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Broad Spectrum Utilities of Microsatellite in Fish and Fisheries

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Abstract

Microsatellites are short segments of repetitive DNA sequences distributed throughout the eukaryotic genome and used as molecular markers for various purposes in applied biology. These are tandem repeats of 1-6 nucleotides like di-, tri-, tetra- or hexa nucleotides occurring at high frequency in the nuclear genomes of different taxa including most of the vertebrates. These constitute only a few percent of the genomes depending on their compactness but have become the markers of choice for high-resolution population analysis due to high variability, ease and accuracy of assaying. In modern trends of genetics, molecular biology, biotechnology and genetic engineering pertinent to animal, plant and microbes, these markers have contributed a lot to upgrade the knowledge and information. These are preferred as extremely valuable tools for genome mapping in many organisms over erstwhile markers and are integrated with other morphological features of various organisms helping to identify species or strains accurately. These have been used extensively since last few decades for versatile purposes in various parts of world and are applied to different organisms where fishes are not an exception. As versatile genetic markers, these have been applied in many studies on genetics and resource management of fishes as well as for analyzing pedigree, population structure, genome variation, evolutionary process and fingerprinting. This strengthens management and protection of fish germplasm. These are also integrated with many other tools of recent advancement in biotechnology, molecular biology and genetic engineering *vis-a-vis* other traditional technologies like captive breeding and fish milt cryopreservation for conserving genetic diversity and rehabilitation of the natural populations of fishes. However, there is still a long way to go before these are applied in each species of fish. The present article reviews a compilation of many references on utilities of microsatellite markers for different purposes applied to various types of fishes and non fishes.

Keywords: Carps; Fish; Genetic diversity; Microsatellites; Population genetics.

1. Introduction

Advancements of scientific knowledge through innovative tools and techniques have changed the approach of gathering information in both biological and non-biological sector. These are unique sequences of DNA of 1–6 bp repeated up to about 100 times at each locus [1]. These are called as “simple sequence repeat” (SSR) by Tautz [2] or “short tandem repeat” (STR) DNA by Edwards, *et al.* [3]. In the context of microsatellite markers in various organisms, these are found at high frequency in the nuclear genomes of most taxa [4]. It was revealed by Schorderet and Gartler [5] that, lower frequencies of CpG dinucleotides in vertebrate genomes have been attributed to methylation of cytosine increasing its chances of mutation to thymine by deamination. Within vertebrates, the dinucleotide repeats like -GT and CA- are the most common microsatellites [6]. These are inherited in a Mendelian fashion [7]. In most vertebrate, microsatellites are only a few percent of the genomes depending on its compactness [8]. Polymorphic SSR markers could be effectively isolated from transcriptomes of non-model organisms [9, 10] and gene-associated microsatellites markers have been isolated across many taxa [11]. This review is intended to scan advancements of information w. r. t microsatellite markers from time to time with their large scale application in different fishes in fisheries and aquaculture. It reviews a compilation of many references on utilities of microsatellite markers for different purposes applied to various types of fishes and non fishes.

2. Development of Microsatellites Markers

Various development protocols based on partial genomic library enriched for microsatellite markers include Liao, *et al.* [12]; Pardo, *et al.* [13]; Abdelkrim, *et al.* [14] and Wang, *et al.* [15]. Massive parallel sequencing protocols have been employed for the development of such markers in many organisms to reduce the cost, labour and time required [14, 16-18]. Next generation sequencing has been successfully used for rapid development of such markers [19-21]. However, marker development following Sanger sequencing has shown to be more effective as described by Malausa, *et al.* [22]. These can provide numerous locus-specific molecular markers and putatively homologous sequences across taxa [23]. These are considered to be the best marker systems to detect inter -varietal polymorphisms [24] and are the most promising PCR-based markers [25].

