Cattle Artificial Insemination in Developing Countries: The Case of Tanzania

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Review Article

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ABSTRACT

Artificial Insemination (AI) is the directly manual placement of an appropriate quantity of good quality semen in the reproductive tract of the female (preferably between 4–16 hours after the onset of standing estrus) through means other than copulation or natural mating. AI is frankly considered as the oldest and most widely used Assisted Reproductive Technology (ART) applied in livestock production since it allows better utilization of sires, reduces the hazards and costs of keeping males, as well as allowing the utilization of multiple sires. The importance of AI for the genetic improvement of the cattle is unquestionable since the technology is considered as an important component of an overall strategy to improve the profitability and sustainability of dairy cattle operations as well as to improve the livelihood of small-scale dairy farmers. However, after over 80 years of the commercial application of this technology in the cow, these technologies have had low adoption rates in Sub-Saharan Africa (SSA) as well as in other regions of the world particularly in the developing countries. This paper reviews the pertinent factors that should be considered in the establishment and efficient operationalization of artificial insemination in developing countries like Tanzania.

Keywords: Artificial insemination; Estrus; Copulation; Assisted reproductive technology; Sires.

INTRODUCTION

Tanzania is a lower-middle income economy (WB, 2020) that is overwhelmingly dependent on agriculture [1]. Livestock farming is a livelihood activity and is critically important for the food and nutritional security in the majority of the population in African countries, including Tanzania. The livestock subsector will be increasingly important in the

use, distribution, and reproduction in any medium, provided the original author and source are credited.

Sub-Saharan Africa (SSA) because the demand for Animal-Sources Food (ASF) is projected to increase due to population growth, increased incomes, and urbanization [2].

According to the Ministry of Livestock and Fisheries Development, Tanzania has the third largest livestock population of the African continent, ranking second in terms of cattle population of 33.9 million of which 96.5% are indigenous cattle breeds, 24.5 million goats, 8.5 million sheep, 3.2 pigs and 0.6 million donkeys. The livestock sector employs about 50% of her population, which is equivalent to 4.6 million households whose income depend on livestock value chain [3,4].

Despite accounting for 11% of the African cattle population, livestock-related activities contribute only 7.4% to the Tanzania's Gross Domestic Product (GDP) and an annual growth at 2.6% which is relatively low. This growth largely reflects increases in livestock numbers, rather than productivity gains [5]. Like in many other African states, livestock farming in Tanzania operates far below the optimum potentials, mainly due to the limited use/employment of technologies to improve sustainability of livestock production. Livestock genetic improvement programs, beginning with selective breeding using statistical prediction methods, such as Estimated Breeding Values (EBVs), and more recently Genomic Selection (GS), in combination with Assisted Reproductive Technologies (ART) have enabled more accurate selection and intense utilization of genetically superior parents for the next generation to accelerate rates of genetic gain [6].

LITERATURE REVIEW

Among others, Artificial Insemination (AI) is the first and the most used biotechnologies in reproduction all over the world; and one of the main objectives for both dairy and beef farm cows is to have high reproductive performances [7,8]. In the context of animal breeding, AI is commonly used to improve the genetic traits of livestock, since it allows for the controlled breeding of animals with desirable characteristic, leading to improved productivity and quality in livestock. However, coverage of artificial insemination in Africa remains low, with less than 2% of breedable females inseminated, with very low level of efficiency mainly due to numerous factors: Infrastructure, management issues, financial constraints, poor heat detection, improper timing of insemination, and the likes Omondi et al., This paper is therefore intending to shade some light on aspects/issues that are of paramount importance for the efficiency of AI service in Tanzania or elsewhere with similar characteristics [9-12].

Genetic diversity

Artificial Insemination (AI), literally the manual placement of semen in the reproductive tract of the female by a method other than natural mating is one of a group of technologies commonly known as Assisted Reproductive Technologies (ARTs) or simply Reproductive Technology (RT) that afford widespread propagation of genes carried by superior males. Artificial insemination is by far the most common method of breeding in intensively kept both dairy and beef cattle, and it remain the most biotechnology widely applied in developing countries as compared to other technologies [13]. However, attempts to boost livestock production through the use of breeding technologies such as AI have been less successful in many developing countries due to multiple factors. Assessment of the genetic diversity of the existing livestock population is one of the important factors that ought to be considered before the implementation of such a programme.

