



DNA Fingerprinting of Crops and Its Significance in Crop Improvement

Chandra Lekha Lanka^{a++}, Mukh Ram^{a#*}
and Singareddy Murali Krishna^{a++}

^a Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, 144411, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i163149

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/100613>

Review Article

Received: 03/04/2023

Accepted: 06/06/2023

Published: 24/06/2023

ABSTRACT

One of the improvements made possible by the era of genomics is DNA fingerprinting. DNA fingerprinting can be used to detect a variety of genetic changes. In breeding programmes fingerprinting is used to improve productivity and performance. Variety differentiation was relied on morphological characteristics prior to the introduction of genomics and proteomics approaches. Although morphological markers have been used for decades, protein-based markers like isozymes were discovered in the middle of the twentieth century and used for fingerprinting and crop genetic variety assessments. But nowadays, the emergence of genome sequencing has led to the widespread use of genetic markers for crop fingerprinting. The discovery of DNA-based genetic markers has improved genetic research. For genetic diversity estimation, crop evolution, gene mapping and phylogeny, diploid/haploid crop appraisal, heterosis analysis, varietal identification by using marker assisted selection (MAS), highly polymorphic DNA markers are generated. The use of DNA markers for crop fingerprinting started with RFLPs that did not involve PCR and subsequently advanced to PCR amplifiable markers such as AFLPs, RAPDs,

⁺⁺ M.Sc. Student;

[#] Assistant Professor;

^{*}Corresponding author: E-mail: mukh.26422@jpu.co.in;

SSRs, ISSRs, SNPs, and GBS. This review will provide an outlook on several types of markers and their significance in DNA fingerprinting of crops and possible applications, as well as suggestions for further research.

Keywords: Crop fingerprint; markers; genetic variability; applications.

1. INTRODUCTION

Somatically stable DNA fingerprints that are truly different to a person were first shown by Alec Jeffreys and colleagues in a series of studies published in 1985. These portions of DNA, known as tandem repeats or minisatellites, provide the basis for DNA fingerprinting [7,9]. Throughout breeding programmes, it is essential to have proper seed cultivation, marketing, and product supervision in addition to proper cultivar identification, cataloguing, and sustainability. By using morphological characteristics and the distinctness, uniformity, and stability (DUS) method, formerly species and variations were defined [67]. Morphological features are less efficient for variety identification due to unpredictable genetic regulation and environmental variation. The advent of modern biotechnology has provided us with new resources that may assist us in enhancing our breeding techniques for plants and gaining a deeper understanding of their genetics [31,33]. Smith and Wilcox discovered restriction enzymes, while Kary Mullis and his colleagues discovered the polymerase chain reaction (PCR), which made it easier to examine the makeup of organisms at the DNA level and generate a genetic fingerprint. DNA fingerprinting, among various molecular methods, has emerged as the most advanced and innovative approach for identifying plant genotypes [49]. A DNA fingerprint is a definite pattern of cultivars determined by DNA markers. A short section of DNA that displays variability between organisms in the form of base deletions, insertions, and substitutions is known as a DNA marker. DNA markers provide different benefits over morphological and biochemical [53] markers for obtaining a genome-specific profile [34,39]. DNA markers are a reliable and cost-efficient method for distinguishing plant genotypes. They also provide an effective explanation for the genetic diversity and variety that exists among different varieties and species.

The use of DNA fingerprinting has allowed for the classification of inbred lines into elite populations and to differentiate cultivars [32]. However, it is unaffected by environmental

factors and changes in gene expression throughout time [38,43]. Although there are non-PCR methods for identifying genetic diversity, such as Restriction Fragment Length Polymorphisms (RFLPs), the majority of novel DNA marker methods rely on amplification by PCR (polymerase chain reaction). These include Random amplification polymorphic DNA (RAPD), Genotyping by sequencing (GBS), Inter Simple Sequence Repeats (ISSR), Simple Sequence Repeats (SSR) and Diversity Arrays Technology (DArT) [48]. This review aims to provide an extensive analysis of the basic concepts of DNA fingerprinting, as well as a comprehensive evaluation of the different methodologies based on their potential for repeatability, accuracy, cost-effectiveness, and discriminatory power. Furthermore, in addition to the use of DNA fingerprinting, its applications in crop development are also thoroughly analysed, along with its potential in the future.

Types of markers used for fingerprinting in crops

Genetic markers are classified into three groups:

- I) Morphological markers (classical or visible markers)
- II) Protein markers (also known as biochemical markers or Isozymes)
- III) Molecular markers (or DNA markers)

2. MORPHOLOGICAL MARKERS

In the beginning, scientists used morphological markers to identify and separate different varieties. A "fingerprint" is a specific characteristic of a genotype that allows for easy and rapid identification. Traits such as color, Fruit form, size, and pubescence of the leaves, as well as the number of flowers on each spike were the most widely utilized morphological markers for variety identification [68]. As technology has progressed, however, the morphological technique has been discredited as a valid means of cultivar recognition and genotypic evaluation. The expression of morphological traits is restricted to the homozygous state and is thus controlled by recessive genes. Due to the

quantitative nature of these characteristics, evaluating and genetic mapping them may be a difficult job. Many crops i.e., sugarcane [58], sugarcane, and peas [64], Napier grass [11], bougainvillea [41] were fingerprinted using morphological markers.

