ISSN (Online): 2091-2609
DOI Prefix: 10.3126/ijasbt
International Journal of Applied Sciences and Biotechnology
(IJASBT)

Review Article

Trends of Biotechnology Applications in Pest Management: A Review

Melaku Alemu

Ethiopian Agricultural Research Council Secretariat, Biotechnology Coordination Directorate, P.O. Box 8115, Addis Ababa, Ethiopia,

Article Information

Received: 20 May 2020
Revised version received: 12 June 2020
Accepted: 15 June 2020
Published: 25 June 2020

Cite this article as:
M. Alemu (2020) Int. J. Appl. Sci. Biotechnol. Vol 8(2): 108-131. DOI: 10.3126/ijasbt.v8i2.28326

***Corresponding author**
Melaku Alemu,
Ethiopian Agricultural Research Council Secretariat, Biotechnology Coordination Directorate, P.O. Box 8115, Addis Ababa, Ethiopia
Email: melaku.alemu22@gmail.com
Cell Phone No: +251911921134

Peer reviewed under authority of IJASBT
© 2020 International Journal of Applied Sciences and Biotechnology

OPEN ACCESS

This is an open access article & it is licensed under a Creative Commons Attribution Non-Commercial 4.0 International (https://creativecommons.org/licenses/by-nc/4.0/)

Abstract

There are many constraints that severely affect the global agricultural production and productivity which include the ever increasing of population growth, degradation of natural resources, climate changes and emerging pests. Among these factors, biotic constraints or pests are known to cause 25-50% or complete loss of plant production. Accordingly, various plant protection technologies have been deployed with the trend of focusing on the use modern biotechnological tools that are proven to be most effective and mandatory. The review covers a wide array of pest management methods ranging from the conventional biological control methods up to molecular breeding techniques. Furthermore, the application of new genetic engineering techniques fueled by new breakthroughs and innovations are the cornerstone of this review. Accordingly, the continuous increasing trend of GM crops cultivation in both crop type and hectare has urged many countries to deploy the technology as a key strategy to enhance their bioeconomy. In fact, plant protection is the discipline that immensely benefit from biotechnology than any other disciplines for ensuring food security and sustainable development. However, in order to fully exploit the enormous potential of biotechnology, appropriate biosafety regulatory frameworks and proper stewardship programs need to be effectively implemented. This integrated approach can promptly help respond to the ever-dynamic threat of pests and hence reliably combat food insecurity and ably contribute to sustainable development.

Keywords: pest management; bio-agents; molecular breeding; genetic engineering; GM Crops production trend; Genome editing

Role of Plant Protection for Improving Agricultural Production and Productivity

According to The Food and Agriculture Organization of the United Nations (FAO) 2017 report "The future of food and agriculture: trends and challenges", the world's population is expected to increase by 2 billion persons in the next 30 years, from 7.7 billion currently to 10 billion in 2050. To this effect, food production must double by 2050 to meet the demand of the world's growing population and innovative strategies are needed to help combat hunger, which already affects more than 1 billion people in the world. On the other hand, human population growth is seen as the main cause of other biologically and ecologically destructive phenomena (Hopfenberg and Pimentel, 2001). FAO (2017) report identifies 15 trends and 10 challenges affecting the world's food systems which will have to be addressed in order for sustainable agricultural services to meet the growing food demand of the world population.

Subsequently, Calicioglu *et al*., (2019) analyzed these future challenges of the agriculture and food systems by focusing on (i) their root causes and trends; and (ii) the inter linkages among the solutions proposed to address the challenges, in which transboundary pests and diseases are described as one of the root cause of challenges.

To this end, the ever increasing of population growth together with the inevitable degradation of natural resources, climate changes and emerging pests are the major constraints that severely affect the trend of global agricultural production and productivity. Among these production challenges and constraints, abiotic factors [temperature (chlling/frost or heat), water (drought or flooding) and salts (high salinity or mineral deficiency] and biotic or biological factors (pests) are responsible for reduction of crop performance and resulting in a lower actual yield than attainable production of crops (Oerke, 2006). In some instances pests remain to be one of the major limiting factors in sustaining the productivity of agriculture. Interestingly these biological factors (pests) can be prevented, controlled and managed there by deploying appropriate plant protection measures. To tackle these challenges, there is a pressing need to evolve towards more sustainable and modern agricultural practices that can revolutionize the bioconomy.

Under the International Plant Protection Convention, a pest is defined as any species, strain, or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (ISPM, 2006). Accordingly, unless otherwise stated, throughout this article the term ‘‘pests’’ refers to plant pathogenic microorganisms (bacteria/mycoplasma, fungi, viruses, nematodes), insects (arthropods or entomophagus/herbivorous/ phytophagus arthropods and mites)and weeds (parasitic higher plants),that affect the growth of plants and consequently reduce the yields and qualities. In general plant protection research deals with five sequential interventions or thematic areas namely (i) survey and surveillance on the distribution, severity, prevalence etc of pests, (ii) detection, diagnosis, identification and characterization of pests, (iii) basic studies on the biology and epidemiology of pests (iv) determine the losses they incur in terms of quality parameters and quantity or yield components and (v) develop control measures or management options (cultural or mechanical, chemical, biological, host plant resistance and integration of two of these or more measures to attain holistic integrated pest management (IPM). In all of these sequential steps, the role of biotechnology is very critical and mandatory.

Plants account for over 80% of the human diet. Depending on the plant and prevailing environment, pests are estimated to be responsible for 25 to 50% or complete loss of agricultural production and productivity (Oerke, 2006; Savary *et al*., 2012; CAST, 2017). This clearly indicates that pests pose serious threats to food security and sustainable development. This calls for devising effective plant protection technologies for the prevention and control of crop losses due to pests in the field (pre-harvest losses) and during storage (post-harvest losses) (Oerke, 2006). In fact, effective pest management requires enhanced skills and most costly inputs due the complex interaction of pests with environment and weather factors or climate changes (Juroszek and Von Tiedemann 2013). This is due to the fact that these pests are difficult to control as their populations are variable in time, space, and genotypes and new aggressive strains are likely to occur leading to outbreaks, invasiveness and global spread. These dynamic complexities of pests urge the deployment of series of reliable plant protection measures ranging from conventional up to modern biotechnology products so as to curb new outbreaks and associated causal factors. Apparently, the sustainable use of effective plant protection measures by itself incredibly contribute to the enhancement of agriculture production and productivity. Thus, plant protection has an obvious role to play in meeting the growing demand for food security and sustainable development (Savary *et al*., 2012).

There are several publishers that produce articles on plant protection. Among these, Lebeda *et al*. (2014) reviewed the 50 years (1965–2014) of publication of plant protection science and indicate the advancements made progressively. The review of crop protection contributions toward agricultural productivity can also be found from CAST (2017) which was produced as part of the series on the need for agricultural innovation to sustainably feed the World by 2050**.** To this end, the present review aimed at enhancing these efforts thereby focusing on the application of biotechnology to plant protection, particularly to pest management aspect to ensure food security and sustainable development.

Role of Biotechnology in Plant Protection and Agriculture

According to the Convention on Biological Diversity (CBD, 1992), the term ‘biotechnology’ means “any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.” Biotechnology can be considered as a series of enabling technologies, which each involve the elucidation and manipulation of living organisms (plants and pests) or their subcellular components to develop useful products, processes and services (Lebeda and Pokorný, 2012; Cano *et al*., 2017). The technologies are among the most exciting, cutting-edge applications of contemporary biological sciences which include DNA based characterization of plants and pests, plant tissue and cell cultures, monoclonal antibody production, molecular breeding techniques, recombinant DNA technology and/or genetic engineering, bioprocess engineering, and bioinformatics (Fermin-Munoz *et al*., 2000; Gianessi *et al*., 2003).

Biotechnology in Plant Protection

Biotechnology application in plant protection can also be broadly divided in to two categories namely (i) characterization of pests and (ii) management of pests. The first application has made significant advances in the rapid and accurate diagnosis of pests and genetic characterization of their populations. This part of biotechnology application is treated separately elsewhere. This first application is found to be so a crucial prerequisite to devise reliable pest management strategies as it enables identification of resistant markers for plants as well as DNA regions of the pests associated with resistance which ultimately speed-up the breeding of cultivars having various traits.

The second part of the application is the subject of this review article and deals with both conventional and modern biotechnological pest management strategies, in which the latter is the current trend which include molecular breeding and genetic engineering techniques. Various reviews describe the application of these biotechnological methods used in pest management (Gianessi *et al*., 2003; Wahab, 2009; Duke 2011). There are also several reviews separately treated for diseases, insect-pests and weeds. Some of them are biotechnology for disease management (Fagwalawa *et al*., 2013; Shamim *et al*., 2013; Vincelli, 2016; Arya 2018; Dayou *et al*., 2018); biotechnology for insect-pest management (DeVilliersand Hoisington, 2011; Stevens *et al*., 2012; Talukdar, 2013; Jaiswal *et al*., 2018) and biotechnology for weed management (Tranel and Horvath,2009; Duke *et al*., 2015; Westwood *et al*., 2018). It can be clearly seen that plant protection is the discipline that immensely benefit from biotechnology in many ways than any other disciplines.

Biotechnology for Improving Agricultural Production and Productivity

There are two series of agricultural technology developments that have been practiced namely "Green Revolution" (1944-1994) and "Gene Revolution" as of 1995 up until now (Ghanian *et al*., 2016; Ameen and Raza, 2017). The "Green Revolution" focused on extensive use of agrochemicals (chemical fertilizers, pesticides and herbicides), heavy machinery and irrigation infrastructure. In addition to these, high-yielding crop varieties (hybrid cereals) developed through conventional plant breeding practices were also used and resulted in the increased crop productivity in some countries. However, the ever-rising global population growth demanded equivalent amount of food production, for which the conventional plant breeding alone, can no longer respond. Thus it was replaced by "Gene Revolution" which is also referred as the era of modern biotechnology that eliminated the barriers of traditional methods of plant breeding through genetic engineering techniques (Ghanian *et al*., 2016).

Actually, biotechnology in agriculture is not only about genetic modification but rather encompasses a number of tools and elements of conventional breeding techniques, bioinformatics, microbiology, molecular genetics, biochemistry, plant physiology and molecular biology. The advances made in cell biology and cellular genetics have resulted with breakthroughs in biotechnology that revolutionized agricultural production for developing plant varieties containing several beneficial characteristics including traits that confer resistance to biotic and abiotic factors. Gene technology identifies desirable traits more quickly and accurately than conventional plant breeding. It can also introduce the genes that control desirable traits into plants with far greater precision and control than conventional methods. The applications of biotechnology in crop improvement and agriculture were reviewed by several scholars (Herdt 2006; Dunwell 2010; Gosal *et al*., 2010; Sharma *et al*. 2012; Nasser 2014; Khan *et al*., 2018b).

Biotechnology for Pest Management

The application of biotechnology in pest management can be broadly divided into two categories namely (i) conventional biotechnology and (ii) modern biotechnology. This review article appears to be unique as it covers the exhaustive and comprehensive application of these two broad categories of biotechnology in pest management. The application ranges from the pioneer conventional management measures (non-transgenic or that do not involve gene transfer) to the ultimate aim of describing the most powerful and modern biotechnological pest management options that dwell on molecular breeding and genetic engineering techniques. Each of the application is referenced across the three pests (diseases, insects and weeds) in a matrix form that ultimately update previous separate reviews and hence aid simultaneous understanding of application for enhanced deployment strategy.

Conventional Biotechnology Products Used in Pest Management

The conventional biotechnology products or the non-transgenic technologies used for the control of pests involve the whole range of bio-agents, tissue culture techniques and biofertilizers.

***1**. Bio-Agents Used for Pest Management:*

Bio-agents are all sort of biological agents consisting of microbial agents, natural enemies, parasitoids and parasites; and botanicals. Several types of biocontrol agents (Barratt *et al*., 2018) and biopestides (Cavoski *et al*., 2011), which are broadly used interchangeably have been used as conventional biotechnology products for the management of pests. These pest control agents are composed of either of the bio-agents (Guleria and Tiku, 2009; Cavoski *et al*., 2011; Enyiukwu *et al*., 2016) and their Secondary metabolites (Mazid *et al*., 2011; Pino *et al*., 2013). These components can be used alone or combined with each other to sustainably maximize the benefits (Barzman *et al*., 2015; Stenberg, 2017).

2. *Integrated Pest Management (IPM) Strategies*

The above-mentioned biological control measures can be more sustainable when combined with each other and enjoyed immense application in devising effective and holistic approach of Integrated Pest Management (IPM) strategies to sustain agricultural production (Nafiu *et al*., 2014). IPM is an ecologically-based pest management strategy that incorporates all appropriate methods into a systematic approach to minimize pest damage. It is globally endorsed as the future paradigm and advocate the integration of six components namely (i) biological control, (ii) host plant resistance, (iii) cultural control, (iv) mechanical and physical control, (v) chemical control and (vi) regulatory control. IPM emphasizes the growth of healthy plant with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms (Barzman *et al*., 2015; Stenberg, 2017; Dara 2019).

3. *Tissue Culture Techniques*

In addition to these, mass production of disease-free planting materials using plant tissue culture techniques are revolutionizing the pest management strategies dealing with host plant resistance. Tissue culture (TC) methods facilitates rapid multiplication of disease-free plants under controlled and aseptic conditions in a relatively short time. Itoffer a rich scope for creation, conservation, and utilization of genetic variability for the improvement of plants (Sharma *et al*., 2012; Gaikwad *et al*., 2017). Tissue culture techniques have been used for mass multiplication of plants and their conservation (Gosal *et al*., 2010; Hussain, *et al*., 2012; El Meskaoui, 2013; Ghaffar *et al*., 2016; Rashid *et al*., 2017; Oseni *et al*., 2018). These in vitro techniques (TC) also enjoyed enormous application for the production of secondary metabolites (Namdeo 2007; El Meskaoui, 2013). Furthermore, TC are also applied for in vitro screening for disease resistant plants (Rai *et al*., 2011; XiaoXing *et al*., 2013; Gao and Sun, 2013; Kumari *et al*., 2014).

Similarly, haploidy technology and protocols are used for production of haploids and double haploids of homozygous plants which significantly impacted the agricultural systems. Nowadays, these biotechnologies represent an integral part of the breeding programmes of many agronomically important crops (Mishra *et al*., 2015; Begheyn *et al*., 2016; Badu *et al*., 2017; Ren *et al*., 2017).

4. *Biofertilizers*

The fertility of the plant growing medium (soil) need to be maintained for the plants to thrive and grow healthy and ably augment the plant protection measures. In this regard microbial biotechnology products such as biofertilizers [Biological Nitrogen Fixing (BNF), Phosphate Solubilizing Bacteria (PSB), Potassium Mobilizing Bacteria (KMB), Plant Growth Promoting Bacteria (PGPB), Mycorrihza] have been used improving soil fertility, plant tolerance and crop productivity (Bhardwaj *et al*., 2014; Ajmal *et al*., 2018; Itelima *et al*., 2018). In recent years Encapsulated biofertilizers or Nano-fertilizers are also found to be effective (Duhan *et al*., 2017; Thakur *et al*., 2018).

Table 1 describes review of the wide array of conventional biotechnology products used for pest management such as (i) Microbial agents , (ii) Bionano-agents, (iii) Natural enemies, predators and entomophagus insects, Parasites, parasitoids and herbivorus/ phytophagus insects, (iv) Sterile Insect Technique (SIT), (v) Botanicals or plant based biocontrol agents, (vi) Biopesticides and (vii) IPM-involving biocontrol agents or biopesticides.

