence in Zambia depends on the availability of the leafhoppers, mainly during the rainy and hot season. MSV leads to total crop loss in extreme situations. To control MSV, farmers need to adopt integrated pest management techniques that involve eliminating diseased plants, utilizing resistant cultivars, and having proper vector control through the use of insecticides or physical barriers. Some maize genotypes, for instance, ZM601, have been found to be resistant to MSV. This is because they carry the ms37 gene, which renders them resistant to the virus. Utilization of resistant varieties like ZM601 can reduce MSV incidence and enable more sustainable maize production in Zambia (Wangai et al., 2017)

Gray leaf sport, caused by the fungus *Cercospora zeae-maydis*, is characterized by the formation of grayish to brown spots on maize leaves. The spots then coalesce to form extensive lesions, which result in premature defoliation, reduced photosynthesis, and loss

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of yield. The disease is most prevalent during the rainy season in cases of prolonged wetness of the leaves and excessive humidity, mostly in agro-ecological zone III and can be disseminated by wind or water splash through spores. Yield loss due to gray leaf spot can be as high as 30% under severe conditions. The disease is controlled with timely fungicide application, crop rotation, elimination of the diseased plant refuse, and use of resistant maize types (Dhami et al., 2015). Every effort is ongoing to control such widespread maize diseases and reduce their contribution towards yield loss in maize production in Zambia. Research, collaboration between agroscientists, and participation of small farmers are core elements for identifying the sustainable approach. Application and release of disease-resistant maize varieties based on classical breeding or biotechnology hold future promise for disease management. Additionally, improved extension services to provide support for disease control practices and dissemination of integrated pest management strategies can be adopted by farmers for their benefit.

Hybrid maize adoption in Zambia has been facilitated by initiatives such as the Farmer Input Support Program (FISP) that provide subsidized inputs to smallholder farmers. Research institutions, including the Zambia Agricultural Research Institute (ZARI) in collaboration with International Maize and Wheat Improvement Center (CIMMYT) and International Institute of Tropical Agriculture (IITA), have been central in developing enhanced maize varieties. Private seed companies, including Syngenta, Pannar, Seed-Co, AMAC, and Maize Research Institute (MRI), have also facilitated the improvement of hybrid maize (Kalinda et al., 2014). Hybrid and open-pollinated varieties (OPVs) now dominate the maize sector in Zambia, with over 60% of the smallholder farmers using hybrid seeds (Kumar, 1994). Some of the hybrids, such as Pan 53 of Pannar Seed Company, are resistant to grey leaf spot and maize streak virus and can produce up to 10 metric tons per hectare. Different studies showed that improved maize varieties result in increased income and poverty reduction (Smale & Mason, 2014; Mason & Smale, 2013).

Given the importance of maize in Zambia and the challenges posed by both biotic and environmental factors, selection and screening of high-yielding, tolerant maize varieties is crucial and this study, conducted at Agri-Wind Farm in Serenje, aims to compare the performance of pre-commercial maize hybrids and available market varieties based on yield, insect and disease resistance as well as conduct a Distinctiveness, Uniformity and Stability test on the pre-commercial hybrids with the view to identifying the most suitable cultivars for local Agro-ecological conditions and to increase maize production in Zambia.

METHODOLOGY

The experiment was conducted at Agri-wind Farm, Serenje, central province, Zambia to determine the performance of different new maize hybrids compared to already existing ones in the Zambian market. Serenje is located at latitude 13.5426º and longitude 30.3436º. Serenje falls under Agro ecological zone II and is characterized by sandy loam to clay loam soils that are moderately leached, acidic and have low water holding capacity. This region receives an average annual rainfall of 975mm, with January being the month of maximum rainfall with a precipitation of 247mm and the growing season is 100-140 days. Average mean for daily temperatures range from 23-26ºC.