Information about genetic diversity and population structure among cattle breeds is essential for genetic improvement, understanding of environmental adaptation as well as utilization and conservation of cattle breeds [14]. Genetic diversity is important in cattle breeding programs as it enhances the herd's ability to withstand diseases; so by introducing a variety of genetic backgrounds, AI can help spread alleles that confer resistance to specific diseases thus reducing the overall vulnerability of the herd. Africa rears about a fifth of the world's cattle (some 300 million head), which comprise a unique combination of two major cattle species -*Bos indicus*, which is widely recognized for the signature hump on its back, and *Bos taurus*, which is of European descent and has no hump [15,16]. According to a study conducted by Okomo-Adhiambo, the East African cattle were closely related since they were found to form a relatively homogenous and genetically unique group of populations that was distinct from the pure *Bos indicus* and *Bos taurus* breeds, though more closely related to *B. indicus* than to the *B. Taurus* [17]. Breeding programs that involve artificial insemination should consider such a trend (genetically homogeneity) as a compromising factor to enhanced reproductive performance: Fertility rates, strong gestation periods, and healthier calves, all of which can be optimized through AI.

In an attempt to enrich the limited information about the response to selection in genomes of highly admixed crossbred cattle in relation to production and adaptation to tropical environments of Tanzania, Cheruiyot et al. reported that the cross-bred cows were mostly cross-breeds of Holstein and Friesian cattle but with a wide variation of admixture [18]. Depending on the goals of the reproduction system, recommended for use in crossbreeding with indigenous cattle are: Friesian, Ayrshire, Jersey and Brown Swiss for dairy production; Angus, Hereford, Charolaise, Brahman, Beefmaster and Bensmara for beef production; and Simentals, Brown Swiss and Red Poll for both dairy and beef production, including Sahiwal, Mpwapwa, Boran and Gir breeds to improve the local zebu population. Since AI allows for the use of genetically superior sires, proper selection lead to improved milk production, meat quality, and overall productivity [19,20]. By selecting sires from different genetic backgrounds, breeders can avoid the negative effects of inbreeding, such as reduced fertility, lower productivity, and increased susceptibility to genetic disorders.

It can generally be admitted that the indigenous cattle breed in Africa are either pure African *Bos taurus* or admixtures of African *Bos indicus* and *Bos taurus* ancestry from 70%–90% or 60%–75%, depending on the admixture model [21]. While the use of AI in Tanzania and in many developing countries elsewhere has had a significant impact on the rate of genetic progress realized in cattle populations, maintaining genetic diversity is essential to support good performance and thus avoiding inbreeding depression. Artificial insemination impacts indirectly genetic diversity by reducing genetic variance, but such a detrimental effect could be reduced by maintaining sufficient number of bulls in the breeding scheme [22]. In addition, a meaningful AI programme ought to include collection and analysis of data on the intensity of male (bull) selection as well as genetic evaluation of the siblings produced, according to a recent study by Van Doormaal [23].

Breeding objectives

Breeding objective is defined as the reason for which animals are specifically bred for, assuming that farmers have made a deliberate choice to genetically improve the next generation of animals in terms of their performance in relation to their present generation [24]. Breeding objectives in cattle artificial insemination are focused on improving the genetic quality and overall performance of a herd. Primary goals can vary depending on the type of cattle (dairy or beef) and the specific needs of the operation, but generally include improving milk production (dairy cattle); increase yield, enhance milk quality or improving the lactation efficiency [25]. In many developing countries in sub-Saharan Africa, cattle production is based on the indigenous breeds, which are adapted to the local environment but characterized by relatively low productivity and generally perform poorly compared to commercial/exotic breeds. Understanding characteristics of reproduction systems and identification of specific trends related to breeding objectives is a first important step to the successful implementation of any breeding program, and well-defined breeding objectives form the basis of sound genetic improvement programs [26,27]. By setting a clear breeding objective it is possible then to make objective decisions in breeding programmes, such as choice of animals to be used as parents in within-line or within-breed selection, choice of which lines or breeds to introduce to the populations system, and to perform evaluation of different investments in breeding programmes [28].

In beef cattle, the breeding objective is geared at enhancing growth and carcass quality, with the focus being to increase growth rate by selecting sires that pass on genes for faster growth and better feed efficiency to reduce time to market; improve carcass quality by focusing on traits such as marbling, lean meat yield, and overall carcass weight to meet consumer preferences or market specifications; and enhance feed efficiency by improving the ability of cattle to convert feed into weight gain efficiently [29-31]. The other breeding objective could be improving reproductive performance [32,33]. Regarding fertility, selecting for sires that exhibit high fertility rates and lower incidence of reproductive disorders, and for calving ease, choosing bulls that produce calves with less difficulty at birth, which can reduce calving complications and improve overall herd health. Generally, the breeding objective provides the criterion to quantify and then maximize the return on investments in the breeding programme.

