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A review on the concept of inbreeding and its impact on livestock

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Abstract
Inbreeding is the breeding between more closely related animals than the average relationship of animals within the population of interest and shares a common ancestry for the last five to six generations. Though it develops inbred lines, prepotent progenies and unmasks and removes recessive deleterious alleles from the population, it is found to reduce the reproductive, fitness and survival performances of offspring due to the inbreeding depression. The more negative outcomes of inbreeding than the positive ones have evolved various ways of avoiding inbreeding. However, it is unavoidable and may occur at the farmers' level during selective breeding programmes. Therefore, it is advised to use the optimum breeding strategies to minimize the rate of inbreeding to within the sustainable levels.

Keywords: Inbreeding, ancestry, inbred lines, inbreeding depression, prepotent progenies

Introduction
Inbreeding is a genetic concept heard by many of us but barely understood by few of us as what it is and how it can be brought to function and misused. It was considered as an immoral concept until the science of genetics was established. People observed that when closely related animals were mated the offspring born were either deformed or weak or dead and considered it as an evil's punishment. Later, geneticists established heredity to be the reason for deformed, weak and dead offspring and not the morality (Vogt *et al*., 2019) [1]. Inbreeding is the process of breeding genetically similar or more closely related animals than the average relationship within the breed or population of interest plus having a common ancestry for the last five to six generations or it is the measure of the probability of identity by descent of two alleles at a given locus in a given individual (Savedge, 2017) [2]. Inbreeding is the opposite of crossbreeding where unrelated animals with no common ancestry for the last five to six generations are mated with each other.
Inbreeding is a strong breeding method used to establish new lines, families, breeds, varieties and to improve the accuracy of selection and crossbreeding results and more likely to occur in small populations. Inbreeding is a known technique to retain the wanted characteristics or exclude the unwanted characteristics. This often results in a trade-off where a desirable trait is magnified at the expense of another (Helmenstine, 2019) [3]. However, the unplanned and uncontrolled inbreeding leads to the poorer reproductive performances and decline in growth, fitness and survival of offspring. This reduction in performances of offspring is called inbreeding depression. Inbreeding can also occur at the farmer's level when the superior animals are selected for breeding considering certain phenotype to be made available to the progenies. When this happens, the breeding population size reduces and unneeded inbreeding occurs. The selective breeding programmes improve the population by selection but one must be aware enough to reduce or minimize the chances of inbreeding.
Consequently, the most evident message that we receive from geneticists is to avoid the occurrence of inbreeding as the most basic genetic consequence of inbreeding is to increase the frequency and pairing of similar alleles or gene variants in the offspring and change the genotype frequency in the offspring. This increases the homozygosity in offspring and also reduces the heterozygosity in offspring by equal numbers. The inbred animals are homozygous as they inherit identical copies of alleles or gene variants from their parents considering that the parents have obtained it from their ancestors or are identical by descent. The degree of homozygosity in an animal can be measured by the inbreeding coefficient or in other words,

we measure the per cent reduction in heterozygosity in relation to the base population through inbreeding coefficient. The base population refers to the breed of interest at a date to which the ancestry is traced and in general the animals are assumed non-inbred (Vogt *et al*., 2019) [1]. The coefficient of inbreeding never reaches 100 per cent and therefore, no strain is ever fully inbred (Anonymous, 2019) [4]. The inbreeding coefficient of progeny X born from Parents B and C can be estimated as:

$F_X = \Sigma [(1/2)^{n + n' + 1} (1 + F_A)]$

Where; F_X= Inbreeding coefficient of animal X;

F_A= Inbreeding coefficient of common ancestor A;

1/2= Fraction of an animal's genetic material that is transmitted to its progeny;

n= Number of generations between animal B and the common ancestor;

n'=Number of generations between animal C and the common ancestor;

+1 = Added to n and n' to account for the additional generation between animal and its parents.

