



Review on Broken-down Resistance to Diseases and Its Management; the Hidden Challenge in Breeding and Production of Banana and Plantains in Developing Countries

Kennedy Elisha Jomanga¹, Shija Shilunga Lucas², Ashiraf Rweyemela Mgenzi³, Magdalena Gaudence Kiurugo⁴, Rosemary Frank Simba⁵, Emiliana Biseko⁶

^{1,3,4,5,6} International Institute of Tropical Agriculture (IITA).

² Africa Inland Church Tanzania (AICT).

ABSTRACT: Resistant breakdown is the genetic vulnerability that is devastating agriculture breeding and production of banana worldwide, therefore threatening burgeoning population. It takes 15 to 20 years for banana breeding pipeline and other stakeholders to release a cultivar that is fully evaluated to farmers. Disease like fusarium wilt disease (race 1) was reported to wipe away Gros Michel and the Tropical Race 4 (TR4) has wiped away all cultivars which were resistant to race 1. Again banana breeding for resistant to sigatoka successively bred and released many hybrids but of recently of these hybrids including FHIA hybrids, Yagambi KM 5, Paka, young Calcutta 4 and T8 has lost their resistance to sigatoka. Due to political and commercial pressures, it is true that most of the released resistant cultivars are from single effective genes. Though durable resistance with a single dominant gene has been a serious challenge to achieve in breeding, this is because of broken-down resistance. This review used online resource to identify some causes of broken resistance in banana and provided some possible solutions to increase durability. Causes of broken resistance includes the practice of monoculture in large area, illegal use of chemicals, multiple infections, evolution of pathogens as the result of recombination, mutations, nature of interaction exhibited by released cultivars, low genetic base in banana, gene flow, through introductions of pathogens and climate change. It is widely accepted that different agronomic practices combined with strategic breeding and release of cultivars can elongate durability of resistant cultivars to pathogens in agricultural system. Through all the literature searched it is being unveiled yet the factors that govern quality and durability of resistance in resistant cultivars. I hereby conclude that breeding for resistance to diseases in banana should go hand in hand with other disease management strategies. This is aimed at increasing durability of resistance to diseases in this highly expensive produced banana and plantain hybrids.

KEYWORDS: Broken resistance, Banana cultivars, Breeding, Hybrids.

1.0. INTRODUCTION

Plant disease causing pathogens are a constant menace to agricultural production and thus to food security, making significant economic losses around the world (Mensez and Romero, 2016). They are of global concern exerting a heavy toll on food crop production, social and political stability of nations (Ristaino et al., 2020). Banana and plantains (banana) as other crop faces many serious bio-constraints which includes fusarium wilt, xanthomonas wilt, weevils, sigatoka, banana bunch top virus disease, nematodes, moko disease, etc. (Buddenhagen, 1986; Alakonya et al., 2018; Wu, et al., 2021; Erere et al., 2021). Yield losses of up to 100% in susceptible banana cultivars are reported due to diseases (De Lapeyre de Bellaire, et al. 2006; Brito et al. 2015). Strategies to fight diseases in commercial and small-scale production account for 30-40% of total production cost, whereas no chemicals yield reduction ranging from 30-100% have been recorded (Sagi et al. 1998). Cultural practices and chemical application have been reported to be ineffective and environmentally hazardous respectively. The use of resistant cultivars is the only reported reliable, cheaper, applicable and sustainable method of disease control to both commercial and smallholder farmers in developing countries (Lorenza et al., 2009; Kobayashi et al., 2014; Adeleke et al., 2021). Thus, genes for resistance to diseases can technically be considered one of the most important natural resources determining the survival of the human species (Mundt, 1994). Breeding



programs were established in the year 1920s to date and many cultivars have been released to be used for production purposes in the past many decades (Bakry et al., 2009). Nevertheless, this control strategy is also likely to become more difficult to achieve, because of expected increase in climate change, human-mediated invasions and disease re-emergence (Anderson et al., 2004).

It is obvious that crop improvement has given the best cultivars, which are rewarding to farmer with their yields, the trader and the consumer with their qualities (Adugna, 2004). The widely grown improved cultivars are genetically uniform, which invites them to a risk of disease epidemics (Adugna, 2004; Lorenza et al., 2009). As it has been reported host plant resistance is the most preferable means of crop protection since it is cost effective and ecological trustworthiness (Arango-Isaza et al., 2016). But, it has been a challenge to the breeders to achieve durable resistance in banana and plantain (Adugna, 2004). The major challenge is broken resistant, which have been widely recorded worldwide in recent years (Daldal et al., 1989; Hollomon, 2015; Arango-Isaza et al., 2016; Djidjou-Demasse et al., 2017). Major risks and uncertainties persist whereby pathogens rapidly overcome disease control methods using resistant cultivars and fungicides (Lo Iacono et al., 2013; Kobayashi et al., 2014). Broken-down resistant phenomenon has endangered the banana industry in developing countries, beside been costly to the banana Breeders, Researchers, farmers and Funders. Breeders spend much time and resources into introgression of resistance traits in banana genotypes, which takes 15 to 20 years. Still most of the banana breeding stations in developing countries are mainly donor funded, so broken resistance report is painful. For example FHIA, Yagambi KM 5, Paka, young Calcutta 4 and T8 were released as highly resistant to sigatoka disease but of recent report shows that they are susceptible to the same disease (Fullerton and Olsen, 1995; Miranda et al., 2006; Pegg et al., 2019; Kimunye et al., 2021). Cavendish were released as resistant cultivar to replace the susceptible Gross Michel but outbreak of new strain TR4 broke the resistance in Cavendish cultivars (Pegg et al., 2019; Thangavelu et al., 2020). This shows that all way-long after 15 to 20 years the released cultivars can lose their resistance within a short period of time. This is a big loss which needs research attention and allocation of resource to minimize the chances of broken resistance in our highly valuable released cultivars. There are need to fine-tune the breeding research objectives to include the management aspect to minimize the chances of broken resistance to save fund spent in breeding. It is reported that the durability of disease resistance in any genotype is affected by the evolutionary potential of the pathogen population (McDonald and Linde (2002). That is to say pathogens with a high evolutionary potential are more likely to overcome genetic resistance than pathogens with a low evolutionary potential. This review used online resources of information to try to bring understanding of the importance of broken resistance and its management aspect for durable resistance in banana and plantain breeding and production. The information can help Breeders, Researchers and Extension Officers to fine-tune breeding objectives and put forward recommendation to farmers for sustainable yield.