Table 1: Conventional biotechnology products used for the management of plant pests

Control method	**Pathogens**	**Insect-pests and mites**	**Weeds**
Microbial agents	antimicrobials (Ahanger *et al*., 2014; O'Brien, 2017; Aboutorabi, 2018); Shukla *et al*., 2019) Endophytes (Mousa and Raizada, 2015; Braga *et al*., 2016) Microbial Detoxification of Mycotoxins (McCormick, 2013)	Entomopathogenic fungi (Dar *et al*., 2017a; Sultana *et al*., 2017; Maina *et al*., 2018) Entomopathogenic nematodes (Gozel and Gozel, 2016); Entomopathogenic Bacteria (Ruiu, 2015); entomopathogens (Lacey *et al*., 2015); Insecticidal bacteria (Saiyad, 2017), Microbial agents (Kergunteuil *et al*., 2016; Gangwar 2017)	Microbial herbicides (Patel and Patel 2015; Harding and Raizada, 2015; Trognitz *et al*., 2016)
Bionano-agents	Control of plant pathogens (Alghuthaym *et al*., 2015; Duhan *et al*., 2017; Kumar *et al*., 2017; Oluwaseun and Sarin, 2017)	Bionano-insecticidal agents Duhan *et al*., 2017; Kitherian, 2017; Lade *et al*. 2017)	Bionano-herbicidal agents (Oliveira *et al*., 2015; Duhan *et al*., 2017; Kumar *et al*., 2017)

Table 1: Conventional biotechnology products used for the management of plant pests (Contd.)

Control method	**Pathogens**	**Insect-pests and mites**	**Weeds**
Natural enemies, predators and entomophagus insects, Parasites, parasitoids and herbivorus/ phytophagus insects		natural enemies (Routray *et al*., 2016; Kenis *et al*., 2017; van Lenteren *et al*., 2018), Predators (Ahmed *et al*., 2016), Parasites-parasitoids (Libersat *et al*., 2018), entomophagus insect (Hidayat *et al*., 2018)	herbivurus insects as natural enemies (Mersie *et al*., 2017), phytophagus insect (Hidayat *et al*., 2018)
Sterile Insect Technique (SIT)		Control of fruit flies (Sarwar, 2015a; Haymer 2016; Nikolouli *et al*., 2018)	
Botanicals or plant-based biocontrol agents	Plants used in diseases management (Gurjar *et al*., 2012; Bhagat *et al*., 2014; Villaverde *et al*., 2016; Zaker 2016), Phytoallexins (Jeandet *et al*., 2014; Singh and Chandrawa, 2017)	Insecticidal Plants (Sarwar, 2015b; Villaverde *et al*., 2016; Hikal *et al*., 2017) Semiochemicals (El-Shafie and Faleiro, 2017; Murali-Baskaran *et al*., 2017; Saha and Chandran, 2017), Pheromones (Kirk, 2017) Antifeedants (Koul 2008) Attractants (Drmic *et al*., 2017), Repellents (Abtew *et al*., 2015) Push-pull technology for insect control (Khan *et al*., 2011;2014; Pickett *et al*., 2014; Bhattacharyya 2017)	Herbicidal plants (Ghosh *et al*., 2015; Villaverde *et al*., 2016; Mondale *et al*., 2018) Allelochemicals (Saxena *et al*., 2016; Muzell Trezzi *et al*., 2016; Xuan *et al*., 2016; Ashraf *et al*., 2017) Push-pull technology for weed control (Khan *et al*., 2011; 2014; Pickett *et al*., 2014)
Biopesticides	Disease control (Villaverde *et al*., 2016; Damalas and Koutroubas, 2018)	Insect control (Kumar 2015; Tijjani *et al*., 2016; Nawaz *et al*., 2016; Villaverde *et al*., 2016; Damalas and Koutroubas, 2018)	Weed control (Villaverde *et al*., 2016)
IPM-involving biocontrol agents or biopesticides	Integrated disease management (IDM) (Pandey *et al*., 2016; Rasool *et al*., 2018; Dara 2019)	Integrated Insect control (Naifu *et al*., 2014; Damos *et al*., 2015; Gangwar, 2017; Dara 2019)	Integrated Weed control (Harker *et al*., 2013; Lamichhane *et al*., 2016; Young *et al*., 2017; Dara 2019)

Molecular Breeding for Pest Management

Among the pest management strategies mentioned above, host plant resistance (HPR) is one of the best control measures that can also be made more reliable and fast using DNA marker-based breeding methods or molecular breeding. DNA markers can be routinely employed in various aspects of plant genome analysis such as characterization of genetic variability, genome fingerprinting, genome mapping, gene localization, analysis of genome evolution, population genetics, taxonomy, plant breeding, and diagnostics (Jonah *et al*., 2011; Chauhan and Kumar, 2015). Thus, molecular markers have proven to be invaluable tools for assessing plants' genetic resources by improving our understanding with regards to the distribution and the extent of genetic variation within and among species.

By using molecular markers, traditional phenotype-based selection methods can be bypassed, which involve growing plants to maturity and closely observing their physical characteristics in order to infer underlying genetic make-up. Lateef (2015) categorized markers in to three major groups based on their complexity: (i) Low-Throughput Marker Systems (RFLP), (ii) Medium-Throughput Marker Systems (RAPD, SSR, AFLP), (iii) High-Throughput Marker Systems (SNP, (KASPar, GBS)]. Alternatively, these markers are also classified as non-PCR based approaches (RFLP) and the remaining markers as PCR-based approaches (Chauhan and Kumar (2015). The advantages and disadvantages of these marker systems are reviewed by some authors (Jonah *et al.*, 2011; Chauhan and Kumar, 2015).

1. *Marker Assisted Breeding*

Marker-assisted selection (MAS) refer to the use of DNA markers that are tightly linked to target loci as a substitute for or to assist phenotype screening. MAS provides opportunities for enhancing the response from selection because molecular markers can be applied at the seedling stage, with high precision and reductions in cost(Hussain 2015; Lateef, 2015; Lema, 2018). In addition to selection of best traits, markers are also used in the breeding and referred as marker assisted breeding (MAB) or molecular plant breeding (Dwivedi *et al.*, 2007; Moose and Mumm, 2008; Tiwari 2017). They can also be used as genomics-assisted breeding (Varshney *et al*., 2005; Peng-fei *et al*., 2017). Other related molecular breeding methods include mutation breeding in crop improvement (Oladosu *et al*., 2016; Raina *et al*., 2016; Lamo *et al*., 2017); TILLING (Targeting Induced Local Lesions in Genomes) (Rashid *et al*., 2011; Wang*et al*., 2012; Sharp and Dong, 2014; Khan *et al*., 2018a). The use of reverse genetics as applied for breeding is referred as reverse breeding and reverse engineering that lead to accelerated breeding (Dirks *et al*., 2009; Gilchrist and Haughn, 2010; Kumari *et al*., 2018). Selected examples of improved lines/cultivars/varieties developed with resistance to pest and diseases through molecular breeding approaches in some crops are reviewed by Khera *et al*., (2013).

2. Variants of Plant Resistance to Pests

Using the above-mentioned molecular methods, plants resistance to pests can be obtained faster than the conventional breeding. There are different types of resistance such as multiple, quantitative and durable resistances (Mundt,2014).Development of durable pest resistant varieties was achieved through gene pyramiding and gene stacking (Pilet-Nayel *et al*., 2017).Pyramiding entails stacking multiple genes leading to the simultaneous expression of more than one gene in a variety to develop durable resistance expression. Gene pyramiding and gene stacking are sometimes alternatively treated in the scientific literature referring to the same process. Anyways, both involves combining two or more genes of interest into a single plant and the combined traits resulting from this process are called stacked traits (Joshi and Nayak, 2010).

In addition to pest resistance, yield determining genes can also be incorporated in the breeding programs to enhance the yield (Ariizumi *et al*., 2013; Nadolska-Orczyk *et al*., 2017) Thus pyramiding of yield affecting genes with other agronomically important genes might be proposed for further improvement. Genetic gain can be improved through enhancing the potential and closing the gaps, which has been evolving and complemented with modern breeding techniques and platforms, mainly driven by molecular and genomic tools, combined with improved agronomic practice (Xu *et al*. 2017).

Table 2 describes the review of molecular breeding techniques used for developing resistant plant varieties against key pests. These are (i) MAS and MAB, (ii)Multiple resistance, (iii) Quantitative resistance (QR), (iv) Durable resistance, (v) Gene pyramiding and (vii) Gene stacking.

Table 2: Molecular breeding for developing resistant plant varieties against key pests

Molecular breeding method	**Resistance to Pathogens**	**Resistance to Insect-pests**	**Resistance to Weeds**
Marker Assisted Selection (MAS) and Marker Assisted Breeding (MAB)	MAS in disease resistance breeding (Ragimekula *et al*., 2013; Farokhzadeh and Fakheri, 2014	MAS insects resistance in rice (Shabanimofred *et al*., 2015; Venkanna *et al*., 2018; Jaiswal *et al*., 2018)	Striga resistance in sorghum (Yasir and Abdalla, 2013, Yohannes *et al*., 2015, Ngugi *et al*., 2015; Ali *et al*., 2016),
Multiple resistance	Multiple disease resistance in barley (Steffenson and Smith, 2006), in rice (Singh *et al*., 2012), in coffee Alkimim *et al*., 2017); implications in MAS (Ali *et al*., 2013);	multiple insects resistance in maize (Badji *et al*., 2018)	multiple resistances to herbicides (Gressel, 2000; Neve *et al*., 2009)
Quantitative resistance (QR)	Dissection and adoption in maize (Yang *et al*., 2017), molecular bases of QR (Vasquez *et al*., 2018)	Resistance to leaf hoppers, and brown plant hopper (Fujita *et al*, 2009; Dhillon and Sharma, 2012)	Resistance to orobanche (Louran *et al*., 2016; Fernández-Aparicio *et al*., 2016)
Durable resistance	Durable management of pathogens (Kou and Wang 2010; Mundt, 2014; Consortium 2016)	Durable management of insect-pests (Mundt, 2014; Sandhu and Kang, 2017)	Durable Sunflower resistance to orobanche (Velasco *et al*., 2016)
Gene pyramiding	Durable Resistance to pathogens (Mekonnen *et al*., 2017; Pilet-Nayel at al., 2017)	Pyramiding of two insect resistance genes in rice (Xu 2013; Liu *et al*., 2016)	Pyramiding of *Striga* resistance genes (Yasir and Abdalla, 2013; Yohann es *et al*., 2015; Ali *et al*., 2016)
Gene stacking	Enhancing resistant to diseases (Consortium 2016; (Das *et al*., 2017)	Insect resistance in rice (Das and Rao, 2015)	stacked herbicide resistant traits (Chauhan *et al*., 2017)

Genetic Engineering for Pest Management

Genetic engineering, also called genetic modification, is the techniques of direct, controlled and artificial modification and manipulation of an organism's genes which is used to change the genetic makeup of cells, including the transfer of genes within and across species boundaries to produce improved or novel organisms. Thus, plant genetic engineering is a technology where the genome of a host crop is engineered with a foreign donor gene regulated by certain gene regulatory sequences. There are different variants of genetic engineering based on the difference of the gene donor and recipients namely transgenics, intragenics, cisgenics and subgenics.

1. Transgenics

Genetic engineering techniques involving gene transfer of foreign gene from unrelated species are referred as transgenics. Most of the GM products of the past two decades belong to this category of genetic engineering. Dramatic progress has been made over the past two decades in manipulating genes from diverse and exotic sources, and inserting them into microorganisms and crop plants to confer resistance to pests, tolerance to herbicides, drought, soil salinity and aluminum toxicity; improved post-harvest quality; enhanced nutrient uptake and nutritional quality; increased photosynthetic rate, sugar, and starch production; increase deffectiveness of biocontrol agents; improved understanding of gene action and metabolic pathways; and production of drugs and vaccines in crop plants(Sharma *et al*., 2012). These are further elaborated after few sections.

2. Intragenics, Cisgenics and Subgenics

There are several other GE techniques that involve gene transfer between closely related species or within same species. Recently, cisgenesis and intragenesis have been developed as new tools aimed to modify crops in response to the major concerns of the general public about transgenic crops relates to the mixing of genetic materials between species that cannot hybridize by natural means. While cisgenesis involves genetic modification using a complete copy of natural genes with their regulatory elements that belong exclusively to sexually compatible plants (same crop species), intragenesis refers to the transference of new combinations of genes and regulatory sequences belonging to that particular species (belonging to the same breedable gene pool). Both concepts imply that plants must only be transformed with genetic material derived from the species itself (cisgenic) or from closely related species capable of sexual hybridization (intragenic) (Holme *et al*., 2013).

Regardless of which of the genome editing systems (described below) are used, the crop that is genome edited is called "subgeneic" (Sticklen, 2015). As mentioned below, the technology associated with development of subgenic crops is a fast-growing technology with a hope to result in the crops of the 21st century that can meet the needs to feed the ever growing world population with the least controversies and public concerns. So far, application of cisgenesis and intragenesis as alternatives to conventional transgenesis are limited to a few species, mainly due to the lack of knowledge of the regulatory sequences required (Espinoza *et al*., 2013; Holme *et al*., 2013; Sticklen, 2015).

There are substantial differences in the biosafety and regulatory issues on transgenics, cisgenics, intragenics and subgenics. Countries considerable vary in implementing either prohibitive and stringent or encouraging and promoting biosafety regulations.

3. RNA Interference (RNAi)

Several functional genomics tools were developed in the recent past that offers specificity and efficacy in silencing members of a gene or multiple gene family. Gene suppression via RNA interference (RNAi) is a method of blocking gene function by inserting short sequences of RNA that match part of the target gene's sequence, thus no proteins are produced. RNAi has provided a way to control pests, introduce novel plant traits and increase crop yield (Younis *et al*., 2014; Meena *et al*., 2017).

4. New Breeding Techniques and Genome Editing Technologies

A range of new genetic modification techniques (nGMs) or new breeding techniques (NBTs)have been rapidly developed in recent years and used to modify the genetic make-up of a plant variety in a more précised way in order to introduce new traits or modify existing ones. These techniques have efficiently accelerated improvement of crop varieties with various useful traits (Georgesand Ray, 2017; Townson, 2017). The development of these nGMs or NBTs has raised worldwide discussions regarding their regulation in which different existing regulatory frameworks for GMO cover nGMs to varying degrees (Eckerstorfer *et al*., 2019).

NBTs include emerging techniques that are more broadly and commonly referred to as 'genome editing' that aim to manipulate DNA at specific locations to rapidly generate potentially useful traits. Genome editing of crop plants is a rapidly advancing technology whereby targeted mutations can be introduced into a plant genome in a highly specific manner and with great precision (Georges and Ray, 2017; Townson, 2017; Jansing *et al*., 2019). Genome editing, which consists of targeting and digesting DNA at a specific site in the genome is an important tool for improved basic understanding of plant gene function analysis. Thus, it is a more precise and accurate technology to effectively develop more productive, highly nutritious and climate-resilient crops (Wolter *et al*., 2019). However, the regulatory framework that covers genome-edited crops in different countries has a major impact on their development and marketability (Jansing *et al*., 2019)

Eckerstorfer *et al*., (2019) listed the range of nGMs techniques namely (i) Genome editing with site-directed nucleases (SDNs), e.g., using clustered regularly interspaced short palindromic repeat (CRISPR)- associated protein-9 (CAS) system directed nucleases, transcription activator-like effector nuclease (TALENs), zinc-finger nucleases (3 ZFNs) or meganucleases. SDN-based techniques can also be applied for multiplex genome editing and "base editing" as well as for modification of transcriptional regulation; (ii) Genome editing directed by synthetic oligonucleotides, referred to as oligonucleotide-directed mutagenesis (ODM)also known as the Rapid Trait Development System (RTDS); (iii) RNA dependent/directed DNA methylation (RdDM);an approach for modifying epigenetic regulation of gene expression; (iv) Cisgenesis and intragenesis; (v) Transgrafting, in particular the use of GM-rootstocks in grafting; (vi) Agro-infiltration, (vii) Haploid induction and accelerated breeding, i.e., examples of techniques developed to assist complex breeding schemes

Among these genome-editing technologies, the CRISPR–Cas9 system has become the tool of choice for gene manipulation and has been extensively used in the last five years because of its, novelty, simplicity, affordability, and feasibility (Sticklen, 2015; Barakate and Stephens, 2016; Bernard *et al*., 2019). The highly precise nature of the genome editing technology CRISPR-Cas enables an unparalleled level of control over the mutation process, allowing immediate pyramiding of multiple beneficial traits into an elite background within one generation (Wolter *et al*., 2019). CRISPR technology is constantly advancing including options for various genetic manipulations like generating knockouts; making precise modifications, multiplex genome engineering, and activation and repression of target genes. It has been used for plant nutritional improvement, enhancement of plant disease resistance and production of drought tolerant plants (Arora and Narula, 2017; Byers 2019; Hahne *et al*., 2019).