3. Utilities of Microsatellite Markers

In modern trends of animal sciences, microsatellite markers have contributed a lot to biotechnology, molecular biology and genetic engineering or recombinant DNA technology in prokaryotes as well as plants and animals. Their applications range from kinship analysis to population genetics and conservation/management [26]. They are powerful DNA markers for quantifying genetic variations within and between populations of species [27]. They are valuable for stock discrimination and population genetics [28, 29]. Various utilities of microsatellite markers in different organisms include an assortment of objectives:-

3.1. Genetic Studies

As per Avise [30] and Linda and Paul [31], microsatellites as molecular genetic markers are powerful equipments to detect genetic uniqueness of individuals, populations or species. According to Collevatti, *et al.* [32], these are essential in studies of genetic variability of different populations. These molecular markers from various model and non-model organisms could provide strong foundations for assessment of fish genetic diversity and identification of species or populations [33]. Tautz and Renz [34] and Weber and Wong [35] reported that, microsatellites have high mutation rate between 10^{-3} and 10^{-4} per gamete per generation with extensive length polymorphism and are used as extremely valuable tool for genome mapping in many organisms [36, 37]. It was revealed by Tong, *et al.* [38] that, many microsatellites have high-mutation rates (average 5×10^{-4} per locus per generation) resulting in high levels of allelic diversity necessary for genetic studies. However, genetic variations have been assessed at much smaller scales in comparison to other markers as per Sunnucks [39] and Boris, *et al.* [40]. Such locii are observed in both coding and non-coding regions of almost all known prokaryotic and eukaryotic genomes [41]. These have created lots of awareness in fisheries and aquaculture pertinent to genetic diversity, population genetics, genomics and allied sciences.

3.2. Population Analysis

According to Estoup, *et al.* [42], microsatellites have become the markers of choice for high-resolution population analysis due to their high variability, ease and accuracy of assaying. These are valuable tools for stock discrimination and population genetics [28, 29]. These markers are valuable tools to investigate genetic variability with applications to conservation and population genetics [43]. As per Abdul Muneer, *et al.* [27], these are powerful DNA markers for quantifying genetic variations within and between populations or species.

3.3. Genome Mapping

Genetic linkage map for a number of aquatic species have been constructed [44-50] using different types of polymorphic markers. Microsatellites are used as genetic markers for genome mapping, kinship and parentage exclusion, population differentiation and stock identification [28, 51-54].

3.4. Pedigree Analysis

Microsatellites give several information in aquaculture for parentage and pedigree analysis in selective breeding; genome mapping and detection of quantitative trait loci (QTL), identification of genetic variability between and within stocks and monitoring genetic changes in stocks; [55-58].

4. Microsatellites in Fisheries

Microsatellite markers integrated with morphological features helps to identify the species or strains more accurately. This strengthens management and protection of fish germplasm resources. These are used extensively since last few decades for versatile purposes in different parts of world applied to diverse organisms where fishes are not exception. Studies of fish genetics and breeding by microsatellite markers appeared in the early 1990s [33]. It was Beckmann and Soller [59], which indicated that microsatellites are used in population genetics of fishes. Di-nucleotides are the dominant microsatellite repeats in most aquaculture species although tri-nucleotide repeats are most abundant in plants [60-62]. Highly polymorphic microsatellite markers have great potential utility as genetic tags for use in aquaculture and fisheries biology. As per estimation of Wright [63] and Mojekwu and Anumudu [64], the frequencies of occurrence of microsatellite motifs are once every 10kb in fishes and are inherited in a co-dominant fashion. Most of the motifs in aquatic animals are variable but GC dinucleotide repeats are extremely rare [65, 66] including aquatic animals as per Edwardsa, *et al.* [67], Somridhivej, *et al.* [68] and Saarinen and Austin [69]. Many important questions linked to population genetics of various fishes have been answered by microsatellite markers as evident by Mc Lean and Taylor [70] studying eulachon *Thaleichthys pacificus* populations from the west coast of northern America. Cross species amplification have been reported by various authors as primers of stickleback and cod have been used in *Merlangius merlangus* (Gadidae) by Rico, *et al.* [71], that of rainbow trout (Family: Salmonidae) in whitefish, *Coregonus nasus* by Patton, *et al.* [72] and of goldfish, *Carassius auratus*, in nine species of cyprinids by Zheng, *et al.* [73]. Genome mapping in fishes have been encouraged by microsatellite markers as evident from various sources to construct genetic maps by analysing the recombination and segregation of the alleles through genotyping in zebra fish, cichlids, common carp, trout and many others. Microsatellites have been used to assess family/parentage identification in many species and used to discriminate fish in mixed family groups [40, 74, 75]. Ahmad, *et al.* [76] used microsatellites based techniques to determine population structure and genetic diversity of fish. A chronology of valuable studies done in fishes using microsatellite markers for various purposes includes Knapik, *et al.* [37]; Ardren, *et al.* [77]; Gilbey, *et al.* [78] and [46, 79] on microsatellite genetic linkage maps; Nikolic, *et al.* [80]; Patel, *et al.* [81]; Sha, *et al.* [82] and Rahman, *et al.* [83] on characterization and identification of microsatellites and Tong, *et al.* [84]; Liao, *et al.* [85] and Mendonca, *et al.* [86] on cross-species locus identification to develop a database of the fishes. Imsiridou, *et al.* [87] studied web database of molecular genetic data from fish stocks Fishgen. According to Barbara, *et al.* [88] the success of transferability of microsatellite loci were directly linked to phylogenetic relationship between the groups tested and the transferability for fish species can be around 70% in congeners, lowering to 60% among genera of the same family. [89, 90], Chauhan, *et al.* [91], Mandal, *et al.* [92], Xu, *et al.* [93] and [14, 29, 94] reported microsatellite polymorphisms and sequences in marine and freshwater fishes for population genetics. Gopalakrishnan, *et al.* [89] and Abdelkrim, *et al.* [14] developed microsatellite markers from catfishes of order Siluriformes. Polymorphism information content of microsatellite markers has been considered in population analysis and biodiversity conservation [95] and management of fish stocks [96]. Abdul-Muneer [97] indicated utilities of highly polymorphic microsatellite markers as genetic tags in aquaculture and use for analyzing pedigree, population structure, genome variation, evolutionary process and fingerprinting. Several studies have been performed to analyze the genetic information of consecutively selected populations of aquatic species to improve breeding strategies [98-101] in Chinese provinces. Abdul-Muneer [97] developed several microsatellite markers in different fresh water species by cross-species amplification.