On the other hand, the degree of inbreeding depends on the closeness of relationship shared between the parents. Breeding of closely related animals for say brothers and sisters or parents and offspring share several similar alleles inherited from their common ancestors and thus shows higher levels (50%) of inbreeding. On the contrary, distantly related animals for say first and second cousins receive comparatively few alleles from their common ancestors and thus produce lesser levels of inbreeding i.e. 12.5% and 6.25%, respectively. The closeness of relationship is measured by the coefficient of relationship that depends on three factors (Vogt *et al*., 2019) [1]. The factors are:

1. Number of common ancestors of parents
2. Number of generations between the common ancestor and the parents
3. Frequent appearance of the common ancestor and inbreeding of the common ancestor(s).

The coefficient of relationship measures the degree of similarity between the genetic constitutions of the parents. The formula to measure the coefficient of relationship for say between parents B and C is:

$R_{BC} = \Sigma [(1/2)^{n + n'} (1 + F_A)] \div \text{Square Root of } (1 + F_B) (1 + F_C)$

If none of the animals is inbred, the coefficient of relationship is estimated as:

$R_{BC}= \Sigma [(1/2)^{n + n'}]$

Where; R = Coefficient of relationship between parents B and C;

F_A, F_B and F_C= Inbreeding coefficients of common ancestor, and of parents B and C;

1/2= the fraction of an individual's genetic material that is transmitted to its progeny;

n = Number of generations between parent B and the common ancestor;

n' = Number of generations between parent C and the common ancestor.

Types of inbreeding: There are two types of inbreeding that are discussed below:

1. **Line breeding:** A type of inbreeding that is concerned with mating of animals where one or more relatives exist more than once in a pedigree (RSPCA, 2019) [5]. It is repeated back cross with parent (Tomar and Tomar, 2016) [6].
2. **Close inbreeding:** Breeding between closely related animals for say between full sibs, parents and offspring, grand-parents and grand-offspring, half sibs etc. is close inbreeding. However, the offspring produced is under the high risk of suffering from inherited disorders. This is due to the increased pairing of similar genes in inbreeding and in case if the genes are defective genes, their pairing up would result in inherited disorders (RSPCA, 2019) [5].

Major reasons for inbreeding: The inbreeding arises due to the following factors:

1. **Small population size:** In a limited population, it is difficult to avoid breeding between the related animals and moreover, the outbred stocks turn into inbred stocks if kept in the limited population size for several generations. This shows that rate of inbreeding depends on the population size. A strain is an inbred strain only after twenty generations of sib-mating and when the inbreeding coefficient is greater than 98.6% or 0.986 (Anonymous, 2019) [4].
2. **Genetic drift:** Genetic drift operates in small population and leads to the disappearance or variation in the number of prevailing alleles or gene variants in a population due to the random sampling of organisms and as a consequence, there is an increase in the homozygosity and dilution of the genetic resources in a population. The homozygosity in a population represents the size of allele frequencies, meanwhile, Oldenbroek and Van der Waaij (2015) [7] reported permanent loss in the genetic resources as the alleles are lost forever. It is also called inevitable inbreeding or allelic drift or the Sewall Wright effect.
3. **Non-random mating**: Non-random mating is the evitable form of inbreeding and is aimed to breed the closely related animals for say, father and daughter, mother and son and brother and sister to obtain similar alleles from the parents, resulting in an increase in homozygosity and inbreeding. However, this reflects the temporary dilution of genetic resources as on minimizing the non-random mating and utilizing the random mating, this cause of inbreeding would fail to exist (Oldenbroek and Van der Waaij, 2015) [7].

Effects of inbreeding: The widely accepted effects of inbreeding are discussed below.

1. **Inbreeding depression:** The decrease in the performance of the offspring produced as a result of crosses between close relatives is called inbreeding depression. There are two hypotheses that suggest the genetic basis of inbreeding depression. First is the partial dominance hypothesis, where expression of the recessive but deleterious alleles in the homozygous state causes inbreeding depression (Davenport, 1908 and Crow, 1952) [8, 9]. The recessive allele in the heterozygotes unmasks and expresses due to the increase in homozygosity. The second hypothesis is the overdominance hypothesis (East, 1908 and Shull, 1908) [10, 11] where superiority per se of heterozygotes over the homozygous parents causes inbreeding depression. Increase in inbreeding would result in reduced frequency of heterozygotes and thus reduction in expression of overdominance. Besides, breakdown of epistatic interaction between the loci acts