Table 3 describe the review of the application of some of the new genetic medication techniques (nGM) or new breeding techniques (NBTs) (i) RNAi, (ii) Cisgenics and intragenics, (iii) Gene editing in general, (iv) Genome editing specifically using CRIPR Cas9 in pest management.

Table 3: Genetic engineering Techniques used for developing pest resistant crops

Genetic engineering method	**Resistance to Pathogens**	**Resistance to Insect-pests**	**Resistance to Weeds**
I. Genetic engineering techniques of the past two decades			
Transgenics	Disease resistance (Vincelli, 2016; Scott *et al*., 2016; Sniezko and Koch, 2017; Dong and Ronald., 2019)	insect pest management (Mabubu *et al*., 2016; Dar *et al*., 2017b; Sniezko and Koch, 2017; Alphey and Bonsall, 2018)	Herbicide-resistant crops (Kniss 2018; Fartyal *et al*., 2018)
Intragenics	diversity in effector genes of banana disease (Stergiopoulos *et al*., 2014), and potato disease (Yang *et al*., 2018)	understanding of the evolution of insect epigenetic systems (Hunt *et al*., 2014)	glyphosate resistance in Chile-pepper (Ortega*et al*., 2018), sugarcane resistance to herbicide (Dermawan *et al*., 2016)
Cisgenics	Genes discovery for cisgenic crops (Kushalappa *et al*., 2016); Cisgenic potato resistance to late blight (Jo *et al*., 2014; Gheysen and Custers, 2017) Cisgenic apple resistant to fire blight and scab (Vanblaere *et al*., 2014; Kost *et al*., 2015)	Insect resistance (Ni *et al*., 2011)	
RNAi	plant disease resistance (Duan *et al*, 2012; Seo *et al*., 2013)	Insect Pest Management (Das 2015; Thakur *et al*., 2016; Jaba and Sharma. 2017)	Parasitic weed management (Aslam *et al*., 2016; Westwood *et al*., 2018)
II. New Breeding Techniques (NBT) developed recently			
Gene editing in general	Plant disease resistance (Andolfo *et al*., 2016; Langner *et al*., 2018);	Plants resistance to insect-pests (Alphey and Bonsall, 2018; Gantz and Akbari, 2018)	Molecular underpinnings of resistance to striga weed (Butt *et al*., 2018);
Genome editing using CRIPR Cas9	Understanding Plant-Pathogen Interactions (Barakate and Stephens, 2016; Ghimire 2017; Borrelli *et al*., 2018; Langner *et al*., 2018)	Insect control (Chen *et al*., 2016; Sun *et al*., 2017)	Weed management (Butt *et al*., 2018; Neve, 2018)

Biotechnology for Food Security and Sustainable Development

The Scope of Biotechnology, GMO and Genetic Engineering

Biotechnology can be used to create many technologies, and GMOs are just one example. Crops that undergo artificially DNA modifications or genetic engineering for beneficial traits improvements are considered as genetically modified (GM) crops. To create a GMO, researchers use genetic engineering technique to turn off an existing gene or add a gene from another source to create a new, desirable characteristic in a product. Genetic engineering has the potential to address the critical constrains of sustainable agriculture and the need for sufficient quantity of healthy food, feed, and biomass feedstock for the industry as well (De Buck *et al*., 2016).

The previous sections are clearly witnessing that biotechnology is more than genetic modification or genetic engineering. Indeed, some of non-genetic transfer aspects of plant biotechnology are potentially the most powerful and the most beneficial such as molecular characterization of pests and tissue culture techniques. There are numerous applications that do not involve genetic modifications. However, it is to be noted that among these applications the use of recombinant DNA technology or transgenic or genetic engineering is the most post powerful and influential for the efficiency and effectiveness of agricultural production and productivity. Biotechnology has therefore opened an exciting frontier in agriculture for maintaining healthy plants that can result in enhanced crop yields and enriched nutritional compositions with an ultimate aim of feeding the ever-growing population

In general GM plants are divided into three groups, depending on the purpose of its generation. GM plants of first generation are those with input traits basically related to increase insect and herbicide resistance, which is the subject of this review article. GM plants of second-generation present output traits related direct to benefit the consumer, aiming mainly to add value to the final product through nutritional improvement or better storage conservation. GM plants of third generation can be so called “green factories” and be used in the production of novel products, like pharmaceuticals and biofuels in an environmentally sustainable manner (Caserta and de Souza, 2017). The last two are sometimes categorized as products of molecular farming and synthetic biology. The ultimate goals of synthetic biology is to design and build engineered biological systems that process information, manipulate chemicals, fabricate materials and structures, produce energy, provide food, and maintain and enhance human health. It can be used in agriculture to modify plants via transgenic seeds to produce specialty chemicals and biofuels, and novel pest control strategies (Goold *et al*., 2018; Wang and Zhang, 2019). Similarly plant molecular farming describes plants as bioreactors for the production of recombinant proteins and other secondary metabolites for commercial and pharmaceutical purposes (Alireza and Nader, 2015; Buyel, 2019).

In general the focal areas and scope of the application of plant biotechnology include (i) Nutritional enhancement and functional foods, (ii) Abiotic stress tolerance, (iii) Increased digestibility, (iv) Increased volumes of biomass for biofuel, (v) Better fiber quality,(vi) Flower color and scent modification, (vii) Production of industrial and pharmaceutical compounds, (viii) Less allergenicity, (ix) Enhanced food flavor and aroma, (x) Healthier oils and (xi) Phytoremediation or bioremediation (Navarro and Hautea, 2011).

More comprehensively, genetic engineering techniques have been used for improved resistance to biotic stresses (Tohidfar and Khosravi, 2015; Alemayehu 2017; (Bhattacharjee *et al*., 2017), biotic and abiotic stress (Dutta and Roy, 2016; Parmar *et al*., 2017; Wijerathna-Yapa, 2017). A similar review on the applications of biotechnology related to management of abiotic stresses, agronomic traits and quality improvements and other beneficial characteristics are under preparation, which will be reported separately elsewhere. Whereas the benefits of GM crops related to pest management are described in Table 4 below.

As mentioned above plant products of biotechnology have been available in the marketfor 23 years since 1996. There are 29 different crops and fruit trees in 42 countries, which have been successfully modified for various traits like herbicide tolerance, insect-pest resistance, disease resistance and quality improvement (Nazir *et al*., 2019). Some of these GM traits related to pest management are indicated in Table 4. GM traits related to quality improvements and other characteristics are not included here which will be reported elsewhere.

Concerns and Controversies on The Safety/Risks of GMO

Ever since GMO products first released in 1992 and widely commercialized in 1996, there have been some biased concerns on their risks lead by campaigns of anti-groups fueled by fear of the fierce competition. Apparently, review of several studies conducted in EU countries concluded that “GM products are not inherently less safe (or not riskier) than those developed by traditional breeding”. The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research, and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not per se more risky than conventional plant breeding technologies (EU, 2010). Similarly, a study based on 15 years of intense research and risk assessment revealed that GM crops do not pose greater risks for human health or the environment than traditionally bred varieties (Adenle, 2015).

Regardless of the huge resources invested to curb the progress of GMO production and reverse the innovations, the weight of the evidence in favor of their safety is overwhelming, as reflected in the position statements of diverse, prestigious scientific societies, scientific review papers, and hundreds of peer-reviewed research papers (Hallerman and Grabau, 2016; Vincelli,2016; Caserta and de Souza 2017).Accordingly, Vincelli (2018) compiled the positions of several National Academies, professional associations, Scientific Boards …etc that declared "there is no scientific evidence and reproducible studies whatsoever that current GE foods, or ingredients made from GE crops pose any risk to humans, animals and environment. They are not different in nature from those created by conventional breeding practices". Indeed, rigorous scientific risk assessment and risk-management regulations/guidelines are in place that nullify the "fear of unknowns". The safety of GM crops is confirmed by peer-reviewed studies usually conducted for 2-4 years and consume most of the product development cost.

Terefe (2018) indicated the list of concerns related to risks to environment, human health, food/feed safety, social, economic and political concerns and recommended case-by-case analyses. It is to be noted that the safety assessment of GM foods generally focuses on: (i) direct health effects (toxicity), (ii) potential to provoke allergic reaction (allergenicity); (iii) specific components thought to have nutritional or toxic properties; (iv) the stability of the inserted gene; (v) nutritional effects associated with genetic modification; and (vi) any unintended effects which could result from the gene insertion. In general, the approaches involve (i) Bioinformatics, (ii) Digestibility/degradation, (iii) Metabolomics, (iv) Feeding trials, (v) Field trials. There are no mysterious and undetectable risks that can escape from these scientific evaluations. Reliable biotechnological method have also be developed for identification of GM crops for biosafety and legitimacy of transgenes (Fraiture *et al*., 2015; Lin and Pan 2016; Nazir *et al*., 2019).

Table 4: List of GM crops targeting pest management

Crop	Common Use	Application of GM traits targeting pest management		
		Disease management	**Insect-pest management**	**Weed management**
Widely commercialized Genetically Modified Crops				
Alfalfa	Animal feed		Insect resistance	Herbicide tolerance
Apple	Food	Fungus resistance		
Canola	Cooking oil, Margarine, Emulsifiers in packaged foods			Herbicide tolerance
Cotton	Fiber, Cotton seed oil, Animal feed		Cotton bollworm resistance	Herbicide tolerance
Maize	high-fructose corn syrup, corn starch, Animal feed		corn borer resistance	2,4-D (herbicide) resistance
Papaya	Food	Papaya Ring Spot Virus		
Potato	Food	Late blight fungus and Virus resistance	Insect resistance	Herbicide tolerance
Soybean	Soybean oil, Animal feed	Soybean dwarf virus and Phytophthora fungus resistance	Insect resistance	Dicamba (herbicide) resistance
Squash	Food	Cucumber Mosaic Virus resistance		
Sugar beet	Food			Herbicide tolerance
Genetically modified crops that have not yet been widely cultivated				
Bean	Food	Virus disease resistance		
Cowpea	Food		Insect resistance (pod borer (*Maruca vitrata*)	
Egg plant	Food		Insect resistance	
Linseed	Food			Herbicide tolerance
Plum	Food	Virus (plum pox virus) resistance		
Rice	Food	Bacterial blight and Fungal disease resistance	Stem borer resistance	Herbicide tolerance
Tomato	Food	Bacterial spot resistance, viral disease resistance	Insect resistance	
Wheat	Food	Powdery mildew resistance		

Source: Tohidfar and Khosravi (2015), Mekonnen *et al*., (2017); ISAAA (2018); Nazir *et al*., (2019) On the contrary, concerns over the lack of knowledge on the safety of GM crops are used as arguments to ban them, or at least to regulate them heavily. Many citizens, politicians and countries generally take those arguments to reinforce misconceptions about GM crop. In this regard Sanchez and Parrott (2017) and Valentinov *et al*., (2018) analyzed the critiques on anti-GMO advocacy and scientific studies usually cited as evidence of adverse effects. Accordingly, a total of 35 studies represent fewer than 5% of all published studies assessing GM food/feed safety were analyzed by Sanchez and Parrott (2017). It was found that most studies often used in the public debate against GM food/crops have been published in journals with lower visibility; eight were even published in journals without a listed impact factor. In general terms, all papers analyzed violate at least one of the basic standards for assessment of GM food/feed safety mentioned above. On the other hand, Valentinov *et al*., (2018) revealed that the anti-GMO advocacy usually involve NGOs having diverse competitive agendas.

Continuous Increasing Trend of GM Crops Production Over the Past 23 Years

Interestingly the benefits and production areas of GM are substantially increasing. Accordingly, a total of 70 countries adopted biotech crops through cultivation and importation in 2018, the 23rd year of continuous biotech crop adoption, according to the Global Status of Commercialized Biotech/GM Crops in 2018 (ISAAA Brief 54) released by the International Service for the Acquisition of Agri-biotech Applications (ISAAA). Twenty-six countries (21 developing and 5 industrialized countries) planted 191.7 million hectares of biotech crops, which added 1.9 million hectares (4.7 million acres) or 1% from 189.8 million hectares) to the record of plantings in 2017. The first 23 years of commercialization of biotech crops (1996 to 2018) has confirmed that biotech crops have delivered substantial agronomic, environmental, economic, health, and social benefits to farmers, and increasingly to the consumers The continuous adoption of biotech crops by farmers worldwide indicate that biotech crops continue to help meet global challenges of hunger, malnutrition, and climate change(ISAAA,2018).Global area of biotech crops has increased ~113-fold from 1.7 million hectares in 1996 to 191.7 million hectares in 2018 – this makes biotech crops the fastest adopted crop technology in recent times. An accumulated 2.5 billion hectares or 6.3 billion acres were achieved in 23 years (1996-2018) of biotech crop commercialization. This increase is due primarily to greater profitability stemming from higher commodity prices, increased global and domestic market demand, and available seed technologies (Raman, 2017; Smyth, 2017; ISAAA, 2018).

Figs.1-3 show the global map of Biotech crop countries and mega-countries, indicating the type of crops and area of production (hectare), top 5 countries and info-graphics as described by ISAAA (2018).

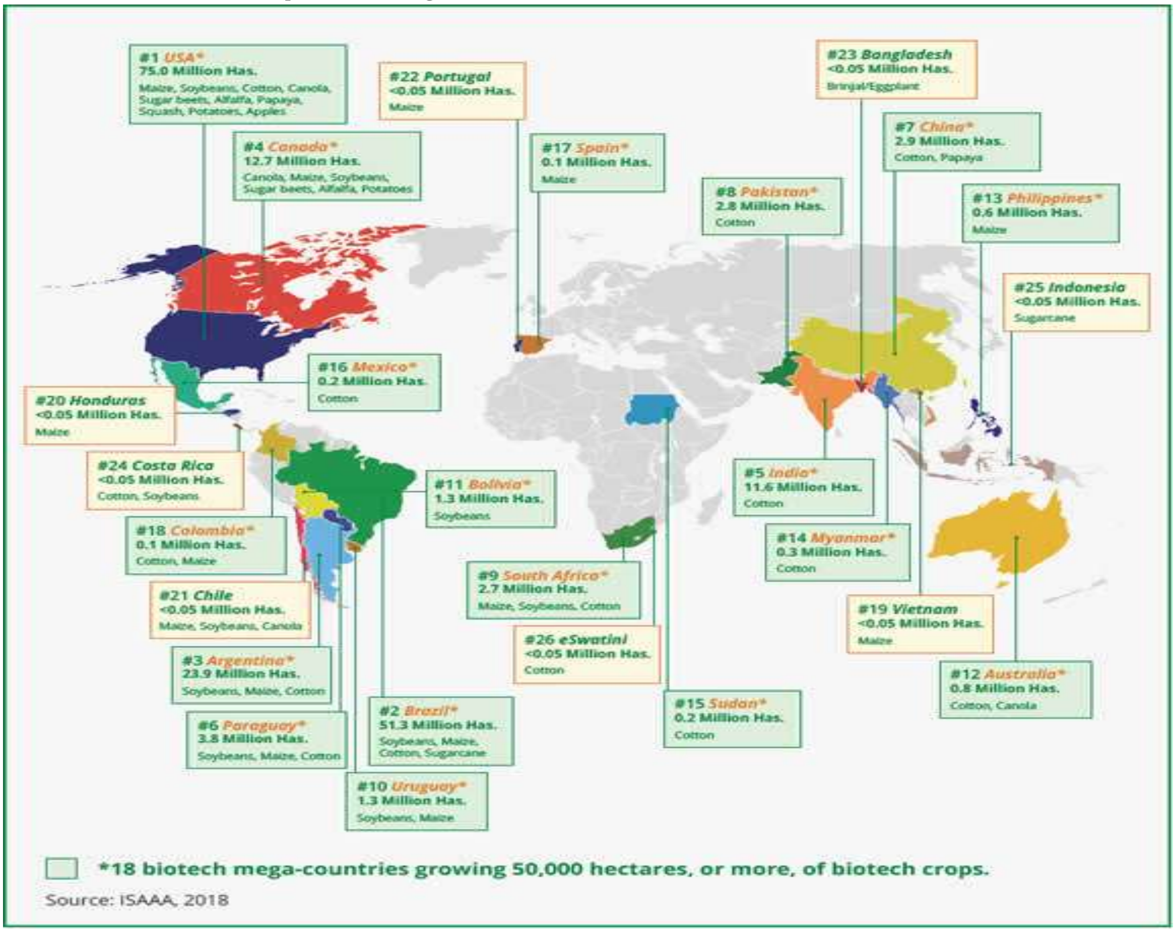

Fig. 1: Global status of commercialized GM crops 2018.