3. PROTEIN MARKERS (ISOZYMES)

Isoenzymes were first discovered in plant research in the early 1960s, and their relevance grew rapidly during the 1970s and 1980s. Isozymes are distinct molecular weights and electrophoretic mobility variations of an enzyme that have the same function or catalytic activity. On the other hand, protein extraction was usually difficult, particularly for plants with a high phenolic composition in their leaves. This was one of the most typical issues that occurred. Another significant issue was the seldom presence of allozyme polymorphism across similar variants. Isozymes were used for fingerprinting around 1960 due to their rapidity, precision, and lack of dependency on external factors [49]. Many methods were used in the isozyme examination. They included sample collection, enzyme isolation, gel electrophoresis, gel colouring, photography, and fingerprinting. The Isozymes assay, on the other hand, has certain problems, such as the breakdown of proteins during the sample collection process. The process of protein extraction in and of itself is laborious and time-consuming. Isozymes were employed in the process of fingerprinting as well as differentiating grapevine [56], Napier grass [11] and garlic [28].

4. MOLECULAR MARKERS (DNA MARKERS)

Molecular markers, also known as DNA markers, are specific compounds that show simple differences between different races of the same species or between distinct species. Several polymorphism-detecting procedures or technologies, such as southern blotting—nucleic acid hybridization, the PCR technique, and the sequencing of DNA, have led to the development of a wide variety of systems for using DNA as a marker [16]. There are two main categories of DNA markers: those that don't rely on polymerase chain reaction (PCR), and those that rely on PCR. On the other hand, DNA sequencing-based markers, such as Single

Nucleotide Polymorphism (SNP) on the basis of expression, were divided into two groups; i.) Dominant markers: The marker is exclusively associated with the one particular form of the trait that the user has chosen to designate. On the contrary, the character's alternate form is not associated with any kind of marker [17], such as RAPD. ii.) Co-dominant marker: Both forms of the designated character have a relationship to the marker [17] such as RFLP (Restriction fragment length polymorphisms), AFLP (Amplified fragment length polymorphisms), SSR (Simple sequence repeat markers), SNP (Single nucleotide polymorphism), EST (Expressed sequence tag), etc. The number of molecular markers is almost uncountably high, and these markers are not influenced either by environment or the phase of the plant's growth in which they are located [72]. Examining the DNA of crops using PCR, non-PCR, and sequence-based markers are summarised in Table 1.

5. NON-PCR BASED MARKERS

Restriction fragment length polymorphisms (RFLPs): In the early 1980s, the Restriction Fragment length Polymorphism (RFLP) system was created as the first and most frequently used marker system. In RFLPs, genetic material is first digested using restriction enzymes like EcoR1, then separated on a gel, and then hybridized (southern hybridized) to DNA-labelled probes in order to identify those with single base differences. Since RFLPs are co-dominant markers, they are able to distinguish DNA fragments from all homologous chromosomes, which enables them to recognize the phase of DNA molecules during which they are coupled. However, DNA analysis with RFLPs is a complicated process that also takes a significant amount of time and money. During hybridization, probes (oligomers) are susceptible to minor temperature fluctuations, making it a difficult procedure [10]. RFLPs require vast amounts of high-quality DNA, which may limit their application under circumstances where the source material is limited.

PCR-based markers: Single-locus and multi-locus approaches are the two categories into which PCR-based methodologies are separated [49]. Here, we provide a quick summary of the two PCR-based marker techniques.