1.1. How do pathogens get infect their hosts

Disease caused by pathogen is any abnormal condition or malfunctions that damages to food production, economic development, ecological resilience, and natural landscapes over human history (Mcmullen and Lamey, 2001; He et al., 2021). Pathogens are responsible for both numerical changes in host populations and evolutionary changes through selection for resistant genotypes (Gilbert, 2002). Infectious diseases are caused by organisms that attack plants and get their nutrition from them (Mcmullen and Lamey, 2001). Nutrients are present in apoplasts or within the cell, therefore, access to these materials involve tissue and cellular degradation by the necrotrophic pathogens, whereas living host cells are manipulated by the biotrophic pathogens in such a way so that nutrients are obtained without killing the host cells (Faulkner and Robatzek 2012). Other group hemibiotrophic pathogens display two phases during the infection process; first is an initial biotrophic phase followed by a necrotrophic stage (Selin et al., 2016). Upon contact with a potential host plant, some pathogens gain entry through the plant epidermal surfaces by employing cascade of enzymes that are capable of degrading plant host cell wall surfaces (Toruno et al., 2016). Or some fungi can directly penetrate the leaf surface using specialized infection structures called appressoria. In some other cases several pre-existing physical barriers such as the cuticle of leaves prevent entry into plant tissues, so that the pathogen has to rely on mainly natural openings, e.g., stomata and hydathodes or wound sites, to gain access (Mcmullen and Lamey, 2001; Gohre and Robertzek, 2008). Once in the apoplastic pathogens secrete effectors that act in the apoplast or inside the cytoplasm of plant cells to manipulate their hosts (Toruno et al., 2016).



1.2. Reaction of banana upon infection

Molecular communication between plant and pathogen commences almost immediately after the pathogen makes contact with the host surfaces (Fujita et al. 2004). Micro-organisms groups including fungi, oomycetes, bacteria, viruses, and nematodes contain pathogenic species that have evolved to exploit living plants as a nutrient sources (van't Slot et al., 2007). Even though pathogens have vast differences in their lifestyles, they share a common dilemma, which is the physical need to interact with the host plant, thereby generating wounds and releasing components from the plant surface, which allow the plant to recognize the invasion (van't Slot et al., 2007). The recognition in this matter are facilitated by protein-protein interactions, which are important factors in the regulation of molecular and cellular mechanisms responsible for both healthy and diseased states of host organisms (Yakubu et al., 2019). Plants are able to resist infection through highly effective and robust means of repelling or being colonized by the majority of pathogens and pests they encounter (Kettles et al., 2016). Diseased state of the plants is an outcome of three way interactions among pathogen, host and the environment, where every component of the interaction is presumed to be in favour of the pathogen (Sharma et al., 2014). The following under are reactions of banana genotypes upon being infected by pathogens under favorable environmental conditions.

1.2.1. Susceptible reaction

Susceptible (compatible) reaction occurs when a pathogen is able to enter the host tissues and being able to establish nutritional relationship, which results in increased multiplication and movement of the pathogens in the host tissues and to other plants. In a compatible plant/microbe interactions, adapted microorganisms have means to avoid or disable this resistance response and promote virulence (Wiesel et al., 2014). Pathogens must evolve mechanisms to overcome the multi-layered plant immune system (Kettles et al., 2016), adaptation and possession of several factors that allows pathogens to infect variety of plant by suppressing plant defense mechanisms ranging from passive barriers to induced defense reactions (Gohre and Robertzek, 2008; Toruno et al., 2016). Allowing a constant nutrient supply from host's roots, xylem or phloem vessels, leaves, flowers, or fruits to the pathogens (Toruno et al., 2016). This is achieved by secreting effector protein molecules of different types into plant cells to interfere with individual defense responses (Gohre and Robertzek, 2008). A susceptible host normally shows significant reduction in growth and performance which is associated by symptom expressions or signs on the host.

