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## New insights into polymorphisms in candidate genes associated with incidence to repeat breeder in Italian buffaloes (*Bubalus bubalis*)

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**ABSTRACT:** This study looked at the reproductive genes that could interact with repeat breeder incidence in Italian buffaloes. Two hundred and forty female Italian buffaloes (120 repeat breeder and 120 apparently normal) were used. Blood samples were collected from each buffalo into tubes encompassing EDTA anticoagulant to isolate DNA. PCR-DNA sequencing elicited nucleotide sequence differences between normal and repeat breeder buffaloes for the reproductive (*MFSD14A*, *PALMD*, *VPS13B*, *BMP*, *MTNR1A*, *TSHR*, *CSGALNACT1*, *CADM2*, *ZNF503*, *KRRI*, *MTPN*, *IGFBP7*, *LEP*, and *ABCC4*) genes. The likelihood of dissemination of all notable nucleotide variations varied noticeably between buffalo groups with and without repeat breeders, depending on Fisher's exact test ( $p < 0.01$ ). All of the reproductive markers under research had the exonic region mutations in repeat breeder buffaloes versus normal ones. The results may confirm the importance of these markers' nucleotide variations as candidates for repeat breeder occurrence and offer a practical buffalo management strategy.

**Keyword:** Italian buffaloes; candidate gene; repeat breeder.

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## INTRODUCTION

Economically important for long-term food production are reproductive features, especially in monotocous animals like cattle and buffalo (Shao et al., 2021). Repeat breeding, or an extended interval between two calves, may be indicative of poor reproduction or sterility. More inseminations, veterinary care, and hormone therapies are required to address this illness, all of which have an impact on current and upcoming lactations (Biochard, 1990). Additionally, extra expenses are spent due to the culling and replacement of animals with reproduction problems (Roxström & Strandberg, 2002). The best option for reducing culling expenses, maintaining significant genetic features, and boosting farm profits is fertility improvement (Dekkers, 1991). With relation to statistical distribution, binary, interval, and continuous attributes have previously been used to classify reproductive characteristics (Berry & Evans 2014). Reproductive characteristics have been classified to make them simpler for understanding and utilizing in livestock and breeding programs (Cammack et al., 2009). These categories include features relating to ovulation, mating, and calving.

Because buffalo are mono-ovulatory, only one follicle typically grows and ovulates during the oestrus phase, which significantly reduces fertility and limits the growth of the buffalo business (Li et al., 2018). The reproductive activity of the buffaloes follows a seasonal pattern, with compromised activity in the summer and regular reproductive cyclicity and conception in the autumn and winter (Das & Khan 2010). Untangling the reproductive endocrinology of buffaloes will help researchers determine the cause of this reproductive restriction (Warriach et al., 2015). Quantitative features that affect reproduction are influenced by a variety of circumstances. Repeat breeding's occurrence in dairy farms can be reduced, and with it, the associated financial loss, by being aware of its underlying causes (Regmi & Dhakal, 2020). Repeat breeding can be caused by a wide range of factors, including insufficient fertilization, premature embryonic death, genital tract congenital or genetic faults, spermatozoa, ova or first zygote defects, microbial or traumatic inflammation, endocrine/hormonal problems, and management flaws (such as failing to identify estrus) (Yusuf et al., 2010). It is anticipated that genetic variants will influence gene expression, which will change the amount of one or more proteins, changing the phenotype of attributes (Musunuru et al., 2010; Lap-

palainen et al., 2013). A way to locate inherited components which affect susceptibility for common economic problems is marker-assisted selection (MAS) (Ashwell et al., 1997; Bishop et al., 1995). In the era of genomic assortment, excellent cow training groups that combine attributes with high-throughput genomic SNP marker data allow the use of selection strategies for emerging functional characteristics, such disease resistance (Buch et al., 2012). Another significant advantage of genetic selection is shortening of generational intervals (Schaeffer, 2006). A novel understanding of the identity of underlying genes and change in the genetic material and how they might affect the characteristic has been claimed to be gained by integrating genetic markers to find significant genes linked with target traits (Li et al., 2014). The term "transcriptome" denotes all the genes in the genome that are accurately and at high throughput during particular physiological and pathological states (Kukurba & Montgomery, 2015).

Recent genome-wide association analysis studies have focused on novel genes related to bovine reproductive performance; however, no studies have yet looked at the relationship between the SNPs in these genes and the frequency of repeat breeders (Li et al., 2018; Mahrouset al., 2022). It is important to note that more research is necessary to follow potential symptoms that can imply reproductive failure from repeat breeder because there is limited knowledge on the reproduction pathways that determine buffalo resistance to or sensitivity to repeat breeder (Li et al., 2018). The molecular alterations may also help to identify repeat breeders and provide crucial information about the interactions between the physiologies of the various reproductive pathways (Sammad et al., 2022; Heidari et al., 2019). The effectiveness of putative reproductive (*MFSD14A*, *PALMD*, *VPS13B*, *BMP*, *MTNR1A*, *TSHR*, *CSGALNACT1*, *CADM2*, *ZNF503*, *KRR1*, *MTPN*, *IGFBP7*, *LEP*, and *ABCC4*) genes as candidates for repeat breeder incidence prediction and tracking in Italian buffaloes was examined in this study employing PCR-DNA sequencing methods.

## MATERIALS AND METHODS

### Dairy buffaloes and research samples

The current study was carried out on 240 pure Italian buffaloes aged 4.5 years. Buffaloes upraised on a private farm in the province of Delta region of northern Egypt of which 120 were repeat breeder and 120 appeared to be normal. Based on breeding history and clinical indications seen by skilled vets,

both groups were selected. All of the animals were raised in stalls with free access to water. It was determined that none of the study animals had ovarian pathologies like ovarian cysts or uterine, cervical, or vaginal inflammation or infection. The buffalo cows in the control group appeared to be in good condition and had a regular estrous cycle, nonetheless, no pregnancies were achieved in the repeat breeder group notwithstanding at least three successful attempts to artificially inseminate or mate with a bull in estrus (Devkota et al., 2022). Visual observation was used to identify estrus in both groups twice daily in the morning and in the evening. All animals were checked for foetal membrane slip and/or fremitus, and rectal palpation was used to confirm pregnancy diagnoses.

Five milliliters of blood were obtained by puncturing the jugular vein of each buffalo. To obtain whole blood and recover DNA samples were placed in tubes containing EDTA as anticoagulant. The Ethical Committee approved the sample collection and animal care techniques utilized in this study, and they complied with Mansoura University's regulations. The Mansoura University Animal Care and Use Committee (MU-ACUC) gave its approval to the study's protocol (code VM.R.23.11.26).

### DNA extraction and PCR amplification

DNA from the genome was extracted using total blood by means of the genetic material JET full blood genomic DNA isolation kit and the producer's directions (Thermo scientific, Vilnius, Lithuania). Using Nanodrop, DNA of good purity and concentration was considered. The following reproductive (*MFSD14A*, *PALMD*, *VPS13B*, *BMP*, *MTNR1A*, *TSHR*, *CSGALNACT1*, *CADM2*, *ZNF503*, *KRR1*, *MTPN*, *IGFBP7*, *LEP*, and *ABCC4*) genes' parts of coding sites (CDS) were amplified. The oligonucleotide sequences for amplification were constructed using the PubMed *Bubalus bubalis* genome. Table 1 provides the primers utilized in the PCR.

The polymerase chain cloning mixture had been treated in a thermal cycler with a final volume of 50 $\mu$ L. The succeeding elements were present in every reaction container: 19 microliters d.d. water, 4 microliters of genetic material, 1 microliters of each primer pair, and 25 microliters of the master combination (Jena Bioscience, Jena, Germany). The PCR combinations remained in use for four minutes at a starting temperature of 95 °C for unwinding. The 34 cycles included one-minute denaturation rounds

at 95 °C, one-minute annealing cycles based on the Table 1 temperature range, and 30-second for elongation at 72 °C, followed by ten minutes of final elongation. The samples were retained at 4 °C. Using agarose gel electrophoresis to obtain demonstrable outcomes and viewing PCR segment configurations underneath UV light, a gel certification technique was used.

### Discovering polymorphism

Before DNA sequencing, Hamburg, Germany-based Jena Bioscience # pp-201s/Munich provided methods to purify PCR for getting rid of primer dimmers, non-specific bands, and other impurities and create the predicted scope's planned amplified product (Boom et al., 1990). Using a Nanodrop (Waltham, Massachusetts, USA, UV-Vis spectrometer Q5000), adequate quality and good concentrations were obtained while measuring PCR output (Boesen-berg-Smith et al., 2012). Sequence analysis of the PCR-produced amplification results has been utilized to find SNPs using normal and repeat breeder buffaloes. The PCR yields were sequenced using the Sanger et al., (1977) outlined enzyme chain terminator technique on an ABI 3730XL DNA sequencer (United States: Applied Biosystems, Waltham).

Chromas 1.45 and BLAST 2.0, the tools to evaluate results of DNA analysis (Altschul et al., 1990). Comparing the reproductive gene PCR results to the GenBank-provided reference gene sequences has revealed polymorphisms. The MEGA6 tool can detect differences in the amino acid categorizations among the examined genes according to sequence matching among the buffaloes under investigation (Tamura et al., 2007).

### Statistical analysis

H<sub>0</sub>: Polymorphisms of reproductive genes could not interact in the incidence to repeat breeder in Italian buffaloes.

H<sub>A</sub>: Polymorphisms of reproductive genes could interact in the incidence to repeat breeder in Italian buffaloes.

Observing the significant distribution of SNPs for the discovered genes between the examined buffaloes was conducted using Fisher's exact test analysis ( $p < 0.01$ ). Graphpad statistical software was used to conduct the statistical analysis (Graphpad prism for Windows version 5.1, Graphpad software, Inc., San Diego, CA, USA).

**Table 1.** Oligonucleotide primers for reproductive genes used to study genetic polymorphisms.

Investigated marker	Sense	Antisense	Accession number	Annealing Temperature (°C)	Size of PCR product (bp)
<i>MFSD14A</i>	5'-GCCAACCGCAGTATCATGCTG-3'	5'-CCAGGCCATACGCCATACTTC-3'	XM_055584984.1	60	457
<i>PALMD</i>	5'-TGGCTTCTAGATGGATCAGC-3'	5'-CTATTCCTTCATTCTTCCC-3'	XM_006045619.1	58	343
<i>VPS13B</i>	5'-AATGAGCTATGTGAATCGCT-3'	5'-ACAACTCGTCATGACTCAGACTCT-3'	XM_055546577.1	60	414
<i>BMP</i>	5'-ATGGTCCTCTGAGCATCCTA-3'	5'-GTGGAGCCTCTGAAGAAG-3'	EF375880.1	60	480
<i>MTNR1A</i>	5'-GTGAGCCTGGCAGTTGCAGAC-3'	5'-CACTCTCCATCTGACCTGAAG-3'	MF173058.1	56	465
<i>TSHR</i>	5'-ATCCGCCTCTGGCACGGCTAC-3'	5'-TGGCATAGAGGAATGGATTGGC-3'	KC415275.1	58	442
<i>CSGALNACT1</i>	5'-CTGCTCGCCCTGGGCTCCCCG-3'	5'-CGGTGGCCTGCTTGACGCCGGC-3'	XM_025275645.3	58	385
<i>CADM2</i>	5'-CGCAGGCCGGTCTCGCTTC-3'	5'-GAACCATCTTATATCAGCTGCA-3'	XM_025278930.3	60	495
<i>ZNF503</i>	5'-TCTCCGCCAGGCTAACCGCCT-3'	5'-CTTATCCGAGCCGGTTGGAG-3'	XM_025285122.3	60	361
<i>KRRI</i>	5'-CCGACGTTGGAGAACCGAGATG-3'	5'-CTAATGATGATATGGATCA-3'	XM_006048659.4	58	278
<i>MTPN</i>	5'-ATGTTGGACAAGGAGTTCATG-3'	5'-GGCACCCAGTGACATTCAGAT-3'	XM_044946911.2	60	266
<i>IGFBP7</i>	5'-AGCTGGGGAGACCCGGCATGC-3'	5'-GACAGGAAGCAATTTCACGCAG-3'	XM_025290001.3	56	380
<i>LEP</i>	5'-CAGTCGGTCTCCTCAAACAGA-3'	5'-TCAGCACCCAGGACTGAGGTC-3'	AF387814.1	58	360
<i>ABCC4</i>	5'-GCAGAAGGGAACTCTGCTC-3'	5'-TATGGTTGAACTACTCTGGTG-3'	XM_045162483.1	60	355

*MFSD14A*= Major facilitator superfamily domain containing 14A; *PALMD*= Palmdelphin; *VPS13B*= Vacuolar protein sorting 13 homolog B; *MTPN*= Bone morphogenic protein; *MTNR1A*= Melatonin receptor 1B; *TSHR*= Thyroid stimulating hormone receptor; *CSGALNACT1*= Chondroitin sulfate N-acetylgalactosaminyltransferase 1; *CADM2*= Cell adhesion molecule 2; *ZNF503*= Zinc finger protein 503; *KRRI*= Small subunit processome component homolog; *MTPN*= Myotrophin; *IGFBP7*= insulin like growth factor binding protein 7; *LEP*= Leptin; and *ABCC4*= ATP-binding cassette sub-family C member 4.