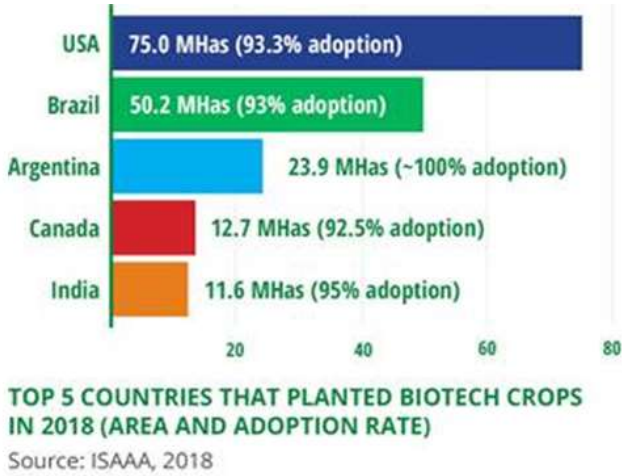

Fig. 2: Top 5 Countries that planted Biotech crops in 2018 (area and adoption rates). [Source: ISAAA, 2018]

Genetic engineering (GE) offers an expanding array of strategies for enhancing pest resistance of crop plants in sustainable ways, including the potential for reduced pesticide usage. Thus, pest management has changed dramatically during the past 23 years by the introduction of transgenes into crops for the purpose of pest management. GE crops are efficiently used in complementary to a diversified IPM plan (Kos *et al*., 2009). Despite the advantages of improving the efficiency of pest control, there are also challenges for successful implementation and sustainable use. One of the biggest challenges for sustainable use of the technology is the evolution of resistance. In this regard, challenges and solutions for successful implementation of an IPM approach were recently reviewed , in which the solutions include refuge compliance (Jin *et al*., 2015; Li *et al*., 2017; Reisig, 2017) and proper stewardship program (Anderson *et al*., 2019).According to ETS (2013) Stewardship program involve considerations at each of the seven stage of the Product Life Cycle namely (i) Research and Discovery, (ii) Product Development (iii) Seed or Plant Production (iv) Marketing and Distribution, (v) Crop Production (vi) Crop Utilization (vii) Product Discontinuation.

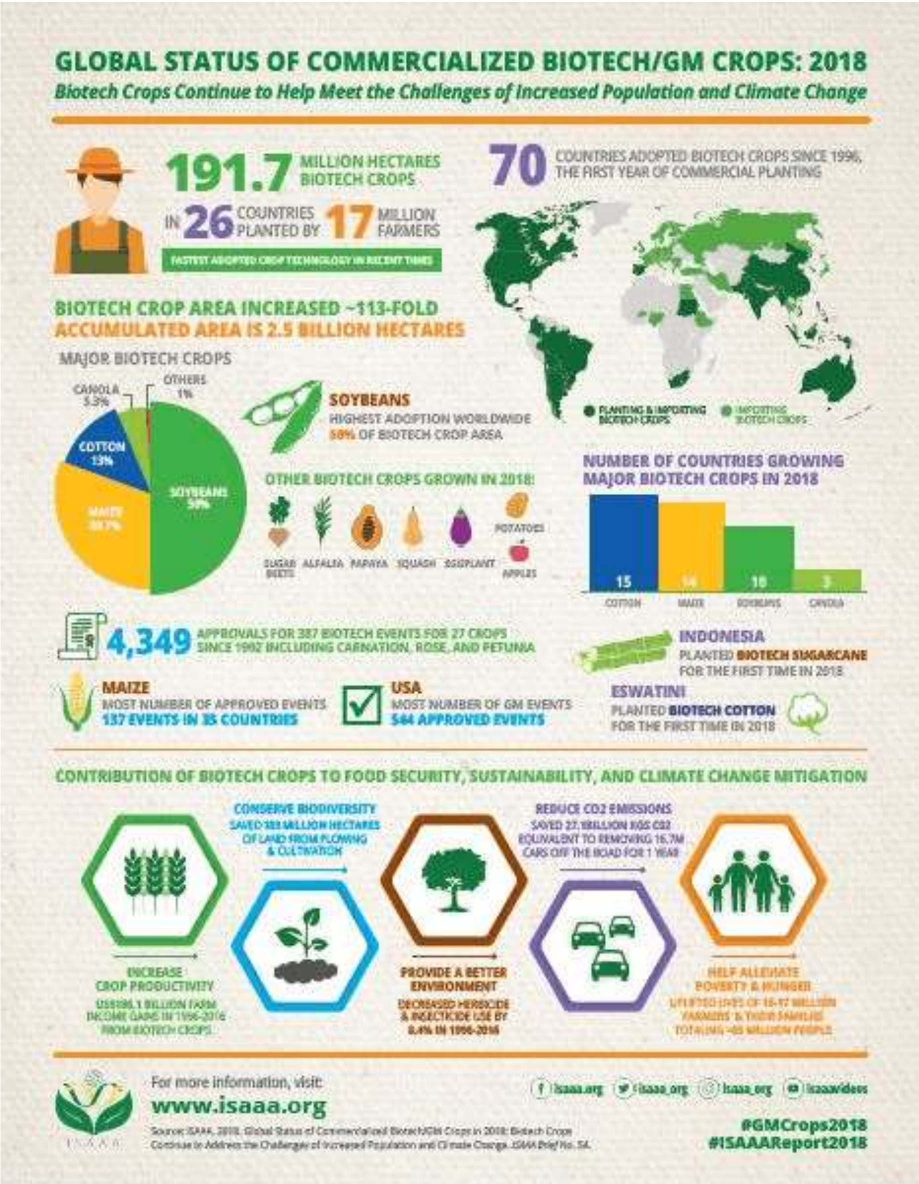

Fig. 3: Infographics of the global status of commercialized GM crops 2018.

Contribution of Biotech Crops to Sustainable Development

Meta-analysis of 147 studies during the past 20 years on Soybean, Maize, Cotton: multitude of benefits revealed that the use of GMO reduced pesticides use by 37%, increased yields by 22%, increased farmer profits by 68% (Klümper and Qaim, 2014).Various review reports showed the role of biotechnology in food security (Abah *et al*., 2010; Tonukari and Omotor, 2010; Najaf and Lee, 2014; Cano *et al*., 2017; Gartland and Gartland, 2018) and in sustainable development (Sharad *et al*., 2010; Adenle, 2015; Björnberg *et al*., 2015). Similarly, the contribution of GMO in food security has been reviewed by several scholars (Qaim and Kouser, 2013; Lamichhane, 2014; Hallerman and Grabau, 2016; Ouyang *et al*., 2017; Raman, 2017; Repalli, 2017; Smyth 2017; Gartland and Gartland, 2018; Terefe, 2018). Similarly, the present review is aiming at presenting the comprehensive and exhaustive account of these diverse applications that witnessed tremendous contribution of biotechnology and GMO in food security and sustainable development. Biotech crops, developed with improved traits such as increased yield, more resistance to pests, improved nutrition, among others, are undeniably necessary to address these global challenges affecting the lives of so many families globally (ISAAA,2018; Gebretsadik and Kiflu 2018).The contributions of GM crops in some countries were reviewed recently (Shetty *et al*., 2018; Anderson *et al*., 2019). It can be witnessed that the commercial applications of GM to horticultural crops lag far behind those of agronomic crops. In some respects, this is to be expected, since the majority of research and investment has been directed to commodities with the commercial value (Gaur *et al*., 2018; Shetty *et al*., 2018).

Biotechnology can also help conduct organic food production. Thus, organic farming can be achieved with the use of biotechnological tools (Dubey, 2014; Cano *et al*., 2017; Taheri *et al*., 2017). In this regard pest management (Brzozowski and Mazourek, 2018), durable molecular breeding (Gheysen and Custers, 2017) are also useful for organic farming. On the other hand, nanobiotechnology has been applied for crop production and precision agriculture (Duhan *et al*., 2017; Elemike *et al*., 2019; Sanzari *et al*., 2019; Shang *et al*., 2019) and plant disease management (Worralle *et al*., 2018). During the past two decades various application of biotechnology have provided reliable solutions to the management of several biotic and abiotic factors. It is to be noted that biotechnology or genetically engineering or GMO is not a panacea (cure-all) or silver bullet or magic bullet for addressing all agricultural constraints. Rather, it should be seen as one of the many undeniable modern tools available for use as the priority enabling strategy that immensely contributes to sustainable development.

Sustainable development is consisting of three interlinked dimensions namely economic profitability, social equity and environmental health aspects. Sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs (Björnberg *et al*., 2015). To this end, biotechnology is providing the building blocks for sustainable development as it can balance developmental needs (social and economic dimensions viz-a-viz food, feed and fiber production, renewable raw materials and energy) and environmental conservation (environment friendly technologies such as pollution prevention, and bioremediation).

In conclusion, as we are leading a competitive Knowledge based economy, doing things as usual cannot take us anywhere. Scientific advances are continuously witnessing that Knowledge and skills are always dynamic and new breakthroughs/innovations are emerging every day for humans to sustainably tap their natural resources and combat food insecurity and hunger. Some of the most disastrous nature's challenges can be addressed upon rigorous advanced scientific studies fueled by new breakthroughs. To this end, instead of being confused with unscientific advocacy of side effects, it is always helpful and mandatory to develop the necessary capacity (skilled manpower, infrastructure, policy and regulations) in order to harness the technology and better cope up with the inevitable emerging and outbreaks of pests that severely threaten sustainable development. It is only through continuous harnessing of such novel technologies that sustainable development can be achieved.

Conflict of Interest

The authors declare that there is no conflict of interest with present publication.

References

Abah J, Ishaq MN and Wada AC (2010) The role of biotechnology in ensuring food security and sustainable agriculture. *African Journal of Biotechnology* **9**(52): 8896-8900.

Aboutorabi M (2018) A Review on the Biological Control of Plant Diseases using Various Microorganisms. *Journal of Research in Medical and Dental Science* **6**(4): 30-35.

Abtew A, Subramanian S, Cheseto X, Kreiter S, Garzia GT and MartinT (2015) Repellency of Plant Extracts against the Legume Flower Thrips Megalurothrips sjostedti (Thysanoptera: Thripidae). *Insects* **6**: 608-625. DOI: 10.3390/insects6030608

Adenle AA (2015) Role of Modern Biotechnology in Sustainable Development; Addressing Social-Political Dispute of GMOs that Influences Decision-Making in Developing countries. *Brief for GSDR* 2015. https://sustainabledevelopment.un.org/content/documents/6539117.

Ahanger RA, Bhatand HA and Dar NA (2014) Biocontrol agents and their mechanism in plant disease management. *Sciencia Acta Xaveriana An International Science Journal* **5**(1): 47-58.

Ahmed KS, Majeed MZ, Haidary AA and Haider N (2016) Integrated pest management tactics and predatory coccinellids: *A review. Journal of Entomology and Zoology Studies* **4**: 591-600.

Ajmal M, Ali HI, Saeed R, Akhtar A, Tahir M, Mehboob MZ and Ayub A (2018) Biofertilizer as an Alternative for Chemical Fertilizers. Research & Reviews: *Journal of Agriculture and Allied Sciences* **7**(1): 1-7.

Alemayehu D (2017). Application of Genetic Engineering in Plant Breeding for Biotic Stress Resistance. *International Journal of Research Studies in Biosciences* **5**(9): 28-35. DOI: 10.20431/2349-0365.0509006

Alghuthaym MA, Almoammar H, Raic M, Said-Galievd E and Abd-Elsalame KA (2015). Myconanoparticles: synthesis and their role in phytopathogens management. *Biotechnology and Biotechnological Equipment* **29**(2): 221-236. DOI: 10.1080/13102818.2015.1008194

Ali F, Pan Q, Chen G, Zahid KR and Yan J (2013). Evidence of Multiple Disease Resistance (MDR) and Implication of Meta-Analysis in Marker Assisted Selection. *PLoS ONE* **8**(7): e68150. DOI: 10.1371/journal.pone.0068150

Ali R, Hash CT, Damaris O, Elhussein A and Mohamed AH (2016). Introgression of Striga Resistance into Popular Sudanese Sorghum Varieties Using Marker Assisted Selection. *World Journal of Biotechnology* **01**(01): 48-58.

Alireza T and Nader RE (2015) Molecular Farming in Plants. DOI: 10.5772/60757

Alkimim ER, Caixeta ET, Sousa TV, Pereira AA, de Oliveira ACB, Zambolim L, Sakiyama NS (2017). Marker-assisted selection provides arabica coffee with genes from other *Coffea* species targeting on multiple resistance to rust and coffee berry disease. *Molecular Breeding* **37**: 6. DOI: 10.1007/s11032-016-0609-1

Alphey N, Bonsall MB (2018). Genetics-based methods for agricultural insect pest management. *Agricultural and Forest Entomology* **20**: 131–140. DOI: 10.1111/afe.12241

Ameen A and Raza S (2017) Green Revolution: A Review. *International Journal of Advances in Scientific Research* **3**(12): 129-137. DOI: 10.7439/ijasr.v3i12.4410

Anderson JA, Ellsworth PC, Faria JC, Head GP, Owen MDK, Pilcher, CD, Shelton, AM, Meissle, M (2019). Genetically Engineered Crops: Importance of Diversified Integrated Pest Management for Agricultural Sustainability. *Frontiers in Bioengineering and Biotechnology* **7**: 24. DOI: 10.3389/fbioe.2019.00024

Andolfo G, Iovieno P, Frusciante L and Ercolano MR (2016). Genome-Editing Technologies for Enhancing Plant Disease Resistance. *Frontiers in Plant Science* **7**: 1813. DOI: 10.3389/fpls.2016.01813

Ariizumi T, Shinozaki Y and Ezura H (2013). Genes that influence yield in tomato. *Breeding Science* **63**: 3–13. DOI: 10.1270/jsbbs.63.3

Arora L and Narula A (2017). Gene Editing and Crop Improvement Using CRISPR-Cas9 System. *Frontiers in Plant Science* **8**: 1932. DOI: 10.3389/fpls.2017.01932

Arya M (2018) Evolving Paradigms in Biotechnology for Management of Crop Diseases. *International Journal of Agriculture, Environment and Biotechnology* **11**(3): 553-564. DOI: 10.30954/0974-1712.06.2018.24

Ashraf R, Sultana B, Yaqoob S and Iqbal M (2017). Allelochemicals and crop management: *A review. Current Science Perspectives* 3(1): 1-13.

Aslam M, Zaman QU, Maqbool MA (2016) Current Status of RNAi Based Crop Breeding. *Journal of Agricultural Basic Sciences* **01**(02): 64-83.

Badji A, Otim M, Machida L, Odong T, Kwemoi DB, Okii D, Agbahoungba S, Mwila N, Kumi F, Ibanda A, Mugo S, Kyamanywa S and Rubaihayo P (2018) Maize Combined Insect Resistance Genomic Regions and Their Co-localization With Cell Wall Constituents Revealed by Tissue-Specific QTL Meta-Analyses. *Frontiers in Plant Science* 9: 895. DOI. 10.3389/fpls.2018.00895

Badu M, Tripathy B, Sahu GS, Jena AK (2017). Role of doubled haploids in vegetable crop improvement. *Journal of Pharmacognosy and Phytochemistry* 6(6): 384-389.