1.2.2. Tolerant reaction

1.2.3. Resistance (immunity) reaction

"Immunity" refers to physiological state of having sufficient biological defenses to avoid infection, disease or unwanted biological invasion (Majia-Teinente et al., 2010). Upon infection a host resistant protein (R-protein) may react incomparably with effector protein from the pathogen in the case of resistance genotypes. Incompatible reactions occurs when a suspected host prevent the development of disease by stopping multiplication and movement of the pathogen with the host. This result in no symptom or signs development and, growth and development of the suspected host is not affected at all. Plants utilize a variety of strategies to defend against pathogen attack. One strategy is to strengthen the cell wall, thereby making a barrier between the plant cell and the pathogen (Richter and Ronald, 2000; Jin and Yin, 2019). For example, enzymes involved in lignin and callose biosynthesis are induced upon pathogen attack. A second strategy the plant utilizes is the production of antimicrobial compounds, such as toxic secondary metabolites, and hydrolytic enzymes (Richter and Ronald, 2000; Jin and Yin, 2019).

Plants possess large arsenals of immune receptors capable of recognizing all pathogen classes (Toruno et al., 2016). When a pathogen successfully penetrates the host need to persist within the apoplastic space (Gohre and Robertzek, 2008). To the other hand plant utilizes the bilayer-innate immune response that involves a combination of localized plasma membrane and intracellular receptors (Selin et al., 2016).

The first layer consists of the recognition of evolutionarily conserved pathogen or microbe associated molecular patterns (PAMPs or MAMPs) by pattern-recognition receptors (PRRs). The immune receptors possessing extracellular domains, such as receptor-like proteins (RLPs) and receptor-like kinases (RLKs), these are capable of recognizing conserved microbial features and eliciting pattern-triggered immunity (PTI) (Wiesel et al., 2014; Selin et al., 2016; Toruno et al., 2016).

The second layer is effector-triggered immunity (ETI) consists of the direct or indirect recognition of effectors by intra-cellular disease resistance (R) protein (Toruno et al., 2016). The intracellular immune receptors possess nucleotide-binding (NB) and leucine-rich repeat (LRR) domain architecture (Wiesel et al., 2014; Selin et al., 2016; Toruno et al., 2016). These receptors specifically recognize pathogen effectors or effector activity, leading to the induction of effector-triggered immunity (ETI) (Toruno et al., 2016).



Breeding for genetic resistance in crops is a foundation of disease management in agriculture (Elizabethlof et al., 2017). The arising of resistance-breaking pathotypes or strains of pathogens in crop production systems (Peressotti et al., 2010), combined with the low genetic base banana has (Waniel et al., 2021), increases the risks of the resistance genes being defeated. When resistance is broken in a cultivar, growers adopt varieties with new resistance genes, resulting in a “boom and bust” cycle (Elizabethlof et al., 2017). The causes of broken resistance in crops is the result of both natural and anthropogenic sources, here under is a brief discussion on why broken resistance occurs.

2.0 WHY BROKEN RESISTANCE

The survivability of most organisms in varied environmental conditions depends on the presence of general resistance mechanisms, conditioned by inbuilt genetic system to maintain those (Sharma et al., 2014). Therefore individuals with genes that improve their survival will be more likely to pass along these genes compared to the rest of the population. Plants have evolved sophisticated mechanisms to perceive pathogen invasion whereby there is direct interaction guided by gene for gene model and indirect interaction guided by guard model (Sharma et al., 2014). These modes of recognition leads to co-evolutionary dynamics between plant and pathogens in different environments (Mejia-Teniente et al., 2010). This lead to both plant and pathogen to be in a life time tag of war and the one which is capable evolving fast will benefit. In many literatures micro-organisms, the pathogen due to their size are cited to be evolving faster than plants, this give them benefit of not being recognized by previously resistant plants.

2.1. What causes broken resistance in banana and plantains

There are several factors that contributes to broken resistance in banana and other crops.

- 2.1.1. Current agricultural cropping strategies rely primarily on the rotation of one cropping genotype over a large areas of land, this exerts selection pressure to the pathogens (Selin et al., 2016). In some cases, resistance can be broken down even when it was deployed in a limited acreage dominated with monoculture, this is particularly a problem in modern agriculture (He et al., 2021). Pathogen reproduction tends to be host-frequency dependent when particular crop species or genotypes are very common. As a result, when susceptible genotypes of a particular species are present at higher frequency, covering a higher proportion of agricultural land, losses to disease for that species will tend to be higher (Garrett and Mundt 1999).
- 2.1.2. Use of chemicals these promotes selection of pathogen isolates capable of overcoming crop resistance (Selin et al., 2016). Repeated use of the same class of pesticides to control a pathogens cause undesirable changes in the gene pool of a pest or pathogen, through this process of selection, the population gradually develops resistance to the pesticide. When host resistance is unavailable or insufficient to suppress disease epidemics, fungicide application becomes inevitable. In the philosophy of free-disease agriculture currently adopted worldwide, fungicides are often overused to guarantee crop yield and quality, particularly for vegetable and ornamental productions in developed regions (Selin et al., 2016).
- 2.1.3. Multiple-infections or disease complex involves pathogens, nematodes and insects damages have been reported to cause broken resistant in previously reported pathogen resistant cultivars (Mwangi, 2008). For example a banana cultivars resistant to fusarium wilt lost its resistant to fusarium wilt disease causing pathogen when nematode first infect the roots of this cultivar (Mwangi, 2014). Nematode wounding damage has also been found to be fundamental to several other disease complexes (Back et al., 2002). Synergistic interactions of nematodes and other pathogens can be positive where an association between nematode and pathogen results in plant damage exceeding the sum of individual damage by pest and pathogen (Back et al., 2002). Under such condition if the banana was resistant to a certain disease causing pathogen then, there is a big possibility of broken resistant phenomenon to occur.
- 2.1.4. Narrow genetic base of banana and plantain (Waniel et al., 2021; Hinge et al., 2022), is a limitation on the diversity of the bred and released resistant cultivars. Since banana and plantain are mainly propagated vegetatively there are no recombination that occurs. This challenge reported led many banana cultivars to be easily succumbed to variety of ever genetically evolving pathogens (Hinge et al., 2022). Under such a circumstances it is easy for resistant banana cultivars to lose its resistant nature due to pathogen pressure and



this is also threatening cultivated banana in the world. It is reported by Bakry et al., (2009), there is possibility of disappearance of banana culture due to the emergence of new diseases is high.