Microsatellite markers have been applied in different fishes from time to time by different authors for different purposes as detailed below:

Table-1. Versatile utilities of microsatellite markers in different fishes

Year	Author (s)	Name of the Species	Work/conclusion
1998	Kanda [102]	Bull trout *Salvelinus confluentus*	Genetics, conservation and comparison of population genetic structure among different genetic markers and hybridization with brook trout
2001	Kanda and Allendorf [103]	Bull trout	Examined population genetic structure using a combination of allozyme, microsatellite and mtDNA variation
2003	Spruell, *et al.* [104]	Bull trout	Supported existence of three major genetically differentiated groups in north-western USA
1993	Estoup, *et al.* [42]	Brown trout *Salmo trutta*	Isolated microsatellites from a partial genomic library and showed that SSRs are useful markers for the construction of genetic maps in fish biology and genetics in aquaculture
1999	Cagigas, *et al.* [105]	Brown trout	Evaluated genetic variability
2002	Was and Wenne [106]	Sea trout	Studied gene flow and heterozygosity changes
2003	Palm, *et al.* [107]	Brown trout	Combined allozyme and microsatellites to investigate genetic divergence
2010	Arslan and Bardakci [108]	Brown trout	Analysed population structure
2016	Baillie, *et al.* [109]	Lake trout *Salvelinus namaycush*	Used microsatellite markers to monitor the genetic and phenotypic diversity in Lake Superior
1996	Morris, *et al.* [110]	Rrainbow trout *Oncorhynchus mykiss*	Reported microsatellites for genetic study
1997	O’ Connell, *et al.* [111]	Rainbow trout	Reported differentiation of populations in Lake Ontario and evaluation of stepwise mutation and infinite allele mutation models
2001	Ozaki, *et al.* [112]	Rainbow trout	Used 51 microsatellite markers to identify several chromosome regions containing putative QTL genes that affect resistance to infectious pancreatic necrosis (IPN)
2004	Beacham, *et al.* [113]	Rainbow trout	Accurately estimated stock composition of Fraser River sockeye salmon
2002	Heath, *et al.* [114]	Chinook salmon *Oncorhynchus tshawytscha*	Relationships between heterozygosity, allelic distance and reproductive traits
2003	Beacham, *et al.* [115]	Chinook salmon	The geographic basis for population structure
1998	Small, *et al.* [116]	*Oncorhynchus kisutch*	Microsatellite markers were used for population structure analysis
2011	Drinan, *et al.* [117]	*Oncorhynchus clarkia lewisii*	Reported 20 microsatellites for determining the patterns of population genetics variation
1998	Brunner, *et al.* [118]	Arctic charr *Salvelinus alpinus*	Microsatellite and mitochondrial DNA assessment of population structure and stocking effects from central Alpine lakes
2005	Lundrigan,	Arctic charr	Studied genetic variation among natural and cultured