Barakate A, Stephens J (2016). An Overview of CRISPR-Based Tools and Their Improvements: New Opportunities in Understanding Plant-Pathogen Interactions for Better Crop Protection. *Frontiers in Plant Science* **7**: 765. Doi: 10.3389/fpls.2016.00765

Barratt BIP, Moran VC, Bigler F, and an Lenteren JC (2018) The status of biological control and recommendations for improving uptake for the future. *BioControl* **63**: 155–167. DOI: 10.1007/s10526-017-9831-y

Barzman M, Bàrberi P, Birch NE, Boonekamp P, Dachbrodt-Saaydeh S, Graf B, Hommel B, Jensen JE, Kiss J, Kudsk P, Lamichhane JR, Messéan A, Moonen AC, Ratnadass A, Ricci P, Sarah JL and Sattin M (2015) Eight principles of integrated pest management. *Agronomy and Sustainable Development*. **35**: 1199–1215 DOI 10.1007/s13593-015-0327-9

Begheyn RF, Lübberstedt T and Studer B (2016) Haploid and Doubled Haploid Techniques in Perennial Ryegrass (*Lolium perenne* L.) to Advance Research and Breeding. *Agronomy* **6**: 60. DOI: 10.3390/agronomy6040060

Bernard G, Gagneul D, Santos HAD, Etienne A, Hilbert JL and Rambaud C (2019) Efficient Genome Editing Using CRISPR/Cas9 Technology in Chicory. *International Journal of Molecular Science* 20: 1155. DOI: 10.3390/ijms20051155

Bhagat S, Birah A, Kumar R, Yadav MS, Chattopadhyay CD (2014). Singh (ed.). *Advances in Plant Biopesticides* 119. DOI: 10.1007/978-81-322-2006-0_7

Bhardwaj D, Ansari MW, Ranjan, Sahoo K and Tuteja N (2014) Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories* **13**: 66. http://www.microbialcellfactories.com/content/13/1/66

Bhattacharjee P, Das U, Reddy MV, Gogoi S, Gangaraja MM (2017). Role and recent advances in genetic engineering and biotechnology for improvement of fruit crops. *Journal of Pharmacognosy and Phytochemistry* **SP1**: 79-87.

Bhattacharyya M (2017) The push-pull strategy: A new approach to the eco-friendly method of pest management in agriculture. *Journal of Entomology and Zoology Studies* **5**(3): 604-607.

Björnberg KE, Jonas E, Marstorp H and Tidåker P (2015) The Role of Biotechnology in Sustainable Agriculture: Views and Perceptions among Key Actors in the Swedish Food Supply Chain. *Sustainability* **7**: 7512-7529; DOI: 10.3390/su7067512

Borrelli VMG, Brambilla V, Rogowsky P, Marocco A, Lanubile A (2018). The Enhancement of Plant Disease Resistance

Using CRISPR/Cas9 Technology. *Frontiers in Plant Science* **9**: 1245. DOI: 10.3389/fpls.2018.01245

Braga RM, Dourado MN and Araújo WL (2016) Microbial interactions: ecology in a molecular perspective. *Brazilian Journal of Microbiology* **47S**: 86-98. DOI: 10.1016/j.bjm.2016.10.005

Brzozowski L and Mazourek M (2018). A Sustainable Agricultural Future Relies on the Transition to Organic Agroecological Pest Management. *Sustainability* **10**: 2023; DOI: 10.3390/su10062023

Butt H, Jamil M, Wang JY, Al-babili S and Mahfouz M (2018) Engineering plant architecture via CRISPR/ Cas9-mediated alteration of strigolactone biosynthesis. *BMC Plant Biology* **18**: 174. DOI: 10.1186/s12870-018-1387-1

Buyel JF (2019) Plant Molecular Farming – Integration and Exploitation of Side Streams to Achieve Sustainable Biomanufacturing. *Frontiers in Plant Science* **9**: 1893. DOI: 10.3389/fpls.2018.01893

Byers SM (2019) CRISPR-CAS9: An Overview of Modern Genetic Editing. *Journal of Bioinformatics and Systematic Biology* **2**: 033-041 DOI: 10.26502/fjbsb006

Calicioglu O, Flammini A, Bracco S, Bellu L and Sims R (2019) The Future Challenges of Food and Agriculture: An Integrated Analysis of Trends and Solutions. *Sustainability* **11**: 222; DOI: 10.3390/su11010222

Cano A, Díaz D and Morgado C (2017) The role of biotechnology in agricultural production and food supply. *Ciencia e Investigación Agraria* **44**(1): 1-11. DOI: 10.7764/rcia.v44i1.1567

Caserta R and de Souza AA (2017) Genetically Modified Plants: Think Twice before Saying "No". *JSM Genetics and Genomics* 4(1): 1021.

Cavoski I, Caboni P and Miano T (2011) Natural Pesticides and Future Perspectives. pp. 170-190. In: Margarita Stoytcheva (Ed.), *Pesticides in the Modern World - Pesticides Use and Management*, ISBN: 978- 953-307-459-7, InTech, Available from: http://www.intechopen.com/books/pesticides-in-the-modern-worldpesticides-use-and-management/natural-pesticides-and-future-perspectives.

CBD (Convention on Biological Diversity) (1992) Convention on Biological Diversity. United Nations. http:/www.cbd.int/doc/legal/cbd-en.pdf

Chauhan BS, Matloob A, Mahajan G, Aslam F, Florentine SK and Jha P (2017) Emerging Challenges and Opportunities for Education and Research in Weed Science. *Frontier in Plant Science* **8**:1537. DOI: 10.3389/fpls.2017.01537

Chauhan P and Kumar P (2015) Molecular Markers: Application in Plant Improvement Programmes. *International Journal of Applied and Pure Science and Agriculture* **01**(07): 74-90.

Chen L, Wang G, Zhu YN, Xiang H and Wang W (2016) Advances and perspectives in the application of CRISPR/Cas9 in insects. *Zoological Research* 37(4): 220-228.

Consortium R (2016) Combining Selective Pressures to Enhance the Durability of Disease Resistance Genes. *Frontiers in Plant Science* **7**:1916. DOI: 10.3389/fpls.2016.01916

Council for Agricultural Science and Technology (CAST) (2017) Crop Protection Contributions toward Agricultural Productivity—A paper in the Series on The Need for Agricultural Innovation to Sustainably Feed the World by 2050. Issue Paper 58. *CAST*, Ames, Iowa.

Damalas CA and Koutroubas SD (2018) Current Status and Recent Developments in Biopesticide Use. *Agriculture* **8**: 13; DOI: 10.3390/agriculture8010013

Damos P, Colomar LAE and Ioriatti C (2015) Integrated Fruit Production and Pest Management in Europe: The Apple Case Study and How Far We Are From the Original Concept? *Insects* **6**: 626-657. DOI: 10.3390/insects6030626

Dar SA, Rather BA and Kandoo A (2017a) Insect pest management by entomopathogenic fungi. *Journal of Entomology and Zoology Studies* **5**(3): 1185-1190.

Dar SA, Wani A and Kandoo AA (2017b) Genetic engineering and insect resistance. *Journal of Entomology and Zoology Studies* **5**(3): 1175-1184.

Dara SK (2019) The New Integrated Pest Management Paradigm for the Modern Age. *Journal of Integrated Pest Management* **10**(1): 12; 1–9. DOI: 10.1093/jipm/pmz010

Das G and Rao GJN (2015) Molecular marker assisted gene stacking for biotic and abiotic stress resistance genes in an elite rice cultivar. *Frontiers in Plant Science*. 6: 698. DOI: 10.3389/fpls.2015.00698

Das G, Patra JK and Baek KH (2017) Insight into MAS: A Molecular Tool for Development of Stress Resistant and Quality of Rice through Gene Stacking. *Frontiers in Plant Science* **8**: 985. DOI: 10.3389/fpls.2017.00985

Das S (2015) RNA Interference: An Environment Friendly Approach for Targeted Pest Management. *Entomol Ornithol Herpetol* **4**: e112. DOI: 10.4172/2161-0983.1000e112

Dayou O, Mwangi M, Egesa AO, Muteti PM and Chumba CI (2018) Application of molecular and biotechnological techniques in plant disease management: A review. *African Journal of Biotechnology* **17**(31): 938-948. DOI: 10.5897/AJB2018.16532

De Buck S, Ingelbrecht I, Heijde M and Van Montagu M (2016) Innovative farming and forestry across the emerging world: the role of genetically modified crops and trees. Gent, Belgium. International Industrial Biotechnology Network (IIBN). ISBN 9789081781237.

Dermawan H, Karan R, Jung JH, Zhao Y, Parajuli S, Sanahuja G and Altpeter F (2016) Development of an intragenic gene transfer and selection protocol for sugarcane resulting in resistance to acetolactate synthase-inhibiting herbicide. Plant Cell Tissue Organ Culture. DOI: 10.1007/s11240-016-1014-5

DeVilliers SM and Hoisington DA (2011) The trends and future of biotechnology crops for insect pest control:Review. *African Journal of Biotechnology* **10**: 4677-4681.

Dhillon MK and Sharma HC (2012) Paradigm Shifts in Research on Host Plant Resistance to Insect Pests Resistance to Insect Pests Resistance to Insect Pests Resistance to Insect Pests. *Indian Journal of Plant Protection* **40**(01): 1-11.

Dirks R, van Dun K, de Snoo CB, van den Berg M, LeliveltCLC, Voermans W, Woudenberg L, de Wit JP, Reinink K, Schut JW, van der Zeeuw E, Vogelaar A, Freymark G, Gutteling EW, Keppel MN, van Drongelen P, Kieny M, Ellul P, Touraev A, Ma H, de Jong H and Wijnker E (2009) Reverse breeding: a novel breeding approach based on engineered meiosis. *Plant Biotechnology Journal* **7**: 837–845. DOI: 10.1111/j.1467-7652.2009.00450.x

Dong OX and Ronald PC (2019) Genetic Engineering for Disease Resistance in Plants: Recent Progress and Future Perspectives. *Plant Physiology* **1**: 26–38. DOI: 10.1104/pp.18.01224

Drmic Z, Tóth M, Lemic D, Grubišic D, Pospišil M and Bažok R (2017) Area-wide mass trapping by pheromone-based attractants for the control of sugar beet weevil (*Bothynoderes punctiventris* Germar, Coleoptera: Curculionidae). Pest Management Science. DOI 10.1002/ps.4601

Duan CG, Wang CH and Guo HS (2012) Application of RNA silencing to plant disease resistance. *Silence* **3**: 5. DOI: 10.1186/1758-907X-3-5

Dubey RK (2014). Role of Organic Agri-Biotech in Green Growth and Sustainable Development. *International Journal of Innovative Research in Science, Engineering and Technology* **3**(1): 8555-8563.

Duhan JS, Kumar R, Kumar N, Kaur P, Nehra K and Duhan S (2017) Nanotechnology: The new perspective in precision agriculture: Review. *Biotechnology Reports* **15**: 11–23. 10.1016/j.btre.2017.03.002.

Duke SO (2011). Comparing Conventional and Biotechnology-Based Pest Management. *Journal of Agricuture and Food Chemistry* **59**: 5793–5798. DOI: 10.1021/jf200961r

Duke SO, Dayan FE, Scheffler BE and Boyette CD (2015) Biotechnology in Weed Control. Kirk-Othmer Encyclopedia of Chemical Technology John Wiley & Sons. DOI: 10.1002/0471238961.herbduke.a01.pub2

Dunwell JM (2010) Crop biotechnology: prospects and opportunities. *Journal of Agricultural Science* 1-11. DOI: 10.1017/S0021859610000833

Dutta S and Roy M (2016) Towards Engineering Transgenics Tolerant to Biotic and Abiotic Stresses in Crop Plants –A Review. *International Journal of Innovative Research in Science, Engineering and Technology* 5: 1577-1556. DOI: 10.15680/IJIRSET.2016.0502077

Dwivedi SL, Crouch JH, Mackil DJ, Xu Y, Blair MW, Ragot M, Upadhyaya HD and Ortiz R (2007) The Molecularization of Public Sector Crop Breeding: Progress, Problems, and Prospects. *Advances in Agronomy* **95**: 163-318. DOI: 10.1016/S0065-2113(07)95003-8

Eckerstorfer MF, Engelhard M, Heissenberger A, Simon S and Teichmann H (2019) Plants Developed by New Genetic Modification Techniques—Comparison of Existing Regulatory Frameworks in the EU and Non-EU Countries. *Frontiers Bioengineering. Biotechnology* 7: 26. DOI: 10.3389/fbioe.2019.00026

El Meskaoui A (2013) Plant Cell Tissue and Organ Culture Biotechnology. and Its Application in Medicinal and Aromatic Plants. *Medicinal Aromatic Plants* **2**: e147. DOI: 10.4172/2167-0412.1000e147

Elemike EE, Uzoh IM, Onwudiwe DC, Babalola OO (2019) The Role of Nanotechnology in the Fortification of Plant Nutrients and Improvement of Crop Production. *Applied Science*. **9**: 499. DOI: 10.3390/app9030499

El-Shafie FAF and Faleiro JR (2017) Semiochemicals and Their Potential Use in Pest Management. 10.5772/66463.

Enyiukwu DN, Ononuju CC, Awurum AN and Nwaneri JA (2016) Modes of Action of Potential Phyto-Pesticides from Tropical Plants in Plant Health Management. IOSR *Journal of Pharmacy* **6**: 01-17. DOI: 10.9790/3013-06710117

Espinoza C, Schlechter R, Herrera D, Torres E, Serrano A, Medina C and Arce-Johnson P (2013) Cisgenesis and Intragenesis: New tools For Improving Crops. *Biological Research* **46**: 323-331. DOI: 10.4067/S0716-97602013000400003

ETS (Excellence Through Stewardship) (2013) Advancing Best Practices in Agricultural Biotechnology. https://www.excellencethroughstewardship.org/

EU (European Union) (2010). A Decade of EU-funded GMO Research (2001-2010) (2013) https://ec.europa.eu/research/biosociety/pdf/a_decade_of_eu-funded_gmo_research.pdf

Fagwalawa LD, Kutama AS and Yakasai MT (2013). Current Issues in Plant Disease Control: Biotechnology and Plant Disease. *Bayero Journal of Pure and Applied Sciences* **6**(2): 121 - 126. DOI: 10.4314/bajopas.v6i2.26

FAO-Food and Agriculture Organizations of the United Nations (2017) The Future of Food and Agriculture: Trends and Challenges; FAO: Rome, Italy, ISBN 9789251095515. http://www.fao.org/3/a-i6583e.pdf.

Farokhzadeh S and AliFakheri B (2014) Marker-assisted Selection for Disease Resistance: Applications in Breeding (Review). *International Journal of Agriculture and Crop Sciences* **7**: 1392-1405.

Fartyal D, Agarwal A, James D, Borphukan B, Ram B, Sheri V, Agrawal PK, Achary MM and Reddy MK (2018) Developing dual herbicide tolerant transgenic rice plants for sustainable weed management. *Scientific Reports* **8**: 11598. DOI: 10.1038/s41598-018-29554-9

Fermin-Munoz GA, Meng B, Ko K, Mazumdar-Leighton S, Guba A and Carroll JE (2000) Biotechnology: A new era for plant pathology and plant protection. *APSnet Feature*. Online. DOI: 10.1094/APSnetFeature-2000-0500

Fernández-Aparicio M, Reboud X and Gibot-Leclerc S (2016) Broomrape Weeds. Underground Mechanisms of Parasitism and Associated Strategies for their Control: A Review. *Frontiers in Plant Science* **7**: 135. DOI: 10.3389/fpls.2016.00135

Fraiture MA, Herman P, Taverniers I, De Loose M, Deforce D, Nancy H and Roosens NH (2015) Current and New Approaches in GMO Detection: Challenges and Solutions. BioMed Research International **2015**, Article ID 392872, 22 DOI: 10.1155/2015/392872

Fujita D, Myint KK, Matsumura M and Yasui H (2009) The genetics of host-plant resistance to rice planthopper and leafhopper. pp 389-400 In: Heong KL, Hardy B, editors. 2009. Planthoppers: new threats to the sustainability of intensive rice production systems in Asia. Los Baños (Philippines): International Rice Research Institute.

Gaikwad AV, Singh SK and Gilhotra R (2017). Plant Tissue Culture-A Review. *Journal of Pharmaceutical Research & Education* **2**(1): 217-220.

Gangwar RK (2017) Role of Biological Control Agents in Integrated Pest Management Approaches. *Acta Scientific Agriculture* **1**: 09-11.