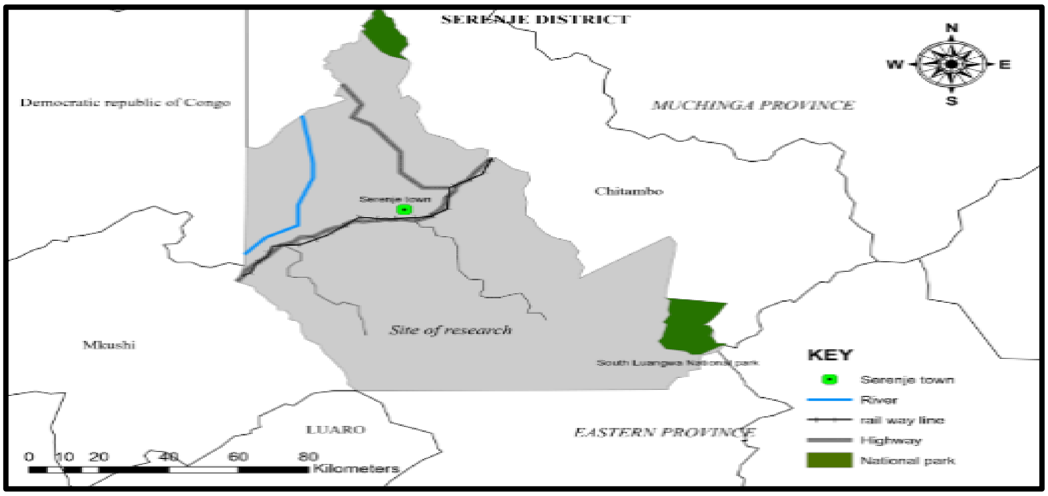

FIG 1: STUDY AREA MAP

*(**Source:** Researcher, 2025)*

A total of 22 varieties were used; 6 pre-commercial varieties (PV17 to PV22) and 16 varieties (V1 to V16) that are on the market. The existing varieties were collected from local seed companies. The experiment was laid out according to a Randomized Complete Block Design (RCBD) with three replications. The size of each experimental unit was 5×1m, consisting two rows with length 5m each and row to row and plant to plant distance 75cm and 20cm respectively. The seeds were planted at a depth of 2.5cm. The treatments above were as follows; pre-commercial as T1= PV17, T2= PV18, T3= PV19, T4= PV20, T5= PV21, T6= PV22, and the existing varieties as, T7= V1, T8= V2, T9=V3, T10=V4, T11=V5, T12=V6, T13=V7, T14=V8, T15=V9, T16=V10, T17=V11, T18=V12, T19=V13, T20=V14, T21=V15, T22=V16.

The land was ploughed 15 days prior to sowing using animals and harrowed for a uniform seedbed. The field was cleared from any tree stumps and weed residues. Compound D was applied at the rate of 300kg/ha (MoALD, 2020) as a starter dose two weeks before planting as a source of NPK. Planting rows measuring 5m were made using a hoe and 3-4 cm deep holes made using a simple pointed stick in all experimental units for seed sowing. One seed per hole was planted maintaining a plant to plant and row to row distance of 20cm and 75cm respectively. In order to maintain an optimum planting density, thinning will be done 10 to 15 days after planting.

Compound D fertilizer was applied at the rate of 300kg/ha during land preparation two weeks before planting. The source of nitrogen used was urea applied at the rate of 300kg/ ha in two split doses with the first half applied at 4 weeks and the second at 8 weeks after emergence (MoALD, 2020).

Pre-emergence herbicides were applied immediately after planting and post- emerging herbicides were applied at a later growth stage after plant emergence or germination, preferably when the maize has attained 4 leaves.

Data for the following observations were collected and recorded;

The following agronomic characteristics and information was recorded in maize:

(a) Disease resistance was determined for Maize Streak Virus, Northern Leaf Blight, and Gray Leaf Spot. Severity of the disease was measured by scoring on a scale 1-5 where 1=resistance. Disease incidence was determined by number of plants expressing the disease expressed as a percentage of plants evaluated.

(b) One hundred seed weight (g) was determined by obtaining the weight of 100 grains

(c) Grain yield (Kg/ha) was calculated and adjusted to 12.5% Moisture Content

(d) Distinctiveness, Uniformity and Stability (DUS): Each maize hybrid was evaluated and data was collected to help characterize it. The data included:

First leaf: Shape of tip, angle between blade and stem

Leaf: Attitude of blade, anthocyanin coloration of sheath, width of blade

Stem: degree of zig zag, anthocyanin coloration of internodes

Tassels: Anthocyanin coloration of brace roots, time of anthesis, anthocyanin coloration of base and glume, anthocyanin coloration of glume excluding base, anthocyanin coloration of anthers, density of spikelet, angle between main axis and lateral branches, attitude of lateral branches, number of primary lateral branches, length of main axis above lowest side branch, length of main axis above upper side branch.

Ear: time of silk emergence, anthocyanin coloration of silk, intensity of anthocyanin coloration of silk.

The data recorded on different parameters from the field were first tabulated in Microsoft Excel (MS- Excel) and the data was subjected to Analysis of Variance (ANOVA) to test for significant differences among treatments using the Field Book by CUMMYT. All the analysis of data was done at 5% dose of significance. Further, Distinctiveness, Uniformity and Stability assessment was conducted to describe and determine the uniqueness of the pre-commercial maize varieties