## RESULTS

SNP variations in amplified DNA nucleotides associated with repeat breeder were found in the results of PCR-DNA sequencing on both normal and repeat breeder buffaloes for the MFSD14A (457-bp), PALMD (343-bp), VPS13B (414-bp), BMP (480-bp), MTNR1A (465-bp), TSHR (442-bp), CS-GALNACT1 (385-bp), CADM2 (495-bp), ZNF503 (361-bp), KRR1 (278-bp), MTPN (266-bp), IGFBP7 (380-bp), LEP (360-bp), and ABCC4 (355-bp) genes. The DNA sequence differences between the sequences of reference genes obtained from GenBank and the reproductive indicators examined in the studied buffaloes were used to verify each SNP that has been discovered (Figures S1–S14).

Table 2 shows the dissemination of a single base variation as well as a type of inherited change for reproductive indicators in normal and repeat breeder buffaloes. The SNPs' Fisher's exact test analysis revealed considerably different occurrences of the investigated markers in the normal and repeat breeder buffaloes ( $p < 0.01$ ). All of the reproductive markers under research had the exonic region mutations, which resulted in different coding DNA sequences in repeat breeder buffaloes versus nor-

mal ones. Thirty SNPs were discovered using DNA sequencing of reproductive genes; 16 of them are synonymous and 15 are non-synonymous. The amino acid variations between the reproductive genes in all the research buffaloes and the reference sequences retrieved in GenBank were used to validate all observed SNPs and the corresponding amino acids (Figures S15–S28).

For the MFSD14A gene (457-bp), two observed recurrent synonymous SNPs, 165CT and 322TC, resulted in 55C and 108G respectively. One recurrent SNPs were found when the PALMD gene (343-bp) was sequenced. Synonymous mutation 36L occurred as a result of 108TC SNP. 175TC and 223TC involved a non-synonymous mutation, resulting in the substitution of the amino acid C59R, and Y75H respectively; were found in DNA sequences of the VPS13B gene (414-bp). The BMP gene (480-bp) contained three non-synonymous SNPs: 47TC, 80CA, and 184GA, which caused the amino acids V16A, P27Q, and V62I to be substituted, respectively. The nucleotide sequence of the MTNR1A gene (465-bp) revealed one recurrent synonymous SNP; 24N resulted from 72CT SNP. The 442-bp TSHR gene's DNA sequence revealed four identified

XM_055584984.1	GCGAACCGCAGTATCATGCTGGC <del>AAAAA</del> AGATCATCATTAAGGACGGAGGCACGCCCTCAA	60
H	GCGAACCGCAGTATCATGCTGGC <del>AAAAA</del> AGATCATCATTAAGGACGGAGGCACGCCCTCAA	60
RR	GCGAACCGCAGTATCATGCTGGC <del>AAAAA</del> AGATCATCATTAAGGACGGAGGCACGCCCTCAA	60
*****		
XM_055584984.1	GGAATAGGTTCTCTAGTGT <del>TTT</del> TATCATGCAGTTATCGTCATCTTTGGAGTTTTCGCT	120
H	GGAATAGGTTCTCTAGTGT <del>TTT</del> TATCATGCAGTTATCGTCATCTTTGGAGTTTTCGCT	120
RR	GGAATAGGTTCTCTAGTGT <del>TTT</del> TATCATGCAGTTATCGTCATCTTTGGAGTTTTCGCT	120
*****		
XM_055584984.1	TGGGGATTATTGACAGCACCCACCTTGGTATTACATGAAACCTCCCTAAACATACA	180
H	TGGGGATTATTGACAGCACCCACCTTGGTATTACATGAAACCTCCCTAAACATACA	180
RR	TGGGGATTATTGACAGCACCCACCTTGGTATTACATGAAACCTCCCTAAACATACA	180
*****		
XM_055584984.1	TTCTGTGATGAATGGCTAATTCAAGGAGTAAGGGTTGTTGTCATTCTCAGTGCCCCCT	240
H	TTCTGTGATGAATGGCTAATTCAAGGAGTAAGGGTTGTTGTCATTCTCAGTGCCCCCT	240
RR	TTCTGTGATGAATGGCTAATTCAAGGAGTAAGGGTTGTTGTCATTCTCAGTGCCCCCT	240
*****		
XM_055584984.1	CTTATTGGTGCCTTCTGATGTTGGGCCGAAATCCTCTTGCTGCTAACAGTATT	300
H	CTTATTGGTGCCTTCTGATGTTGGGCCGAAATCCTCTTGCTGCTAACAGTATT	300
RR	CTTATTGGTGCCTTCTGATGTTGGGCCGAAATCCTCTTGCTGCTAACAGTATT	300
*****		
XM_055584984.1	TTCACGTGTGCCCAATTCTTAAATGAAAATCAGCCCATGGTGGTACTTGTGTTATC	360
H	TTCACGTGTGCCCAATTCTTAAATGAAAATCAGCCCATGGTGGTACTTGTGTTATC	360
RR	TTCACGTGTGCCCAATTCTTAAATGAAAATCAGCCCATGGTGGTACTTGTGTTATC	360
*****		
XM_055584984.1	TCTGTTCTGGGGTTTGCAGTGACTTCTCGTGGTATTGCAATATGAGATATA	420
H	TCTGTTCTGGGGTTTGCAGTGACTTCTCGTGGTATTGCAATATGAGATATA	420
RR	TCTGTTCTGGGGTTTGCAGTGACTTCTCGTGGTATTGCAATATGAGATATA	420
*****		
XM_055584984.1	ACCCAAGAACATGAAAAGTATGCCGTATGCCCTGG 457	
H	ACCCAAGAACATGAAAAGTATGCCGTATGCCCTGG 457	
RR	ACCCAAGAACATGAAAAGTATGCCGTATGCCCTGG 457	
*****		

**Figure S1.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_055584984.1| and MFSD14A marker (457-bp) sequences.

XM_006045619.4	TGGCTTCTAGATGGAATCAGCAGTGGAAAAGAGCAGGAAGAGATGAAGAAGCAAAATCAA	60
H	TGGCTTCTAGATGGAATCAGCAGTGGAAAAGAGCAGGAAGAGATGAAGAAGCAAAATCAA	60
RR	TGGCTTCTAGATGGAATCAGCAGTGGAAAAGAGCAGGAAGAGATGAAGAAGCAAAATCAA	60
	*****	*****
XM_006045619.4	CAAGACCAGCACCAGATCCAGGTTCTAGAACAAAGTATCCTCAGACTTGAGAAAAGAGATC	120
H	CAAGACCAGCACCAGATCCAGGTTCTAGAACAAAGTATCCTCAGACTCGAGAAAAGAGATC	120
RR	CAAGACAGCACCAGATCCAGGTTCTAGAACAAAGTATCCTCAGACTTGAGAAAAGAGATC	120
	*****	*****
XM_006045619.4	CAAGATCTGAAAAGGCTGAACCTGCAAATCTCAACCAATGAAGAAGCAATTAAAGAAA	180
H	CAAGATCTGAAAAGGCTGAACCTGCAAATCTCAACCAATGAAGAAGCAATTAAAGAAA	180
RR	CAAGATCTGAAAAGGCTGAACCTGCAAATCTCAACCAATGAAGAAGCAATTAAAGAAA	180
	*****	*****
XM_006045619.4	CTGAAATCAGTTGAGAGGACAACAGAACAGAACATAATAAGGTCGTGAAGGTGAAAAGGAA	240
H	CTGAAATCAGTTGAGAGGACAACAGAACAGAACATAATAAGGTCGTGAAGGTGAAAAGGAA	240
RR	CTGAAATCAGTTGAGAGGACAACAGAACAGAACATAATAAGGTCGTGAAGGTGAAAAGGAA	240
	*****	*****
XM_006045619.4	GAAACATCAGGAGAGTCAGTTGAAGACATCTATGCTAATATCCCCGACCTTCCAAAATCC	300
H	GAAACATCAGGAGAGTCAGTTGAAGACATCTATGCTAATATCCCCGACCTTCCAAAATCC	300
RR	GAAACATCAGGAGAGTCAGTTGAAGACATCTATGCTAATATCCCCGACCTTCCAAAATCC	300
	*****	*****
XM_006045619.4	TACATACCTTCAGGTTAAGGAAGGAAAGAAATGAAGGAATAG	343
H	TACATACCTTCAGGTTAAGGAAGGAAAGAAATGAAGGAATAG	343
RR	TACATACCTTCAGGTTAAGGAAGGAAAGAAATGAAGGAATAG	343
	*****	*****

**Figure S2.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb| XM\_006045619.4| and *PALMD* marker (343-bp) sequences.

XM_055546577.1	AATGAGCTATGTGAATCGCTACATCAAGAACCTAAAGCCGTAGATCTACAGCTTCGCT	60
H	AATGAGCTATGTGAATCGCTACATCAAGAACCTAAAGCCGTAGATCTACAGCTTCGCT	60
RR	AATGAGCTATGTGAATCGCTACATCAAGAACCTAAAGCCGTAGATCTACAGCTTCGCT	60
	*****	*****
XM_055546577.1	ATGGGGTGGAGACGTGGTTCTCAGCAAGCTGGAGTTAAATGGAGCTGCTGGAGCAGGA	120
H	ATGGGGTGGAGACGTGGTTCTCAGCAAGCTGGAGTTAAATGGAGCTGCTGGAGCAGGA	120
RR	ATGGGGTGGAGACGTGGTTCTCAGCAAGCTGGAGTTAAATGGAGCTGCTGGAGCAGGA	120
	*****	*****
XM_055546577.1	ATTGAAATTACCAATTCACTTTTTAAAGTGGACATATTCTGAACTGAGGATCCATGTACC	180
H	ATTGAAATTACCAATTCACTTTTTAAAGTGGACATATTCTGAACTGAGGATCCACGTACC	180
RR	ATTGAAATTACCAATTCACTTTTTAAAGTGGACATATTCTGAACTGAGGATCCATGTACC	180
	*****	*****
XM_055546577.1	ATGGACAAAATCTGGGTCAGAACCCAGTGGTAATTACCATCAATACAATGGAAATGCATT	240
H	ATGGACAAAATCTGGGTCAGAACCCAGTGGTAATTACCATCAATACAATGGAAATGCATT	240
RR	ATGGACAAAATCTGGGTCAGAACCCAGTGGTAATTACCATCAACACAATGGAAATGCATT	240
	*****	*****
XM_055546577.1	GAAACTTAAAGATGGAATACAGGGATGATCATGAAAGCTGTGGTTCTAATTCTACCAACCG	300
H	GAAACTTAAAGATGGAATACAGGGATGATCATGAAAGCTGTGGTTCTAATTCTACCAACCG	300
RR	GAAACTTAAAGATGGAATACAGGGATGATCATGAAAGCTGTGGTTCTAATTCTACCAACCG	300
	*****	*****
XM_055546577.1	TAGTACTACTGAGAACACAAAAACATCAGCAAAACCCCGAAGAATTCAACAGGCCACTCC	360
H	TAGTACTACTGAGAACACAAAAACATCAGCAAAACCCCGAAGAATTCAACAGGCCACTCC	360
RR	TAGTACTACTGAGAACACAAAAACATCAGCAAAACCCCGAAGAATTCAACAGGCCACTCC	360
	*****	*****
XM_055546577.1	CACAGATCCTGATTGCCACCAGGCTATGTACAGACTCTGATCAGACGAGTTGT	414
H	CACAGATCCTGATTGCCACCAGGCTATGTACAGACTCTGATCAGACGAGTTGT	414
RR	CACAGATCCTGATTGCCACCAGGCTATGTACAGACTCTGATCAGACGAGTTGT	414
	*****	*****

**Figure S3.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_055546577.1| and *VPS13B* marker (414-bp) sequences.

frequent synonymous SNPs; 87CT, 126TC, 177CT, and 372CT, which were associated with the amino acids 29S, 42T, 59I, 42S and 124V.