as the third hypothesis to partly explain inbreeding depression (Templeton and Read, 1994) [12]. Like heterosis, inbreeding severely affects low heritable traits i.e. fertility, fitness and survival traits of an offspring. Moreover, it is found to reduce the immune system function and thus may lead to the risk of tumor development and failure of defense system against infectious diseases. The effects are shown in numerous studies on cattle, sheep, horses, swine and laboratory animals. Such effects are called inbreeding depression that increases with the increase in inbreeding (Falconer and Mackay, 1996; De Rose and Roff, 1999; RSPCA, 2019) [13, 14, 5].

2. **Reduction of genetic diversity:** Reduction in genetic diversity leads failure of organisms to survive over varying environments and adapt over time. This leads to the gradual reduction in the overall biological fitness of organisms (Helmenstine, 2019) [3].
3. **Increase in homozygosity:** Inbreeding results in a decrease in the frequency of pairing of unalike genes in the offspring and promotes pairing of like genes in the offspring i.e. decrease in heterozygosity and accompanied with increases in homozygosity. Homozygosity increases with later generations and therefore the recessive genes that were once masked in heterozygotes tend to appear in homozygotes due to repeated inbreeding. This has been opined to be the most basic genetic outcome of inbreeding (Helmenstine, 2019) [3].
4. **Unmasking of deleterious genes:** The recessive deleterious genes gets unmasked in inbreds due to homozygosity that at one point are associated with abnormalities and death of the offspring which otherwise were in low numbers or masked or hidden by the dominant counterparts (genes) in outbreds. The genetic nature of genes in inbreds is almost always recessive. However, a single recessive gene cannot express itself for sex linked traits and has to be essentially in paired form for the expression. The probability of occurrence of genes in paired form increases with inbreeding as it is known to increase the proportion of like genes in the inbred population. Once the recessive harmful genes get unmasked and expresses in offspring, both the offspring and the parents (carrier of recessive harmful genes) can be culled or eliminated from the herd of breeder (Vogt *et al*., 2019) [1].
5. **Enhanced prepotency:** Most of the inbreeding outcomes are undesirable for the breeders, however, it is still found to be a valuable tool in animal breeding and this is due to its ability to uniformly stamp the characteristics of the parents into their progenies. Due to the fact that inbreeding increases homozygosity or the frequency of alike genes no matter if it is good or bad, dominant or recessive, the reproductive cells of the progenies will have identical genetic makeup as of their parents. If uniform genetic makeup involves large number of dominant genes, then the progenies would uniformly display the dominant characteristics of the parents (Vogt *et al*., 2019) [1].

Applications of inbreeding: The various applications of inbreeding are discussed below (Vogt *et al*., 2019) [1]:

1. Defect-free progenies can be produced as a result of inbreeding considering it as a sort of progeny testing.
2. Inbreeding enhances response to selection in case heritability is low.
3. Inbreeding creates genetically improved breeds, varieties or strains that breed true for 'type' i.e. represents a group of qualitative phenotypes or specific body attributes (ones that are especially defined by an outline i.e. conformation).
4. Inbreeding leads to the origination of distinct inbred lines by crosses made between diverse genetic populations within a species. Meanwhile, if inbreeding is continued for long time in the developed lines, there are chances that the frequency of gene changes in the lines which were earlier less in the population and tend to increase in all or nearly all the animals in some lines and none or very few in the animals of other lines.
5. As we keep 1 bull for 40-50 cows and 2 bulls for 80-100 cows, it is depicted that the herd bull(s) serves as the quickest means to improve the herd or population.
6. Hybrid vigour tends to increase when two genetically distinct pure inbred lines are crossed to each other i.e. considering it as crossbreeding.
7. Also, inbreeding coefficient of relationship is helpful in the various situations. For example, a farmer may sell one of his bulls at higher price related to the bull that was previously sold for a higher price depending on the coefficient of relationship. The higher the coefficient of relationship between the two bulls, the better is its use as a sales point. Besides, the coefficient of relationship is practically useful in estimation of the performance value of an untested animal, however, this requires the average performance value of a related tested animal, breed, herd or group to which tested and untested animal belongs and the coefficient of relationship between the tested and untested animals.