Gantz VN and Akbari OS (2018) Gene editing technologies and applications for insects. *Current Opinion in Insect Science* **28**: 66–72. DOI: 10.1016/j.cois.2018.05.006

Gao D and Sun L (2013) *In vitro* Screening and Molecular Characterization. of a Bacterial Blight Resistance Gene in Rice. *Journal of Rice Research* **1**: 104. DOI: 10.4172/jrr.1000104

Gartland KMA and Gartland JS (2018) Contributions of biotechnology to meeting future food and environmental security needs. *The EuroBiotech Journal* **2**(1): DOI: 10.2478/ebtj-2018-0002

Gaur RK, Verma RK and Khurana SMP (2018) Genetic Engineering of Horticultural. Crops: Present and Future. In: Rout, G.R., Peter, K.V. (Eds.), Genetic Engineering of Horticultural Crops. Academic Press, Elsevier pp. 23–46. DOI: 10.1016/B978-0-12-810439-2.00002-7

Gebretsadik K and Kiflu A (2018) Challenges and Opportunities of Genetically Modified Crops Production; Future Perspectives in Ethiopia, Review. *The Open Agriculture Journal* **12**: 240-150. DOI: 10.2174/1874331501819010240

Georges F and Ray H (2017) Genome editing of crops: A renewed opportunity for food security. *GM Crops and Food* **8**:1-12, DOI: 10.1080/21645698.2016.1270489

Ghaffar I, Shams F, Khalid A, Ashraf F, Rehman R and Fareed MI (2016) Recent advances in molecular tactics for crop improvements. *International Journal of Biotechnology and Food Science* **4**(5): 72-80.

Ghanian M, Ghoochani OM and Dorani M (2016) The Gene Revolution: Is it a Solution for Solving Food Insecurity Issues? *Annals of Agricultural and Crop Sciences* **1**(3): 1012.

Gheysen G and Custers R (2017) Why Organic Farming Should Embrace Co-Existence with Cisgenic Late Blight–Resistant Potato. *Sustainability* **9**: 172; DOI: 10.3390/su9020172

Ghimire B (2017) Use of Crispr/Cas9 for Development of Disease Resistant Cultivars in Plant Breeding. *International Journal of Applied Science and Biotechnology* **5**(4): 403-409. DOI: 10.3126/ijasbt.v5i4.18523

Ghosh RK, Shamurailatpam D, Ghosh A, Sentharagai S and Labar A (2015) Use of botanical herbicides in system intensification. *Indian Journal of Weed Science* **47**: 401–407.

Gianessi L, Sankula S and Reigner N (2003) Plant Biotechnology: Potential Impact for Improving Pest Management in European Agriculture. A Summary of Nine Case Studies. The National Center for Food and Agricultural Policy. Full Report: www.ncfap.org.

Gilchrist E and Haughn G (2010) Reverse genetics techniques: engineering loss and gain of gene function in plants. *Briefings in Functional Genomics* **9**(2): 103-110. DOI: 10.1093/bfgp/elp059

Goold HD, Wright P and Hailstones D (2018) Emerging Opportunities for Synthetic Biology in Agriculture. *Genes* 9: 341. DOI: 10.3390/genes9070341

Gosal SS, Wani SH and Kang MS (2010) Biotechnology and Crop Improvement. *Journal of Crop Improvement* **24**:153–217. DOI: 10.1080/15427520903584555

Gozel U and Gozel C (2016). Entomopathogenic Nematodes in Pest Management. DOI: 10.5772/63894.

Gressel J (2000) Molecular biology of weed control. *Transgenic Research* **9**: 355–382. DOI: 10.1023/A:1008946628406

Guleria S and Tiku AK (2009) Botanicals in Pest Management: Current Status and Future Perspectives Chapter 12. pp. 317-329. In: R. Peshin, A.K. Dhawan (eds.), Integrated Pest Management: Innovation-Development. Process, DOI: 10.1007/978-1-4020-8992-3_12

Gurjar MS, Ali S, Akhtar M and Singh KS (2012) Efficacy of plant extracts in plant disease management. Agricultural Sciences 3 425-433. 10.4236/as.2012.33050

Hahne G, Tomlinson L and Nogué F (2019). Precision genetic engineering tools for next-generation plant breeding. Plant Cell Reports 38:435–436.DOI: 10.1007/s00299-019-02400-6

Hallerman E and Grabau E (2016) Crop biotechnology: a pivotal moment for global acceptance. *Food and Energy Security* **5**(1): 3–17. d DOI: 10.1002/fes3.76

Harding DP and Raizada MN (2015) Controlling weeds with fungi, bacteria and viruses: a review. *Frontiers in Plant Science* **6**: 659. DOI: 10.3389/fpls.2015.00659

Harker KN and O'Donovan JT (2013) Recent Weed Control, Weed Management, and Integrated Weed Management. *Weed Technology* **27**: 1–11. DOI: 10.1614/WT-D-12-00109.1

Haymer D (2016) Molecular genetics and insect pest management. *Review Agron. Noroeste Argent* **36**(1): 9-18.

Herdt RW (2006) Biotechnology in Agriculture. Annual Review of Environmental. *Resources*. 31:265–95. DOI: 10.1146/annurev.energy.31.031405.091314

Hidayat R, Irsan C and Setiawan A (2018) Diversity of Phytophagous and Entomophagous Insect on Yellow Alder Flower (*Turnera subulata* J.E SM and *Turnera ulmifolia* L.) Around The Palm Oil (*Elaeis guineensis* J.) Plantations. *Science and Technology Indonesia* **3**(3): 130-133. DOI: 10.26554/sti.2018.3.3.130-133

Hikal WM, Baeshen RS and Said-Al Ahl MAH (2017) Botanical insecticide as simple extractives for pest control. Cogent Biology 3: 1404274. DOI: 10.1080/23312025.2017.1404274.

Holme IB, Wendt T and Holm PB (2013) Intragenesis and cisgenesis as alternatives to transgenic crop development. *Plant Biotechnology Journal* **11**: 395–407. DOI: 10.1111/pbi.12055

Hopfenberg R and Pimentel D (2001) Human Population Numbers as a Function of Food Supply. *Environment, Development and Sustainability* **3**: 1–15. DOI: 10.1023/A:1011463231976

Hunt BG, Glastad KM, Yi SV and Goodisman MAD (2014) The Function of Intragenic DNA Methylation: Insights from Insect Epigenomes. *Integrative and Comparative Biology* 1–10. DOI: 10.1093/icb/ict003

Hussain A, Qarshi IA, Nazir H and Ullah I (2012) Plant Tissue Culture: Current Status and Opportunities. *InTech*. pp. 1-28. DOI: 10.5772/50568.

Hussain B (2015) Modernization in plant breeding approaches for improving biotic stress resistance in crop plants. *Turkish Journal of Agriculture and Forestry* **39**: DOI: 10.3906/tar-1406-176

ISAAA (International Service for the Acquisition of Agri-biotech Applications) (2018). Global Status of Commercialized Biotech/GM Crops in 2018: Biotech Crop Adoption Surges as Economic Benefits Accumulate in 23 Years. ISAAA Brief No. 54. ISAAA: Ithaca, NY.

ISPM (International Standard for Phytosanitary Measures) (2006) Glossary of phytosanitary terms. International Standard for Phytosanitary Measures No. 5. Rome, Italy: FAO. https://www.ippc.int/largefiles/adopted_ISPMs _previous versions/en/ISPM_05_2006_En_2006-07-04.pdf.

Itelima JU, Bang WJ, Onyimba IA, Sila MD and Egbere OJ (2018) Bio-fertilizers as key player in enhancing soil fertility and crop productivity: A Review. *Direct Research Journal of Agriculture and Food Science* 6(3): 73-83.

Jaba J and Sharma P (2017) Advance towards Host Mediated RNA Interference Insect Pest Management. *Advances in Biotechnology and Microbiology* **5**:. 555666. DOI: 10.19080/AIBM.2017.05.555666

Jaiswal DK, Raju SVS, Kumar GS, Sharma KR, Singh DK and Vennela PR (2018) Biotechnology in Plant Resistance to Insects. *Indian Journal of Agriculture and Allied Sciences* **4**(1): 1-18.

Jansing J, Schiermeyer A, Schillberg S, Fischer R and Bortesi L (2019) Genome Editing in Agriculture: Technical and Practical Considerations. *International Journal of Molecular. Science* **20**: 2888; DOI: 10.3390/ijms20122888

Jeandet P, Hébrard C, Deville MA, Cordelier S, Dorey S, Aziz A and Crouze J (2014) Deciphering the Role of Phytoalexins in Plant-Microorganism Interactions and Human Health. *Molecules* **19***:* 18033-18056; DOI: 10.3390/molecules191118033

Jin L, Zhang H, Lu Y, Yang Y, Wu K, Tabashnik BE and Wu Y (2015) Large-scale test of the natural refuge strategy for delaying insect resistance to transgenic Bt crops. *Nature Biotechnology* **33**(2): 169-179. DOI: 10.1038/nbt.3100

Jo KR, Kim CJ, Kim SJ, Kim TY, Bergervoet M,Jongsma MA, Visser, RGF, Evert Jacobsen, E and Vossen, JH (2014) Development of late blight resistant potatoes by cisgene stacking. *BMC Biotechnology* **14**: 50. DOI: 10.1186/1472-6750-14-50

Jonah PM, Bello LL, Lucky O, Midau A and Moruppa SM (2011) The Importance of Molecular Markers in Plant Breeding Programmes Review. *Global Journal of Science Frontier Research* **11**(5): 5-12.

Joshi RK and Nayak S (2010) Gene pyramiding-A broad spectrum technique for developing durable stress resistance in crops. *Biotechnology and Molecular Biology Review* **5**(3): 51-60.

Juroszek P and Von Tiedemann A (2013) Plant pathogens, insect pests and weeds in a changing global climate: a review of approaches, challenges, research gaps, key studies and concepts. *Journal of Agricultural Science* **151**: 163–188. DOI: 10.1017/S0021859612000500

Kenis M, Hurle BP, Hajek A and Cock MJW (2017) Classical biological control of insect pests of trees: facts and figures. *Biological Invasions* **19**: 3401–3417. DOI: 10.1007/s10530-017-1414-4

Kergunteuil A, Bakhtiari M, Formenti L, Xiao Z, Defossez E and Rasmann S (2016) Biological Control beneath the Feet: A Review of Crop Protection against Insect Root Herbivores. *Insects* **7**: 70; DOI: 10.3390/insects7040070

Khan A, Abidi I, Bhat MA, Dar ZA, Ali G, Shikari AB and Khan MA (2018a) Tilling and Eco-Tilling – A Reverse Genetic Approach for Crop Improvement. *International Journal of Current Microbiology and Applied Science* **7**(06): 15-21. DOI: 10.20546/ijcmas.2018.706.003.

Khan FF, Ahmed K, Ahmed A and Haider S (2018b) Applications of Biotechnology in Agriculture- Review Article. *World Journal of Biotechnology* **2**: 135-138. DOI: 10.33865/wjb.002.01.0014

Khan ZR, Midega CAO, Pittchar JO, Pickett JA and Bruce TJA (2011) Push–pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa. *International Journal of*

Agricultural Sustainability **9**(1): 162–170, DOI: 10.3763/ijas.2010.0558

Khan ZR, Midega CAO, Pittchar JO, Murage AW, Birkett MA, Bruce TJA and Pickett JA (2014). Achieving food security for one million sub-Saharan African poor through push – pull innovation by 2020. *Philos Trans R Soc Lond B Biol Sci* **369**: 20120284.DOI: 10.1098/rstb.2012.0284

Khera P, Pandey MK and Varshney RK (2013) Pest and diseases: Old and new threats – Modern breeding tools to tailor new crop cultivars. *Secheresse* **24**: 261-73. DOI: 10.1684/sec.2014.0410

Kirk WDK (2017) The aggregation pheromones of thrips (Thysanoptera) and their potential for pest management. *International Journal of Tropical Insect Science* **37**(2): 41–49. DOI: 10.1017/S1742758416000205

Kitherian S (2017) Nano and bio-nanoparticles for insect control. *Research Journal of Nanoscience and Nanotechnology* **7**: 1-9. DOI: 10.3923/rjnn.2017.1.9

Klümper W and Qaim M (2014) A Meta-Analysis of the Impacts of Genetically Modified Crops. *PLoS ONE* **9**(11): e111629. DOI: 10.1371/journal.pone.0111629.

Kniss AR (2018) Genetically Engineered Herbicide-Resistant Crops and Herbicide-Resistant Weed Evolution in the United States. *Weed Science* **66**: 260–273. DOI: 10.1017/wsc.2017.70

Kos M, van Loon JJA, Dicke M and Vet LME (2009) Transgenic plants as vital components of integrated pest management. *Trends in Biotechnology* **27**(11): 621-627. DOI: 10.1016/j.tibtech.2009.08.002

Kost TD, Gessler C, Jänsch M, Flachowsky H, Patocchi A and Broggini BL (2015) Development of the First Cisgenic Apple with Increased Resistance to Fire Blight. *PLoS ONE* **10**(12): e0143980. DOI: 10.1371/journal.pone.0143980

Kou Y and Wang S. (2010) Broad-spectrum and durability: understanding of quantitative disease resistance. *Current Opinion in Plant Biology* **13**: 181–185. DOI: 10.1016/j.pbi.2009.12.010

Koul O (2008) Phytochemicals and Insect Control: An Antifeedant Approach. *Critical Reviews in Plant Sciences* **27**:1–24. DOI: 10.1080/07352680802053908

Kumar M, Shamsi TN, Parveen R and Fatima S (2017). Application of Nanotechnology in Enhancement of Crop Productivity and Integrated Pest Management. pp. 361-371. R. Prasad *et al*. (eds.), Nanotechnology, DOI: 10.1007/978-981-10-4573-8_17

Kumar V (2015) A review on efficacy of biopesticides to control the agricultural insect's pest. *International Journal of Agricultural Science Research* **4**(8): 168-179

Kumari P, Nilanjaya and Singh NK (2018) Reverse breeding: Accelerating innovation in Plant breeding. *Journal of Pharmacognosy and Phytochemistry* **SP1**: 1811-1813.

Kumari V, Kumar A. Chaudhary H K, Prasad R, Jambhulkar S and Sharma S (2014) *In vitro* screening method: An efficient tool for screening *Alternaria* blight resistance/tolerance during early generations in Ethiopian mustard (*Brassica carinata* A. Braun). *African Journal of Agricultural Research* **9**(1): 137-143. DOI: 10.5897/AJAR12.2211

Kushalappa AC, Yogendra KN, Sarkar K, Kage U and Karre S (2016) Gene discovery and genome editing to develop cisgenic crops with improved resistance against pathogen infection. *Canadian Journal of Plant Pathology* **38**(3): 279-295. DOI: 10.1080/07060661.2016.1199597

Lacey LA, Grzywacz D, Shapiro-Ilan DI, Frutos R, Brownbridge M and Goettel MS (2015) Insect pathogens as biological control agents: Back to the future. *Journal of Invertebrate Pathology* **132**: 1-41. DOI: 10.1016/j.jip.2015.07.009

Lade BD, Gogle DP and Nandeshwar SB (2017) Nano Bio Pesticide to Constraint Plant Destructive Pests. *Journal of Nanomedicine Research* **6**(3): 00158. DOI: 10.15406/jnmr.2017.06.00158

Lamichhane JR, Devos Y, Beckie HJ, Owen MDK, Tillie P, Messéan A and Kudsk P (2016) Integrated weed management systems with herbicide-tolerant crops in the European Union: lessons learnt from home and abroad, *Critical Reviews in Biotechnology*, DOI: 10.1080/07388551.2016.1180588

Lamichhane SA (2014) Genetically Modified Foods-Solution for Food Security. *International Journal of Genetic Engineering and Biotechnology* **5**(1): 43-48.