	et al. [119]		populations in North America
1996	Angers and Bernatchez [120]	Brook charr *Salvelinus fontinalis*	For cross-species amplification in
2003	Adams and Hutchings [121]	Brook charr	Assessed genetic variation using microsatellite markers to identify population structure
1998	Beacham and Dempson [122]	Atlantic salmon *Salmo salar L.*	Population structure from the Conne river, Newfoundland
1999	Nielsen, *et al.* [123]	Atlantic salmon	Microsatellite analysis of extinct and extant populations
1999	Norris, *et al.* [124]	Atlantic salmon	Investigated genetic diversity between farmed and wild populations
1999	Tessier and Bernatchez [125]	Atlantic salmon	Microsatellite analysis of DNA was performed from archived scales to compare the population structure among four sympatric landlocked populations
2000	Norris, *et al.* [126]	Atlantic salmon	Parentage and relatedness determination in farmed fishes
2003	Nelson, *et al.* [127]	Sockeye salmon	Population structure of the central coast of British Columbia
2003	Elliott and Reilly [128]	*Salmo salar L.*	Evaluated genetic divergence
2004	Wennevik, *et al.* [129]	*Salmo salar* L.	Analysed genotype distributions in Atlantic salmon populations
2006	Neville, *et al.* [130]	Salmonids	Assessed connectivity in salmonids using microsatellites
2016	Faulks and Östman [131]	Salmonids	Assessed the microsatellite genetic diversity and population structure of three salmonid species to aid in formulating appropriate conservation management plans.
1996	Bentzen, *et al.* [132]	Atlantic cod *Gadus morhua*	Distinguished north western and south eastern populations
2011	Larsen, *et al.* [133]	Atlantic cod	Studied salinity tolerance gene expression through microsatellite markers
2000	Senanan and Kapuscinski [134]	Northern pike *Esox lucius*	Studied genetic relationships among 14 populations in the North Central United States and in six populations from Quebec, Alaska, Siberia and Finland
2000	Lundy, *et al.* [135]	European hake *Merluccius merluccius*	Temporal and spatial genetic variation in spawning grounds in the Bay of Biscay
1997	May, *et al.* [136]	Sturgeons *Acipenser* and *Scaphirhynchus*	Studied for microsatellite genetic variation through cross-species amplification
2002	Henderson and King [137]	Atlantic sturgeon *Acipenser oxyrinchus*	Population delineation and broodstock management
1998	Chenoweth, *et al.* [138]	*Lates calcarifer* and *Sparus aurata*	Studied genetic variability on the basis of allozyme, microsatellites and RAPD markers
1999	Neff, *et al.* [139]	Blue gill *Lepomis macrochirus*	Microsatellite evolution in sunfish Centrarchidae
1999	Reilly and Ward [140]	Patagonian tooth fish *Dissostichus eleginoides*	Determined population structure
2006	Rogers, *et al.* [141]	Patagonian tooth fish	Genetic structure of the populations on the Patagonian shelf and Atlantic and western Indian Ocean Sectors of the Southern Ocean
1999	Takagi, *et al.* [142]	Tuna of the genus *Thunnus*	To develop PCR primers for microsatellite loci and its application for population genetic study
2002	Appleyard, *et al.* [143]	Big eye tuna	Genetic stock structure in the Indian Ocean using mitochondrial DNA and microsatellites
2011	Davies, *et al.* [144]	Albacore Tuna *Thunnus*	Identified 12 microsatellite loci in North Atlantic and Mediterranean Sea populations