Since the breeding objective in any livestock species is to increase the profit by improving production efficiency, the practice always involves consideration of multiple traits, even in situations where output of a single trait is dominant [34]. In the optimal selection index, the relative importance of a trait is scaled by its economic value, derived as marginal profit related to a change in expression of defined size [35]. Cattle breeding programmes have historically been focused on generating profit by selecting for high-performing animals in order to increase the frequency of favorable gene combinations in economically important traits for a given production system and, thereby increase profitability. In dairy cattle, both reproductive and productive performances such as age at first service, number of services per conception, age at first calving, calving intervals, duration of lactation and milk yield, among others; while for beef cattle, objective metrics such as estimated breeding values to measure economic traits like growth rate, carcass conformation and composition, efficiency of feed conversion, and the like are the most considered [36]. In many developing countries, AI is still used primarily to genetically improve production animals, by producing progeny that are most appropriate to a given management environment and therefore support food production or as a source of income.

Infrastructure and accessibility

Assisted Reproductive Technologies (ARTs) or reproductive biotechnology had a limited impact in Africa due to different factors including a lack of infrastructure [37]. Infrastructure and accessibility are major for the successful implementation of cattle artificial insemination since proper facilities and resources help ensure efficient AI procedures, maintain cattle health, and maximize the success rates of insemination. Tanzania, like many other developing countries in Africa, is constrained by having limited facilities and equipments needed for an efficient operationalization of Artificial Insemination (AI) [38]. In a study conducted by Mugwaban in South Africa, it was clearly indicated that low-income farmers were still struggling to access inputs and services to drive their animals' productivity [39]. Since effective artificial insemination requires reliable transportation to move semen and equipment, in remote or rural areas with poor road networks, this can be a major hurdle leading to delays and reduced effectiveness of the AI process. In a recent study conducted to assess the quality of cryopreserved dairy bulls' semen in Tanzania, it was observed that among the contributing factors to low semen parameters was the leakage of storage and transportation containers and the delay of refilling of liquid nitrogen. Related to infrastructure is the power supply which is more often not reliable, making it difficult to maintain the necessary low temperature needed for quality of semen.

Proper artificial insemination requires skilled personnel. In many African countries (including Tanzania), there is a shortage of trained Artificial Insemination Technicians (AITs). Different studies conducted within and outside have identified/assessed a number of factors that influence the uptake and intensity of AI adoption, and one of the key concern is farmers' knowledge and skills on AI technology [40-43]. Without adequate training programmes, local farmers may struggle to apply AI techniques effectively, given the fact that appropriate heat detection and proper record-keeping are among the key components for an efficient AI. Similarly, there is often a lack of awareness about the benefits and methods of AI among farmers [44]. Educational outreach and extension services are needed to inform farmers about how AI can improve cattle productivity.

Other challenges to the accessibility of AI services include cost and the support services. AI services and the associated technologies can be expensive to an extent that smallholder farmers who make up a large portion of the agricultural sector in the country and in Africa as whole, may find the costs prohibitive, thus limiting their access to these services. Such a trend has been reported in countries like Ethiopia; Kenya [45-47,11]. Artificial insemination is more effective when accompanied by support services such as veterinary care, nutrition management, and herd health programmes, since inadequate support services can reduce the success rates of AI.

Training and education

Training and education are major factors in the adoption of cattle Artificial Insemination (AI) in Tanzania and widely Africa, impacting knowledge and skill development that will in turn equip farmers and technicians with the knowledge and skills needed to perform AI procedures correct [48-50]. This includes understanding reproductive physiology, handling and thawing semen, and the actual insemination process. Without this knowledge, the adoption rate of AI can be low due to lack of confidence or improper techniques. Training and education equally results to improved rates of AI, by imparting best practices in timing of insemination, heat detection, and reproductive management [51]. Higher success rates will encourage farmers to adopt to AI as they could see tangible benefits in their herds' improvement. Equally, training programmes can raise awareness about the benefit of AI such as improved breed quality, better disease resistance, and higher milk yields. Educated farmers are more likely to appreciate these advantages and hence invest in AI technologies [52,53].

Artificial insemination has proven to be a very effective reproductive technology that selectively increases genetic gain through increased selection pressure on males. Economic benefits of AI are many: it enables the manipulation of estrous cycles of females to institute efficient insemination programmes; ensures effective use of semen (i.e., increased number of offspring from a superior sire, and frozen semen can provide about 200 AI doses from one ejaculate); it prevents the overuse of males at the same time facilitating its commercial distribution; and plays a role in the prevention of venereal diseases such as trichomonosis and campylobacteriosis [54-56]. Education can also help in the efficient use of resources, such as enhancing proper storage and handling of semen and understanding the nutritional and health needs of the cows to maximize the success of AI [57,58]. Trained individuals are better equipped to troubleshoot and address issues related to AI, such as handling complications or adapting practices to local conditions. This problem-solving ability can lead to more effective and widespread adoption.