Lamo K, Bhat DJ, Kour K and Solanki SPS (2017) Mutation Studies in Fruit Crops: A Review. International Journal of Current. *Microbiology and Applied Science* **6**(12): 3620-3633. Doi: 10.20546/ijcmas.2017.612.418

Langner T, Kamoun S and Belhaj K (2018) CRISPR Crops: Plant Genome Editing Toward Disease Resistance. *Annual Review Phytopathology* **56**: 479-512. DOI: 10.1146/annurev-phyto-080417-050158

Lateef DD (2015) DNA Marker Technologies in Plants Applications for Crop Improvement. *Journal of Biosciences and Medicines* **3**: 7-18. DOI: 10.4236/jbm.2015.35002

Lebeda A and Pokorný R (Editors) (2012) Biotech-Crops and their Utilization in Plant Protection against Diseases and Pests. *Plant Protection Science* **48**: S1–S2. DOI: 10.17221/85/2012-PPS

Lebeda A, Kroftová V, Kůdela V and Braunová M (2014) Fifty-year anniversary of Plant Protection Science. *Plant Protection Science* **50**: 53–63. DOI: 10.17221/29/2014-PPS

Lema M (2018) Marker Assisted Selection in Comparison to Conventional Plant Breeding: Review Article. Agricultural Research & Technology: *Open Access Journal* **14**(2): 555914. DOI: 10.19080/ARTOAJ.2018.14.555914

Li Y, GaoY and Wu K (2017) Function and effectiveness of natural refuge in IRM. *Current Opinion in Insect Science* **21**: 1–6. DOI: 10.1016/j.cois.2017.04.007

Libersat F, Kaiser M and Emanuel S (2018) Mind Control: How Parasites Manipulate Cognitive Functions in Their Insect

Hosts. *Frontiers in Psychology* **9**: 572. DOI: 10.3389/fpsyg.2018.00572

Lin CH and Pan TM (2016) Perspectives on Genetically Modified Crops and Food Detection. *Journal of Food and Drug Analysis* **24**: 1-8. 10.1016/j.jfda.2015.06.011

Liu Y, Chen L, Liu Y, Dai H, He J, Kang H, Pan G, Huang J, Qiu Z, Wang Q, Hu J, Liu L, Chen Y, Cheng X, Jiang L and Wan J (2016) Marker assisted pyramiding of two brown planthopper resistance genes, Bph3 and Bph27 (t), into elite rice Cultivars. *Rice* **9**: 27. DOI 10.1186/s12284-016-0096-3

Louarn J, Boniface MC, Pouilly N *et al*. (2016) Sunflower Resistance to Broomrape (Orobanche cumana) Is Controlled by Specific QTLs for Different Parasitism Stages. Front. Plant Sci. 7:590. DOI: 10.3389/fpls.2016.00590

Mabubu JI, Nawaz M and Hua H (2016) Advances of transgenic *Bt*-crops in insect pest management: An overview. *Journal of Entomology and Zoology Studies* **4**(3): 48-52

Maina UM, Galadima IB, Gambo FM and Zakaria D (2018) A review on the use of entomopathogenic fungi in the management of insect pests of field crops. *Journal of Entomology and Zoology Studies* **6**(1): 27-32.

Mazid M, Khan TA and Mohammad F (2011) Role of secondary metabolites in defense mechanisms of plants. *Biology and Medicine* **3**(2): 232-249.

McCormick SP (2013) Microbial Detoxification of Mycotoxins. *Journal of Chemical Ecology*. 39:907–918. DOI: 10.1007/s10886-013-0321-0

Meena AK, Verma LK and Kumhar BL (2017) RNAi, It's Mechanism and Potential use in Crop Improvement: A review. *International Journal of Pure and Applied Bioscience* **5**(2): 294-311. DOI: 10.18782/2320-7051.2890

Mekonnen T, Haileselassie T and Tesfaye K (2017) Identification, Mapping and Pyramiding of Genes/Quantitative Trait Loci (QTLs) for Durable Resistance of Crops to Biotic Stresses. *Journal of Plant Pathology and Microbiology* **8**: 412. DOI: 10.4172/2157-7471.1000412

Mersie W, Alemayehu L, Strathie L, McConnachie A, Terefe S, Negeri M and Zewdie K (2018) Host range evaluation of the leaf-feeding beetle, *Zygogramma bicolorata* and the stem-boring weevil, *Listronotus setosipennis* demonstrates their suitability for biological control of the invasive weed, *Parthenium hysterophorus* in Ethiopia. Biocontrol Science and Technology. DOI: 10.1080/09583157.2018.1545220

Mishra R, Rao GJN, Rao RN and Kaushal P (2015) Development and Characterization of Elite Doubled Haploid Lines from Two Indica Rice Hybrids. *Rice Science* **22**(6): 290-299. DOI: 10.1016/j.rsci.2015.07.002

Mondal D, Ghosh, A, Kumar A, Gosh R and Bandopadhyay (2018). Botanical herbicides in system intensification. An approach towards sustainability in environment and agriculture. *Indian Farmer* **5**(01): 001-009.

Moose SP and Mumm RH (2008) Molecular Plant Breeding as the Foundation for 21st Century Crop Improvement. *Plant Physiology* **147**: 969–977. DOI: 10.1104/pp.108.118232

Mousa WK and Raizada MN (2015) Biodiversity of genes encoding anti-microbial traits within lant associated microbes. *Frontiers in Plant Science* **6**:231. DOI: 10.3389/fpls.2015.0023

Mundt CC (2014) Durable resistance: A key to sustainable management of pathogens and pests. Review. *Infection, Genetics and Evolution* **27**: 446–455.

Murali-Baskaran KR, Sharma KC, Kaushal P, Kumar J, Parthiban P, Senthil-Nathan S and Mankin RW (2017) Role of kairomone in biological control of crop pests-A review. *Physiological and Molecular Plant Pathology* 1-13. 10.1016/j.pmpp.2017.07.004.

Muzell Trezzi M, Vidal RA, Balbinot Junior AA, Bittencourt HH and da Silva Souza Filho AP (2016) Allelopathy: driving mechanisms governing its activity in agriculture. *Journal of Plant Interactions* **11**: 53-60, DOI: 10.1080/17429145.2016.1159342

Nadolska-Orczyk A, Rajchel IK, Orczyk W and Gasparis S (2017) Major genes determining yield-related traits in wheat and barley. *Theoretical and Applied Genetics* **130**: 1081–1098. DOI: 10.1007/s00122-017-2880-x

Nafiu BS, Dong H and Cong, B (2014) Principles of Biological Control in Integrated Pest Management. *International Journal of Applied Research and Technology* **3**(1): 104 – 116.

Najaf MBF and Lee BH (2014) Biotechnology and its Impact on Food Security and Safety. *Current Nutrition and Food Science* **10**: 94-99. DOI: 10.2174/1573401310666140306225243

Namdeo AG (2007) Plant Cell Elicitation for Production of Secondary Metabolites: A Review. *Pharmacognosy Reviews* **1**(1): 69-79.

Naseer I (2014) Role of Plant Biotechnology in the Advancement of Classical Agriculture. *International Journal of Chemical and Biochemical Sciences* **1**(2): 31-40.

Navarro MJ and Hautea RA (2011) Communication Challenges and Convergence in Crop Biotechnology. International Service for the Acquisition of Agri-biotech Applications (ISAAA): Ithaca, New York and SEAMEO Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA): Los Baños, Philippines.

Nawaz M, Mabubu JI and Hua H (2016) Current status and advancement of biopesticides: Microbial and botanical pesticides. *Journal of Entomology and Zoology Studies* **4**(2): 241-246.

Nazir S, Iqbal MZ and Sajid-ur-Rahman (2019) Molecular Identification of Genetically Modified Crops for Biosafety and Legitimacy of Transgenes. DOI: 10.5772/intechopen.81079

Neve P (2018) Gene drive systems: do they have a place in agricultural weed management? *Pest Management*

Science **74**: 2671–2679. DOI 10.1002/ps.5137. DOI: 10.1002/ps.5137

Neve P, Vila-Aiub M and Roux F (2009) Evolutionary-thinking in agricultural weed management. *New Phytologist* **184**: 783–793. DOI: 10.1111/j.1469-8137.2009.03034.x

Ngugi K, Ngugi AJ, Osama S and Mugoya C (2015) Combating Striga Weed in Sorghum by Transferring Resistance Quantitative Trait Loci Through Molecular Marker Assisted Introgression. *Journal of Plant Breeding and Genetics* **03**(03): 67-76.

Ni X, Li X, Chen Y, Guo F, Feng J and Zhao H (2011) Metamorphosis of Cisgenic Insect Resistance Research in the Transgenic Crop Era. pp. 258-259. In: Liu T. *et al*. (eds.). Recent Advances in Entomological Research. Higher Education Press, Beijing and Springer-Verlag Berlin Heidelberg. DOI: 10.1007/978-3-642-17815-3_15

Nikolouli K, Colinet H, Renault·D, Enriquez T, Mouto L, Gibert P, Sassu F, Cáceres C, Stauffer C, Pereira R and Bourtzis K (2018) Sterile insect technique and *Wolbachia* symbiosis as potential tools for the control of the invasive species *Drosophila suzukii. Journal of Pest Science* **91**: 489–503. DOI: 10.1007/s10340-017-0944-y

O'Brien PA (2017) Biological control of plant diseases. *Australasian Plant Pathology.* **46**(4): 293-304. DOI: 10.1007/s13313-017-0481-4

Oerke EC (2006) Crop Losses to Pests. *Journal of Agricultural Science* **144**: 31–43. DOI: 10.1017/S0021859605005708

Oladosu Y, Rafii MY, Abdullah N, Hussin G, Ramli A, Miah G and Usman M (2016) Principle and application of plant mutagenesis in crop improvement: a review. *Biotechnology and Biotechnological Equipment* **30**(10): 1-16, DOI: 10.1080/13102818.2015.1087333

Oliveira HC, Stolf-Moreira R, Martinez CBR, Grillo R, de Jesus MB and Fraceto LF (2015) Nanoencapsulation enhances the post-emergence herbicidal activity of atrazine against mustard plants. *PLoS ONE* 10: e132971. DOI: 10.1371/journal.pone.0132971

Oluwaseun AC and Sarin NB (2017) Impacts of Biogenic Nanoparticle on the Biological Control of Plant Pathogens. *Advances in Biotechnology and Microbiology* **7**(3): DOI: 10.19080/AIBM.2017.07.555711

Ortega JL, Rajapakse W, Bagga S, Apodaca K, Lucero Y and Sengupta-Gopalan C (2018) An intragenic approach to confer glyphosate resistance in chile (*Capsicum annuum*) by introducing an *in vitro* mutagenized chile *EPSPS* gene encoding for a glyphosate resistant EPSPS protein. *PLoS ONE* **13**(4): e0194666. DOI: 10.1371/journal.pone.0194666

Oseni OM, Pande V and Nailwal TK (2018) A Review on Plant Tissue Culture, A Technique for Propagation and Conservation of Endangered Plant Species. *International Journal of Current Microbiology and Applied Sciences* **7**(7): 3778-3786. DOI: 10.20546/ijcmas.2018.707.438

Ouyang B, Gu X and Holford P (2017) Plant genetic engineering and biotechnology: a sustainable solution for future food security and industry. *Plant Growth Regulators* **83**: 171–173. DOI: 10.1007/s10725-017-0300-5

Pandey AK, Sain SK and Singh P (2016) A Perspective on Integrated Disease Management in Agriculture. *Bio Bulletin* **2**(2): 13-29.

Parmar N, Singh KH, Sharma D, Singh L, Kumar P, Nanjundan J, Khan YJ, Chauhan, DK and Thakur AK (2017) Genetic engineering strategies for biotic and abiotic stress tolerance and quality enhancement in horticultural crops: a comprehensive review. *3 Biotech* **7**: 239. DOI: 10.1007/s13205-017-0870-y

Patel R and Patel DR (2015) Biological Control of Weeds with Pathogens: Current status and Future trends. *International Journal of Pharmacy and Life Science* **6**(6): 4531-4550.

Peng-fei L, Lübberstedt T and Ming-liang X (2017) Genomics-assisted breeding - A revolutionary strategy for crop improvement. *Journal of Integrative Agriculture* **16**(12): 2674–2685. DOI: 10.1016/S2095-3119(17)61813-6

Pickett JA, Woodcock CM, Midega CAO and Khan ZR (2014) Push–pull farming systems. *Current Opinion in Biotechnology* 26:125–132. DOI: 10.1016/j.copbio.2013.12.006

Pilet-Nayel ML, Moury B, Caffier V, Montarry J, Kerlan MC, Fournet S, Durel C-E and Delourme R (2017) Quantitative Resistance to Plant Pathogens in Pyramiding Strategies for Durable Crop Protection. *Frontiers in Plant Science* 8: 1838. DOI: 10.3389/fpls.2017.01838

Pino O, Sánchez Y and Rojas MM (2013) Plant secondary metabolites as an alternative in pest management. I: Background, research approaches and trends. *Rev. Protección Veg.* **28**(2): 81-94.

Qaim M and Kouser S (2013) Genetically Modified Crops and Food Security. *PLoS ONE* **8**(6): e64879. DOI: 10.1371/journal.pone.0064879

Ragimekula N, Varadarajula NN, Mallapuram SP, Gangimeni G and Reddy RK (2013) Marker Assisted Selection in Disease Resistance. *Journal of Plant Breeding and Genetics* **01**(02): 90-109.

Rai MJ, Kalia BK, Singh R., Gangola MP and Dhawan AK (2011) Developing stress tolerant plants through in vitro selection. An overview of the recent progress. *Environmental and Experimental Botany* **71**: 89–98. DOI: 10.1016/j.envexpbot.2010.10.021

Raina A, Khursheed S, Amin R, Tantray YR, Parveen K and Khan S (2016) Role of Mutation Breeding in Crop Improvement- Past, Present and Future. *Asian Research Journal of Agriculture* **2**(2): 1-13. Article no. ARJA.29334. DOI: 10.9734/ARJA/2016/29334

Raman R (2017) The impact of Genetically Modified (GM) crops in modern agriculture: A review. *GM Crops and Food* **8**(4): 195-208, DOI: 10.1080/21645698.2017.1413522

Rashid B, Tariq M, Khalid A, Shams F, Ali Q, Ashraf F, Ghaffar I, Khan MI, Rehman R and Husnain T (2017) Crop improvement: new approaches and modern techniques.

Plant Gene and Trait **8**(3): 18-30. DOI: 10.5376/pgt.2017.08.0003

Rashid M, He G, Guanxiao Y and Khurram Z (2011) Relevance of tilling in plant genomics. *Ausralian Journal of Crops Science* **5**(4): 411-420.

Rasool K, Rasool, F, Bhat NA, Mushtaq N, Wani TA, Alam S, Kumar S, Saxena A, Bhat S and Yousuf S (2018) IDM: A new approach to disease management. *International Journal of Chemical Science* **2**(2): 07-11.

Reisig DD (2017) Factors Associated with Willingness to Plant Non-Bt Maize Refuge and Suggestions for Increasing Refuge Compliance. *Journal of Integrated Pest Management* **8**(1): 9; 1–10. DOI: 10.1093/jipm/pmx002

Ren H, Wu P, Trampe B, Tian X, Lubberstedt T and Chen S (2017) Novel technologies in doubled haploid line development. *Plant Biotechnology Journal* **15**: 1361–1370. DOI: 10.1111/pbi.1280

Repalli SK (2017) GM Foods or Not. *International Journal of Information Research and Review* **04**: 4505-4511.

Routray S, Dey D, Baral S, Das AP and Mahantheshwara B (2016) Genetic improvement of natural enemies: A review. *Agricultural Reviews* **37**(4): 325-332. DOI: 10.18805/ag.v37i4.6463

Ruiu L (2015) Insect Pathogenic Bacteria in Integrated Pest Management. I*nsects* **6**: 352-367; DOI: 10.3390/insects6020352

Saha T and Chandran N (2017) Chemical ecology and pest management: A review. *International Journal of Chemical Studies* **5**(6): 618-621.

Saiyad SA (2017) Application of *Bacillus thuringiensis* as an effective tool for insect pest control. *Journal of Agriculture and Veterinary Science* **10**(7): 27-29. DOI: 10.9790/2380-1007012729

Sanchez MA and Parrott WA (2017) Characterization of scientific studies usually cited as evidence of adverse effects of GM food/feed. *Plant Biotechnology Journal* **15**: 1227–1234. DOI: 10.1111/pbi.12798

Sandhu S and Kang MS (2017) Advances in Breeding for Resistance to Insects. In: Arora R., Sandhu S. (eds) Breeding Insect Resistant Crops for Sustainable Agriculture. Springer, Singapore. DOI: 10.1007/978-981-10-6056-4_3

Sanzari I, Leone A, Ambrosone A (2019) Nanotechnology in Plant Science: To Make a Long Story Short. *Frontiers Bioengineering and Biotechnology.* **7**: 120. DOI: 10.3389/fbioe.2019.00120

Sarwar M (2015a) Birth Control for Insects: The Sterile Insect Technique (SIT) for Controlling Fruit Fly (Tephritidae: Diptera) by Releasing Sterile Males. *International Journal of Animal Biology* **1**(5): 253-259.