Impact of inbreeding on livestock: The impacts of inbreeding on various species of livestock are discussed below:

1. Pig:

a. Growth traits: A study on piglets produced from second parity dams reveal increase in their birth weight and weaning weight and decrease in post weaning daily gain (Mikami *et al*., 1977) [15]. On the other hand, a study on various growth traits by Culbertson *et al.* (1997) [16] revealed reduction of 21 day litter weight by 0.15kg for 10% inbreeding in Hampshire breed. Besides, it took 3.2 and 2.6 days more to reach to 104.5 kg body weight in Hampshire and Duroc, respectively for every 10% increase in inbreeding.

b. Reproduction traits: Hauser *et al.* (1952) [17] reported slower rate of sexual maturity in inbred lines in comparison to outbred lines. Moreover, in a research conducted at the Midwest Regional Swine Breeding Laboratory, Dickerson *et al.* (1954) [18] points out that for each 10 per cent increase in inbreeding, there is a decrease of 0.20, 0.35 and 0.38 piglets per litter at, birth, 21 days and 56 days, respectively. It was confirmed by the similar reports of Kock *et al.* (2009) [19] which states reduction in litter size at weaning by 0.19 and 0.29 piglets in Large White and Landrace breeds, respectively as a consequence of 10% litter inbreeding. Similarly, 10% dam inbreeding resulted in loss of 0.16 and 0.21

piglets in Large White and Landrace breeds, respectively.

c. Carcass traits: King and Roberts (1959) [20] observed an increase in carcass weight of Large White pigs by 0.21kg and decrease in middle back fat thickness and streak thickness by 0.37mm and 0.36mm, respectively. Similar results of reduction in back fat thickness by 0.34mm in the offspring's of second parity dams were observed by Mikami *et al*. (1977) [15]. On the contrary, a linear decline of daily carcass gain by 1.6g for 0.1 increases in inbreeding coefficient was observed by Christensen *et al*. (1994) [21].

2. Cattle

a. **Growth traits:** It was observed that the birth weight of Hereford cattle declined by 1.24% as mentioned by Panicke *et al*. (1975) [22] and later, the post-weaning gain in Hereford cattle was found to depress by 0.24 kg per per cent inbreeding (Gengler *et al*., 1998) [23]. Inbreeding is also found to curtail the body condition score by 0.27 units as manifested by Wall *et al*. (2005) [24]. Further, Inbreeding depression has negatively affected the longevity of cows and was more intense when the coefficient of inbreeding exceeded beyond 12.5%. In this context, Holstein, Jersey and Ayrshire cows were 1.25, 1.28 and 1.36 times, respectively more likely to be culled than the non-inbred cows when the inbreeding coefficient ranged between 12.5-18.25%. Similarly, Holstein, Ayrshire and Jersey cows were 1.51, 1.58, and 1.31 times, respectively more likely to be culled than non-inbreds when the inbreeding coefficient exceeded beyond 25% (Sewalem *et al*., 2006) [25].

b. **Reproduction traits:** An increase in number of days open in linebred Holstein cows by 21 days was essayed by Beckett *et al*. (1979) [26]. In addition, Smith *et al*. (1998) [27] reflected a narrow but diminishing effect on the age at first calving and first calving interval of Holstein cows in registered herds by extending it by 0.36 and 0.26 days, respectively per 1% increase in inbreeding. Another negative impact of inbreeding depression was mentioned in the study of Cassell *et al*. (2003) [28] who reported decline in calving rate of Holsteins and Jerseys by 4 and 6%, respectively in their first parity. It was the result of 10% maternal or foetal inbreeding in Holsteins and 10% maternal inbreeding in Jersey cows, however, foetal inbreeding depression was not significant in Jerseys. This was later confirmed by Wall *et al*. (2005) [24] where they stated 2.8 days increase in the calving interval of in-bred Holsteins with an inbreeding coefficient of 10%. An increment in days to first insemination, probability to return to estrus at first service and number of inseminations by 1.7 days, 1% and 0.03 numbers were reported as a result of inbreeding depression. Moreover, these effects enhanced at higher levels of inbreeding. In addition to these findings, the Irish Holstein Friesian cows inbred to a level of 12.5% exhibited exhibited higher cases of dystocia and stillbirth by 2 and 1%, respectively along with increase in calving interval and age at first calving by 8.8 and 2.5 days, respectively. Besides, survival ability to second lactation was found to be reduced by 4% (Parland *et al*., 2007) [29].