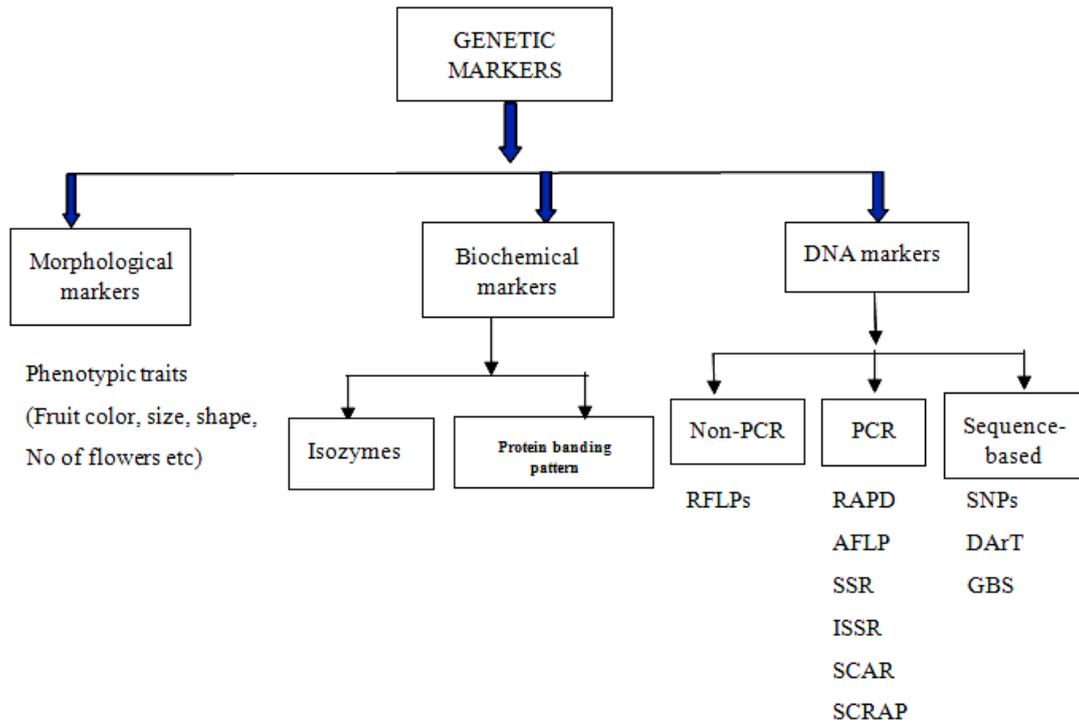


Fig. 1. Different kinds of genetic markers used in crop improvement [3&29]

Table 1. A brief history of the distinct marker systems utilized for fingerprinting the DNA of several crops that are economically significant

Type of marker	Crops	References
Morphological marker	Wheat, Sugarcane	[65,51]
Isozyme marker	Napier grass	[11]
NON-PCR based markers		
RFLP	tomato, Rice, peanuts	[47,24,50]
PCR based markers		
RAPD	Potato, Wheat, Maize, Ginger, Rice	[45,57,62]
AFLP	Cotton, Rice, Wheat	[1,12,63]
SSR	Soybean, Wheat, Maize, Sugarcane	[4,26,32,70]
ISSR	Tomato, Rice, Maize, Lemon grass, Chickpea, Wheat	[42,62,40,2,23,20]
Sequence based markers		
SNPs	Potato, Maize, Ginger, Wheat, Potato, Chickpea	[61,66,30,44,18]
DArT	Groundnut, Wheat	[50,19]
GBS	Maize	[69]

Amplified fragment length polymorphisms (AFLP): To provide a more precise banding pattern, the Amplified fragment length polymorphism marker approach involves PCR & RFLP. In this method, the DNA in a sample is broken up into pieces using restriction enzymes, just like in RFLP analysis. However, only a small number of these pieces are then tested using a more specific type of PCR [42]. Primers are used in this strategy because they have the ability to bind themselves efficiently to respective target

regions (restriction sites and adapter), in addition to a few nucleotides that are located nearby the restriction sites. This needs a large amount and good quality of DNA. AFLPs are less expensive than RAPDs, have greater repeatability, and can identify larger levels of polymorphisms than RFLPs. AFLPs were applied as a helpful approach to monitor genetic diversity in sweet potato, cotton, soybean, and Bt rice. Additionally, AFLPs were utilized for fiber-quality attributes, tagging of essential agronomic factors, and

fingerprinting studies in sorghum, wheat, mango, and sweet potato [73].

Simple sequence repeat markers (SSRs): Short tandem repeats and Microsatellites are other names for SSRs. Short tandem repeats (SSRs) are repeating sequences of nucleotides that are between 6 and 10 base pairs long and can be found all over the genome [35]. DNA fingerprinting by SSRs is a straightforward method that requires only two components: a set of primers or adjacent markers and gel electrophoresis to differentiate the products of PCR. Silver nitrate staining, radiography, ethidium bromide staining, and fluorography are used to verify the banding patterns [49]. In comparison to RFLPs and RAPDs, this marker system is locus-specific, repeatable, and has a high level of polymorphism. SSRs are co-dominant in nature. These markers have emerged as the standard marker for many plant-related advancements because they are highly variable and cover a large part of the genome.

Randomly amplified polymorphic DNA (RAPD): Under Polymerase chain reaction assisted markers, RAPD markers were commonly applied in fingerprinting research [25,49]. William and his co-workers improved RAPD [71]. This method amplifies random sequences from a DNA template by utilizing one random, short primer (2–10 base pairs) that binds to many different genomic regions [71]. This results in PCR fragments from the whole genetic material. Later, the generated multilocus banding patterns were observed by using an UV transilluminator, which had previously been examined by electrophoresis. Since sequence variations in either of the binding sites of primers create polymorphisms between individuals, RAPD markers are dominant. The use of RAPDs as systematic characteristics is constrained since it can be difficult to establish trait similarities and because of their low repeatability [8,57,59].