Sarwar M (2015b) The Killer Chemicals for Control of Agriculture Insect Pests: The Botanical Insecticides. International Journal of Chemical and Biomolecular Science. **1**(3): 123-128.

Savary S, Ficke A, Aubertot JN and Hollier C (2012) Crop losses due to diseases and their implications for global food production losses and food security. *Food Security*.DOI: 10.1007/s12571-012-0200-5

Saxena R, Tomar RS and Kumar M (2016) Allelopathy: A Green Approach for Weed Management and Crop Production. *International Journal of Current Research in Biosciences and Plant Biology* **3**(4): 43-50. DOI: 10.20546/ijcrbp.2016.304.008

Scott P, Thomson J, Gryzwacz D, Savary S, Strange R, Ristaino, JB and Korsten L (2016) Genetic modification for disease resistance: a position paper. *Food Security*. DOI: Savary S, Ficke A, Aubertot JN and Hollier C (2012) Crop losses due to diseases and their implications for global food production losses and food security. *Food Security*. DOI: 10.1007/s12571-016-0591-9

Seo JK, Wu J, Lii Y, Li Y and Jin H (2013) Contribution of Small RNA Pathway Components in Plant Immunity. *Molecular Plant Microbe Interaction* **26**(6); 617–625. DOI: 10.1094/MPMI-10-12-0255-IA

Shabanimofred M, Yosop MR, Ashkani S, Musa MH, Adam NA, Haifa I, Harun AR and Latif MA (2015) Marker-assisted selection for rice brown planthopper (*Nilaparvata lugens*) resistance using linked SSR markers. *Turkish Journal of Biology* **39**: 666-673. DOI: 10.3906/biy-1406-78

Savary S, Ficke A, Aubertot JN and Hollier C (2012) Crop losses due to diseases and their implications for global food production losses and food security. *Food Security*. DOI: 10.3906/biy-1406-78

Shamim M, Pandey P, Singh A, Yadav P, Bhowmick PK , Srivastava D, Kumar D, Khan NA, Dwivedi DK and Singh KN (2013) Role of biotechnology in plant diseases management: An overview. *Journal of Genetic and Environmental Resources Conservation* **1**(1):215-221.

Shang Y, Hasan K, Ahammed GJ, Li M, Yin H and Zhou Z (2019) Applications of Nanotechnology in Plant Growth and Crop Protection: A Review. *Molecules* **24**: 2558. DOI: 10.3390/molecules24142558

Sharad S, Jaya D and Jha AK (2010) Role of biotechnology in sustainable development. *International Journal of Research in Ayurveda and Pharmacy* **1**(1): 43-46

Sharma HC. Crouch JH, Sharma KK, Seetharama N and Hash CT (2012) Applications of biotechnology for crop improvement: prospects and constraints Review. *Plant Science* **163**: 381-395. DOI: 10.1016/S0168-9452(02)00133-4

Sharp P and Dong C (2014) TILLING for Plant Breeding. In: Fleury, D. and R. Whitford (eds.), Crop Breeding: Methods and Protocols, Methods in Molecular Biology, vol. 1145, DOI: 10.1007/978-1-4939-0446-4_13

Shetty MJ, Chandan K, Krishma HC and Aparna GS (2018) Genetically modified crops: An overview. *Journal of Pharmacognosy and Phytochemistry* **7**(1): 2405-2410

Shukla N, Singh EANK, Kabadwa BC, Sharma R, Kumar J (2019). Present Status and Future Prospects of Bio-Agents in Agriculture. *International Journal of Current Microbiology and Applied Sciences* 8(4): 2138-2153. Doi: 10.20546/ijcmas.2019.804.251

Singh A, Singh VK, Singh SP, Pandian RTP, Ellur RK, Singh D, Bhowmick PK, Krishnan SG, Nagarajan M, Vinod KK, Singh UD, Prabhu KV, Sharma TR, Mohapatra T and Singh AK (2012) Molecular breeding for the development of multiple disease resistance in Basmati rice. *AoB Plants* 2012 pls029; DOI: 10.1093/aobpla/pls029

Singh R and Chandrawat KS (2017) Role of Phytoalexins in Plant Disease Resistance. *International Journal of Current Microbiology and Applied Sciences.* ***6***(1): 125-129. DOI: 10.20546/ijcmas.2017.601.016

Smyth SJ (2017) Genetically modified crops, regulatory delays, and international trade. *Food and Energy Security* **6(**2): 78–86. DOI: 10.1002/fes3.100

Sniezko R and Koch J (2017). Breeding trees resistant to insects and diseases: putting theory into application. *Biological Invasions* **19**: 3377–3400. DOI: 10.1007/s10530-017-1482-5

Steffenson BJ and Smith KP (2006) Breeding Barley for Multiple Disease Resistance i n the Upper Midwest Region of the USA. *Czech Journal of Genetics and Plant Breeding* **42**(3): 79–85. DOI: 10.17221/3646-CJGPB

Stenberg JA (2017) A Conceptual Framework for Integrated Pest Management. *Trends in Plant Science* **22**(9): 759- 769. 10.1016/j.tplants.2017.06.010.

Stergiopoulos I, Cordovez V, Okmen B, Beenen HG, Kema GHJ and De Wit PJGM (2014) Positive selection and intragenic recombination contribute to high allelic diversity in effector genes of *Mycosphaerella fijiensis*, causal agent of the black leaf streak disease of banana. *Molecular Plant Pathology* **15**(5): 447–460. DOI: 10.1111/mpp.12104

Stevens J, Dunse K, Fox J, Evans S and Anderson M (2012) Biotechnological Approaches for the Control of Insect Pests in Crop Plants. In: Anderson *et al*. (Eds) Pesticides – Advances in Chemical and Botanical Pesticides. pp.270-308 DOI: 10.5772/46233

Sticklen M (2015) Transgenic, Cisgenic, Intragenic and Subgenic Crops. *Advances in Crop Science and Technology* **3**: e123. DOI: 10.4172/2329-8863.1000e123

Sultana R, Kumar S and Yanar D (2017) Application of *Entomopathogenic* fungi for insect-pests control. *Journal of Entomology and Zoology Studies* **5**(6): 07-13.

Sun D, Guo Z, Liu Y and Zhang Y (2017) Progress and Prospects of CRISPR/Cas Systems in Insects and Other Arthropods. *Frontiers in Physiology* **8**: 608. d DOI: 10.3389/fphys.2017.00608

Taheri F, Azadi H and D'Haese MD (2017) A World without Hunger: Organic or GM Crops? *Sustainability* **9**: 580; DOI: 10.3390/su9040580

Talukdar D (2013) Modern Biotechnological Approaches in Insect Research. *International Research Journal of Science and Engineering* **1**(3): 71-78. DOI: 10.1155/2013/782450

Terefe M (2018) Biosafety Issues of Genetically Modified Crops: Addressing the Potential Risks and the Status of GMO Crops in Ethiopia. *Cloning and Transgenesis* **7**: 164. DOI: 10.4172/2168-9849.1000164

Thakur N, Mundey JK and Upadhyay SK (2016) RNAi Implications in Entomological Research and Pest Control. 10.5772/61814

Thakur S, Thakur S and Kumar R (2018) Bio-Nanotechnology and its Role in Agriculture and Food Industry. *Journal of Molecular Genetic and Medicine* **12**: 324. DOI: 10.4172/1747-0862.1000324

Tijjani A, Bashir KA, Mohammed I, Muhammad A, Gambo A and Musa H (2016) Biopesticides for Pests Control: A Review. *Journal of Biopesticides and Agriculture* **6**(1): 6-13.

Tiwari A (2017) Plant Breeding: A Prospect in Developing World. *EC Microbiology* **8.5**: 272-278.

Tohidfar M and Khosravi S (2015) Transgenic crops with an improved resistance to biotic stresses. A review. *Biotechnology Agronomy and Social Environment* **19**(1): 2-70

Tonukari NJ and Omotor DG (2010) Biotechnology and food security in developing countries. *Biotechnology and Molecular Biology Reviews* **5**(1): 013-023.

Townson J (2017) Recent developments in genome editing for potential use in plants. *Bioscience Horizons.* DOI: 10.1093/biohorizons/hzx016

Tranel PJ and Horvath DP (2009) Molecular Biology and Genomics: New Tools for Weed Science. *BioScience* **59**(3): 207–215. DOI: 10.1525/bio.2009.59.3.5

Trognitz F, Hackl E, Widhalm S and Sessitsch A (2016) The role of plant–microbiome interactions in weed establishment and control. *FEMS Microbiology Ecology* **92**(10). DOI: 10.1093/femsec/fiw138

Valentinov V, Hielscher S, Everding S and Pies I (2018) The anti-GMO advocacy: an institutionalist and systems-theoretic assessment. Kybernetes DOI: 10.1108/K-01-2018-0016

van Lenteren JC, Bolckmans K, Kohl J, Ravensberg WJ and Urbaneja A (2018) Biological control using invertebrates and microorganisms: plenty of new opportunities. *BioControl* **63**: 39–59. DOI: 10.1007/s10526-017-9801-4

Vanblaere T, Flachowsky H, Gessler C and Broggini GAL (2014) Molecular characterization of cisgenic lines of apple 'Gala' carrying the Rvi6 scab resistance gene. *Plant Biotechnology Journal* **12**: 2-9. DOI: 10.1111/pbi.12110

Varshney RK, Graner A and Sorrells ME (2005) Genomics-assisted breeding for crop improvement. *Trends in Plant Science* **10**: 621-630. DOI: 10.1016/j.tplants.2005.10.004

Vasquez AX, Soto Sedano JC and López Carrascal CE (2018) Unraveling the molecules hidden in the gray shadows of quantitative disease resistance to pathogens. *Acta Biologica Colombiana* **23**: 5-16. DOI: 10.15446/abc.v23n1.66487

Velasco L, Pérez-Vich B and Fernández-Martínez JM (2016) Research on resistance to sunflower broomrape: an integrated vision. *OCL* 2**3**(2): D203. DOI: 10.1051/ocl/2016002

Venkanna V, Hari Y, Rukminidevi K, Satish Chandra B, Raju J,Malathi S and Reddy PRR (2018) Markers Assisted Selection for Pyramiding of Gallmidge Resistance Genes in Kavya, a Popular Rice Variety. *International Journal of Current Microbiology and Applied Science* **7**(04): 745-753. DOI: 10.20546/ijcmas.2018.704.083

Villaverde JJ, Sandin-Espana P, Sevilla-Moran B, Lopez-Goti C and Alonso-Prados JL (2016) Biopestides from Natural Products: Current Development, Legislative Framework and *Future Trends. BioResources* **11**(2): 5618-5640. DOI: 10.15376/biores.11.2.Villaverde

Vincelli P (2016) Genetic Engineering and Sustainable Crop Disease Management: Opportunities for Case-by-Case Decision-Making: Review. *Sustainability* **8**: 495; DOI: 10.3390/su8050495

Vincelli, P (2018) Consumption of Genetically Engineered (=GMO1) Crops: Examples of Quotes from Position Papers of Scientific Organizations. https://research.ncsu.edu/ges/files/2018/09/Quotes-from-Science-Academies-on-Consuming-GMO-Crops-v18.pdf

Wahab S (2009) Biotechnological approaches in the management of plant pests, diseases and weeds for Sustainable Agriculture. *Journal of Biopesticides* **2**(2): 115-134.

Wang F and Zhang W (2019) Synthetic biology: Recent progress, biosafety and biosecurity concerns, and possible solutions. *Journal of Biosafety and Biosecurity* **1**: 22-30. DOI: 10.1016/j.jobb.2018.12.003

Wang TL, Uauy C, Rabson F and Till B (2012) TILLING in extremis. *Plant Biotechnology Journal* **10**: 761–772. DOI: 10.1111/j.1467-7652.2012.00708.x

Westwood JH, Charudattan R, Duke SO, Fennimore SA, Marrone P, Slaughter DC, Swanton C and Zollinger R (2018) Weed Management in 2050: Perspectives on the Future of Weed Science. *Weed Science* **66**(3): 275-285. DOI: 10.1017/wsc.2017.78

Wijerathna-Yapa A (2017) Transgenic plants: resistance to abiotic and biotic stresses. *Journal of Agriculture and Environment for International Development* **111**(1): 245-275. DOI: 10.12895/jaeid.20171.643

Wolter F, Schindele P and Puchta H (2019) Plant breeding at the speed of light: the power of CRISPR/Cas to generate directed genetic diversity at multiple sites. *BMC Plant Biology*. **19**: 176. DOI: 10.1186/s12870-019-1775-1

Worrall EA, Hamid A, Mody KT, Mitter N and Pappu HR (2018) Nanotechnology for Plant Disease Management. *Agronomy* **8**: 285. DOI: 10.3390/agronomy8120285

XiaoXing L, Ping L and AiPing Z (2013) *In vitro* selection of sheath blight resistance germplams in rice. *African Journal of Microbiology Research* **7**(35): 4422-4429, DOI: 10.5897/AJMR2013.5659

Xu Y, Li P, Zou C, Lu Y, Xie C, Zhang X, Prasanna BM and Olsen MS (2017) Enhancing genetic gain in the era of molecular breeding. *Journal of Experimental Botany* **68**(11): 2641–2666. DOI: 10.1093/jxb/erx135

Xu J (2013) Pyramiding of two *BPH* resistance genes and *Stv-b* gene using marker-assisted selection in *Japonica* rice. *Crop Breeding and Applied Biotechnology* **13**: 99-106. DOI: 10.1590/S1984-70332013000200001

Xuan TD, Anh LH, Khang DT, Tuyen PT, Minh TN, Khanh TD, Trung KH (2016) Weed Allelochemicals and Possibility for Pest Management. *International Letters of Natural Sciences* **56**: 25-39. d DOI: 10.18052/www.scipress.com/ILNS.56.25

Yang L, Ouyang HB, Fang ZG, Zhu W, Wu EJ, Luo, GH, Shang LP, Zhan J (2018) Evidence for intragenic recombination and selective sweep in an effector gene of *Phytophthora infestans. Evolutionary Applications* **11**: 1342–1353. DOI: 10.1111/eva.12629

Yang Q, Balint-Kurti P, Xu M (2017) Quantitative Disease Resistance: Dissection and Adoption in Maize. *Molecular Plant* **10**: 402–413. DOI: 10.1016/j.molp.2017

Yasir AG, Abdalla HM (2013) Introgression of *Striga* Resistance Genes into a Sudanese Sorghum Cultivar, Tabat, Using Marker Assisted Selection (MAS). *Greener Journal of Agricultural Sciences* **3**: 550-556. DOI: http://doi.org/10.15580/GJAS.2013.7.061013654

Yohannes T, Abraha T, Kiambi D, Folkertsma R, Hash CT, Ngugi K, Mutitu E, Abraha N, Weldetsion M, Mugoya C, Masiga CW, de Villiers S (2015) Marker-assisted introgression improves Striga resistance in an Eritrean Farmer-Preferred Sorghum Variety. *Field Crops Research* **173**: 22–29. DOI: 10.1016/j.fcr.2014.12.008

Young SL, Pitla SK, Van Evert FK, Schueller JK, Pierce FJ (2017) Moving integrated weed management from low level to a truly integrated and highly specific weed management system using advanced technologies. *Weed Research* **57**: 1–5. DOI: 10.1111/wre.12234

Younis A, Siddique MI, Kim CK, Lim KB (2014) RNA Interference (RNAi) Induced Gene Silencing: A Promising Approach of Hi-Tech Plant Breeding. *International Journal of Biological Science* **10**(10): 1150-8. DOI: 10.7150/ijbs.10452

Zaker M (2016) Natural Plant Products as Eco-friendly Fungicides for Plant Diseases Control- A Review. *The Agriculturists* **14**(1): 134-141. DOI: 10.3329/agric.v14i1.29111