c. **Production traits:** A negative impact of inbreeding on production traits through an increased risk of inbreeding depression is observed in various literatures. In Hereford cattle, the inbreeding depression for 1% increase in inbreeding was predicted to be up to –30 kg milk and –1.0 kg fat (Panicke *et al*., 1975) [22]. It was confirmed by the study of Smith *et al*. (1998) [27] where the estimated lifetime inbreeding depression for 1% increase in inbreeding was –177 kg milk, –6 kg fat and –5.5 kg protein along with decline in the productive life and milking days by 6 and 4.8 days, respectively. Similarly, Thompson *et al*., (2000a,b) [30, 31] reported reduction in lactation length in Holstein (10% inbreeding) and Jersey (5% inbreeding) cows by 2-8 days and 3-5 days, respectively. On the other hand, Parland *et al*. (2007) [29] illustrated undesirable increase in somatic cell scores by 0.03 units in 12.5% inbred Irish Holstein Friesian cows.

d. **Economic efficiency:** Inbred animals are economically inefficient and generally bring economic losses of ` 1408-1536 over their life time (Meyer, 2017) [32]. Similar reports were earlier reported by Smith *et al*. (1998) [27].

3. Poultry:

a. Growth traits: A decline in body weight of male and female in male line turkey by 210g and 130g, respectively at 17 weeks of age was observed by Cahaner *et al*. (1980) [33]. However, Tongsiri *et al*. (2019) [34] did not observe any such negative effects of inbreeding on the body weight traits of Thai chicken except that at 1% increase in inbreeding coefficient, body weight at day 1 reduced by 0.09g.

b. Reproduction traits: Wilson (1948) [35] obtained zero regression for fertility for every 1% increase in inbreeding. However, contradictory results were obtained by Abplanalp (1974) [36] where he mentioned decrease in hatchability by 9% and 3% due to embryo inbreeding and hen inbreeding, respectively. This was in support with the findings of Sewalem *et al*. (1999) [37] where they reported that for each 10% increase in the degree of embryo inbreeding and hen inbreeding, mean hatchability decreased by 4·17% and 2.93%, respectively in the egg weight line. In addition, they also mentioned delay in age at first egg by 1 day. Sewalem *et al*. (1999) [37] further observed decline in mean per cent fertile eggs by 1.01% and 0.88% due to hen and mate inbreeding, respectively for each 10% increase in the degree of inbreeding in "egg weight line". Similar results of decline in fertilized eggs by 0.4 – 1% for every 1% increase in inbreeding was obtained in different strains of White Leghorn and New Hampshire layer hens, respectively by Szwaczkowski *et al*. (2003) [38].

c. Production traits: It is noted that for every 1% increase in inbreeding there is decrease in egg production rate by 1.4% (Wilson, 1948)[35]. Also, for every 10% increase in inbreeding of the hen there is decrease in egg number and egg weight from age at first egg to 42 week by 1.75-3.84% and 0.51-0.61%, respectively (Sewalem *et al*., 1999) [37]. Similarly, egg weight in female lines of turkey was found to reduce by 1.5g for every 10% increase in inbreeding, however, results were inconsistent in the male lines of turkey (Cahaner *et al*., 1980)[33]. Reduction in egg number was also reported by Kamali *et al*. (2007) [39].