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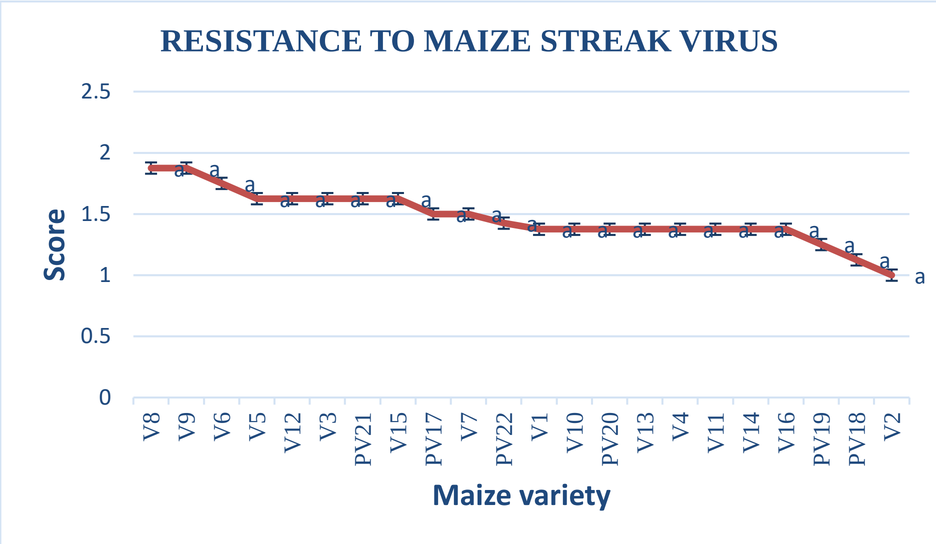
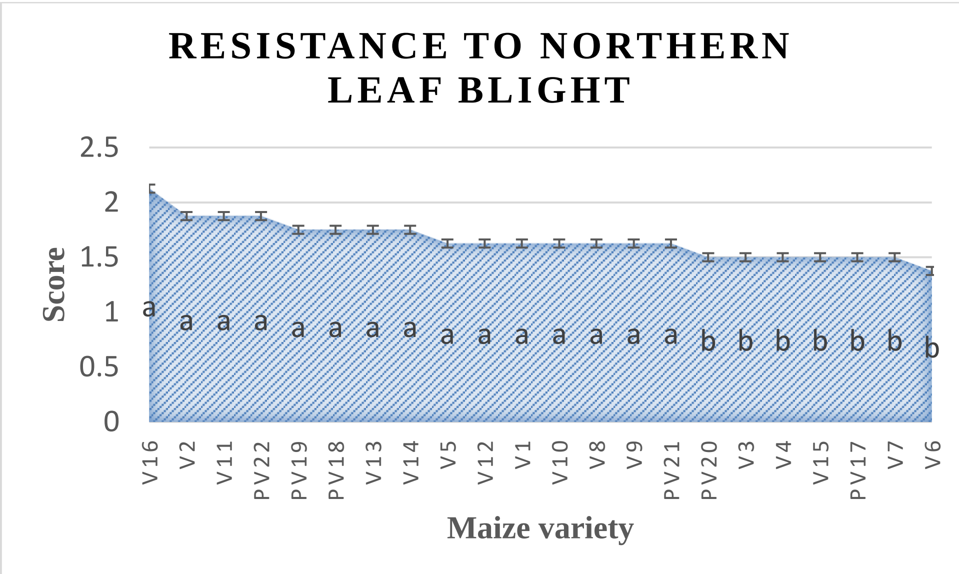
RESULT PRESENTATION AND INTERPRETATION

GRAPGH 1: VARIETAL RESITANCE TO MAIZE STREAK VIRUS



the graph shows the different scores for both the pre-commercial and existing maize hybrid resistance to maize streak virus (MSV). the scores range from 1 to 2.25. V2 outperformed all other varieties with a score of 1, indicating that is resistant to MSV.

GRAPGH 2 VARIETAL RESITANCE TO NORTHERN LEAF BLIGHT



the graph above shows the different scores for the various maize hybrid resistance to northern leaf blight. Scores range from 1.375 to 2.125 V6 showed the most resistance to NLB. Among the pre-commercial varieties, PV17 showed the most resistance with a score of 1.7.

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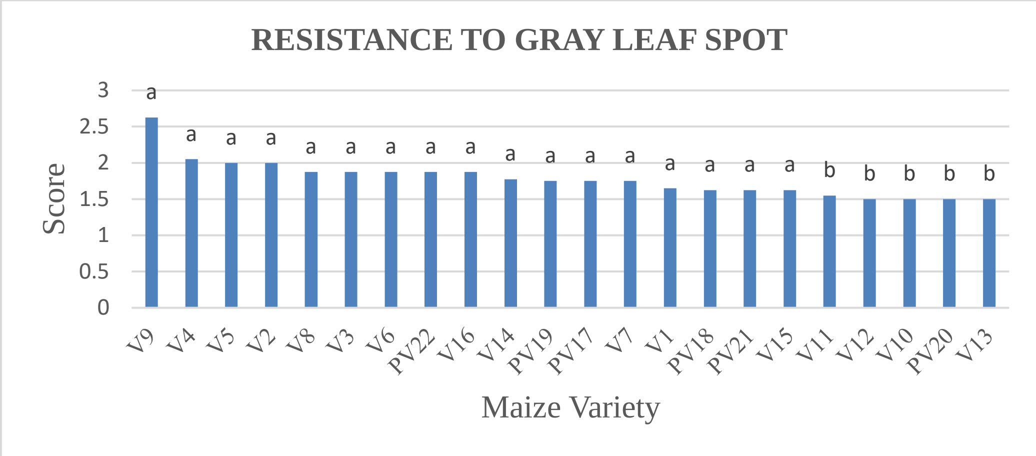
GRAPGH 3: VARIETAL RESITANCE TO GREY LEAF SPOT



Graph 2 shows scores for resistance to GLS with V13 with the most resistance scoring, 1.5.
The table below presents a detailed summary of disease scores for all maize genotypes assessed during the experiment.