For the CSGALNACT1 gene (385-bp), one synonymous SNP was found; the results of 135GA was 45T. Three recurrent synonymous SNPs; 105GA, 168TC,

and 354GT cleared during DNA sequencing of the CADM2 (495-bp) gene, which resulted in the amino acids 50R, 56N, and 118T, respectively. One recurrent non-synonymous SNP, 217GC, was elaborated using DNA sequencing of the ZNF503 gene (361-bp), which led to the substitution of the amino acid

EF375880.1	ATGGTCCTCTGAGCATCCTAGAACATCCTCTTCTTGGGACTGGCTTTATGGAA 60
H	ATGGTCCTCTGAGCATCCTAGAACATCCTCTTCTTGGGACTGGCTTTATGGAA 60
RR	ATGGTCCTCTGAGCATCCTAGAACATCCTCTTCTTGGGACTGGCTTTATGGAA 60
*****	*****
EF375880.1	CATAGGGTCCAATGACACCGGTAGGGCAGCCCTTATGGCCACCTGGCTGAGGCCCT 120
H	CATAGGGTCCAATGACACAGGTAGGGCAGCCCTTATGGCCACCTGGCTGAGGCCCT 120
RR	CATAGGGTCCAATGACACCGGTAGGGCAGCCCTTATGGCCACCTGGCTGAGGCCCT 120
*****	*****
EF375880.1	ACCTTGCCCCGTGATTAGGGAGCTGCTAGAACAGGAGCCCTGGCAAGCTGCAGAGGAAGCCG 180
H	ACCTTGCCCCGTGATTAGGGAGCTGCTAGAACAGGAGCCCTGGCAAGCTGCAGAGGAAGCCG 180
RR	ACCTTGCCCCGTGATTAGGGAGCTGCTAGAACAGGAGCCCTGGCAAGCTGCAGAGGAAGCCG 180
*****	*****
EF375880.1	CGGGTCTTAGGGCATCCCTTACGGTATATGCTGGAGTTGACCGTTAGCTGACGCA 240
H	CGGGTCTTAGGGCATCCCTTACGGTATATGCTGGAGTTGACCGTTAGCTGACGCA 240
RR	CGGGTCTTAGGGCATCCCTTACGGTATATGCTGGAGTTGACCGTTAGCTGACGCA 240
*****	*****
EF375880.1	AGTGGACACCCCTAGGGAAAACCGCACCATTGGGGCCACCATGGTAGGGCTGGTGGAGGCCA 300
H	AGTGGACACCCCTAGGGAAAACCGCACCATTGGGGCCACCATGGTAGGGCTGGTGGAGGCCA 300
RR	AGTGGACACCCCTAGGGAAAACCGCACCATTGGGGCCACCATGGTAGGGCTGGTGGAGGCCA 300
*****	*****
EF375880.1	CTGGCTAGTGTAGCAAGGGCTCTAGAGGCTCTGGCACATACAGACCCCTGGACTTTCT 360
H	CTGGCTAGTGTAGCAAGGGCTCTAGAGGCTCTGGCACATACAGACCCCTGGACTTTCT 360
RR	CTGGCTAGTGTAGCAAGGGCTCTAGAGGCTCTGGCACATACAGACCCCTGGACTTTCT 360
*****	*****
EF375880.1	CTGAGACCAAACCGGGTAGCATAACCAACTAGTCAGACCCACTGTGGTTACGCCATCAA 420
H	CTGAGACCAAACCGGGTAGCATAACCAACTAGTCAGACCCACTGTGGTTACGCCATCAA 420
RR	CTGAGACCAAACCGGGTAGCATAACCAACTAGTCAGACCCACTGTGGTTACGCCATCAG 420
*****	*****
EF375880.1	CTTCACCTAACTCATTCCCACCTCTCTGCCATGTGGAGCCCTGGGTCCAGAAAAGCCA 480
H	CTTCACCTAACTCATTCCCACCTCTCTGCCATGTGGAGCCCTGGGTCCAGAAAAGCCA 480
RR	CTTCACCTAACTCATTCCCACCTCTCTGCCATGTGGAGCCCTGGGTCCAGAAAAGCCA 480
*****	*****

**Figure S4.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|EF375880.1| and *BMP* marker (480-bp) sequences.

MF173058.1	GTGAGCCCTGGCAGTTGCAGACCTGCTGGTGGCCGTGATCCGTACCCCTGGCGCTGGCG 60
H	GTGAGCCCTGGCAGTTGCAGACCTGCTGGTGGCCGTGATCCGTACCCCTGGCGCTGGCG 60
RR	GTGAGCCCTGGCAGTTGCAGACCTGCTGGTGGCCGTGATCCGTACCCCTGGCGCTGGCG 60
*****	*****
MF173058.1	TCTATAGTTAACGATGGTGGAGCCTGAGCTCCCTGCAATTGCCAACTTAGTGGCTTCTG 120
H	TCTATAGTTAACGATGGTGGAGCCTGAGCTCCCTGCAATTGCCAACTTAGTGGCTTCTG 120
RR	TCTATAGTTAACGATGGTGGAGCCTGAGCTCCCTGCAATTGCCAACTTAGTGGCTTCTG 120
*****	*****
MF173058.1	ATGGGCTTGAGCGTCATCGGGTCCGTTCAATATCACGGGAATTGCCATCAACCGCTAT 180
H	ATGGGCTTGAGCGTCATCGGGTCCGTTCAATATCACGGGAATTGCCATCAACCGCTAT 180
RR	ATGGGCTTGAGCGTCATCGGGTCCGTTCAATATCACGGGAATTGCCATCAACCGCTAT 180
*****	*****
MF173058.1	TGCTGCATCTGCCACAGCCTCAGATACGACAACTGTTAGCAGCACAAAATTCCCTCTG 240
H	TGCTGCATCTGCCACAGCCTCAGATACGACAACTGTTAGCAGCACAAAATTCCCTCTG 240
RR	TGCTGCATCTGCCACAGCCTCAGATACGACAACTGTTAGCAGCACAAAATTCCCTCTG 240
*****	*****
MF173058.1	TACGTGTTCTGATATGGCTGCTGACGTTGCGGATCGTGGCCAAACCTGTGTGGGG 300
H	TACGTGTTCTGATATGGCTGCTGACGTTGCGGATCGTGGCCAAACCTGTGTGGGG 300
RR	TACGTGTTCTGATATGGCTGCTGACGTTGCGGATCGTGGCCAAACCTGTGTGGGG 300
*****	*****
MF173058.1	ACCCCTGCGGTACGACCCGGAGGATCTATTCTGACCTTACACAGTCGGTCAAGCTCAGCC 360
H	ACCCCTGCGGTACGACCCGGAGGATCTATTCTGACCTTACACAGTCGGTCAAGCTCAGCC 360
RR	ACCCCTGCGGTACGACCCGGAGGATCTATTCTGACCTTACACAGTCGGTCAAGCTCAGCC 360
*****	*****
MF173058.1	TACACGATGCCGTGGTGGTCTTCATTCAGTTCCAAATGCTCGTAGTCATCTCTG 420
H	TACACGATGCCGTGGTGGTCTTCATTCAGTTCCAAATGCTCGTAGTCATCTCTG 420
RR	TACACGATGCCGTGGTGGTCTTCATTCAGTTCCAAATGCTCGTAGTCATCTCTG 420
*****	*****
MF173058.1	TACCTGAGAATCTGGGCCCTGGTCTTCAGGTCAAGATGGAGAGTG 465
H	TACCTGAGAATCTGGGCCCTGGTCTTCAGGTCAAGATGGAGAGTG 465
RR	TACCTGAGAATCTGGGCCCTGGTCTTCAGGTCAAGATGGAGAGTG 465
*****	*****

**Figure S5.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|MF173058.1| and *MTNR1A* marker (465-bp) sequences.

KC415275.1	ATCCGCCCTCTGGCAGCGCTACGTCATCATGCTGGGGGCTGGGTTGCTGCTTCCCTGCTC 60
H	ATCCGCCCTCTGGCAGCGCTACGTCATCATGCTGGGGGCTGGGTTGCTGCTTCCCTGCTC 60
RR	ATCCGCCCTCTGGCAGCGCTACGTCATCATGCTGGGGGCTGGGTTGCTGCTTCCCTGCTC 60
*****	
KC415275.1	GCCCTGCTCCCTTTGGGGAAATAAGCAGCTATGCCAAGGTCAAGTCAGCATCTGCCTGCCCATG 120
H	GCCCTGCTCCCTTTGGGGAAATAAGCAGCTATGCCAAGGTCAAGTCAGCATCTGCCTGCCCATG 120
RR	GCCCTGCTCCCTTTGGGGAAATAAGTAGCTATGCCAAGGTCAAGTCAGCATCTGCCTGCCCATG 120
*****	
KC415275.1	GACACTGAGACTCTCTTGCCTGGCGTACATTATCCTCGTCTGTTACTCAACATCGTT 180
H	GACACTGAGACTCTCTTGCCTGGCGTACATTATCCTCGTCTGTTACTCAACATCGTT 180
RR	GACACCGAGACTCTCTTGCCTGGCGTACATTATCCTCGTCTGTTACTCAACATCGTT 180
*****	
KC415275.1	GCCTTATCATCGCTGTGCCTTACGTGAAGATCTACATCACAGTCCGAAATCCCCAC 240
H	GCCTTATCATCGCTGTGCCTTACGTGAAGATCTACATCACAGTCCGAAATCCCCAC 240
RR	GCCTTATCATCGCTGTGCCTTACGTGAAGATCTACATCACAGTCCGAAATCCCCAC 240
*****	
KC415275.1	TACAAACCCGGGGGACAAAGATACTAGAATTGCCAAAGGATGGCTGTGATCTTCACT 300
H	TACAAACCCGGGGGACAAAGATACTAGAATTGCCAAAGGATGGCTGTGATCTTCACT 300
RR	TACAAACCCGGGGGACAAAGATACTAGAATTGCCAAAGGATGGCTGTGATCTTCACT 300
*****	
KC415275.1	GACTTCATGTGCATGGCCCCAATCTCTTCTACGCTCTGTCGGCCCTTATGAACAAGCCT 360
H	GACTTCATGTGCATGGCCCCAATCTCTTCTACGCTCTGTCGGCCCTTATGAACAAGCCT 360
RR	GACTTCATGTGCATGGCCCCAATCTCTTCTACGCTCTGTCGGCCCTTATGAACAAGCCT 360
*****	
KC415275.1	CTCATCACCGTCACCAATTCCAAATCTTGCCTCTCTACCCACTTAACCTCTGT 420
H	CTCATCACCGTCACCAATTCCAAATCTTGCCTCTCTACCCACTTAACCTCTGT 420
RR	CTCATCACCGTCACCAATTCCAAATCTTGCCTCTCTACCCACTTAACCTCTGT 420
*****	
KC415275.1	GCCAATCCATTCTCTATGCCA 442
H	GCCAATCCATTCTCTATGCCA 442
RR	GCCAATCCATTCTCTATGCCA 442
*****	

**Figure S6.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|KC415275.1| and *TSHR* marker (442-bp) sequences.

XM_025275645.3	CTGCTCGCTGGGCCTCCCGGGTGGTGGTCTGCTCGTGCCTCTGCTGCGTGGCGTCT 60
H	CTGCTCGCTGGGCCTCCCGGGTGGTGGTCTGCTCGTGCCTCTGCTGCGTGGCGTCT 60
RR	CTGCTCGCTGGGCCTCCCGGGTGGTGGTCTGCTCGTGCCTCTGCTGCGTGGCGTCT 60
*****	
XM_025275645.3	GTCCTCTACATGCTGCCGACGCCGAGGGGGCATGATGAGGCCAGGGGCTGCCAGG 120
H	GTCCTCTACATGCTGCCGACGCCGAGGGGGCATGATGAGGCCAGGGGCTGCCAGG 120
RR	GTCCTCTACATGCTGCCGACGCCGAGGGGGCATGATGAGGCCAGGGGCTGCCAGG 120
*****	
XM_025275645.3	GCCAACGGCCCCACGGGAGGGGGCTCCAGGGCGGCGTCTGGCTGGAGGAGCGT 180
H	GCCAACGGCCCCACGGGAGGGGGCTCCAGGGCGGCGTCTGGCTGGAGGAGCGT 180
RR	GCCAACGGCCCCACGGGAGGGGGCTCCAGGGCGGCGTCTGGCTGGAGGAGCGT 180
*****	
XM_025275645.3	CACCGCGACACGTGGAGGCTCAAGAGGCAATTGCGCAGCTGCAAGGAGGAGCTGCAA 240
H	CACCGCGACACGTGGAGGCTCAAGAGGCAATTGCGCAGCTGCAAGGAGGAGCTGCAA 240
RR	CACCGCGACACGTGGAGGCTCAAGAGGCAATTGCGCAGCTGCAAGGAGGAGCTGCAA 240
*****	
XM_025275645.3	GAGCGGAGCGAGCAGCTGAAGGCCGCGCAGCTGGCGGGGAGGCCGCCGGGTGCCCG 300
H	GAGCGGAGCGAGCAGCTGAAGGCCGCGCAGCTGGCGGGGAGGCCGCCGGGTGCCCG 300
RR	GAGCGGAGCGAGCAGCTGAAGGCCGCGCAGCTGGCGGGGAGGCCGCCGGGTGCCCG 300
*****	
XM_025275645.3	GGCAGGGCCCAGGCCGACCTGCTGGCTTCCCTGCGCTCGCAGGTGGACAGGGCGGAGGTG 360
H	GGCAGGGCCCAGGCCGACCTGCTGGCTTCCCTGCGCTCGCAGGTGGACAGGGCGGAGGTG 360
RR	GGCAGGGCCCAGGCCGACCTGCTGGCTTCCCTGCGCTCGCAGGTGGACAGGGCGGAGGTG 360
*****	
XM_025275645.3	CACGCCGGCGTCAGCAGGCCACCG 385
H	CACGCCGGCGTCAGCAGGCCACCG 385
RR	CACGCCGGCGTCAGCAGGCCACCG 385
*****	

**Figure S7.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_025275645.3| and *CSGALNACT1* marker (385-bp) sequences.