Overall, investing in training and education is key to overcoming barriers to AI adoption, such as lack of knowledge, misconceptions, and resistance to change. By addressing these challenges, training programs can enhance the effectiveness and uptake of cattle AI, ultimately contributing to improved livestock productivity and profitability in Africa.

Economic viability

Artificial insemination and *In-Vitro* Produced (IVP)-embryos for Embryo Transfer (ET) are two reproductive technologies that result in genetic gain by propagating offspring from animals with greater genetic merit [59]. However, the current review will be limited to the artificial insemination since despite all the improvements, embryos generated *in vitro* still differ from their *in vivo* derived counterparts [60]. There are three components that ought to be analyzed in the determination of economic viability of AI: costs, benefits, and efficiency. In terms of cost implication in AI, it is essential to consider the initial investment in terms of equipment such as insemination guns, storage tanks for semen, including thawing units; and training costs since proper training is necessary for those performing the insemination [61,62]. High-quality semen from proven sires can be expensive, but it is often cheaper than maintaining a bull [63-65]. Other costs to consider are the labour and time spent to perform the AI including the need for skilled technicians if not done in-house, and the cost implication in the regular maintenance of equipment as well as storage facilities [66].

Regarding the benefits, artificial insemination allows access to superior genetics from bulls that may not be physically present on the farm, leading to improved herd quality over time [67,68]. AI reduces the chance of inbreeding and increases genetic diversity; as well as minimizing the risk of sexually transmitted diseases that can be spread by bulls. AI is cost efficient since it eliminates the cost of maintaining a bull in terms of feed, housing and healthcare. Well-managed AI programmes are expected to lead to higher conception rates compared to natural mating, hence increased fertility rates [69-72]. The timing flexibility of AI allows for more precise control over breeding times and synchronization, resulting to an improved overall herd management, including the facilitation of better record keeping and genetic management.

The efficiency of artificial insemination could be measured by conception rates, herd size and technological advancements. An average conception rate is typically around 35%-40% for lactating animals and 55%-60% for maiden heifers but can vary depending on many factors such as proper management i.e., timing, heat detection, and handling of semen [73,74]. Artificial insemination can be more economical for larger herds due to reduced per-unit costs of semen and labour efficiency, while advances in AI techniques and semen quality continue to improve success rates and reduce costs [75,76]. In general, AI can be economically viable and beneficial, especially for operations aiming to enhance genetic quality and efficiency. The initial costs can be offset by the long-term gains in herd improvement and health. However, the specific economic viability will depend on factors such as herd size, management practices, and local market conditions. Evaluating the costs and benefits specific to your operation is important for determining the overall economic impact.

Reproductive performance

Reproductive performance of AI denotes to how effectively artificial insemination achieves successful pregnancies and births in the inseminated animals. Reproductive performance in AI is a multifaceted aspect involving semen quality, training of Artificial Insemination Technicians (AITs), the skill of inseminator, reproductive health of the animals (especially the females), and environmental as well as management factors. The quality of the semen used is crucial, and factors such as sperm concentration (sometimes referred to as sperm count), motility, morphology, viscosity, liquefaction, pH, and vitality/viability affect success rates [77-79]. Regarding the timing, proper timing of AI relative to the ovulation cycle increases the likelihood of conception; sometimes dictating for careful monitoring and/or synchronization [80-82].

The skill of the person performing the AI and the technique used can impact the results. Once the tip of the AI catheter has been brought close to the cervix, the next step is to insert it into the opening of the cervix. This is often one of the more challenging steps in the AI process; so accurate placement of semen in the reproductive tract is essential [83-85]. Equally important is the health and fertility status of the recipient (female) play a significant role. Any existing reproductive disorders or infections can decrease success rates [86,87]. From the environmental point of view, it has been established that conception rates to artificial insemination is higher during the months of high temperature and humidity [88]. There are many non-environmental factors that influence the cows' fertility too: Unstable nutrition, diseases, litter in a barn and stresses (oxidative, metabolic, etc.) experienced by cows [89,90].

Local adaptation

Local adaptation in cattle Artificial Insemination (AI) is the practice of using genetic material from cattle that are adapted to specific environmental conditions and management practice in a particular place/region. The concept focuses on improving the success rate of AI and overall herd performance by aligning genetic traits with local conditions. Key aspects of local adaptation in cattle AI includes: Genetic selection (both breed and genetic traits selection); environmental adaptation; management practices (feeding/nutrition, housing and facilities); reproduction performance (fertility rates, calving ease); economic considerations (cost effectiveness, return on investment); and implementation.