TABLE 1: DISEASE SCORE FOR GLS, NLB AND MSV

Genotype	Grey Leaf Spot	Northern Leaf Blight	Maize Streak Virus
V5	2	1.625	1.625
PV19	1.75	1.75	1.25
V12	1.5	1.625	1.625
V1	1.65	1.625	1.375
PV18	1.625	1.75	1.125
V10	1.5	1.625	1.375
PV20	1.5	1.5	1.375
V2	2	1.875	1
V8	1.875	1.625	1.875
V13	1.5	1.75	1.375
V3	1.875	1.5	1.625
V6	1.875	1.375	1.75
V4	2.05	1.5	1.375
V11	1.55	1.875	1.375
PV22	1.875	1.875	1.425
V9	2.625	1.625	1.875
PV21	1.625	1.625	1.625
V15	1.625	1.5	1.625
V14	1.775	1.75	1.375
PV17	1.75	1.5	1.5
V7	1.75	1.5	1.5
V16	1.875	2.125	1.375
CV (%)	25.7	18.4	34.1
Grand Mean	1.8	1.7	1.5
LSD	1.0	0.6	1.0
n Replicates	2	2	2

TABLE 2:

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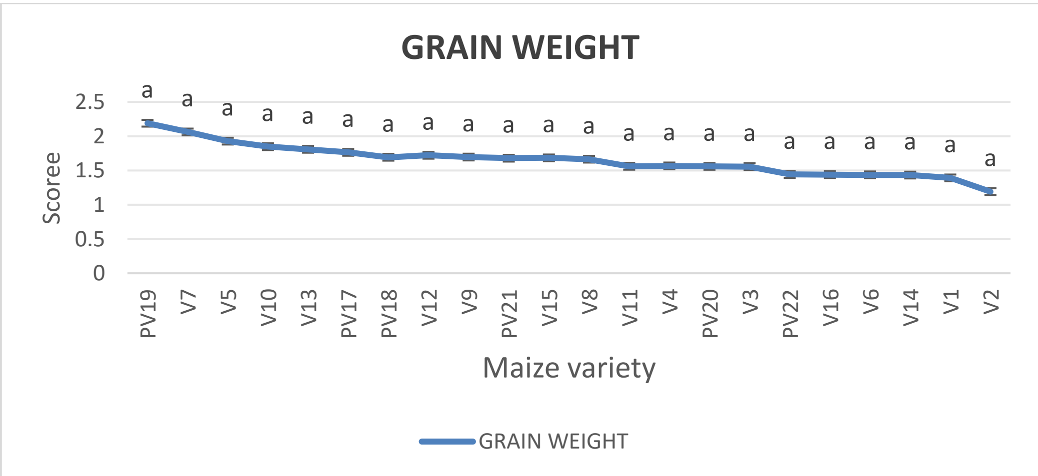
VARIETAL RESITANCE TO FALL ARMY WORMS

Genotype	FAW Score
V3	1.925
V2	1.975
PV19	2.125
V1	2.15
PV18	2.375
V12	2.5
V15	2.5
V10	2.625
V4	2.625
V11	2.625
PV22	2.625
V9	2.625
PV21	2.625
V14	2.625
V16	2.625
PV20	2.65
V13	2.75
PV17	2.75
V5	3
V6	3
V7	3
V8	3.625
CV (%)	44.4
Grand Mean	2.6
LSD	2.4
n Replicates	2

Results on fall army worm resistance show that V3 and V2 out performed all other varies with scores of 1.925 and 1.975 respectively, followed by PV19. the least resistant was V8 with a score of 3.625.