XM_025278930.3	CGCAGGCCCGTTCTCGCTTCTACAGTGTCTCGGGCTCTGCTACAAGCGGCTGCTTC	60
H	CGCAGGCCCGTTCTCGCTTCTACAGTGTCTCGGGCTCTGCTACAAGCGGCTGCTTC	60
RR	CGCAGGCCCGTTCTCGCTTCTACAGTGTCTCGGGCTCTGCTACAAGCGGCTGCTTC	60
*****	*****	*****
XM_025278930.3	AAGAATAAAGTAAAGGCAGCCAAGGGCAGTTCCACTCACACAGAAATGTAACGGTTGTT	120
H	AAGAATAAAGTAAAGGCAGCCAAGGGCAGTTCCACTCACACAGAAATGTAACGGTTGTT	120
RR	AAGAATAAAGTAAAGGCAGCCAAGGGCAGTTCCACTCACACAGAAATGTAACGGTTGTT	120
*****	*****	*****
XM_025278930.3	GAAGGCGGAAC TGCAATT TGACCTGCAGGGT GATCAAATGATAATACCTCCCTCCAG	180
H	GAAGGCGGAAC TGCAATT TGACCTGCAGGGT GATCAAATGATAACACCTCCCTCCAG	180
RR	GAAGGCGGAAC TGCAATT TGACCTGCAGGGT GATCAAATGATAATACCTCCCTCCAG	180
*****	*****	*****
XM_025278930.3	TGGTCAAATCCAGCTAACAGACTCTGTACTTTGATGACAAGAACGCTTAAGAGACAAAT	240
H	TGGTCAAATCCAGCTAACAGACTCTGTACTTTGATGACAAGAACGCTTAAGAGACAAAT	240
RR	TGGTCAAATCCAGCTAACAGACTCTGTACTTTGATGACAAGAACGCTTAAGAGACAAAT	240
*****	*****	*****
XM_025278930.3	AGAATCAGCTGGTCTGGGCTCTGGCATGAACTGAGTATCAGCGTCAGTGAIGTCTCT	300
H	AGAATCAGCTGGTCTGGGCTCTGGCATGAACTGAGTATCAGCGTCAGTGAIGTCTCT	300
RR	AGAATCAGCTGGTCTGGGCTCTGGCATGAACTGAGTATCAGCGTCAGTGAIGTCTCT	300
*****	*****	*****
XM_025278930.3	CTGTCTGATGAAGGACAGTACACCTGTTCTTACAATGCCGTCAAACGTCAG	360
H	CTGTCTGATGAAGGACAGTACACCTGTTCTTACAATGCCGTCAAACGTCAG	360
RR	CTGTCTGATGAAGGACAGTACACCTGTTCTTACAATGCCGTCAAACGTCAG	360
*****	*****	*****
XM_025278930.3	GCCTATCTCACTGCTCTGGGTGTCCTGAGAACCTCAAATTAGTGGATTTCATCCCCA	420
H	GCCTATCTCACTGCTCTGGGTGTCCTGAGAACCTCAAATTAGTGGATTTCATCCCCA	420
RR	GCCTATCTCACTGCTCTGGGTGTCCTGAGAACCTCAAATTAGTGGATTTCATCCCCA	420
*****	*****	*****
XM_025278930.3	GTTATGGAGGGAGACTTGATGCAGCTGACTTGTAAAAACATCTGGTAGTAAACCTGCAGCT	480
H	GTTATGGAGGGAGACTTGATGCAGCTGACTTGTAAAAACATCTGGTAGTAAACCTGCAGCT	480
RR	GTTATGGAGGGAGACTTGATGCAGCTGACTTGTAAAAACATCTGGTAGTAAACCTGCAGCT	480
*****	*****	*****
XM_025278930.3	GATATAAGATGGTTC 495	
H	GATATAAGATGGTTC 495	
RR	GATATAAGATGGTTC 495	
*****	*****	*****

**Figure S8.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_025278930.3| and *CADM2* marker (495-bp) sequences.

XM_025285122.3	TCTCCGCCAGGCTAACCGCCTGCCATCAAGGTGCTGAAGATGCTGACGGCACGGACTGG	60
H	TCTCCGCCAGGCTAACCGCCTGCCATCAAGGTGCTGAAGATGCTGACGGCACGGACTGG	60
RR	TCTCCGCCAGGCTAACCGCCTGCCATCAAGGTGCTGAAGATGCTGACGGCACGGACTGG	60
*****	*****	*****
XM_025285122.3	CCATATTTCGACCCCTGAGTACCTGCAGCCCCCTGCCCTCCACTCCCGTCAGCCCCATAGA	120
H	CCATATTTCGACCCCTGAGTACCTGCAGCCCCCTGCCCTCCACTCCCGTCAGCCCCATAGA	120
RR	CCATATTTCGACCCCTGAGTACCTGCAGCCCCCTGCCCTCCACTCCCGTCAGCCCCATAGA	120
*****	*****	*****
XM_025285122.3	GCTCGATGCCAAGAAGAGGCCCGCTGGCGTGTGGCCAAACATGCTCGCAGATCGGGAA	180
H	GCTCGATGCCAAGAAGAGGCCCGCTGGCGTGTGGCCAAACATGCTCGCAGATCGGGAA	180
RR	GCTCGATGCCAAGAAGAGGCCCGCTGGCGTGTGGCCAAACATGCTCGCAGATCGGGAA	180
*****	*****	*****
XM_025285122.3	GCCCCGACCCCTCGCCCTCGTCAAACCTCCCTCAGTGGCCTCCAAACGGGGGTGGCACGGG	240
H	GCCCCGACCCCTCGCCCTCGTCAAACCTCCCTCAGTGGCCTCCAAACGGGGGTGGCACGGG	240
RR	GCCCCGACCCCTCGCCCTCGTCAAACCTCCCTCAGTGGCCTCCAAACGGGGGTGGCACGGG	240
*****	*****	*****
XM_025285122.3	CGGTGCCGGCGCCGGCGCGGGGGCGACAAGGAGCCTAACAGTGGGCCCTCAAGCTGAG	300
H	CGGTGCCGGCGCCGGCGCGGGGGCGACAAGGAGCCTAACAGTGGGCCCTCAAGCTGAG	300
RR	CGGTGCCGGCGCCGGCGCGGGGGCGACAAGGAGCCTAACAGTGGGCCCTCAAGCTGAG	300
*****	*****	*****
XM_025285122.3	CGACATCGGCGTGGAGAGACAAGTGTGAGTTCAAGCCGTACTCCAAACCCGGCTCGGATAA	360
H	CGACATCGGCGTGGAGAGACAAGTGTGAGTTCAAGCCGTACTCCAAACCCGGCTCGGATAA	360
RR	CGACATCGGCGTGGAGAGACAAGTGTGAGTTCAAGCCGTACTCCAAACCCGGCTCGGATAA	360
*****	*****	*****
XM_025285122.3	G 361	
H	G 361	
RR	G 361	
*	*	

**Figure S9.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_025285122.3| and *ZNF503* marker (361-bp) sequences.

XM_006048659.4	CCGACGCTCGGAGAACCGAGATGAATCTGAACCTCTCACTGTTCCAGATGGTTGGAAGGAG	60
H	CCGACGCTCGGAGAACCGAGATGAATCTGAACCTCTCACTGTTCCAGATGGTTGGAAGGAG	60
RR	CCGACGCTCGGAGAACCGAGATGAATCTGAACCTCTCACTGTTCCAGATGGTTGGAAGGAG	60
*****	*****	*****
XM_006048659.4	CCAGCTTCTCAAAGAGGACAATCCCAGAGGACTCTGGAGGAGAGCAGTTTGCAACT	120
H	CCAGCTTCTCAAAGAGGACAATCCCAGAGGACTCTGGAGGAGAGCAGTTTGCAACT	120
RR	CCAGCTTCTCAAAGAGGACAATCCCAGAGGACTCTGGAGGAGAGCAGTTTGCAACT	120
*****	*****	*****
XM_006048659.4	TTGTTCCGAAATACAGAGAGGCTTACTTGAAGAGTGTGCTGCCATTGGTACAGAAAGCC	180
H	TTGTTCCGAAATACAGAGAGGCTTACTTGAAGAGTGTGCTGCCATTGGTACAGAAAGCC	180
RR	TTGTTCCGAAATACAGAGAGGCTTACTTGAAGAGTGTGCTGCCATTGGTACAGAAAGCC	180
*****	*****	*****
XM_006048659.4	TTGAATGAACATCATGTTAATGCCACCTGGACCTGATTGAGGGCAGCATGACTGTCTGC	240
H	TTGAATGAACATCATGTTAATGCCACCTGGACCTGATTGAGGGCAGCATGACTGTCTGC	240
RR	TTGAATGAACATCATGTTAATGCCACCTGGACCTGATTGAGGGCAGCATGACTGTCTGC	240
*****	*****	*****
XM_006048659.4	ACCACCAAGAACAGACATTGATCCATATATCATCATTAG	278
H	ACCACCAAGAACAGACATTGATCCATATATCATCATTAG	278
RR	ACCACCAAGAACAGACATTGATCCATATATCATCATTAG	278
*****	*****	*****

**Figure S10.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_006048659.4| and *KRR1* marker (278-bp) sequences.

XM_044946911.2	ATGTGCGACAAGGAGTTCATGTGGGCCCTGAAAAAACGGAGACCTAGATGAGGTGAAAGAC	60
H	ATGTGCGACAAGGAGTTCATGTGGGCCCTGAAAAAACGGAGACCTAGATGAGGTGAAAGAC	60
RR	ATGTGCGACAAGGAGTTCATGTGGGCCCTGAAAAAACGGAGACCTAGATGAGGTGAAAGAC	60
*****	*****	*****
XM_044946911.2	TATGTGCCAAGGGAGAACAGATGTCACCCGGACACTAGAAAGGTGGAAGAACGCTTTCAT	120
H	TATGTGCCAAGGGAGAACAGATGTCACCCGGACACTAGAAAGGTGGAAGAACGCTTTCAT	120
RR	TATGTGCCAAGGGAGAACAGATGTCACCCGGACACTAGAAAGGTGGAAGAACGCTTTCAT	120
*****	*****	*****
XM_044946911.2	TATGCAGCAGATTGGACAGCTTGAATTCCTGGAAATTCTGCTGCTGAAAGGAGCAGAT	180
H	TATGCAGCAGATTGGACAGCTTGAATTCCTGGAAATTCTGCTGCTGAAAGGAGCAGAT	180
RR	TATGCAGCAGATTGGACAGCTTGAATTCCTGGAAATTCTGCTGCTGAAAGGAGCAGAT	180
*****	*****	*****
XM_044946911.2	ATTAATGCTCCAGATAAACATCATATCACACCTCTTCTGCTGCCGTCTGAAGGTCTAT	240
H	ATTAATGCTCCAGATAAACATCATATCACACCTCTTCTGCTGCCGTCTGAAGGTCTAT	240
RR	ATTAATGCCCCAGATAAACATCATATCACACCTCTTCTGCTGCCGTCTGAAGGTCTAT	240
*****	*****	*****
XM_044946911.2	GTTTCTCGCGTGAATTGCTTCTGTC 266	
H	GTTTCTCGCGTGAATTGCTTCTGTC 266	
RR	GTTTCTCGCGTGAATTGCTTCTGTC 266	
*****	*****	*****