- 2.1.5. The nature of interaction between resistant genes and the pathogen avirulent genes. Pathogen and plant genes involved in gene for gene model of direct interaction are subject to different evolutionary forces and since virulence is recessive (Richter and Ronald, 2000). A small loss of-function mutation in the avirulence gene of the pathogen allows it to become virulent on the host (Richter and Ronald, 2000). So loss in resistance is expected fast than where there is indirect interaction. For example vertical (gene for gene-few genes) resistance is near complete but can be easily evaded due to the continuous evolution of pathogens, leading to rapid breakdown of resistant varieties after they are released for commercial utilization (Carlier et al., 2021; He et al., 2021). Horizontal resistance which involves many genes, is incomplete and often requires additional disease control approaches to ensure better harvest but is more durable compared to vertical resistance due to the minor and accumulative contribution of each gene to the resistant phenotypes (He et al., 2021).
- 2.1.6. Pathogen possession of expanded genome, transposable elements and dispensable chromosomes have been reported to aid adaptation and increased virulence of many pathogens leading to broken resistance in the suspected host (Arango et al., 2016; Friesen, 2016; Noar et al., 2022). It has been shown that transposable element induce gene alterations, can cause resistance gene inactivation and diversification (Richter and Ronald, 2000). A good examples are reported in maize and banana that insertion or inversion of transposable element disrupted genes that confer resistance to diseases (Arango et al., 2016; Richter and Ronald, 2000). Plant pathogens can adapt to quantitative resistance, eroding its effectiveness (Carlier et al., 2021). Adaptability is governed by the genetic flexibility of the pathogen population and its reproductive efficiency. The mechanisms underlying the adaptation of pathogen populations to xenobiotics and to plant *R* genes are basically the same: in both cases, pathogen fitness is reduced, and the pathogen evolves in response to this selection pressure (Djidjou-Demasse et al., 2017).
- 2.1.7. Recombination in sexually reproduced pathogens result in high recombinants that facilitates the exchange of genetic material, this helps pathogens to adapt to changing environments and adapt to new host easily (Zhan et al., 2007). So sexually reproduced pathogen produce new strain/isolate which might be challenging to the released resistant cultivars. An advantage of sex to the pathogen is that new combinations of genes can come together through recombination each generation, leading to a high degree of genotype diversity that may enable some component of the pathogen population to survive in a threatening environment (McDonald and Linde 2002). It was concluded by Zhan et al. (2007), that sexual reproduction facilitates the evolution of parasites to overcome host resistance.
- 2.1.8. Climate change scenarios, the continued survival of most organisms depends on the presence of specific genetic systems to maintain diversity in the face of a changing environment (Yáñez-López et al., 2012; Burdon and Zhan, 2020). The effect of climate change on the profile or quantity of effector molecules are obvious due to the fact that, effectors are proteins (Yáñez-López et al., 2011). Plant diseases, both endemic and recently emerging, are spreading and exacerbated by climate change (Ristaino et al., 2020). Of greater concern may be the expected increase in climatic variability (IPCC, 2012), which could increase the number of diseases and pests of importance in a given locality, as well as the yearly fluctuations of their prevalence (Mundt, 2014). The climate influences the incidence as well as temporal and spatial distribution of plant diseases (Yáñez-López et al., 2012). Fluctuations in rainfall patterns and temperature can induce severe epidemics in plants because some types of pathogens will be favored by the changes (Rosenzweig and Tubiello, 2007). This can accelerate mutation or favour recombination of pathogens ultimately increased fitness of the pathogens.
- 2.1.9. Gene flow results in producing new strains that might be a source of broken resistance in released resistant cultivars. Gene flow is a process in which particular alleles (genes) or individuals (genotypes) are exchanged among geographically separated populations of pathogens. For strictly asexual organisms that do not recombine particular genes with the recipient population, entire genotypes are exchanged among populations and we will refer to this process as genotype flow (McDonald and Linde 2002). In spite of the absence of a sexual



reproductive cycle, some pathogens have high potential to develop new pathotypes by asexual means such as mutation, heterokaryosis and parasexualism (Djidjou-Demasse et al., 2017). This is reported to increase fitness of pathogens therefore increasing its ability to outfit resistances of suspected host.