GRAPH 4: MAIZE GRAIN WEIGHT OF THE VAROUS HYBRIDS



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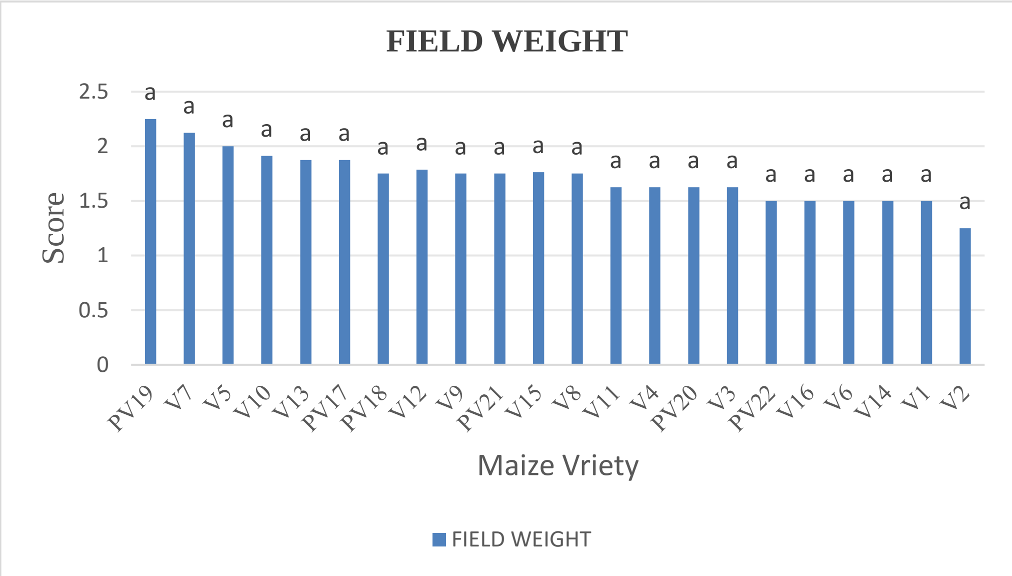
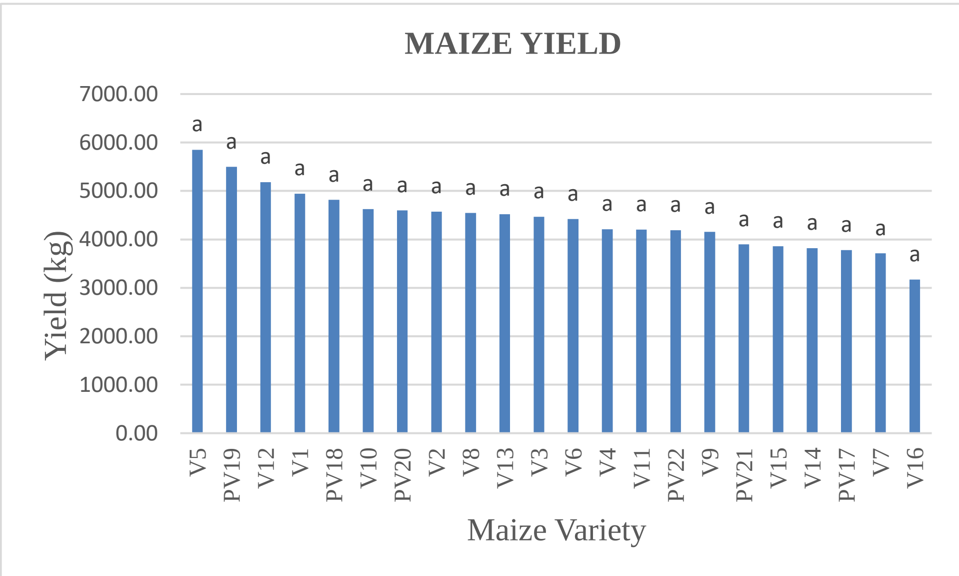
The above graph shows the grain weight of the various maize varieties. There was no significant difference among all maize hybrids and the grain weight ranged from 2.1895 kg (V5) to 1.1919kg V16, with a grand mean o 1.7kg.

GRAPH 5: MAIZE FIELD WEIGHT OF THE VAROUS HYBRIDS



The graph above shows the field weight, a yield related parameter, of the maize hybrids which directly translates into yield. V5 achieved the highest field weight of 2.25 kg, followed closely by PV19 weighing 2.125kg. the lowest field weight was observed in genotype V16 with a weight of 1.12kg.

GRAPH 6: MAIZE YIELD OF THE VAROUS HYBRIDS



The graph above shows the yield of each maize hybrid from the one with highest yield to the least yielding variety. The overall results show that V5, PV19, V12, V1, PV18, V10, PV20, V2, V8, V13 and V3, showed superiority as they yielded above the grand mean yield of 44104kg/ha with V5 out performing all other varieties.

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TABLE 3: YIELD AND YIELD RELATED DATA

Genotype	100 Seed Weight	Field Weight	Maize Yield
V5	0.0225	2.25	5850.70
PV19	0.0195	2.125	5498.18
V12	0.02	2	5178.90
V1	0.02	1.9125	4944.15
PV18	0.022	1.875	4814.75
V10	0.022	1.875	4625.13
PV20	0.0185	1.75	4596.48
V2	0.0195	1.7875	4573.18
V8	0.0195	1.75	4545.38
V13	0.019	1.75	4518.63
V3	0.0255	1.7625	4469.43
V6	0.0255	1.75	4417.80
V4	0.0225	1.625	4208.70
V11	0.0185	1.625	4201.05
PV22	0.0175	1.625	4191.28
V9	0.019	1.625	4155.80
PV21	0.019	1.5	3896.58
V15	0.019	1.5	3861.13
V14	0.0225	1.5	3818.10
PV17	0.02	1.5	3781.05
V7	0.0305	1.5	3709.80
V16	0.0175	1.25	3167.68
CV (%)	17.8	40.7	42.1
Grand Mean	0.0	1.7	4410.2
LSD	0.0	1.5	3846.3
n Replicates	2	2	2