**Figure S11.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_044946911.2| and *MTPN* marker (266-bp) sequences.

G73R. The nucleotide sequence of the *KRR1* gene (278-bp) revealed one synonymous SNP; 56A resulted from 168GA SNP. Two recurrent SNPs in the *MTPN* gene (266-bp) were discovered using DNA sequencing; 45AG and 189TC, resulted in synonymous mutations, 15L and 63A, respectively. Three recurrent non-synonymous SNPs were found in the *IGFBP7* gene (380-bp); 38GC, 107TC, and 161AC changed the amino acids R13P, V36A and Q54P, respectively. Two recurrent synonymous SNPs, 93GA, and 216GA induced amino acids 31L, and 72P were found in the *LEP* gene (360-bp). Four recurrent SNPs in the *ABCC4* gene (355-bp) were discovered using DNA sequencing; one of these, 294CT resulted in

synonymous mutations, 98I. While the non-synonymous mutation brought about by the SNPs 65CT, 109AG and 306GT led to the substitution of the amino acids S22L, R37G, and L102F, respectively

## DISCUSSION

### Efficiency of investigated reproductive genes as candidates for repeat breeder incidence

For the effective exploitation of disease-resistant cattle or the complete eradication of ill animals, knowledge of the genes, it is necessary to understand the fundamental mutations and interactions that contribute to resistance (Pal & Chakravarty, 2020). The reproductive (*MFSD14A*, *PALMD*, *VPS13B*, *BMP*,

XM_025290001.3	AGCTGGCGAGACCCCGCATGCATGCGGCTGCTGCCCGGTGTGCGGCCGCCGGAGGGCG	60
H	AGCTGGCGAGACCCCGCATGCATGCGGCTGCTGCCCGGTGTGCGGCCGCCGGAGGGCG	60
RR	AGCTGGCGAGACCCCGCATGCATGCGGCTGCTGCCCGGTGTGCGGCCGCCGGAGGGCG	60
*****		
XM_025290001.3	AGCGTGCAGGGGTGCGCGCGCCAGGGGCACTGCGGCCGGGTATGGAGTGCCTGA	120
H	AGCGTGCAGGGGTGCGCGCGCCAGGGGCACTGCGGCCGGGTATGGAGTGCCTGA	120
RR	AGCGTGCAGGGGTGCGCGCGCCAGGGGCACTGCGGCCGGGTATGGAGTGCCTGA	120
*****		
XM_025290001.3	AGAGCCCAAGAGGCCAAGGGTAAGCCGGCAGCAGCAGGCCGGCGTTGTGAGCG	180
H	AGAGCCCAAGAGGCCAAGGGTAAGCCGGCAGCAGCAGGCCGGCGTTGTGAGCG	180
RR	AGAGCCCAAGAGGCCAAGGGTAAGCCGGCAGCAGCAGGCCGGCGTTGTGAGCG	180
*****		
XM_025290001.3	GCGTGTGTGCAAGAGCCGCTACCCCGTGTGCGGAGCGACGGTGTACCTACTCCA	240
H	GCGTGTGTGCAAGAGCCGCTACCCCGTGTGCGGAGCGACGGTGTACCTACTCCA	240
RR	GCGTGTGTGCAAGAGCCGCTACCCCGTGTGCGGAGCGACGGTGTACCTACTCCA	240
*****		
XM_025290001.3	GCGGCTGCCAGCTGCAGCCGAGCCTCAGGGCCAGAGCCGGGGAGAAGGCCATCA	300
H	GCGGCTGCCAGCTGCAGCCGAGCCTCAGGGCCAGAGCCGGGGAGAAGGCCATCA	300
RR	GCGGCTGCCAGCTGCAGCCGAGCCTCAGGGCCAGAGCCGGGGAGAAGGCCATCA	300
*****		
XM_025290001.3	CCCAGGTCAAGGGCACCTCGGAGCAAGGTCCTCCATCGTACACCCCCCAAGGACA	360
H	CCCAGGTCAAGGGCACCTCGGAGCAAGGTCCTCCATCGTACACCCCCCAAGGACA	360
RR	CCCAGGTCAAGGGCACCTCGGAGCAAGGTCCTCCATCGTACACCCCCCAAGGACA	360
*****		
XM_025290001.3	TCTGGAATGTCACTGGTGCCT 380	380
H	TCTGGAATGTCACTGGTGCCT 380	380
RR	TCTGGAATGTCACTGGTGCCT 380	380
*****		

**Figure S12.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_025290001.3| and *IGFBP7* marker (380-bp) sequences.

AF387814.1	CAGTCCGTCTCCCAAACAGAGGGTCACTGGTTGGACTTCATCCCTGGCTCCACCT 60	60
H	CAGTCCGTCTCCCAAACAGAGGGTCACTGGTTGGACTTCATCCCTGGCTCCACCT 60	60
RR	CAGTCCGTCTCCCAAACAGAGGGTCACTGGTTGGACTTCATCCCTGGCTCCACCT 60	60
*****		
AF387814.1	CTCCTGAGTTGTCCAAGATGGACAGACATTGGCGATCTACCAACAGATCTCACCAGT 120	120
H	CTCCTGAGTTGTCCAAGATGGACAGACATTAGCGATCTACCAACAGATCTCACCAGT 120	120
RR	CTCCTGAGTTGTCCAAGATGGACAGACATTGGCGATCTACCAACAGATCTCACCAGT 120	120
*****		
AF387814.1	CTGCCTTCCAGAAATGTGGTCCAATATCTAAATGACCTGGAGAACCTCCGGACCTTC 180	180
H	CTGCCTTCCAGAAATGTGGTCCAATATCTAAATGACCTGGAGAACCTCCGGACCTTC 180	180
RR	CTGCCTTCCAGAAATGTGGTCCAATATCTAAATGACCTGGAGAACCTCCGGACCTTC 180	180
*****		
AF387814.1	CACCTGCTGGCCGCTCCAAAGAGCTGCCCTTGCGCAGGTCAAGGGCCCTGGAGAGTTG 240	240
H	CACCTGCTGGCCGCTCCAAAGAGCTGCCCTTGCGCAGGTCAAGGGCCCTGGAGAGTTG 240	240
RR	CACCTGCTGGCCGCTCCAAAGAGCTGCCCTTGCGCAGGTCAAGGGCCCTGGAGAGTTG 240	240
*****		
AF387814.1	GAGAGCTTGGCGTCGCTCTGGAGCCTCCCTACTCCACCGAGGTGGCCCTGAGC 300	300
H	GAGAGCTTGGCGTCGCTCTGGAGCCTCCCTACTCCACCGAGGTGGCCCTGAGC 300	300
RR	GAGAGCTTGGCGTCGCTCTGGAGCCTCCCTACTCCACCGAGGTGGCCCTGAGC 300	300
*****		
AF387814.1	CGGCTGCAGGGGTCACTACAGGACATGTTGCGGCAGCTGGACCTCAGTCCTGGGTGCTGA 360	360
H	CGGCTGCAGGGGTCACTACAGGACATGTTGCGGCAGCTGGACCTCAGTCCTGGGTGCTGA 360	360
RR	CGGCTGCAGGGGTCACTACAGGACATGTTGCGGCAGCTGGACCTCAGTCCTGGGTGCTGA 360	360
*****		

**Figure S13.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|AF387814.1| and *LEP* marker (360-bp) sequences.

*MTNR1A*, *TSHR*, *CSGALNACT1*, *CADM2*, *ZNF503*, *KRR1*, *MTPN*, *IGFBP7*, *LEP*, and *ABCC4* genes in repeat breeder and healthy Italian buffaloes were identified in this study utilizing sequenced amplified PCR products. The findings show that there are differences between the SNPs involving the two categories. The assessed buffaloes had a considerable

nucleotide polymorphism dispersion ( $p < 0.01$ ), according to the Fisher's exact test. It is crucial to emphasize that, when compared to the relevant datasets obtained from GenBank, the variations discovered and materials readily accessible in this context offer fresh information on the markers under consideration.

XN_045162483.1	GCAGAAAGCGAACTTCTGCTCGCCCTGTTGCTGGTGGCTAAACCCCTGTTAAAAAT	60
H	GCAGAAAGCGAACTTCTGCTCGCCCTGTTGCTGGTGGCTAAACCCCTGTTAAAAAT	60
RR	GCAGAAAGCGAACTTCTGCTCGCCCTGTTGCTGGTGGCTAAACCCCTGTTAAAAAT	60
	*****	*****
XN_045162483.1	TGGTCACAAACGGAATTAGAACAGATGACATGTACTCGGTGCTTCCAGAAAGATCGCTC	120
H	TGGTCACAAACGGAATTAGAACAGATGACATGTACTCGGTGCTTCCAGAAAGATCGCTC	120
RR	TGGTCACAAACGGAATTAGAACAGATGACATGTACTCGGTGCTTCCAGAAAGATCGCTC	120
	*****	*****
XN_045162483.1	CCAGTGCCTTGGAGAAGAGCTGCAAGGGTACTGGGATCAAGAAAGTTAACAGAGGCCAGAA	180
H	CCAGTGCCTTGGAGAAGAGCTGCAAGGGTACTGGGATCAAGAAAGTTAACAGAGGCCAGAA	180
RR	CCAGTGCCTTGGAGAAGAGCTGCAAGGGTACTGGGATCAAGAAAGTTAACAGAGGCCAGAA	180
	*****	*****
XN_045162483.1	GGATGGACAGGAACCCCTTTAGTGAAGCAATCGTAAAGTGTACTGGAAATCCTATT	240
H	GGATGGACAGGAACCCCTTTAGTGAAGCAATCGTAAAGTGTACTGGAAATCCTATT	240
RR	GGATGGACAGGAACCCCTTTAGTGAAGCAATCGTAAAGTGTACTGGAAATCCTATT	240
	*****	*****
XN_045162483.1	GGATGGACAGGAACCCCTTTAGTGAAGCAATCGTAAAGTGTACTGGAAATCCTATT	300
H	GGATGGACAGGAACCCCTTTAGTGAAGCAATCGTAAAGTGTACTGGAAATCCTATT	300
RR	GGATGGACAGGAACCCCTTTAGTGAAGCAATCGTAAAGTGTACTGGAAATCCTATT	300
	*****	*****
XN_045162483.1	AATTTGGGAATGTTACATTTCTGAGGAAGGCCACAGAGTAGTTCAACCCATA	355
H	AATTTGGGAATGTTACATTTCTGAGGAAGGCCACAGAGTAGTTCAACCCATA	355
RR	AATTTGGGAATGTTACATTTCTGAGGAAGGCCACAGAGTAGTTCAACCCATA	355
	*****	*****

**Figure S14.** Analysis of nitrogenous bases matching for DNA in healthy and repeat breeder buffaloes using GenBank gb|XM\_045162483.1| and *ABCC4* marker (355-bp) sequences.

In recent studies, unique genes that are specifically related to the prevalence of bovine repeat breeders have been discovered using genome-wide association analysis for our investigated markers (Li et al., 2018; Mahrous et al., 2022), however, no research have yet looked into the relationship between repeat breeder risk and the SNPs in these genes. The gene sequences from the *Bubalus bubalis* employed in our study, which was published in PubMed, are the first to show this connection. The variance of the reproductive (*MFSD14A*, *PALMD*, *VPS13B*, *BMP*, *MTNR1A*, *TSHR*, *CSGALNACT1*, *CADM2*, *ZNF503*, *KRR1*, *MTPN*, *IGFBP7*, *LEP*, and *ABCC4*) markers and how they relate to repeat breeder in Italian buffaloes have not, to our knowledge, been the subject of any prior research. However, the candidate gene technique has been used to monitor the validity of bovine fertility features. For instance, Egyptian buffaloes showed a connection between *IGF-I* genetic variations and issues with reproduction (Ramadan et al., 2018). Buffaloes with *MTNR1A* gene polymorphisms had seasonal suppression of fertility (Rangashamaiah et al., 2022). The frequency of repeat breeding in Egyptian buffaloes have been investigated in relation to the polymorphisms of the *LEP*, and *BMP* genes (Mahrous et al., 2022; El-Debaky et al., 2020). Buffalo genetic variations in the *FSHR* and *ESR* genes and were correlated with the frequency of repeat breeders (Fouda et al., 2021). *LHR* gene polymorphisms and Egyptian buffalo fertility was also investigated (Sosa et al., 2016). *CYP19A1*

gene polymorphisms were associated with anoestrus susceptibility and inactive ovaries in water buffaloes when a candidate gene approach to anoestrus was investigated (El-Bayomi et al., 2018; Abbaset al., 2014). Also discovered in Murrah buffaloes were polymorphisms in the *HSP70* gene, which may be related to post-partum anoestrus (Kumar et al., 2017).