Genotyping by sequencing (GBS): GBS is a novel method that has emerged with the advent of NGS (next-generation sequencing) to take advantage of the large range of genetic variation present in plants [15]. This bioinformatically intensive approach has the potential to provide a comprehensive analysis of genetic variation throughout the whole genome (i.e., including exons & introns). During the preparation of the sample, steps like isolating and measuring the DNA, digesting it with restriction enzymes, joining it with the appropriate adapters, and amplifying it with PCR primers that are specific to the

adapters are done. Grouping samples, selecting a size range, adjusting the concentration, and making a sample sheet are the steps that make up the library's construction. For the subsequent two phases, sequencing and SNP recognition, several bioinformatic methods have been applied e.g., Minia, Bowtie 2, Fastx-collapse, BCF, SAM tools [52]. Genotyping by sequencing may be the most appealing technology for crop fingerprinting due to parallel identification of SNPs because it is an easy, economical, accurate, highly reproducible, and rapid method.

Inter simple sequence repeats (ISSRs): Since 1994, for DNA profiling, ISSR markers have been commonly used. ISSR are multi-locus genetic markers that can be amplified with PCR. By using particular microsatellite segments between 16 and 20 bases in length as primers, this approach amplifies inter-specific SSR sequences of varying lengths to generate multi-locus markers. ISSRs are highly polymorphic, highly repeatable, and easy than RAPD. These are usually non-transferable and dominating. However, as polymorphic nature is high in this type of marker, these are often used in phylogenetics, genetic variability, whole-gene analysis, gene marking, and research on genetic linkage.

Single nucleotide polymorphism (SNPs): Single nucleotide polymorphisms (SNPs) are a common kind of genetic variation in individuals. Lander first presented the concept of SNPs in 1996 [5]. This type of marker is widely used and has proven to be accurate. In SNPs, among genotypes, there is variation in the sequences of DNA or one nucleotide base. Based on nucleotide alterations, SNPs are classified as transversions and transitions. In plants, the levels of SNPs are typically in the range of one SNP per one hundred to three hundred base pairs. SNPs can be found at varying rates in different chromosomal locations inside gene coding regions, regions of DNA sequence that occur between genes on a chromosome and non-coding portions of genes. The genetic stability and abundance of SNPs, along with the technology of sequencing chips, make it possible to do large-scale screening. It is now very easy and affordable to find many SNPs in a short period in wide range of cultivated plants. Since there are two alleles per locus, SNPs are a remarkable tool for data management as they make a massive collection of marker information. SNPs are less significant per locus than microsatellites because they lack information per locus [69].

Table 2. A review of several marker systems for fingerprinting of DNA

Marker description	RAPD	SSR	RFLP	AFLP	SNP	ISSR
Genomic coverage	Whole genome	Whole genome	Low-moderate	Whole genome	Whole genome	Whole genome
Genomic abundance	High	Moderate to high	High	High	Very high	Moderate
Reproducibility	Low	High	High	High	High	Moderate
Multiplex ratio	Moderate	Medium/high	Low	High	Moderate to high	Moderate
Quality of DNA required	Low	Moderate	High	Moderate	High	Low
Level of polymorphism	High	High	Moderate	High	High	Moderate
Marker index	Moderate	Moderate to high	Low	Moderate to high	Moderate	Moderate
Automation	Moderate	Moderate/High	Low	Moderate/High	High	Moderate
Cost per assay	Low	Moderate to high	Moderate to high	Moderate	High	Low

Source: [29]

6. DNA FINGERPRINTING APPLICATIONS

Genotyping, assessing genetic diversity, and protecting food crops are just a few of the many uses for DNA fingerprinting in plant sciences that are discussed here.

7. GENOTYPING OF CULTIVARS

DNA fingerprinting helps to find out how pure a variety is, which in turn stops the sale of contaminated seeds. Genetic markers are also an accurate way to trace the origin of newly developed cultivars. New crop varieties can be registered under the Breeders' Rights Guidelines to safeguard their intellectual property [32]. Plant Breeders Rights Rules require DNA fingerprinting in order to secure varieties. SSR markers are ideal for genetic analysis of asexually propagated cultivars since they are extremely repeatable. SNP markers have recently received a lot of interest as a method to recognize vegetatively propagated species. Because of the high amount of cross-pollination, particularly during the seed cycle, when alien pollen pollinates the egg and introduces new genetic variants, genotyping seed propagated plants through marker-assisted selection is complicated. For this, innovative and reliable technology is necessary; The DArT technology is being utilized to differentiate between seed propagated varieties [36]. SSR assessment is applied to detect chimera clones and genotype somatic mutations [46]. AFLPs, on the other hand, are utilized to identify *In-vitro*

generated crops since these changes are hereditary, beneficial, and have prolonged regeneration cycles [37].