4. Horse:

a. Growth traits: Dusek (1980) [40] did not observe any difference between inbreds and non-inbreds of Kladrub Black horse strain in relation to the body measurements and weight.

b. **Reproduction traits:** No inbreeding effects were observed on the conception rate and fertility of Kladrub Black horse strain by Dusek (1980) [40]. Similar result was reported in Thoroughbred horses by Mahon and Cunningham (1982) [41]. On the contrary, Langlois and Blouin (2004) [42] reported decline in reproductive productivity of French horses by 0.5-1% for 1% increase in inbreeding. Moreover, foaling rate was also found to reduce at various levels of inbreeding by Cothran *et al*. (1984) [43] and Sairanen *et al*. (2009) [44].

c. **Performance traits:** The negative inbreeding effect was recorded for Norwegian cold blooded trotters by Klemetsdal (1998) [45]. The average performance of horses declined by 0.036, 0.145 and 0.66 phenotypic standard deviation units when inbred to a level of 7.5, 15 and 32% respectively. Similar results were obtained by Radomska *et al*. (1983) [46]. On the contrary, positive responses have been obtained by other researchers for say, Chmiel *et al*. (2001) [47] and Sierszchulski *et al*. (2005) [48].

5. **Goat and sheep:** Leroy (2014) [49] revealed 0.137% decrease in the performance of traits for 1% inbreeding level. Let us study the impact of inbreeding on individual traits in sheep and goat.

a. **Growth traits:** Positive effects of inbreeding were observed by Khan *et al*. (2007) [50] in terms of birth weight, pre-weaning daily gain and weaning weight in comparison to non-inbreds. However, post-weaning daily gain declined in comparison to non-inbreds. In this context, Venkataramanan *et al*. (2016) [51] observed contrary results in Nilagiri sheep. They reported reduction in growth at 1 per cent inbreeding level ranging from 0.04kg in weaning weight to 0.10kg in yearling weight. Similar results were observed by Van Wyk *et al*. (2009) [52] in his study on Dormer sheep.

b. **Reproduction traits:** Kidding interval in inbreds was comparatively higher by 33 days in comparison to non-inbreds or it was found to increase by 1.696 days in inbreds for 1% increase in inbreeding. Similarly, weight at the first service and first kidding also reduced among inbreds (Khan *et al*., 2007) [50]. Besides, negative effects of inbreeding were also observed by Lamberson *et al*. (1982) [53] in his study on Hampshire sheep. They reported 1.2% decrease in ewe fertility, 0.27kg decrease in ewe breeding weight and 0.35 days delay in conception from the time of ram introduction when maintained at the 1% ewe inbreeding level. Similarly, net reproduction rate was found to reduce by >1% for every 1% increase in inbreeding (Ercanbrack and Knight, 1991) [54].

c. **Production traits:** Gipson (2002) [55] observes reduction (%) in overall milk, fat and protein production in swiss breeds (Alpine, Toggenberg and Saanen) and lower producing breeds of goats (Lamancha and Nubian) by 0.42 and 0.19, 0.41 and 0.22, and 0.39 and 0.18, respectively for every 1 per cent increase in inbreeding. Similar negative reports were observed for fleece production in sheep by Ercanbrack and Knight (1991) [54].

d. **Economic efficiency:** Inbreeding level of 20-25% showed economic loss of ` 438 in terms of ewe's production in the year 1991 and was found to increase to 928.44 at inbreeding level 50% in the same year (Ercanbrack and Knight, 1991) [54]. In addition, inbreeding has its effect on the host's resistance to diseases and was found to be associated with reduced disease resistance to infectious pathogens (Ferguson and Drahushchak, 1990; Roelke *et al*., 1993; Coltman *et al*., 1999 and Meaghre, 1999) [56-59]. Most of these researches have been performed on wild animals, fishes and only few have been traced for domestic animals.