- 2.1.10. Mutation is the ultimate source of genetic variation, directly leading to changes in the DNA sequence of an individual gene and thus creating new alleles in populations. Populations with more alleles have greater gene diversity than populations with few alleles. Mutation is the process that creates new virulent strains of plant pathogens that break major gene resistance (McDonald and Linde 2002). If the resistance was based on a single R gene, a single mutation event at the corresponding Avr locus would result in a new virulent pathotype causing the resistance to ‘bust’ (Pink and Hand, 2002). Several models have been developed to examine how negative effects of disease on host fitness select for the evolution of resistance and how negative effects of resistance on parasite fitness select for the evolution of virulence (Simms, 1996). The number of mutations required for virulence acquisition was another parameter related to resistance durability by Harrison (2002). He compared the relative durability of resistance in several plant-virus pathosystems and showed that the more mutations are required for virulence, the more durable was the resistance.
- 2.1.11. Introduction events also present a window of evolutionary opportunity for the pathogens. Plant disease epidemics resulting from introduction of exotic fungal pathogens are a well-known phenomenon (Braisier 2001). Limited resistance in the host and excessive aggressiveness in the pathogen (reflecting their lack of prior coevolution) can result in an explosive outbreak of disease (Braisier 2001).
- 2.1.12. Another important factor is genetic background, which refers to the presence or absence of quantitative trait loci (QTLs) that are responsible for disease resistance. The presence of QRLs have been shown to protect major resistance genes from breakdown in viral, fungal and nematode pathosystems (Palloix et al., 2009). The mechanism underlying the QRLs enhanced durability of major resistance gene showed that QRLs increase the number and affect the nature of mutations required to break resistance (Quenouille et al. 2013).

3.0. WHY INVEST IN MINIMIZING THE CHANCES OF BROKEN RESISTANCE

Despite the fact that disease resistant cultivars have been successfully used for disease control (Leach et al., 2001). Several Scientists including Breeders, Genetists and Researchers sight resistance genes as a limited and potentially non-renewable resource (Leach et al., 2001; Lo lacono et al., 2013). So once a pathogens has evolved to overcome the resistance in the cultivars, the resistance genes have permanently lost their value in breeding (Leach et al., 2001; Lo lacono et al., 2013). In actual fact released cultivars are obtained through tidies activities which involves travelling within and without the countries, communicating, conducting/seating in endless meetings. While the actual process of introgression of resistance genes is one of the sleepless activities in research. All and others uses a lot of funds from Donors, brain etc. It also has long known that the development of disease symptoms is not solely determined by the pathogen responsible, but rather the complex interrelationship between host, pathogen and prevailing environmental conditions (Back et al., 2002). This calls for management of interrelated factors that influences development of a disease in the agricultural system. Here under is the discussion of why should we protect the released cultivars against losing their resistance to diseases.

3.1. Time taken for breeding banana cultivar

Banana breeding program is a time-consuming process that involves huge manpower to complete the breeding procedures, which makes it cumbersome in tracking the status of hybridization details (Kumar et al., 2020). It takes 15 to 20 year for a banana hybrid to be obtained whereas for other crops like cereals and legumes it takes 2 to 3 years. Improvement of edible bananas through conventional breeding is a challenging task owing to its recalcitrant nature for seed set, prolonged crop duration (Kumar et al., 2020). In addition, the need of huge man power at different stages of progeny development and evaluation.

3.2 Nature of resistant genes possessed by the host plant

The knowledge on the quality and durability of resistance for both vertical (qualitative resistance) and horizontal resistant (quantitative resistance) are not known. It been proved that some resistance in some cultivars controlled by few major genes are durable resistant while many others lose their resistant easily (Lo lacono et al., 2013). Similarly with resistance in some cultivars



controlled by many minor genes have been reported to be durable and not in others with similar nature (Lo lacono et al., 2013). This brings a lot of confusion in breeding since there no anymore trusted genes sources to assure breeders with durable resistance. Then the whole breeding process of selecting parents for crossing becomes a probability.

3.3. Cost of breeding

Funding for banana and plantain breeding basically depends on donors, in developing countries there no many governments that have devoted their resource to fund breeding banana and plantains programs. This is possibly because of the banana nature which is dominated by long life cycle and sterility which does not assure of quick returns from breeding programs. As it have been mentioned above it takes 15 to 20 years of funding banana breeding program activities for it to give out a new hybrid. This long time awaiting with the challenge of broken resistant ends up in a serious pain to farmers, breeders,

3.4. Complexity related to biology and introgression

Breeding banana is a difficult exercise due to complexities resulting from parthenocarpy, sterility, polyploidy and vegetative propagation (Nansamba et al., 2020). The low fertility and seed germination of cultivated bananas is a handicap for breeders (Bakry et al., 2008). The physiological and reproductive barriers like low pollen, poor receptacle stigma etc. possessed by the plant itself is the serious limitation in breeding (De Langhe et al., 2008; Brown et al., 2017). Seed production is very limit due to the above and the germination of the few viable seeds are affected by several other factors. Seed yield is influenced by time of pollination, environmental conditions, genetic variation in female fertility, differences observed among pollinations made between the basal and distal hand, and variation associated with the relative contributions of the acuminata and balbisiana genomes (Simmonds 1962). This makes breeding banana unique, the uniqueness lies in the fact that in banana which is almost sterile, raising sexual progeny in sufficient numbers to combine desirable characters and at the same time resulting in another sterile plant is indeed very difficult. Fertilization in banana does not involve the usual processes of reduction division on both sides, re-assortment and segregation of gene complexes, giving only a remote chance of success, as practice has confirmed (Bakry et al., 2008). Simmonds (1962), proposed that continuous clonal propagation of diploids has led to an accumulation of structural chromosomal changes that restrict normal meiosis and pollen fertility and reduce expected recombination.