8. ANALYSIS OF GENETIC VARIABILITY

In molecular marker technology, recent advancements have become a significant approach to understanding genetic variation and expanding breeding techniques [54]. Pedigree assessment is commonly used for this purpose, as it is an effective method of determining genetic drift. Markers are employed in collection of genetic resources, improved breeding resources, and other cultivars to estimate or quantify genetic diversity, which aids in the identification of germplasm, the development of PGR data systems, and the evolution of varietal information structures. Plant breeders may utilize genetically profiled and DNA fingerprinted breeding material, which helps in the classification of breeding lines and pure lines into different heterotic classes and allows them to choose the most effective crossover method for improving hybrid vigour. These findings are useful in cross-pollinated crop breeding for identifying different parents and exploiting maximal heterosis [60]. For drought resistance, sixteen different genotypes of rice were examined using SSR markers in order to determine their level of genetic diversity. Drought tolerance was discovered in the cultivars Giza 178, Giza179, and GZ1368- S-5- 4 [21].

9. FOOD/CROP PROTECTION

Cultivars protection and germplasm assessment can both benefit from advanced genotyping techniques. The UPOV (International Union for the Protection of New Varieties of Plants) is constantly developing and applying new fingerprint methods to make sure that new plant varieties are unique, uniform, and stable [6,27]. It is well accepted that fingerprinting is an effective technique for identifying malpractices in food products as well as medications. A good illustration of this would be the practise of combining more costly basmati varieties with less expensive non-basmati varieties. To address this problem, numerous markers for adulteration studies have been recommended [6,22]. Microsatellite markers are often used to map the genomes of several plant types, and microsatellite linkage maps are now accessible in some significant crops (maize, wheat, soybean, rice, chickpea) for genetic analysis. Further, MAS uses fingerprinting methods to enable breeders to speed up the assessment of traits in fewer generations [14].

10. CONCLUSION AND FUTURE PROSPECTS

As early as the nineteenth century, variety differentiation was identified on the basis of the external morphology of plants. The development of NGS technology in the 21st century has made genetic analysis by sequencing the benchmark for identifying individuals by using their DNA. Gene sequencing, genetic diversity estimation, crop diversification and phylogeny, heterosis analysis, and evaluation of diploid/haploid crops, as well as cultivar differentiation, have all benefited from advances in molecular markers combined with increased performance technologies. In genetic diversity assessments and gene sequencing, RAPDs and AFLPs have been frequently employed. When it's necessary to test sites over the entire genome, both approaches come in handy. Therefore, there are certain limits. The rapid changes in gene expression, high polymorphism level, and great repeatability of SSR markers have led to their increased adoption. Genetic studies and sequence analysis, as well as the advancement of powerful bioinformatic tools, have made it possible to quickly identify unique genomic areas for crop DNA fingerprinting. Advances and discoveries in sequencing technologies should be promoted, as well as the development

of cost-effective genotyping-by-sequencing technologies.

In the future, a worldwide DNA fingerprinting library for all crops should be created, with DNA fingerprints of all major crop types registered under PBR rules. As both Pakistan and India appeal to the trademark "Basmati Rice," this system will also be useful in settling trademark conflicts between countries [13]. Such problems will be avoided in the future when it comes to the creation of a world library of agricultural types. The fingerprinting of newly developed plant varieties is proposed as a method for securing plant breeders' rights and ensuring the continued availability of novel varieties across national borders. Therefore, for reliable protection of cultivars and fingerprinting of DNA in developing and less developed nations, cost-effective large DNA fingerprinting methods are needed [55].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Abdalla AM, Reddy OUK, El-Zik KM, Pepper AE. Genetic diversity and relationships of diploid and tetraploid cottons revealed using AFLP. *Theor Appl Genet.* 2001;102(2-3):222-9.
2. Adhikari S, Saha S, Bandyopadhyay TK, Ghosh P. Efficiency of ISSR marker for characterization of *Cymbopogon* germplasms and their suitability in molecular barcoding. *Plant Syst Evol.* 2015;301(1):439-50.
3. Ahmad F, Akram A, Farman K, Abbas T, Bibi A, Khalid S, et al. Molecular markers and marker assisted plant breeding: current status and their applications in agricultural development. *J Environ Agric Sci.* 2017;11:35-50.
4. Akkaya MS, Bhagwat AA, Cregan PB. Length polymorphisms of simple sequence repeat DNA in soybean. *Genetics.* 1992;132(4):1131-9.
5. Al-Samarai FR, Kazaz AA et al. Molecular markers: An introduction and applications. *European journal of molecular biotechnology.* 2015;9(3):118-30.
6. Archak S. Plant DNA fingerprinting: An overview. *AG Biotech Net.* 2000;2:1-6.
7. Archak S, Lakshminarayananreddy V, Nagaraju J. High-throughput multiplex