The primary source of adaptation and selection is mutation (Chu & Wei, 2019). All of the reproductive markers that were being studied in this situation had exonic region mutations, which led to altered coding DNA sequences in repeat breeder buffaloes compared to healthy ones. Using DNA sequencing of reproductive genes, 30 SNPs were found; 16 of them are synonymous, and 15 are non-synonymous. Non-synonymous mutations alter protein sequences, and people who have these mutations are frequently the subject of natural selection (Chu, & Wei, 2019). The encoded amino acid at the mutant location is altered by genetic variation brought on by non-synonymous SNPs, which can result in structural and functional alterations in the mutated protein (Dakal et al., 2017). For a very long time, it was believed that selection on synonymous mutations was either nonexistent or very weak (Chu & Wei, 2019). In order to accurately characterize the investigated reproductive genes at the molecular level and to understand the physiological differences in reproductive performance between normal and repeat breeder buffaloes, our study discovered polymorphisms on the basis

**Table 2.** Single base differential dissemination as well as category of inherited alteration for reproductive markers in normal and repeat breeder buffaloes.

Gene	SNPs	Normal n = 120	Repeat breeder n = 120	Total n = 240	kind of inherited alteration	Amino acid order and sort
<i>MFSD14A</i>	C165T	-	72	72/240	Synonymous	55 C
	T322C	-	85	85/240	Synonymous	108 G
<i>PALMD</i>	T108C	91	-	91/240	Synonymous	36 L
<i>VPS13B</i>	T175C	48	-	48/240	Non-synonymous	59 C to R
	T223C	-	63	63/240	Non-synonymous	75 Y to H
	T47C	-	98	98/240	Non-synonymous	16 V to A
<i>BMP</i>	C80A	58	-	58/240	Non-synonymous	27 P to Q
	G184A	76	-	76/240	Non-synonymous	62 V to I
<i>MTNR1A</i>	C72T	49	-	49/240	Synonymous	24 N
	C87T	-	83	83/240	Synonymous	29 S
<i>TSHR</i>	T126C	-	38	38/240	Synonymous	42 T
	C177T	69	-	69/240	Synonymous	59 I
	C372T	-	103	103/240	Synonymous	124 V
<i>CSGALNACT1</i>	G135A	47	-	47/240	Synonymous	45 T
	G150A	91	-	91/240	Synonymous	50 R
<i>CADM2</i>	T168C	63	-	63/240	Synonymous	56 N
	G354T	39	-	39/240	Synonymous	118 T
<i>ZNF503</i>	G217C	-	98	98/240	Non-synonymous	73 G to R
<i>KRR1</i>	G168A	107	-	107/240	Synonymous	56 A
	A45G	46	-	46/240	Synonymous	15 L
<i>MTPN</i>	T189C	-	104	104/240	Synonymous	63 A
	G38C	-	58	58/240	Non-synonymous	13 R to P
	T107C	-	112	112/240	Non-synonymous	36 V to A
<i>IGFBP7</i>	A161C	92	-	92/240	Non-synonymous	54 Q to P
	G93A	71	-	71/240	Synonymous	31 L
<i>LEP</i>	G216A	-	86	86/240	Synonymous	72 P
	C65T	-	89	89/240	Non-synonymous	22 S to L
<i>ABCC4</i>	A109G	-	109	109/240	Non-synonymous	37 R to G
	C294T	-	74	74/240	Synonymous	98 I
	G306T	93	-	93/240	Non-synonymous	102 L to F

Single base difference dispersal for reproductive markers in normal and repeat breeder buffaloes showed a highly significant variation ( $p < 0.01$ ) according to Fisher's exact analysis.

*MFSD14A* = Major facilitator superfamily domain containing 14A; *PALMD* = Palmdelphin; *VPS13B* = Vacuolar protein sorting 13 homolog B; *BMP* = Bone morphogeneic protein; *MTNR1A* = Melatonin receptor 1B; *TSHR* = Thyroid stimulating hormone receptor; *CSGALNACT1* = Chondroitin sulfate N-acetylgalactosaminyltransferase 1; *CADM2* = Cell adhesion molecule 2; *ZNF503* = Zinc finger protein 503; *KRR1* = Small subunit processome component homolog; *MTPN* = Myotrophin; *IGFBP7* = insulin like growth factor binding protein 7; *LEP* = Leptin; and *ABCC4* = ATP-binding cassette sub-family C member 4. A = Alanine; C = Cisteine; F = Phenylalanine; G = Glycine; H = Histidine; I = Isoleucine; L = Leucine; N = Asparagine; P = Proline; Q = Glutamine; R = Arginine; S = Serine; T = Threonine; V = Valine; and Y = Tyrosine.

of translated DNA sequence to be of greater value than intronic parts.

### Role of investigated genes in reproduction

A protein-coding gene called major facilitator superfamily domain containing 14A (MFSD14A) has product homology to the family of solute carrier proteins (Doran et al., 2016). Additionally, MFSD14A functions as a component of cellular fundamentals, a molecular controller of transporter action, and a biological tool involved in trans-membrane transport (Sreedharan et al., 2011). The nuclear transfer transcripts in pig blastocyst stage were discovered to be negatively controlled by *MFSD14A* (Whitworth, et al., 2011), and the gene may also play a role in mouse spermatogenesis (Doran, 2016). Two SNPs in the *MFSD14A* gene have been linked to characteristics of buffalo milk production (Liu et al., 2018). A cytosolic protein involved in the phosphorylation of p53 is encoded by the palmdelphin (*PALMD*) (Moioli et al., 2013). The variance in milk yield is likely to be caused by the *PALMD* gene (Seo et al., 2016; Moioli, et al., 2013). *PALMD* polymorphisms had a significant impact on back fat thickness in a research to identify probable causative mutations associated to pig production attributes (Martínez-Montes et al., 2017). These *PALMD* functional studies suggest that it may be a key target gene that regulates variables related to reproductive performance.

The eye, hematological system, and central nervous system all develop and function as a result of the potential trans-membrane protein that the vacuolar protein sorting 13 homolog B (*VPS13B*) gene encodes (Liu et al., 2018). Protein transport has been identified as the primary biological utility of *VPS13B*, and it may play a role in vesicle-mediated transport as well as protein sorting within cells. In a prior investigation, *VPS13B* was discovered inside a QTL linked to the shape of the legs in dairy cattle (Van den Berg et al., 2014). Additionally, it was hypothesized that attributes related to milk production in Holstein cattle as well as female fertility were linked to the genomic region on BTA14 encompassing *VPS13B* (Capitan et al., 2014).

The secreted factor known as transforming growth factor (TGF) was initially discovered to influence cell proliferation (Roberts & Sporn, 1990). The proteins can be divided into two main groups according to cell signaling pathways: activins/transforming growth factors and bone morphogenetic proteins/growth differentiation factors (Chang et al., 2002). Among the BMP family memberships expressed in-

side the uterus, ovary, granulosa cells, and oocyte are BMP 2, 3, 4, 5, 6, 7 and 15 (Tanwar & McFarlane, 2011; Sun et al., 2010; Otsuka et al., 2001). They provide significant biological tasks as controllers of ovarian follicle growth, female reproductive tract discrepancy, blastocyst embedding in the uterus, and organogenesis and morphogenesis during embryo expansion (Kishigami & Mishina, 2005). The *BMP* gene has been the subject of numerous investigations in mammals, including cattle (Baloza et al., 2017), sheep (Ibrahim, 2019), and goats (Latifah & Saa, 2021; Ortiz et al., 2015). The blastocyst rate was shown to be substantially correlated with *BMP* SNPs by Lari et al., (2012).

Photoperiod and melatonin have been identified as the hypothalamus level modulators of the reproductive axis in a number of ovine investigations (Karsch et al., 2013). The pineal gland produces melatonin hormone in direct proportion to the length of darkness (Malpaux et al., 2001). The nighttime plasma melatonin content was highest in winter and lowest in summer in the Mediterranean buffaloes that had a seasonal reproductive tendency (Parmeggiani et al., 1994). Subcutaneous insertion of sustained-release melatonin implants in buffaloes during summer anestrus lengthens the daily presence of melatonin, simulating the effect of short days, and has been extensively investigated for the activation of the reproductive axis (Kavita et al., 2018). Only the melatonin receptor 1A gene (MTNR1A) is connected to reproductive seasonality of the G-protein couple receptors melatonin receptor 1A gene (*MTNR1A*) and melatonin receptor 1B gene (*MTNR-RIB*), to which melatonin binds (Dubocovich et al., 2020).

Animal reproduction research have used hormones and antibiotics as therapies because hormones are crucial to animal reproduction (Refsdal, 2000). Seasonal cycles of body weight and reproduction are significantly influenced by thyroid hormones (Barrett et al., 2007). By chance, buffalo are a species that go into estrus seasonally. Thyroid hormone resistance (THR) has also been shown to be highly correlated with the THR mutation (Işik et al., 2013). The genes involved in the metabolic pathways that impact animal fertility have already been extensively studied (Morfeld & Brown, 2014). One of these genes, *CSGALNACT1*, is necessary for healthy cartilage development (Watanabe et al., 2010). The *CSGALNACT1* gene was hypothesized to affect bovine follicle growth by altering the degree of expression that controls glucose metabolism (Li et al., 2018). Buffalo reproductive efficiency was discovered to be

correlated with cell adhesion molecule 2 (*CADM2*) (Song et al., 2013). One SNP at the bovine *CADM2* gene was connected to the number of days between conception and the first calving as well as the first and second calving (Li et al., 2018).

The target genes for buffalo reproductive features include *ZNF503*, *KRR1*, and *MTPN* (Lappalainen et al., 2013). *ZNF503* enhances cell invasion and proliferation in mammary epithelial cells, which has a key role in embryogenesis (Shahi et al., 2015; Chang et al., 2013). *KRR1* has been linked to polycystic ovarian syndrome (PCOS) in European populations (Day et al., 2015). *MTPN* is crucial for the development of cells and skeletal muscles (Makina et al., 2015) and is associated with the process of antigen recognition, a crucial step in the immune reaction (Wang & Wang, 2012). The elevated expression of these three genes in buffalo granulosa cells raises the possibility that they took part in dominant follicle selection (Li et al., 2018). *IGFBP7* and follistatin share sequence similarity (Kato, 2000), the latter of which was once thought to be an inhibitor of FSH secretion (Jorgez et al., 2004) and is essential for ovarian and folliculogenesis (Muttukrishna et al., 2004). Additionally, *IGFBP7* was discovered to be expressed in the granulosa cells of the large antral follicles of the pig ovary (Wandji et al., 2002) and the bovine corpus luteum (Casey et al., 2004). Therefore, we assume that *IGFBP7* is in some way responsible for the regulation of follicle development and ovulation (Li et al., 2018).

The versatile peptide hormone leptin, which is mostly generated by adipocytes, plays a crucial role in reproduction alongside controlling energy expenditure and body weight (Wiles et al., 2014). Leptin and its receptors have been discovered to be expressed in buffalo ovaries. Contrary to the widely held idea that leptin primarily affects the neuro-endocrine component of reproduction, this clearly demonstrates that leptin directly engages in ovarian activity (Reshma et al., 2016). According to Fu et al., (2016), the ovary has leptin receptors that can control steroidogenesis and improve the oocyte's ability to support later embryonic development. The *ABCC4* gene was linked to the number of services per conception (NSC). Since it affects prostaglandin efflux from cells, this gene appears to be crucial to support pregnancy in the endometrium of pregnant cows (Spencer et al., 2013) and pigs (Seo et al., 2014). Prostaglandin plays a number of roles in re-

production, including conceptus implantation and maternal recognition of pregnancy—processes that are intimately connected to NSC. The expression of *ABCC4* was substantially linked with residual feed intake (RFI) in Angus cattle and was up-regulated in animals with high RFI (Chen et al., 2012). Nucleotide sequence variants in *ABCC4* was linked to marbling score in Nelore cattle (Feitosa et al., 2014). The recently proposed theory is that *ABCC4*, which is highly polymorphic and acts in fundamental metabolic pathways, may have effects on reproductive and meat quality (De Camargo et al., 2015).