3.5. Effect of climate change

Climate change triggers effects on the incidence and severity of disease for crops in agriculture and wild plants in natural communities (Burdon and Zhan, 2020). From an agricultural point of view, these changes have major implications for the geographic temporal and spatial distribution of crops and their associated pathogens and the extent and reliability of production (Yáñez-López et al., 2012; Burdon and Zhan, 2020). The environment may affect plant pathogen, therefore, survival, vigor, rate of multiplication, sporulation, direction, distance of dispersal of inoculum, rate of spore germination and penetration can be affected (Yáñez-López et al., 2012). Changes in the fate of an individual pathogen species an increase or a decrease leading to local extinction or may be surpassed by consequent increases or decreases in host fitness, generating “knock-on” effects in the structure of whole plant communities (Burdon and Zhan, 2020). This implies that the effects of climate change on pathogens evolution is a continuous process and fast while banana breeding is moving at a slow pace. There is a need to adopt means to minimize the effects of climate change impact on resistant cultivars to elongate the durability of resistance in our precious cultivars. Otherwise broken resistance gene will continue to affect our released cultivars continuously.

3.6. Technical challenges

Plant breeding is a vital agriculture industry that needs to be fostered, stimulated and technology amalgamation in this area can act like an incubator for scalable improvement (Tiwari, 2017). Researchers and farmers essentially require authentic high-yielding cultivars to maximize the output and traditional methods based on the phenotypic selection are complex and irreproducible to identify authentic cultivars (Hinge et al., 2022). In developing countries the use of technologies like tissue culture, mutagenesis, gene-sequencing, gene editing, interspecific or inter-generic hybridization, genetic modification, marker-assisted selection (MAS), disease diagnostics and bio-protection for crop improvement have not been widely used. And whenever such technologies are used lack of equipped laboratories and technical staffs are major challenge that face banana breeding in developing countries. As the result of these, developing countries banana breeding research depends sole getting services from developed nations for their



services, this makes breeding highly expensive. This reflects on how important our released cultivars are so precious need to be kept and protected.

3.7. Banana sources of resistance challenge

Many sources of resistance to diseases in banana and plantain are still not well understood as the result of that breeding becomes like gambling. We have not accumulated enough information to know the best males to use in breeding for resistance, which its resistance quality and durability is well elucidated. This creates complexity in terms of breeding plan and results expected is not sometimes assured. So losing banana cultivars resistant to diseases in breeding banana fis very painful excise that needs research attention. There are several researches which have been undertaken and are ongoing to unveil the hidden behaviors that makes genes durable resistant to diseases in banana.

3.8. Lack of loyalty among scientist/Researchers

Broken resistance is the serious enemy of loyalty among banana stakeholders, this calls for quick intervention to maintain loyalty among researchers and the community we save. According to Woodruff, (1997), customer loyalty can be considered to be the source of a competitive gain, as it has a substantial influence on enterprises' performance. For this case farmers are the customers of all banana breeding programs and our performances depends on our customer's loyalty to the product we give to them. So the better the resistance of the released banana cultivars has a positive influence on the loyalty between Breeders/ Researchers and the Farmers. This calls for Breeders and Pathologists in general to be virtue in what is said to be resistant should be resistant and not otherwise, to keep the breeding legacy uplifted.

3.9. Long durability requirement in banana and plantains

Durable resistance is the adequacy of the resistance throughout the useful lifetime expected from a variety. This may vary according to the cycle of varietal replacement in a plant breeding program. Thus, the time requirement for durability for some vegetable crops with a high variety turnover may be less than that needed for cereals (Leach et al., 2001). For crop like banana due to the life cycle of the plant together with complications brought by introgration of resistant gene into a new cultivars replacement of a variety is longer than any other major crop known. Therefore protection a variety from broken resistant is a fundamental thing with banana and plantain production.

3.10. Life cycle of banana and plantain

Depending on the cultural conditions, the duration of the cycle of banana and plantain is a varietal characteristic that is subject to wide variations. It ranges from 9 to 18 months, according to the variety, which is relatively critical in terms of the production potential of banana plantations. For this sake yield assessment research takes time to complete with a lot of complexity interms of data analysis due to variation in time of maturity. To release a variety is bound to delay due to this complications associated with the life cycle of banana and plantain.

3.11. Protection of environment and biota

Food demand is growing fast due to increase in human population whereas food production is growing at decreasing rate, this calls for production increase. This food production increase should adhere to national and international agreed protocol of conserving the environment and the biodiversity. So the use of chemicals and other hazardous practices to control pathogens need to either to be regulated or stopped to save the biota.

3.12. Acceptable method of breeding

Conventional banana breeding that involves manual pollination is the only acceptable method of breeding in many developing countries. The method is face with a lot of challenges like sterility of banana and plantains, polyploidy nature of banana that hinders meiosis process in many banana genotypes, long regeneration time and complexity related to evaluation at different levels. All these reasons and other contributes slowing of the breeding of banana without alternative. Rapid technique like the use of genetically modified banana, mutation breeding etc for improved diseases resistant are either acceptable for research purposes under confined environments or not at all. This is leading to many research programs to focus on conventional breeding.

3.13. Variety/cultivar preferences

Breeders and Pathologists in their areas of specialization have tried to focus on improving resistance to disease and yield in banana and plantain. Many genotypes have proved to meet the objective of improved yield and diseases resistance. But there have been a



danger of eventual failure if proper consideration of whether or not it satisfies a user/consumer need. Therefore very few cultivars meet these requirements of release out of hundreds of hybrids produced during breeding program. This have serious cost implication that a thousand or hundreds hybrids are produced sometime one qualifies. This calls for endeavors to protect these few cultivars that qualifies, otherwise the whole tiresome and expensive will end in a serious loss to the program if broken resistance occurs.