- microsatellite marker assay for detection and quantification of adulteration in Basmati rice (*Oryza sativa*). Electrophoresis. 2007;28(14):2396-405.
8. Bagley MJ, Anderson SL, May B. Choice of methodology for assessing genetic impacts of environmental stressors: polymorphism and reproducibility of RAPD and AFLP fingerprints. Ecotoxicology. 2001;10(4):239-44.
 9. Bangarwa SK, Balwan KLS, Choudhary M, Choudhary MK. An introduction to DNA-markers and their role in crop improvement. Pharm J. 2021;10(7):638-43.
 10. Ben-Ari G, Lavi U. Marker-assisted selection in plant breeding. In: Plant biotechnology and agriculture. Academic Press. 2012;163-84.
 11. Bhandari AP, Sukanya DH, Ramesh CR. Application of isozyme data in fingerprinting Napier grass (*Pennisetum purpureum* Schum.) for germplasm management. Genet Resour Crop Evol. 2006;53(2):253-64.
 12. Chandel G, Datta K, Datta SK. Detection of genomic changes in transgenic Bt rice populations through genetic fingerprinting using amplified fragment length polymorphism (AFLP). GM Crops. 2010;1(5):327-36.
 13. Chandola HV. Basmati Rice: Geographical indication or mis-indication. J World Intellectual Property. 2006;9(2):166-88.
 14. Chukwu SC, Rafii MY, Ramlee SI, Ismail SI, Oladosu Y, Okporie E, et al. Marker-assisted selection and gene pyramiding for resistance to bacterial leaf blight disease of rice (*Oryza sativa* L.). Biotechnol Biotechnol Equip. 2019;33(1):440-55.
 15. Chung YS, Choi SC, Jun TH, Kim C. Genotyping-by-sequencing: A promising tool for plant genetics research and breeding. Hortic Environ Biotechnol. 2017;58(5):425-31.
 16. Collard BCY, Jahufer MZZ, Brouwer JB, Pang ECK. An introduction to markers, quantitative trait loci (QTL) mapping and marker-assisted selection for crop improvement: the basic concepts. Euphytica. 2005;142(1-2):169-96.
 17. Datta D, Gupta S, Chaturvedi SK, Nadarajan N. Molecular markers in crop improvement. Vol. 208. Kanpur: Indian Institute of Pulses Research. 2011;24.
 18. Deokar A, Sagi M, Tar'an B. Genome-wide SNP discovery for development of high-density genetic map and QTL mapping of Ascochyta blight resistance in chickpea (*Cicer arietinum* L.). Theor Appl Genet. 2019;132(6):1861-72.
 19. El-Esawi MA, Witczak J, Abomohra AEF, Ali HM, Elshikh MS, Ahmad M. Analysis of the genetic diversity and population structure of Austrian and Belgian wheat germplasm within a regional context based on DArT markers. Genes. 2018;9(1):47.
 20. Etmnan A, Pour-Aboughadareh A, Mohammadi R, Ahmadi-Rad A, Noori A, Mahdavian Z, et al. Applicability of start codon targeted (SCoT) and inter-simple sequence repeat (ISSR) markers for genetic diversity analysis in durum wheat genotypes. Biotechnol Biotechnol Equip. 2016;30(6):1075-81.
 21. Gaballah MM, Metwally AM, Skalicky M, Hassan MM, Brestic M, El Sabagh A, et al. Genetic diversity of selected rice genotypes under water stress conditions. Plants (Basel). 2020;10(1):27.
 22. Ganopoulos I, Argiriou A, Tsafaris A. Adulterations in Basmati rice detected quantitatively by combined use of microsatellite and fragrance typing with High Resolution Melting (HRM) analysis. Food Chem. 2011;129(2):652-9.
 23. Gautam AK, Gupta N, Bhadkariya R, Srivastava N, Bhagyawant SS. Genetic diversity analysis in chickpea employing ISSR markers. Agrotechnology, 5(2). 2016;9881:2168.
 24. Ge S, Sang T, Lu BR, Hong DY. Rapid and reliable identification of rice genomes by RFLP analysis of PCR-amplified Adh genes. Genome. 2001;44(6):1136-42.
 25. Gomes S, Martins-Lopes P, Lima-Brito J, Meirinhos J, Lopes J, Martins A, et al. Evidence for clonal variation in 'Verdeal-Transmontana' olive using RAPD, ISSR and SSR markers. J Hortic Sci Biotechnol. 2008;83(4):395-400.
 26. Gupta PK, Rustgi S, Sharma S, Singh R, Kumar N, Balyan HS. Transferable EST-SSR markers for the study of polymorphism and genetic diversity in bread wheat. Mol Genet Genomics. 2003;270(4):315-23.
 27. He B, Geng R, Cheng L, Yang X, Ge H, Ren M. Genetic diversity and fingerprinting of 33 standard flue-cured tobacco varieties for use in distinctness, uniformity, and stability testing. BMC Plant Biol. 2020;20(1):378.
 28. Ipek M, Ipek A, Simon PW. Comparison of AFLPs, RAPD markers, and isozymes for