1999	Leclerc, *et al.* [145]	North American *Morone saxatilis*	Determined population structure
2003	Brown, *et al.* [146]	Striped bass *Morone saxatilis*	Demonstrated nuclear microsatellite and mitochondrial marker for estimation of population structure
2000	Yue, *et al.* [147]	*Scleropages formosus*	Rapid isolation and characterization of microsatellites from the genome of Asian arowana
2002	Yu, *et al.* [148]	Japanese anchovy *Engraulis japonicus*	Analysed population structure
2002	Hauser, *et al.* [149]	Snapper *Pagrus auratus*	Found significant decline in genetic diversity reducing adaptability, population persistence and productivity in New Zealand
2003	O'Malley, *et al.* [150]	Red drum *Sciaenops ocellatus*	Assessed the genetic components of wild and hatchery populations
2001	Palma, *et al.* [151]	Gilthead seabream *Sparus aurata*	Variation in allozymes and three microsatellite loci was assessed in populations of wild and cultured stocks
2004	Alarcon, *et al.* [152]	Gilthead seabream	Population genetic analysis
2003	Salgueiro, *et al.* [153]	Endangered fish *Anaecypris hispanica*	Studied genetic structure in the Portuguese Guadiana drainage
2004	Chistiakov, *et al.* [154]	Sea bass *Dicentrarchus labrax*	For development of linkage relationships
2004	Liang, *et al.* [155]	Hucho trout *Hucho taimen* Pallas	For genetic analysis
2007	Perales-Flores, *et al.* [156]	Farmed catfish *Ictalurus punctatus*	Microsatellite variability analysis from Tamaulipas, Mexico
2011	Liu, *et al.* [157]	Mandarin Fish *Siniperca chuatsi*	Isolated 40 microsatellite markers
2015	Yi, *et al.* [101]	Mandarin fish	Microsatellite analysis of genetic diversity and genetic structure in five consecutive breeding generations
2011	Olivatti, *et al.* [158]	Neotropical fish *Leporinus friderici*	Heterologous amplification and characterization of microsatellite markers
2012	Zaganini, *et al.* [159]	Neotropical fish *Astyanax altiparanae*	Isolation and characterization of microsatellite loci and cross-species amplification
2012	Ribolli, *et al.* [160]	Neotropical catfish *Pimelodus maculates*	Genetic characterization in the upper Uruguay river population
2011	Jamsari, *et al.* [161]	Snakehead murrel *Channa striata*	Identified 7 polymorphic microsatellite markers
2012	Luo, *et al.* [162]	Endangered fish Gunther *Schizothorax biddulphi*	Rapid development of microsatellite markers using next generation sequencing and cross-species amplification.
2013	Kim, *et al.* [163]	*Gobiobotia brevibarba*	Reported development and characterization of polymorphic microsatellite marker for this endangered freshwater fish in Korea
2013	[164]	European whitefish, *Coregonus lavaretus L.*	Performed PCR microsatellite multiplex assay to establish population structure, hybridization and conservation status
2013	Gupta, *et al.* [165]	*Notopterus notopterus*	Developed microsatellite markers by cross-species amplification of primers in other species of families notopteridae and osteoglossidae
2016	Landinez-Garcia and Marquez [166]	*Ichthyoelephas longirostris*	Developed and characterized 24 polymorphic microsatellite loci for this freshwater fish using next generation sequencing to explore population genetics
1994	Brooker, *et al.* [167]	Cold water teleost and mammals	Reported difference in organization of microsatellite
2000	De Woody and Avise [168]	Marine, freshwater and anadromous fishes	Microsatellite variation compared with other animals
2003	Clark [169]	Teleostei (bony fish)	Genomics and mapping
2009	De Abreu, *et al.* [170]	*Pseudoplatystoma reticulatum*	Genetic variability of two populations from the upper Paraguay river basin

2010	Griffiths, *et al.* [171]	*Dipturus batis*	Revealed spatially segregated cryptic species in the critically endangered fish the common skate
2017	Joshi, *et al.* [25]	General application in fisheries	Presented an overall view on utilities of microsatellite markers

Existence of such a vast array of information on various applications of microsatellite markers indicates the potential utilities of this novel tool. It is worth mentionable that, the technique has large impact on various aspects of different fishes in different parts of the globe.

5. Microsatellites in Carps

Studies similar as above descriptions are also not less in carps as compared to other species of fishes. Microsatellites and other markers are already being applied to population genetics studies and for family identification in aquaculture genetics research and in the longer term marker-assisted selection (using genetic markers closely linked to quantitative trait loci) are expected to improve the efficiency of selective breeding for at least some traits in different carps. There exists a huge reference describing the utilities of microsatellite markers in various carps.