4.0. HOW CAN WE PRESERVE RESISTANT CULTIVARS

Minimizing risk of broken resistance in banana and plantain is crucial for sustainable banana production ultimate increased yield. It is reported that inherent quality and durability of a plant resistance gene is a direct function of the amount of fitness penalty imposed on the pathogen (Leach et al., 2001).The most durable resistance genes are those that require multiple mutations from the pathogen for virulence, with mutations causing the highest fitness penalty (Palloix et 2009).Therefore enhancing durability of crop resistance to plant pathogens is the key goal of virulence management in crop production (Lo Iacono et al., 2013). It is reported that once the resistance genes have been introduced into plant varieties, their efficacy can be preserved only by manipulating external factors (Consortium, 2016). It is emphasized that durability of resistance is not merely a property of genes; it is the property of the cropping system (Adugna, 2004). Despite the recognition of the importance and effects on the evolution of the pathogen and durability of resistance gene, there is less attention paid to these important aspect of crop improvement (Lo Iacono et al., 2013). In banana and plantain durability of a cultivar for the practical purpose is longer compared to other crops like cereals and vegetables which are easily replaced by new released varieties. The following are some of the important aspects to be included in the course of banana and plantain breeding and production for sustainable yield.

4.1. Redefining the breeding objectives

Breeding for resistance should not be the only goal of breeding program, but the objectives should further identify the factors that govern quality and durability of resistant gene in resistant cultivars. Since it have been reported that qualitative resistance is generally regarded as “short-lived,” because the effect of the R gene is essentially neutralized by loss of the corresponding avirulence gene function in the pathogen (Lo Iacono et al., 2013). Again quantitative resistant is regarded as incomplete need to be supplemented by other agronomic practices to make it durable (Lo Iacono et al., 2013). Though report by Leach et al., (2001) explain that there many examples of resistant genes controlled by major gene which have been resistant for 30 to 90 years. This implies that breeding for resistant should not be the only goal to achieve but rather identifying the factors that govern the quality and durability of the resistant genes. Contrary to all these Palloix et al., (2009), commented that polygenic resistance proved more durable than monogenic, but breeding strategies give priority to major resistance, this jeopardize the progress in durability expected from polygenic resistance.Need for further research to improve breeding objective for better cultivar resistance.

4.2. Mode of deployment of resistant cultivars

The integration of new species and traits in cropping systems must be accompanied by recommendations on how to deploy them so that the expected resistance are effectively provided (Lamichhane et al., 2018). If a cultivar deployed uniformly in the field, genetically controlled plant resistance is often quickly overcome by pathogens, resulting in dramatic losses (Rimbaud et al., 2018). Several strategies have been proposed to constrain the evolutionary potential of pathogens and thus increase resistance durability (Mundt, 2014; Rimbaud et al., 2018).These includes the following strategies that helps to reduce diseases effects by increasing resistance durability in agricultural system.

a). Resistant gene rotations , that is recurring succession of different crop cultivars in the same field.Temporal gene deployment may include 1) sequential release of resistance genes where by each variety is used until populations reach the breakdown population level and is immediately replaced by another variety. 2) Variety rotations from season to season or recycling of resistance genes. Rotation of varieties with different resistances prevents selection of compatible isolates in populations of soil-borne pathogens. According to Harahap and Silitonga (1988), gene rotation can be effectivein areas of intensive agricultural production where there are adequate and intensive disease surveys in collaboration with plant breeders (Elizabethlof et al., 2017).

b). Gene pyramidingthat is different resistance sources/genes,this is done by providing a wide array of horizontal resistance cultivar (Mundt, 2019; Ramalingam et al., 2020). In some areas although a single gene confers resistance to the existing pathogen population, the large-scale use of this gene results in the breakdown of resistance (Adugna, 2004).To delay



such breakdown, pyramiding of more than one resistance gene is effective. Gene pyramids are expected to considerably extend the durability of resistance because of the low probability for the pathogen to assemble multiple, rare virulence genes by mutation and/ or recombination (Adugna, 2004; Elizabethlof et al., 2017).

c). Cultivar mixtures that is different cultivars combined in the same field. This refers to a homogeneous, spatial mixture of different genotypes of one plant species in a field. According to Burdon (1993), the concept of mixtures is to shield individuals carrying one particular resistance with a range of others carrying other resistance genes. Disease resistance in variety mixtures depends on slowing down the development of the best-adapted race on each component. Mechanisms by which disease reductions are obtained in mixtures include a decrease in susceptible tissue and therefore a decrease in inoculum potential within the mixture, an increase in distance for spores to move from one susceptible plant to another, the physical barrier of resistant plants and possibly cross-protection whereby the defensive mechanisms of one component of the mixture may be activated by an a virulent isolate from another component (Garret and Cox, 1999). Plant genotypes selected for agricultural mixtures should be chosen to exhibit complementary growth traits, as well as complementary resistance characteristics. In a mixture of cultivars with different resistant genes, pathogens are restricted to susceptible hosts and spore losses on resistant plants results in considerable reduction in disease severity (Lannou 2001). A resistance gene deployed in a mixture will have less exposure to the pathogen population than if the same gene was deployed in monoculture of the same total crop area (Lannou 2001; Elizabethlof et al., 2017).