From the table above the recorded data on maize yield and related parameters (table 2) provide valuable insights into the performance of different genotypes. Among the genotypes evaluated, V5 emerged as the highest-yielding variety, producing 5850.70 kg/ha, followed closely by PV19 (5498.18 kg/ha) and V12 (5178.90 kg/ha). These genotypes exhibited a favorable balance between 100-seed weight and field weight, which likely contributed to their superior performance.

DISCUSSION

The results of this study show significant variation in Maize Streak Virus (MSV) resistance across different maize genotypes, with some varieties demonstrating superior resistance while others appear more susceptible. The best-performing variety in terms of resistance to MSV was PV18, which recorded the lowest disease score of 1.125, closely followed by PV19 at 1.25. These two varieties demonstrated high resistance and could be considered viable options for commercial release, particularly in regions where MSV is a persistent threat.

Other pre-commercial varieties such as PV20 (1.375), PV17 (1.5), and PV21 (1.625) showed moderate resistance. These varieties may still be recommended for cultivation in areas where MSV outbreaks occur at low intensities, such as Serenje and other regions with moderate MSV prevalence. However, their resistance levels suggest that they might require integrated disease management practices, such as crop rotation, vector control, and selective breeding for enhanced resistance, if they are to be widely adopted in high-risk areas.

On the contrary, V8 and V9, which both recorded higher disease scores (1.875), exhibited lower resistance to MSV. This level of susceptibility raises concerns, as it suggests that these varieties may not perform well in MSV - prone areas, especially where the disease pressure is high. Their vulnerability of these hybrids highlights the need for further breeding improvements to enhance their resistance before they can be recommended for widespread cultivation. The Zambian Variety Registration Committee (VRC) prioritizes disease resistance as a key criterion in the approval of new maize varieties. According to CIMMYT (2019) and FAO (2020) guidelines, maize varieties with disease resistance scores above 1.5 may struggle to meet registration standards in regions where MSV prevalence is high. In this context, PV18 (1.125) and PV19 (1.25) emerge as the most promising candidates for commercial release. They fall within the acceptable resistance threshold and could contribute to stable yields and increased productivity in high-risk areas. These findings align with previous studies conducted by Manda (2018), which emphasized that high resistance to MSV is a critical factor for the successful commercialization of maize varieties in Zambia. Similarly, research in Nigeria highlighted that pre-commercial maize varieties with disease scores ranging from 1.1 to 1.3 had better adaptability in high-risk MSV areas, as they required fewer chemical interventions, and demonstrated increased resilience under field conditions. This further supports the potential of PV18 and PV19 as viable options for large-scale adoption in Zambia.

Pre-commercial lines PV19, PV18, and PV17 demonstrated moderate resistance to Northern Leaf Blight (NLB), with recorded resistance scores of 1.75, 1.75, and 1.5, respectively. These scores align with the CIMMYT (2019) guidelines, which suggest that maize varieties should maintain resistance levels below major susceptibility thresholds to ensure yield stability and disease tolerance. Among these, PV17 exhibited the highest resistance (1.5), making it the strongest candidate for potential commercial release. Further, the study identified PV17, PV61, and PV20 as promising varieties for improved NLB resistance, as their resistance scores fell within the acceptable range for potential release. However, further regional testing is required to validate their performance across different agro-ecological zones before large-scale commercialization.

The grand mean resistance score for the gray leaf spot (GLS) in the evaluated maize genotypes was 1.8, indicating moderate resistance across the tested varieties. This finding aligns with previous studies that have reported moderate resistance levels in maize genotypes under field conditions (Prasanna et al., 2018). The moderate resistance observed in this study suggests that while many genotypes possess some level of tolerance to GLS, there is significant room for improvement through targeted breeding programs. The pre-commercial varieties PV18, PV20, and PV21 showed highest resistance (1.5 and 1.625), well associated with the good-performing market varieties V12 and V10 (1.5 each). On the other hand, V9 (2.625) was the most susceptible, which was higher than the ≤2.0 threshold set by CIMMYT and FAO for disease-resistant genotypes. The results indicate variation in resistance to GLS, highlighting the importance of genetic selection in breeding enhanced tolerance in high-risk production environments.

Table 1 presents a detailed summary of disease scores for all maize genotypes assessed during the experiment. As clearly seen from the table, GLS appeared to be the most severe among the three diseases, with an overall average disease score of 1.8. The level of susceptibility varied widely among genotypes, as reflected in the relatively high coefficient of variation (25.7%). Some genotypes, such as V12, V10, and PV18, showed strong resistance with scores as low as 1.5, while V9 emerged as the most vulnerable, recording the highest disease score of 2.625. This suggests that V9 would require significant genetic improvement to withstand GLS pressure in the field.