Table-2. Versatile applications of microsatellite markers in carps

Year	Author (s)	Name of the Species	Work/conclusion
2004	Gopalakrishnan, *et al.* [172]	*Gonoproktopterus curmuca*	Successfully developed polymorphic microsatellite markers through cross-species amplification of primers from other cyprinids
1992	Goff, *et al.* [173]	*Danio rerio*	Microsatellites are abundant in genome and are highly polymorphic
1999	Postlethwait, *et al.* [174]	*Danio rerio*	Studied the zebra fish genome and concluded that it is the only cyprinid having full capacity of modern genomics techniques applied to the analysis of its genome
1999	Shimoda, *et al.* [175]	*Danio rerio*	Informed that 2000 markers of microsatellite (CA) repeats provide 1.2 centi morgan (cM) average resolution (about 0.74 megabase/cM)
2000	Kelly, *et al.* [176]	*Danio rerio*	Genetic linkage mapping of zebra fish genes
2010	Rouchka [177]	*Danio rerio*	Microsatellite markers studies
2005	Das, *et al.* [178]	*Labeo rohita*	Isolated and characterized polymorphic microsatellites and their cross-species amplification in related species
2009	Gopalakrishnan, *et al.* [90]	*Labeo rohita*	Carried out characterization of dinucleotide microsatellite repeats in *Labeo* species
1997	Naish, *et al.* [179]	*Catla catla*	Reported microsatellite marker study of wild and hatchery populations using tetranucleotide repeats to examine genetic structure of the wild populations and comparative levels of genetic variation
1998	Naish and Skibinski [180]	*Catla catla*	National Bureau of Fish Genetics Resource, Lucknow, India (1999) reported that the primers for one of the microsatellite loci developed for *C. catla* (G1) also amplified a polymorphic locus in *L. rohita*.
2000	Basavaraju, *et al.* [181]	*Catla catla*	Genetic improvement of carps
2000	Mair, *et al.* [182]	*Catla catla*	Genetic improvement of Indian and common carp
2001	Mc Connell, *et al.* [183]	*Catla catla*	Described five polymorphic microsatellite loci
2001	Mohindra, *et al.* [184]	*Catla catla*	Carried out cross-species amplification of *C. catla* G1 primer in *Catla catla* from Gobind Sagar and sequenced the loci in *Labeo dero, L. dyocheilus, L. rohita*, and *Morulius calbasu*
2005	Alam and Islam [96]	*Catla catla*	Population genetic structure
2002	Yue and Orban [185]	Silver crucian carp *Carassius auratus gibelio*	To study polymorphic microsatellites cross-amplification
2010	Zheng, *et al.* [186]	*Carassius auratus gibelio*	Developed 59 polymorphic trinucleotide and tetranucleotide microsatellite markers for cross-species amplification in

			Carassius auratus
1997	Crooijmans, *et al.* [187]	*C. carpio*	Microsatellite markers in common carp
2000	Sun and Liang [188]	*C. carpio*	Described a genetic linkage map constructed for *C. carpio* and *Cyprinus pellegrini*, using 262 microsatellites markers developed from *C. carpio*, crucian carp (*Carassius carassius*) and *D. rerio* as well as RAPDs and other DNA markers
2000	Tanck, *et al.* [189]	*C. carpio*	Genetic characterization of wild Dutch common carp
2001	David, *et al.* [190]	*C. carpio*	Polymorphism in ornamental and common carp strains by AFLP analysis and microsatellite markers
2001	[191]	French and Czech carp *C. carpio*	Genetic variability in reared stocks based on allozymes and microsatellites
2003	Bartfai, *et al.* [192]	Common carp	Studied gene flow and heterozygosity changes and genetic analysis of two brood stocks by RAPD and microsatellites
2003	Kohlmann, *et al.* [193]	Cyprinus carpio L.	Genetic variability and structure of common carp populations
2004	Zhou, *et al.* [194]	Cyprinus carpio L.	Genetic variation analysis within and among six varieties in China
2005	Kohlmann, *et al.* [195]	Cyprinus carpio	Microsatellite-based genetic variability and differentiation of domesticated, wild and feral common carp
2005	Lehoczky, *et al.* [196]	Hungarian common carp	Preliminary studies on the genetic variability of six strains using microsatellite DNA markers
2009	Mao, *et al.* [197]	*Cyprinus carpio*	Evaluated genetic divergence
1995	Kellogg, *et al.* [198]	Cichlids	Tested for multiple paternity
1996	Lee and Kocher [199]	*Oreochromis niloticus*	Usefulness of microsatellite markers for genetic mapping
1996	Zardoya, *et al.* [6]	*Cichlids*	Reported phylogenetic relationship within family Cichlidae and other families of the suborder Labroidei applying flanking regions (MFRs)
1997	Ambali [200]	*Oreochromis shiranus* and *O. shiranus chilwae*	Studied relationship between domestication and genetic diversity by using primers of Nile tilapia
2000	Fiumera, *et al.* [201]	*Prognathochromis perrieri*	Used microsatellite loci to study a captive breeding program for *ex situ* conservation of the Lake Victoria cichlid over several generations
2001	Taylor, *et al.* [202]	Cichlid	Determined four polymorphic microsatellite loci for studying nine populations
2002	Salzburger, *et al.* [203]	Cichlids	Reported introgressive hybridization between an ancient and genetically distinct species
2002	Carleton, *et al.* [204]	*Oreochromis niloticus*	For tilapia genome analysis
2012	Bezault, *et al.* [23]	*Oreochromis niloticus*	Successfully tested and analysed cross-species amplification of microsatellite markers from different African cichlid
2005	Liao, *et al.* [205]	Grass carp *Ctenopharyngodon idella*	Microsatellite diversity of grass carp in the Yangtze River system
2006	Antoro, *et al.* [206]	*Epinephelus coioides*	Studied genetic diversity collected from six sites from Thailand and Indonesia
2010	Dubut, *et al.* [207]	European cyprinids	Developed five multiplex PCR sets optimized to analyze 41 cyprinid specific polymorphic microsatellite loci