- diversity assessment of garlic and detection of putative duplicates in germplasm collections. J Am Soc Hortic Sci. 2003;128(2):246-52.
29. Iqbal M, Shahzad R, Shahzad R, Bilal K, Qaisar R, Nisar A, et al. DNA fingerprinting of crops and its applications in the field of plant breeding. J Agric Res. 2021;59(1):13-28.
 30. Ismail NA, Rafii MY, Mahmud TMM, Hanafi MM, Miah G. Molecular markers: a potential resource for ginger genetic diversity studies. Mol Biol Rep. 2016;43(12):1347-58.
 31. Jaccoud D, Peng K, Feinstein D, Kilian A. Diversity arrays: A solid state technology for sequence information independent genotyping. Nucleic Acids Res. 2001;29(4):E25.
 32. Jamil S, Shahzad RAHIL, Yasmeen ERUM, Rahman SU, Younas M, Iqbal MZ. DNA fingerprinting of Pakistani maize hybrids and parental lines using simple sequence repeat markers. Pak J Bot. 2020;52(6):2133-45.
 33. Jeffreys AJ, Wilson V, Thein SL. Individual-specific 'fingerprints' of human DNA. Nature. 1985;316(6023):76-9.
 34. Karihaloo JL. DNA fingerprinting techniques for plant identification. Plant Biol Biotechnol. Plant Genomics and Biotechnology. 2015;11:205-21.
 35. Kelkar YD, Strubczewski N, Hile SE, Chiaromonte F, Eckert KA, Makova KD. What is a microsatellite: A computational and experimental definition based upon repeat mutational behavior at A/T and GT/AC repeats. Genome Biol Evol. 2010;2:620-35.
 36. Kopecký D, Bartoš J, Christelová P, Černoch V, Kilian A, Doležel J. Genomic constitution of Festuca x Lolium hybrids revealed by the DArTFest array. Theor Appl Genet. 2011;122(2):355-63.
 37. Kumar M, Chaudhary V, Sirohi U, Sharma VR, Naresh RK. Application of molecular markers and their utility in genetic studies of floricultural crops: A review. Int J Agric Environ Biotechnol. 2019;12(3):229-47.
 38. Kumari V, Kumawat P, Rajput SS, Kumar M. Molecular markers and their role in crop improvement; 2021.
 39. Lateef DD. DNA marker technologies in plants and applications for crop improvements. J Biosci Med. 2015;03(5):7-18.
 40. Lenka D, Tripathy SK, Kumar R, Behera M, Ranjan R. Assessment of genetic diversity in quality protein maize (QPM) inbreds using ISSR markers. J Environ Biol. 2015;36(4):985-92.
 41. Leonardi C, Romano D. Characteristics of Bougainvillea types widespread in the East of Sicily. Italus hortus. Italy; 2003.
 42. Liu CJ, Witcombe JR, Pittaway TS, Nash M, Hash CT, Busso CS, et al. An RFLP-based genetic map of pearl millet (*Pennisetum glaucum*). Theor Appl Genet. 1994;89(4):481-7.
 43. Liu LW, Wang Y, Gong YQ, Zhao TM, Liu G, Li XY, et al. Yu. Assessment of genetic purity of tomato (*Lycopersicon esculentum* L.) hybrid using molecular markers. Sci Horti. 2007;115:7-12.
 44. Mangini G, Nigro D, Margiotta B, De Vita P, Gadaleta A, Simeone R, et al. Exploring SNP diversity in wheat landraces germplasm and setting of a molecular barcode for fingerprinting. Cereal Res Commun. 2018;46(3):377-87.
 45. McGregor CE, Lambert CA, Greyling MM, Louw JH, Warnich L. A comparative assessment of DNA fingerprinting techniques (RAPD, ISSR, AFLP and SSR) in tetraploid potato (*Solanum tuberosum* L.) germplasm. Euphytica. 2000; 113(2):135-44.
 46. Meng Y, Zhao N, Li H, Zhai H, He S, Liu Q. SSR fingerprinting of 203 sweetpotato (*Ipomoea batatas* (L.) Lam.) varieties. J Integr Agric. 2018;17(1):86-93.
 47. Miller JC, Tanksley SD. Effect of different restriction enzymes, probe source, and probe length on detecting restriction fragment length polymorphism in tomato. Theor Appl Genet. 1990;80(3):385-9.
 48. Nadeem MA, Nawaz MA, Shahid MQ, Doğan Y, Comertpay G, Yıldız M, et al. DNA molecular markers in plant breeding: current status and recent advancements in genomic selection and genome editing. Biotechnol Biotechnol Equip. 2018;32(2):261-85.
 49. Nybom H, Weising K, Rotter B. DNA fingerprinting in botany: past, present, future. Investig Genet. 2014;5(1):1.
 50. Olukolu BA, Mayes S, Stadler F, Quat Ng N, Fawole I, Dominique D, et al. Genetic diversity in Bambara groundnut (*Vigna subterranea* (L.) Verdc.) as revealed by phenotypic descriptors and DArT marker analysis. Genet Resour Crop Evol. 2012;59(3):347-58.