## CONCLUSIONS

Using PCR-DNA sequencing, single nucleotide variations (SNPs) in the genes were found for reproductive (*MFSD14A*, *PALMD*, *VPS13B*, *BMP*, *MTNR1A*, *TSHR*, *CSGALNACT1*, *CADM2*, *ZNF503*, *KRR1*, *MTPN*, *IGFBP7*, *LEP*, and *ABCC4*) indicators in normal and repeat breeder Italian buffaloes. These special functional variations present a promising opportunity to lower the occurrence of repeat breeders by using genetic markers in conjunction with normal wellbeing during buffalo selection. Future approaches to dealing with repeat breeders may be facilitated based on the gene domains here.

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## CONFLICT OF INTEREST

There are no competing interests, according to the authors.

## REFERENCES

Abbas, H. S., El-Magd, M. A., El-Bayomi, K. M. & Sosa, G. A. (2014). Detection of SNPs in exon7 locus of Cyp19 gene and their association with anestrus in Egyptian buffaloes (*Bubalus bubalis*). *Benha Veterinary Medical Journal*, 26, 151–160.

Altschul, S.F., Gish, W., Miller, W., Myers, E.W. & Lipman, D. J. (1990). Basic local alignment search tool. *Journal of Molecular Biology*, 215, 403–410.

Ashwell, M.S., Rexroad Jr, C. E., Miller, R. H., Van Raden, P.M. & Da, Y. (1997). Detection of loci affecting milk production and health traits in an elite US Holstein population using microsatellite markers. *Animal Genetics*, 28, 216–222.

Baloza, S. H., Abo-Salem, M. E. S. & Hemed, S. A. (2017). Effect of genetic variations in BMP 4 gene (exon 2 plus part of intron 0) on infertility in Egyptian Buffalo cows. *Benha Journal of Applied Sciences*, 2, 37–41.

Barrett, P., Ebling, F. J. P., Schuhler, S., Wilson, D., Ross, A.W., Warner, A., Jethwa, P., Boelen, A., Visser, T. J., Ozanne, D. M. (2007). Hypothalamic thyroid hormone catabolism acts as a gatekeeper for the seasonal control of body weight and reproduction. *Endocrinology*, 148, 3608–17.

Berry, D.P. & Evans, R. (2014). Genetics of reproductive performance in seasonal calving beef cows and its association with performance traits. *Journal of Animal Science*, 92, 1412–1422.

Bishop, M. D., Hawkins, G.A. & Keeler, C.L. (1995). Use of DNA markers in animal selection. *Theriogenology*, 43, 61–70.

Boesenborg-Smith, K. A., Pessarakli, M. M. & Wolk, D. M. (2012). Assessment of DNA Yield and Purity: An Overlooked Detail of PCR Troubleshooting. *Clinical Microbiology Newsletter*, 34, 1–6.

Boichard, D. (1990). Estimation of the economic value of conception rate in dairy cattle. *Livestock Production Science Journal*, 24, 187–204.

Boom, R., Sol, C. J., Salimans, M. M. & Jansen, C. L. (1990). Wertheim-van Dillen PM, Noordaa JVD. Rapid and simple method for purification of nucleic acids. *Journal of Clinical Microbiology*, 28, 495–503.

Buch, L.H., Kargo, M., Berg, P., Lassen, J. & Sørensen A. C. (2012). The value of cows in reference populations for genomic selection of new functional traits. *Animals*, 6, 880–886.

Cammack, K., Thomas, M. & Enns, R. (2009). Reproductive traits and their heritabilities in beef cattle. *The Professional Animal Scientist Journal*, 25, 517–528.

Capitan, A., Michot, P., Baur, A., Saintilan, R., Hoze, C., Valour, D., Guillaume, F., Boichon, D., Barbat, A. & Boichard, D. (2014). Genetic tools to improve reproduction traits in dairy cattle. *Reproduction Fertility Development*, 27, 14–21.

Casey, O. M., Fitzpatrick, R., Mcinerney, J. O., Morris, D. G., Powell, R., & Sreenan, J. M. (2004). Analysis of gene expression in the bovine corpus luteum through generation and characterisation of 960 ESTs. *Biochimica et Biophysica Acta - Gene Structure and Expression*, 1679, 10–7.

Chang, H., Brown, C.B. & Matzuk, M.M. (2002). Genetic analysis of the Mammalian transforming growth factor superfamily. *Endocrinology Reviews*, 23, 787–823.

Chang, S. L., Liu, Y. C., Chen, S. Y., Huang, T. H., Liu, P. T. & Liu, F. C. (2013). Identification of two evolutionarily conserved 5' cis-elements involved in regulating spatiotemporal expression of Nolz-1 during mouse embryogenesis. *PLOS One*, 8, e54485.

Chen, Y., Arthur, P. F., Barchia, I. M., Quinn, K., Parnell, P. F., Herd, R. M. (2012). Using gene expression information obtained by quantitative real-time PCR to evaluate Angus bulls divergently selected for feed efficiency. *Animal Production Science*, 52, 1058–67.

Chu, D. & Wei, L. (2019). Nonsynonymous, synonymous and nonsense mutations in human cancer-related genes undergo stronger purifying selections than expectation. *BMC Cancer*, 19, 359.

Dakal, T.C., Kala, D., Dhiman, G., Yadav, V., Krokhotin, A. & Dokholyan, N.V. (2017). Predicting the functional consequences of non-synonymous single nucleotide polymorphisms in IL8 gene. *Scientific Reports*, 7, 6525.

Das, G.K. & Khan, F.A. (2010). Summer anestrus in buffalo-A review. *Reproduction in Domestic Animals*, 45:e483–e494.

Day, F. R., Hinds, D. A., Tung, J. Y., Stolk, L., Styrkarsdottir, U., Saxena, R., Bjonnes, A., Broer, L., Dunger, D. B. & Halldorsson, B. V. et al. (2015). Causal mechanisms and balancing selection inferred from genetic associations with polycystic ovary syndrome. *Nature Communication*, 6, 8464.

De Camargo, G. M., Aspilcueta-Borquis, R. R., Fortes, M. R., Porto-Neto, R., Cardoso, D. F., Santos, D. J., Lehnert, S. A., Reverter, A., Moore, S. S. & Tonhati, H. (2015). Prospecting major genes in dairy buffaloes. *BMC Genomics*, 16, 872.

Dekkers, J. (1991). Estimation of economic values for dairy cattle breeding goals: bias due to sub-optimal management policies. *Livestock Production Science Journal*, 29, 131–149.

Devkota, B., Shah, S. & Gautam, G. (2022). Reproduction and Fertility of Buffaloes in Nepal. *Animals*, 13, 70.

Doran, J., Walters, C., Kyle, V., Wooding, P., Hammett-Burke, R. & Colledge, W.H. (2016). Mfsd14a (Hiat1) gene disruption causes globozoospermia and infertility in male mice. *Reproduction*, 152, 91–99.

Dubocovich, M. L., Cardinali, D. P., Delagrange, P. R. M., Krause, D. N., Strosberg, D. & Sugden, D. (2000). Melatonin Receptors. In Girdlestone, D. (ed.) The IUPHAR Compendium of Receptor Characterization and Classification, 2nd ed. London, UK. 270–277.

El-Bayomi, K. M., Saleh, A. A., Awad, A., El-Tarabany, M. S., El-Qalioubi, H. S., Afifi, M., El-Komy, S., Essawi, W. M., Almadaly, E.A. & El-Magd, M. A. (2018). Association of CYP19A1 gene polymorphisms with anoestrus in water buffaloes. *Reproduction and Fertility Development*, 30, 487–497.

El-Debaky, H., Mahmoud, K. M., Abd El-Rezik, K. A., Sosa, A. S. A., Kandiel, M. M. M. & Ahmed, Y. F. (2020). PCR-SSCP and Sequencing Analysis for Studying Leptin Gene Polymorphism and Its Association with Reproductive Status of Egyptian Buffalo. *Egyptian Journal of Veterinary Science*, 51, 11–21.

Feitosa, F. L. B., Pereira, A. S. C., Venturini, G. C., Tonussi, R. L., Espeigolan, R., & Gordo, D. M. et al. (2014). Genome wide association study between copy number variation regions with marbling score in Nelore cattle. In: Proceedings, 10th World Congress of Genetics Applied to Livestock Production. Vancouver.

Fouda, M., Hemed, S., El-Bayomi, K., El-Araby, I., Hendam, B. & Ateya, A. (2021). Genetic polymorphisms in FSHR/ALUI and ESR $\alpha$ /BGII loci and their association with repeat breeder incidence in buffalo. *Journal of the Hellenic Veterinary Medical Society*, 72, 2869–2878.

Fu, Y.F., Li, L., Li, B., Fang, X. & Ren, S. (2016). Long form leptin receptor and SNP effect on reproductive traits during embryo attachment in Suzhong sows. *Animal Reproduction Science*, 168, 57–65.

Heidari, M., Kafi, M., Mirzaei, A., Asaadi, A. & Mokhtari, A. (2019). Effects of follicular fluid of preovulatory follicles of repeat breeder dairy cows with subclinical endometritis on oocyte developmental competence. *Animal Reproduction Science*, 205, 62–69.

Ibrahim, A. H. M. (2019). Association of growth performance and body conformational traits with BMP4 gene variation in Barki lambs. *Growth Factors*, 37, 153–163.

İşik, E., Beck, P. P., Campi, I., Özön, A., Alikasifoğlu, A., Gönc, N. & Kandemir N. (2013). Thyroid hormone resistance: a novel mutation in thyroid hormone receptor beta (THR $\beta$ ) gene - case report. *Turkish Journal of Pediatrics*, 55, 322–7.

Jorgez, C. J., Klysk, M., Jamin, S. P., Behringer, R. R., & Matzuk, M. M. (2004). Granulosa cell specific inactivation of follistatin causes female fertility defects. *Molecular Endocrinology*, 18, 953–67.

Karsch, F. J., Bittman, E. L., Foster, D. L., Goodman, R. L., Legan, S. J. & Robinson, J. E. (2013). Neuroendocrine basis of seasonal reproduction. *Recent Progress in Hormone Research*, Academic Press, New York, USA.

Kato, M. V. (2000). A secreted tumor-suppressor, mac25, with activin-binding activity. *Molecular Medicine*, 6, 126–35.

Kavita, K., Phogat, J. B., Pandey, A. K., Balhara, A. K., Ghuman, S. S. & Gunwant, P. (2018). Effects of melatonin supplementation prior to Ovsynch protocol on ovarian activity and conception rates in anestrous Murrah buffalo heifers during out of breeding season. *Reproductive Biology*, 18, 161–168.

Kishigami, S. & Mishina, Y. (2005). BMP signaling and early embryonic patterning. *Cytokine Growth Factor Reviews*, 16, 265–278.

Kukurba, K. R. & Montgomery, S. B. (2015). RNA Sequencing and Analysis. *Cold Spring Harbor Protocols*, 13, 951-69.

Kumar, R., Ghosh, M., Kumar, N., Balhara, A. K., Gupta, M., Sharma, R. K. & Singh, I. (2017). Polymorphism in 5' untranslated region of heat-shock protein 70 gene as marker of post-partum anoestrus in Murrah buffaloes. *Reproduction Domestic Animal*, 52, 505-512.

Lappalainen, T., Sammeth, M., Friedlander, M. R., Hoen, P. A., Monlong, J., Rivas, M. A., Gonzalez-Porta, M., Kurbatova, N., Griebel, T. & Ferreira, P. G. et al. (2013). Transcriptome and genome sequencing uncovers functional variation in humans. *Nature*, 501, 506-11.

Lappalainen, T., Sammeth, M., Friedlander, M. R., Hoen, P. A., Monlong, J., Rivas, M. A., Gonzalez-Porta, M., Kurbatova, N., Griebel, T. & Ferreira, P. G. et al. (2013). Transcriptome and genome sequencing uncovers functional variation in humans. *Nature*, 501, 506-11.

Lari, A. M., Mohebbi-Fani, M. & Rowshan-Ghasrodashti, A. (2012). Causes of culling in dairy cows and its relation to age at culling and interval from calving in Shiraz, Southern Iran. *Veterinary Research Forum*, 3, 233-237.