In the present context of mentioning significance of microsatellite markers in Indian Major Carps, Alam and Islam [96] reported on population genetic structure of *Catla catla* (Hamilton), Chauhan, *et al.* [91] reported in *Cirrhinus mrigala*; Chauhan and Rajiv [208] reviewed utilities of molecular markers in fisheries and aquaculture, Sahu, *et al.* [209] developed SSR markers using next generation sequencing in *Labeo rohita* in Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India. Singh, *et al.* [210] assessed genetic variation in samples of *Labeo calbasu* from twelve riverine locations across India using nine polymorphic microsatellite loci. Fish Microsat is a database of microsatellite sequences of fishes and shellfishes [41] from *Lates calcarifer, Ctenopharyngodon idella, Hypophthalmichthys molitrix, Labeo rohita, Oreochromis niloticus, Fenneropenaeus indicus, Penaeus monodon* and *Macrobrachium rosenbergii*. The database contains 4398 microsatellite sequences of 41 species belonging to 15 families from the Indian subcontinent. The author of this article (Tripathy) as per Meher, *et al.* [211] used ten microsatellite markers to assign offspring parentage assessing their feasibility to resolve parentage in *Labeo rohita* selective breeding programmes *in lieu* of conventional PIT tag marking. Sultana, *et al.* [212] used five species specific microsatellite markers to assess the genetic variability and level of inbreeding among different populations of *Labeo rohita* collected from six different hatcheries. Sahoo, *et al.* [213] used genotype data of 140 microsatellite markers to construct genetic linkage map of rohu using Joinmap ver. 4.1. As per Sahoo, *et al.* [213], the genome length of rohu was estimated to be 3087.9 cM and its genetic linkage map may facilitate systematic searches of the genome to identify genes associated with commercially important characters and marker-assisted selection programmes of this species.

6. Conclusion

Microsatellite has emerged as potential genetic tool *en route* optimum utilization to answer many unsolved questions in various organisms including fishes and non fishes. These are presumed as very powerful genetic markers. In fishery, these are used for many purposes like, studying genetic variations of closely related species, pedigree analysis, identifying fish stock etc. for meaningful conservation strategies in fisheries and aquaculture management and many more. As versatile genetic markers, these have been applied in many studies on genetics and resource management of fish. This tool can be integrated with many other tools of recent advancement in biotechnology and molecular biology, genetic engineering vis-a-vis other traditional technologies like captive breeding and sperm cryopreservation for conserving genetic diversity and rehabilitation of the natural populations of fish species. Using microsatellite markers, the linkage relationships between marker loci and genes, associated with economic or quality traits, could be established and QTLs mapped for better stocks and strains. All these studies would enhance aquaculture production by marker assisted selection breeding Erico, *et al.* [214]. However, there is still a long way to go before these are applied in each species of fish.

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