d). Mosaics that is different cultivars in different fields of a continuous landscape (Rimbaud et al., 2018).Strategies to improve plant resistance management rely on careful selection of resistance sources and their combination at various spatio-temporal scales. The land scape is a dynamic mosaic of fields cultivated with crop types .Eachcrop type is composed of either a pure cultivar or a mixture and each cultivar may carry one or several resistance genes. Each resistance gene targets one or several pathogenicity traits, with complete or partial efficiency and maybe expressed from the beginning of the season or later. For two R genes (R1 and R2) deployed in an agricultural landscape, the simplest mosaic strategy consists of the repeated planting, over cropping seasons, of half the field with a cultivar bearing R1 and the other half with a cultivar bearing R2 (Djidjou-Demasse et al., 2017).

To conclude the above, Rimbaud et al., (2018), according to him four strategies above offered the same short-term epidemiological control, whereas rotations provided the best long-term option, after all sources of resistance had broken down. Acoording to Djidjou-Demasse et al. (2017), strategy performance depended principally on the fitness costs of adaptive mutations, epidemic intensity before resistance deployment and landscape connectivity. Mosaics were at least as good as pyramiding strategies in most production situations tested. This is calling for Breeders and Researchers to have ready many cultivars with different levels and sources of resistance released so that they can be used in case acultivar lose its resistance. This is to ensure farmers have sustainable production to feed the growing populations

4.3. Combining the different management methods that aim in reducing amount of inoculum

It seems logical that integrated management has the potential to increase the durability of resistance as compared to using the same resistance in a non-integrated manner (Mundt et al., 2002). Individual control measures used alone often bring only small benefits and may become ineffective in the long term. When control measures that act in diverse ways are combined into integrated disease management tactics, their effects are complementary resulting in far more effective overall control (Makkouk et al., 2014). Optimization is done of all possible measures that operate in different ways such that they complement each other and can be applied together in farmers' fields as one overall control package ((Jones, 2004; Thresh, 2003). Each strategy needs to be affordable by farmers and fulfill the requirements of being environmentally and socially responsible. It must also be compatible with control measures already in use against other pests and pathogens (Makkouk et al., 2014).This would thus decrease the probability that a resistance-breaking genotype will be present in the pathogen population. In addition, combining management practices may present the pathogen population with multiple barriers to overcome (Mundt et al., 2002).

4.4. Imposing and strengthening laws and regulations that restrict movement of infected agricultural plants and their products within and outside the countries.

Plant quarantine is one of the very important procedure that helps in minimizing problem related to diseases occurrence. It involves legal enforcement of the measures aimed to prevent pests from spreading or to prevent them from multiplying further in case they have already gained entry and have established in new restricted areas.Prevent the introduction of new pests from foreign countries,



prevent spread of already established diseases from one part of the country to another. Legislation to enforce farmers to apply effective control measures to prevent damage by already established pests and prevent the adulteration and misbranding of pesticides. Laws are enacted to allow the determination of permissible residue tolerance levels in food stuffs and regulate the activities of people engaged in pest control operations and application of hazardous chemicals.

Therefore different countries on the earth they are urged to enact laws and regulation that will regulate the movement of plant materials within and outside by preventing or restrict infected materials to get into their country.

4.5. Increasing loyalty and integrity of researchers, breeders and pathologists

Breeders, Researchers and pathologists need to be virtue, that is strive towards living in compliance with one's full potential, intellectually as well as following good moral conducts in order to achieve goals set by the breeding program. According to Aristotle virtue as 'the state of character which makes a man good and which makes him do his work well (Ross and Brown, 2009). It is important to adhere to values and norms which are core concepts in moral reflection about research integrity. A breeding program is the sum of breeding pipelines to achieve breeding targets for a set of market/target segments. Any pipeline should have a clear deliverable/product to be handed at the end of the pipeline and a clear customer that is a target population of environments in which the final product is to be grown. Must have a clear descriptions on the target clients and product traits that are valued for production and consumption. Scientists in general need to optimize the plant genotype, by choosing the most promising resistance genes and gene combinations regarding the durability of resistance. If all the proper procedures, regulation and rules are followed there is high chances of obtaining excellent product from research.

5.0 CONCLUTION AND RECOMMENDATION

The use of integrated approaches by including host plant resistance into a crop management system can help to achieve a durable crop resistance phenotype (Pink, 2002). Resistance is a dynamic phenomenon may change over time, therefore continued monitoring is vital to determine whether management recommendations remain valid or need to be revised in light of changing circumstances or new knowledge gained. So the need to design breeding in such way to include the use of the released resistant cultivars is important factor that will help bringing back feedback to breeders early that it is now. We therefore recommend the following things to be done to help achieving the objective of breeding for durable resistant;

1. Research need to be done to identify the factors that govern quality and durability of resistance in banana, plantain and wilt banana.
2. Breeding objectives need to go together with the identification of the best agronomic practices that will combine suitably with the released resistant cultivars. Despite this understanding, the most widely adopted 'resistance breeding' strategy throughout the 20th century remained the production of varieties with single gene (Pink and Hand, 2002).
3. There need for research to test disease resistance gene deployment strategy that will suit different environment to increased durability.
4. Study on predicting of durability of resistant in banana are not there, there are need to conduct such study to be sure of product durability.

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