Latifah, L. & Saa N.R. (2021). Single nucleotide Polymorphism gen BMP4 pada kambingberdasarkan data GenBank. *Journal of Tropical Animal Research*, 2,1, 24-29

Li, J., Liu, J., Campanile, G., Plastow, G., Zhang, C., Wang, Z., Cassandro, M., Gasparrini, B., Salzano, A., Hua, G., Liang, A. & Yang, L. (2018). Novel insights into the genetic basis of buffalo reproductive performance. *BMC Genomics*, 9, 814.

Li, J., Liu, X., Yang, J., Wang, H., Jiang, J., Liu, L., He, S., Ding, X., Liu, J. & Zhang, Q. (2014). Targeted resequencing of GWAS loci reveals novel genetic variants for milk production traits. *BMC Genomics*, 15, 1-9.

Liu, J. J., Liang, A. X., Campanile, G., Plastow, G., Zhang, C., Wang, Z., Salzano, A., Gasparrini, B., Cassandro., M. & Yang, L. G. (2018). Genome-wide association studies to identify quantitative trait loci affecting milk production traits in water buffalo. *Journal of Dairy Science*, 101, 433-444.

Mahrous, K. F., El-Kader, H. A. M., Abdelhafez, M. A., Aboelenin, M. M., Balabel, E. A., Mabrouk, D. M., El Malky, O. M. & Hassan, M. S. (2022). Genetic structure of some candidate genes of repeat breeder syndrome in Egyptian buffaloes. *Journal of genetic engineering and biotechnology*, 20, 110.

Makina, S. O., Muchadeyi, F. C., Van Marle-Koster, E., Taylor, J. F., Makgahela, M. L., & Maiwashe, A. (2015). Genome-wide scan for selection signatures in six cattle breeds in South Africa. *Genetics Selection Evolution*, 47, 92.

Malpaux, B., Migaud, M., Tricoire, H. & Chemineau, P. (2001). Biology of mammalian photoperiodism and the critical role of the pineal gland and melatonin. *Journal of Biological Rhythms*, 16, 336-347.

Martínez-Montes, A. M., Fernandez, A., Pérez-Montarello, D., Alves, D., Benítez, R., Núñez, Y., Ovilo, C., Ibañez-Escríche, N., Folch, J. & Fernandez, A. (2017). Using RNA-Seq SNP data to reveal potential causal mutations related to pig production traits and RNA editing. *Animal Genetics*, 48, 151-165.

Moioli, B., Scatà, M. C., Steri, R., Napolitano, F. & Catillo, G. (2013). Signatures of selection identify loci associated with milk yield in sheep. *BMC Genetics*, 14, 76.

Moioli, B., Scatà, M., Catillo, G., Napolitano, F. & Pilla, F. (2013). Whole-genome genotyping for detecting mutations in the genes that are directly responsible for the trait variation. Page P0621 in Proc. Plant and Animal Genome XXI, San Diego, CA.

Morfeld, K. A. & Brown, J. L. (2014). Ovarian acyclicity in zoo African elephants (*Loxodonta africana*) is associated with high body condition scores and elevated serum insulin and leptin. *Reproduction, Fertility and Development*, 28, 640-7.

Musunuru, K., Strong, A., Frank-Kamenetsky, M., Lee, N. E., Ahfeldt, T., Sachs, K.V., Li, X., Li, H., Kuperwasser, N. & Ruda, V. M. (2010). From noncoding variant to phenotype via SORT1 at the 1p13 cholesterol locus. *Nature*, 466, 714-9.

Muttukrishna, S., Tannetta, D., Groome, N., & Sargent I. (2004). Activin and follistatin in female reproduction. *Molecular and Cellular Endocrinology*, 225, 45-56.

Ortiz, W. H., Quirino, C. R., Silva, A., Oliveira, C. S., Serapiao, R. V., Pacheco, A. & Bartholazzi, A. (2015). Association between BMP4 gene polymorphism and in vitro embryo production traits in Gyr cows. *Revista Colombiana de Ciencias Pecuarias*, 28, 156-164.

Otsuka, F., Yamamoto, S., Erickson, G. F. & Shimasaki, S. (2001). Bonemorphogenetic protein-15 inhibits follicle stimulating hormone (FSH) action by suppressing FSH receptor expression. *Journal of Biological Chemistry*, 276, 11387-11392.

Pal, A. & Chakravarty, A. K. (2020). Disease resistance for different livestock species. *Genetics and Breeding for Disease Resistance of Livestock*, 19, 271-96.

Parmeggiani, A., Di Palo, R., Zicarelli, L., Campanile, G., Esposito, L., Seren, E., Accorsi, P. A & Sofai, S. M. (1994). Melatonin and reproductive seasonality in the buffalo cow. *Agricoltura Ricerca*, 153, 41-48.

Ramadan, S. I., Abo-Gamil, Z. H. & El-Qaliouby, H. S. (2018). Polymorphism of IGF-1 and Its Receptor (IGF-1R) Genes and Their Association with Fertility Problems of Egyptian Buffaloes. *Alexandria Journal of Veterinary Sciences*, 59, 119-124.

Rangashamaiah, M. M., Ghuman, S. S. & Cheema, R. (2022). Association of melatonin receptor 1a (MTNR1A) gene polymorphism with seasonal suppression of fertility in buffaloes. *Buffalo Bulletin*, 41, 749-763.

Refsdal, A.O. (2000). To treat or not to treat: a proper use of hormones and antibiotics. *Animal Reproduction Science*, 60, 109-19.

Regmi, G. & Dhakal, I.P. (2020). Systemic levels of iron, phosphorus, and total protein in normocyclic versus repeat breeder Holstein Friesian crossbred cows of Kesharbag, Chitwan. *Nepalese Veterinary Journal*, 13, 2353-2357.

Reshma, R., Mishra, S. R., Thakur, N., Parmar, M. S., Somal, A., Bharti, M. K., Pandey, S., Chandr, V., Chouhan, V. S., Verma, M. R., Singh, G., Sharm, G. T., Maurya, V. P. & Sarkara, M. (2016). Modulatory role of leptin on ovarian functions in water buffalo (*Bubalus bubalis*). *Theriogenology*, 86, 1720-1739.

Roberts, A.B. & Sporn, M. B. (1990). The transforming growth factors. In: Sporn, M.B., Roberts, A.B. (Eds.), *Peptide Growth Factors and Their Receptors*, Part I. Springer-Verlag Berlin, 419-472.

Roxström, A. & Strandberg, E. (2002). Genetic analysis of functional, fertility-, mastitis-, and production-determined length of productive life in Swedish dairy cattle. *Livestock Production Science Journal*, 125-135.

Sammad, A., Khan, M. Z., Abbas, Z., Hu, L., Ullah, Q., Wang, Y., Zhu, H. & Wang, Y. (2022). Major Nutritional Metabolic Alterations Influencing the Reproductive System of Postpartum Dairy Cows. *Metabolites*, 12, 60.

Sanger, F., Nicklen, S. & Coulson, A. R. (1977). DNA sequencing with chain-terminating inhibitors. *The Proceedings of the National Academy of Sciences*, USA, 74, 5463-5467.

Schaeffer, L. R. (2006). Strategy for applying genome-wide selection in dairy cattle. *Journal of Animal Breeding and Genetics*, 123, 218-223.

Seo, H., Choi, Y., Shim, J., Yoo, I., & Ka, H. (2014). Prostaglandin Transporters ABCC4 and SLC20A1 in the Uterine Endometrium and Conceptus During Pregnancy in Pigs. *Biology of Reproduction*, 90, 5.

Seo, M., Lee, H. J., Kim, K., Caetano-Anolles, K., Jeong, J.Y., Park, S., Oh, Y. K., Cho, S. & Kim, H. (2016). Characterizing milk production related genes in Holstein using RNA-seq. Asian-australas. *Journal of Animal Science*, 29, 343.

Shahi, P., Slorach E.M., Wang, C.Y., Chou, J., Lu, A., Ruderisch, A. & Werb, Z. (2015). The transcriptional repressor ZNF503/Zeppe2 promotes mammary epithelial cell proliferation and enhances cell invasion. *Journal Biological Chemistry*, 290, 3803-13.

Shao, B., Sun, H., Ahmad, M. J., Ghanem, N., Abdel-Shafy, H., Du, C., Deng, T., Mansoor, S., Zhou, Y., Yang, Y., Zhang, S., Yang, L. & Hua, G. (2021). Genetic features of reproductive traits in bovine and Buffalo: lessons from bovine to Buffalo. *Frontiers in Genetics*, 12, 617128.

Song, L. J., Wu, J. F., Yang, Z. B., Guo, L., Zhang S. J. & Wu, J.J. (2013). Investigation of transferability of BovineSNP50 BeadChip from cattle to water buffalo for genome wide association study. *Molecular Biology Reports*, 40, 743-50.

Sosa, A. S. A., Mahmoud, K. M., Kandiel, M. M. M., Eldebaky, H. A. A., Nawito, M. F. & Abou El Roos, M. E. A. (2016). Genetic Polymorphism of Luteinizing Hormone Receptor Gene in Relation to Fertility of Egyptian Buffalo. *Biotechnology Journal*, 12, 1-11.

Spencer, T. E., Forde, N., Dorniak, P., Hansen, T. R., Romero, J. J. & Lonergan, P. (2013). Conceptus-derived prostaglandins regulate gene expression in the endometrium prior to pregnancy recognition in ruminants. *Reproduction*, 146, 377-87.

Sreedharan, S., Stephansson, O., Schiöth, H. B. & Fredriksson, R. (2011). Long evolutionary conservation and considerable tissue specificity of several atypical solute carrier transporters. *Gene*, 478, 11–18.

Sun, R. Z., Lei, L., Cheng, L., Jin, Z. F., Zu, S. J. & Shan, Z. Y. (2010). Expression of GDF-9, BMP-15 and their receptors in mammalian ovary follicles. *Journal of Molecular Histology*, 41, 325–32.

Tamura, K., Dudley, J., Nei, M. & Kumar, S. (2007). MEGA4: Molecular Evolutionary Genetics Analysis (MEGA) Software Version 4.0. *Molecular Biology Evolution*, 24, 1596–1599.

Tanwar, P.S. & McFarlane, J.R. (2011). Dynamic expression of bone morphogenetic protein 4 in reproductive organs of female mice. *Reproduction*, 142, 573–9.

Van den Berg, I., Fritz, S., Rodriguez, S., Rocha, D., Boussaha, M., Lund, M. S. & Boichard, D. (2014). Concordance analysis for QTL detection in dairy cattle: A case study of leg morphology. *Genetics Selection Evolution*, 46, 31.

Wandji, S. A., Gadsby, J. E., Barber, J. A. & Hammond, J. M. (2000). Messenger ribonucleic acids for IGFBP-7 and connective tissue growth factor (CTGF) are inversely regulated during folliculogenesis and early luteogenesis. *Journal of Endocrinology*, 141, 2648–57.

Wang, L. & Wang, Y. (2012). Molecular characterization, expression patterns and subcellular localization of Myotrophin (MTPN) gene in porcine skeletal muscle. *Molecular Biology Reproduction*, 39, 2733–8.

Warriach, H. M., McGill, D.M., Bush, R.D., Wynn, P.C. & Chohan, K.R. (2015). A review of recent developments in buffalo reproduction - a review. *Asian-Australasian Journal of Animal Sciences*, 28, 451–455.

Watanabe, Y., Takeuchi, K., Onaga, S. H., Sato, M., Tsujita, M., Abe, M., Natsume, R., Li, M., Furuichi, T. & Saeki, M. (2010). Chondroitin sulfate N-acetylgalactosaminyltransferase-1 is required for normal cartilage development. *Biochemistry Journal*, 432, 47–55.

Whitworth, K. M., Zhao, J., Spate, L. D., Li, R. & Prather, R. S. (2011). Scriptaid corrects gene expression of a few aberrantly reprogrammed transcripts in nuclear transfer pig blastocyst stage embryos. *Cellular Reprogramming*, 13, 191–204.

Wiles, J.R., Katchko, R.A., Benavides, E.A., O'Gorman, C.W., Escudero, J.M., Keisler, D.H., Stanko, R.L., & Garcia, M.R. (2014). The effect of leptin on luteal angiogenic factors during the luteal phase of the estrous cycle in goats. *Animal Reproduction Science*, 148, 121–129.

Yusuf, M., Toshihiko, N., Ranasinghe, B., Gautam, G., Long, S., Yoshida, C., Koike, K. & Hayashi, A. (2010). Reproductive performance of repeat breeders in dairy herds. *Theriogenology*, 73, 1220–1229.