51. Perera MF, Arias ME, Costilla D, Luque AC, García MB, Romero CD, et al. Genetic diversity assessment and genotype identification in sugarcane based on DNA markers and morphological traits. *Euphytica*. 2012;185(3):491-510.
52. Peterson GW, Dong Y, Horbach C, Fu YB. Genotyping-by-sequencing for plant genetic diversity analysis: A lab guide for SNP genotyping. *Diversity*. 2014;6(4):665-80.
53. Pradeep Reddy M, Sarla N, Siddiq EA. Inter simple sequence repeat (ISSR) polymorphism and its application in plant breeding. *Euphytica*. 2002;128(1):9-17.
54. Ramesh P, Mallikarjuna G, Sameena S, Kumar A, Gurulakshmi K, Reddy BV, et al. Advancements in molecular marker technologies and their applications in diversity studies. *J Biosci*. 2020;45:1-15.
55. Rohland N, Reich D. Cost-effective, high-throughput DNA sequencing libraries for multiplexed target capture. *Genome Res*. 2012;22(5):939-46.
56. Royo JB, Cabello F, Miranda S, Gogorcena Y, Gonzalez J, Moreno S, et al. The use of isoenzymes in characterization of grapevines (*Vitis vinifera*, L.). Influence of the environment and time of sampling. *Sci Hortic*. 1997;69(3-4):145-55.
57. Salem HH, Ali BA, Huang TH, Qin DN, Wang XM, Xie QD. Use of random amplified polymorphic DNA analysis for economically important food crops. *J Integr Plant Biol*. 2007;49(12):1670-80.
58. Selvi A, Nair NV, Balasundaram N, Mohapatra T. Evaluation of maize microsatellite markers for genetic diversity analysis and fingerprinting in sugarcane. *Genome*. 2003;46(3):394-403.
59. Sherman A, Rubinstein M, Eshed R, Benita M, Ish-Shalom M, Sharabi-Schwager M, et al. Mango (*Mangifera indica* L.) germplasm diversity based on single nucleotide polymorphisms derived from the transcriptome. *BMC Plant Biol*. 2015;15:277.
60. Silva KJD, Pastina MM, Guimarães CT, Magalhães JV, Pimentel LD, Schaffert RE, et al. Genetic diversity and heterotic grouping of sorghum lines using SNP markers. *Sci Agric*. 2020;78(6).
61. Simko I. One potato, two potato: haplotype association mapping in autotetraploids. *Trends Plant Sci*. 2004;9(9):441-8.
62. Singh A, Sengar RS. DNA fingerprinting based decoding of indica rice (*Oryza sativa* L.) via molecular marker (SSR, ISSR, & RAPD) in aerobic condition. *Adv Crop Sci Technol*. 2015;3:167.
63. Talebi R, Fayyaz F. Quantitative evaluation of genetic diversity in Iranian modern cultivars of wheat (*Triticum aestivum* L.) using morphological and amplified fragment length polymorphism (AFLP) markers. *Biharean Biol*. 2012;6:14-8.
64. Tar'an B, Zhang C, Warkentin T, Tullu A, Vandenberg A. Genetic diversity among varieties and wild species accessions of pea (*Pisum sativum* L.) based on molecular markers, and morphological and physiological characters. *Genome*. 2005;48(2):257-72.
65. Terzi V, Morcia C, Gorrini A, Stanca AM, Shewry PR, Faccioli P. DNA-based methods for identification and quantification of small grain cereal mixtures and fingerprinting of varieties. *J Cereal Sci*. 2005;41(3):213-20.
66. Tian HL, Wang FG, Zhao JR, Yi HM, Wang L, Wang R, et al. Development of maizeSNP3072, a high-throughput compatible SNP array, for DNA fingerprinting identification of Chinese maize varieties. *Mol Breed*. 2015;35(6):136.
67. Tiwari JK, Rastogi NK, Chandrakar PK, Sarawgi AK, Verulkar SB. Varietal identification of four rice varieties from Chhattisgarh through DUS characterization. *Indian J Plant Genet Resour*. 2013;26(3):238-40.
68. Walsh BM, Hoot SB. Phylogenetic relationships of Capsicum (Solanaceae) using DNA sequences from two noncoding regions: the chloroplast atpB-rbcL spacer region and nuclear waxy introns. *Int J Plant Sci*. 2001;162(6):1409-18. doi: 10.1086/323273.
69. Wang N, Yuan Y, Wang H, Yu D, Liu Y, Zhang A, et al. Applications of genotyping-by-sequencing (GBS) in maize genetics and breeding. *Sci Rep*. 2020;10(1):16308.
70. Wang Z, Pan Y, Luo J, You Q, Xu L, Zhang H, et al. SSR-based genetic identity of sugarcane clones and its potential application in breeding and variety extension. *Sugar Tech*. 2020;22(3):367-78.
71. Williams JG, Kubelik AR, Livak KJ, Rafalski JA, Tingey SV. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nucleic Acids Res*. 1990;18(22):6531-5.

72. Winter P, Kahl G. Molecular marker technologies for plant improvement. *World J Microbiol Biotechnol.* 1995;11(4):438-48.
73. Zargar M, Romanova E, Trifonova A, Shmelkova E, Kezimana P. AFLP-analysis of genetic diversity in soybean [*Glycine max* (L.) Merr.] cultivars Russian and foreign selection; 2017.

© 2023 Lanka et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:
<https://www.sdiarticle5.com/review-history/100613>