Avoidance of inbreeding: After studying the more negative outcomes of inbreeding than the positive ones, the first thought that rose in the minds of geneticists is to reduce or avoid the chances of inbreeding in population which can be met by following practices:

1. **Avoidance of inbreeding by dispersal:** Dispersal or distribution of animals from their birth group or other group or place to another group or place is a widespread mechanism of avoiding inbreeding and is generally practiced among mammals and birds. This is a sex-biased dispersal and favours dispersal of same sex of a species. Till now the practice is followed among fishes, amphibians, reptiles and insects. This favours separation of close relatives and thus minimizes inbreeding (Pusey, 1987 [60]; Waldman and Mckinnon, 1993 [61]; Waldbauer and Sternburg, 1979 [62]) [60-62].
2. **Avoidance of inbreeding by providing extra-pair or group of animals or newer techniques in the herd:** For those species who show very low dispersal rates or where dispersal of animals is difficult, it becomes essential to either provide new males/group of animals in the herd or flock for breeding or to use advanced techniques like Artificial Insemination with the semen of unrelated breeds, Embryo Transfer Technology (ETT) etc. with the purpose of minimizing inbreeding (Pusey and Wolf, 1996) [63].
3. **Avoidance of inbreeding by maintaining the effective population size of herd/ flock of animals:** It is advised to keep the population size of the herd or flock large enough to limit the genetic drift from operating. This increases the genetic variation in a population and thus limits the loss of genetic diversity and disappearance of gene variants or alleles from the population. This facilitates the chances of mating between unrelated animals and thus minimizes inbreeding accompanied with increase in heterozygosity and decrease in homozygosity. The effective population size should be such that the rate of inbreeding does not exceed more than 1% per generation (Wakchaure and Ganguly, 2015) [64].
4. **Avoidance of inbreeding by delayed maturation or reproductive suppression:** This method was found evident in laboratory and wild animals by Hanby and bygott (1987) [65]; Blouin and Blouin (1988) [66]; Dewsbury (1988) [67] and wolff (1992) [68]. Their studies contemplated that siblings failed to mate because their maturation was delayed. In the authors opinion, this delay can be done either by nutritional manipulations above the maintenance heads (for say; keeping the maintenance requirements constant and altering the growth requirements between the groups or providing energy dense feed to one group whereas, bulky feed to other

group) or separate rearing of opposite sex so that puberty is delayed or providing heifer/cow or bull/teaser bull to opposite sexes at different time periods to achieve puberty at different time periods.

5. **Avoidance of inbreeding by good record keeping:** By far, this is the best way to minimize or manage the rate of inbreeding. For this to happen, the breeder must know the degree of relationship the animals share among them in any herd (Thomas, 2016) [69].
6. **Avoidance of inbreeding by avoiding keeping of a bull too long:** A general way by which one can restrict or limit inbreeding in any herd is by avoiding keeping of a bull for too long, so that the bull does not breed with his own daughters. On the other hand, daughters must be allowed to graze separately and bred to an unrelated bull (Thomas, 2016) [69].
7. **Avoidance of inbreeding by facilitating crossbreeding:** Breeding between two distinct pure inbred lines represents crossbreeding and keeps inbreeding away from accumulating in the herd. Moreover, the average performance of progenies exceeds the average performances of parents due to heterosis (Thomas, 2016) [69].
8. **Avoidance of inbreeding by use of electronic tools:** Various computerized breeding programmes like, MateSel are available for breeders to check the pedigrees and optimize breeding outcomes. A breeder can prepare the breeding list of unrelated animals within a herd or population to maximize the effects of desired traits and minimize inbreeding (Thomas, 2016) [69].
9. **Avoidance of inbreeding by monitoring inbreeding coefficient and development of policies:** Both inbreeding coefficient and development and regulation of policies at any appropriate level are required to control the level of inbreeding.

Conclusion
Breeding of more closely related animals than the average relationship of animals within the breed or population of interest is inbreeding. The parents must have a common ancestor within the last five or six generations for their progeny to be considered as inbreds. Despite inbreeding being a valuable tool in terms of unmasking and removal of recessive deleterious alleles from the population and increase in the development of prepotent progenies and distinct inbred lines, the low reproductive efficiency and growth rates and increased hereditary diseases and mortality rates have brought concerns in the minds of geneticists. The more negative outcomes of inbreeding than the positive ones have then evolved various methods of avoidance of inbreeding. However, inbreeding is unavoidable and therefore it seems a highly useful strategy to manage the rate of inbreeding or losses of genetic diversity to within the sustainable levels. It is therefore advised to use the optimum breeding strategies to minimize the rate of inbreeding.

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