For NLB, the overall disease severity was slightly lower, with a mean score of 1.7 and a CV of 18.4%, indicating less variation in resistance levels across genotypes. Despite this, some varieties stood out. V6 demonstrated the strongest resistance with a score of 1.375, while V16 showed the highest susceptibility at 2.125. Most other genotypes fell within a narrow range, suggesting that resistance to NLB is relatively stable across the tested varieties.

MSV displayed the highest level of variability among the three diseases, with a coefficient of variation of 34.1%. This wide range of disease scores suggests that different maize varieties responded to MSV in markedly different ways. The most resistant genotype was V2, which recorded the lowest score of 1.0, while PV22 and V9 were the most susceptible, both scoring 1.875. Given the high variability in MSV resistance, selective breeding could be an effective strategy for improving tolerance in susceptible genotypes.

The least significant difference (LSD) values provided further clarity on the results. With LSD values of 1.0 for GLS and MSV, and 0.6 for NLB, small differences in NLB scores were statistically more meaningful than those in GLS and MSV. This means that even slight improvements in NLB resistance across genotypes could have a significant impact. The overall mean scores confirmed that GLS was the most severe disease, followed by NLB and MSV. This indicates that while efforts to improve resistance to all three diseases are important, special attention should be given to managing GLS, which showed the highest average severity across genotypes.

The results on maize varieties` resistance to FAW (table 2) indicated that among the pre-commercial varieties, PV19 (2.125) and PV18 (2.375) emerged as the most resistant. Similarly, other varieties, such as V2 (1.975) and V3 (1.925), exhibited even better performance in disease resistance. On the other hand, PV20 (2.65) and PV22 (2.625) emerged as the most susceptible among the pre-commercial varieties. Likewise, several other available varieties, including V10, V16, and V14 (all 2.625), showed high susceptibility, indicating their greater vulnerability to disease pressure. The optimal FAW resistance rating, as proposed by CIMMYT and FAO, is generally ≤2.0 for a variety to qualify as highly resistant under field conditions (Prasanna et al., 2018). Further, these results indicate that PV19 and PV18 are eligible for the FAO and CIMMYT resistance levels and are strong candidates for consideration by Zambia's Variety Registration Committee. However, varieties like PV20 and PV22 may benefit from further genetic improvement. Factors contributing to variation in resistance include genetic predisposition, environment, or pressure from the pest in trials, as seen from studies that also stressed the role of genotype-environment interactions in developing pest resistance. These findings also point to the requirement for including multi-trait selection to develop resistant varieties that can resist FAW, particularly due to heightened instances of pests caused by climate change (Day et al., 2017).

The highest 100-seed weight was recorded in V7 at 0.0305 g, which was significantly higher than the grand mean. This suggests a potential for greater yield per plant. However, the heavier seed weight could also impact planting density and pose challenges for mechanical harvesting. The pre-commercial lines showed notable variation in 100-seed weight, ranging from PV19 (0.0195 g) and PV18 (0.022 g), which had competitive seed weights, to PV22 (0.0175 g) and V16 (0.0175 g), which had the lowest seed weights. According to FAO and CIMMYT standards, an optimal balance is sought between maximum seed size - as larger seeds generally have higher germination rates - and seed count per unit area, as excessively large seeds can reduce planting density, ultimately hindering overall yield (CIMMYT, 2019). Based on the results, PV19, PV18, and PV10, with 100-seed weights of 0.0195 g to 0.022 g, fall within the acceptable range for top yield performance, and would be suitable for release because they balance seed size and yield potential. In contrast, varieties like PV22 and V16, with lower 100-seed weights (0.0175 g), may face challenges related to market preference and yield stability, though their smaller seed size could enhance planting efficiency by increasing the number of seeds per unit area. Studies have indicated that while seed size is a critical trait, overall yield stability and other agronomic traits such as disease resistance and drought tolerance tend to be more significant in the choice of a variety for release. Therefore, the best 100-seed weight varieties in this study are PV19 and PV18, since they have a proper balance between seed size and other desirable traits.

The highest weight of the fields was that of V5 (2.25 kg), nearly equaled by PV19 (2.125 kg), each with good yields and comparable with the highest-performing existing varieties. PV18 registered field weights of 1.875 kg, slightly under V5 but nonetheless good where moderate yield would be expected in an area. The pre-commercial lines PV19, PV18, and PV20 with field weights of 2.125 kg, 1.875 kg, and 1.75 kg, respectively, are a testament to CIMMYT's (2019) emphasis on releasing varieties with high yield potential.

V5 provided the highest yield of 5850.70 kg/ha, followed by PV19 at 5498.18 kg/ha. Both of these lines are far above the grand mean, indicating their high yielding ability and suitability for commercial release under optimal conditions of growth. Other pre-commercial lines such as PV18 (4814.75 kg/ha), PV20 (4596.48 kg/ha) also performed quite well and provided competitive yields that are within the acceptable range for commercial farming. However, other types such as PV21 (3896.58 kg/ha), PV17 (3781.05 kg/ha), and V7 (3709.80 kg/ha) with less yield than the grand mean are less productive and could not be certified by Zambia's Variety Registration Committee (VRC) for widespread release. The findings agree with CIMMYT (2019), which emphasized high yield in maize breeding programs both for food security and economic sustainability. In short, V5 and PV19 are the high-yielding lines for a combination of yield, and would most likely be considered for release, while lower-yielding lines such as V16 would have to be bred further or exposed to agronomic improvement in order to meet the requirements.

In contrast, V16 and PV22 recorded the lowest yields, at 3167.68 kg/ha and 4191.28 kg/ha, respectively. These varieties also had lower 100-seed weights (0.0175 g), which may have affected overall productivity. The variety V7 stood out with the highest 100-seed weight (0.0305 g), indicating the potential for larger and possibly more vigorous seeds. However, excessively large seeds can sometimes reduce the number of seeds per unit area, affecting planting efficiency and final yield potential.

The field weights varied significantly across the genotypes, ranging from 2.25 kg in V5 to 1.25 kg in V16, with a coefficient of variation (CV) of 40.7%, highlighting substantial differences among the varieties. The grand mean maize yield was recorded at

4410.2 kg/ha, with a least significant difference (LSD) of 3846.3 kg/ha, suggesting statistically significant variation in yield performance.

These findings generally suggest that V5, PV19, and V12 are among the most promising varieties for high-yield maize production. Conversely, V16 and PV22 may face limitations due to their lower seed weight and reduced field performance. While seed size plays a crucial role in germination and establishment, factors such as disease resistance, drought tolerance, and adaptability to different environmental conditions must also be considered in selecting the best-performing varieties for large-scale production.

With regards to the DUS, the analysis revealed significant distinctions in most phenotypic characteristics among the evaluated varieties. Among the six pre-commercial varieties (1–6), certain traits were consistently dominant, such as a predominantly pointed first leaf tip shape (1) and a uniformly intense anthocyanin coloration of the brace roots (9). In contrast, the existing commercial varieties (7–22) displayed greater variability, particularly in leaf angles and stem characteristics, with some exhibiting a pronounced zigzag stem growth pattern (3).

Differences were also observed in anthesis duration between the two groups. The pre-commercial hybrids averaged 70 days to anthesis, whereas some of the available commercial hybrids required up to 75 days. These findings suggest that pre-commercial hybrids exhibit improved anthocyanin coloration and shorter growth duration, which may enhance their adaptability to local environmental conditions.

The ANOVA results at a significance level of ($p = 0.05$) indicated significant differences among the analyzed maize genotypes for all measured parameters. Among the pre-commercial genotypes, PV19 and PV18 exhibited significantly higher yields compared to other pre-commercial varieties, with PV19 achieving 5498.18 kg/ha and PV18 producing 4814.75 kg/ha. These were significantly superior in disease resistance, particularly against Maize Streak Virus (MSV) and Northern Leaf Blight (NLB), meeting the standards for potential commercial release. PV17, while yielding lower (3781.05 kg/ha), demonstrated the highest resistance to NLB (1.5 resistance score), making it is a valuable candidate for disease-prone regions. Conversely, PV21 and PV22 displayed lower yields and weaker disease resistance, making them less suitable for immediate commercialization. The statistical analysis confirms that PV19, PV18, and PV17 are the most promising pre-commercial hybrids, while V5, an existing commercial variety, remains a top performer with the highest yield (5850.70 kg/ha).

CONCLUSION

The present research provides a holistic evaluation of available and pre-commercial maize hybrids in the Zambian market on the basis of ear and plant characteristics, shoot and root lodging, disease resistance, FAW resistance, moisture, and yield components. Key findings reveal that pre-commercial varieties V2 and V6 were extremely resistant to maize streak virus (MSV) and Northern Leaf Blight (NLB), respectively, while recent varieties like V18 and V19 were equally very resistant. This aligns with the quality standards of the Zambia Variety Release Committee, which prefer highly disease-resistant hybrids to minimize yield loss. In addition, V3 and V2 were highlighted for their resistance to FAW, an important characteristic considering the prevalent pest pressures in Zambian maize production.

Yield-associated traits, specifically, 100-seed weight, field weight, and plot yields, reveal that both available and pre-commercial hybrids have competitive performance within the recommended standards. Top yield performers, for example, V5, V19, and V1, maintained consistent, meeting or exceeding Zambia's average yield target of 4000 kg/ha. With the overall performance in all the traits measured, hybrids V5, V3, and V1, along with pre-commercial varieties PV19, PV17, and PV18 emerge as top contenders.

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