On genetic selection, because AI allow males to produce more offspring, fewer males are needed thus only the few best males for use as parents are chosen, increasing the selection intensity [91]. Choosing breeds or strains of cattle that are already adapted to local environmental conditions such as temperature, humidity, and feed availability [92]. Selecting for traits that are advantageous in the local context, such as heat tolerance in hot climates or disease resistance in areas with specific pathogens [93,94]. To conform with environmental adaptation, the use of semen from bulls that have been selected or bred in similar climatic conditions to those of target area will increase the fertility rates. Similarly, incorporating genetics that confer resistance to locally prevalent diseases can improve herd health and reproductive success [95].

Feeding and nutrition forms one of the vital components of management practices in any AI program. To optimize growth and reproduction, it requires the alignment of genetic traits of the cattle with the types of feed and nutrition that are locally available [96,97]. The other equally important component under management practices is housing and facilities, for it is imperative to ensure that the genetics chosen are suitable for the type of housing and facilities available, in order to keep comfort and productivity [98]. Regarding the reproductive performance, it is urged that the use of semen from bulls with proven high fertility in similar conditions will improve the fertility rates [99]. For the calving ease, it is recommended to select for traits that reduce the likelihood of calving difficulties, which can be influenced by local management practices.

One aspect on economic consideration would involve evaluation of the cost-effectiveness of using locally adapted genetics *versus* imported semen from other regions or countries. Various studies have been conducted to assess factors that influence the utilization of AI, particularly examining the cost implication [54,100]. The other economic consideration is the assessment of the long-term benefits in terms of herd productivity and profitability from using locally adapted genetic material. The implementation of AI will involve the incorporation of local adaptation principles, which might include working with local breeders and geneticists [101]. Provision of education and training to farmers on the benefits and methods of using locally adapted genetics ought to be a continuously conducted activity.

Government policies and support

Government policies and support for cattle AI play an important role in enhancing livestock productivity, improving herd genetics, and ensuring the sustainability of the dairy and beef industries. There are several ways through which the government policies and support in cattle AI could be significant: Funding and grants; training and extension services, regulatory framework; research and development; infrastructure development; market access and promotion; disease control and husbandry; insurance and risk management; and policy development and advocacy.

Governments may offer subsidies to offset the costs of AI services, including semen, equipment, and training of farmer [102-104]. At the same time, funding for research on AI techniques, genetics (approved bulls), and reproductive health helps improve the efficiency and effectiveness of AI programmes. Training programmes for farmers and AITs on the best practices for AI, including the proper techniques for semen handling and insemination is essential because without adequate training, valuable AI equipment and semen could be seriously damaged [105,106].

Together with the trainings, extension services are needed to provide ongoing advice and assistance to farmers on AI and reproductive management [107,108]. In establishing standards for the quality of semen, AI equipment, and procedures to ensure safety and effectiveness, there should be some kind of regulatory framework [109,110]. This goes along with requirements for certification and licensing of AI technicians and facilities in order to maintain high-quality service.

Many breeding programmes have been implemented in developing countries but the majority of them have been unsuccessful. The failures are largely attributed by lack of government support for Research and Development (R&D) initiatives focused on improving AI technology, including advances in genetics and reproductive health [111,112]. Regarding the infrastructure development, governments, investors or Non-Governmental Organizations (NGOs) should also invest in infrastructure such as AI centres, semen storage facilities, and diagnostic laboratories [113]. Infrastructure development should equally support for the logistics of transporting and storing semen, including refrigerated transport systems. In any efficient AI program, there ought to be some activities that will promote the benefits of AI to farmers and encourage adoption while improving possibilities for the export of high-quality semen and AI technology within and outside markets.

The artificial insemination industry should do extensive work to ensure that semen brought into the herd is free of infectious disease agents. Monitoring and controlling diseases that could affect cattle reproduction and AI programmes should be regular in any AI establishment; together with guidelines as well as support for biosecurity practices to prevent the spread of diseases through AI [114,115]. Depending on the settings, provision of insurance schemes to reduce the financial risks associated with AI such as failures or complications may be established, as well as training on managing risks related to AI and cattle reproduction. Stakeholders engagement in the development of AI policies and regulations including advocacy of AI to policymakers/legislation and funding is very necessary.

Community engagement

Community engagement in cattle artificial insemination can be vital for improving livestock productivity and sustainability. At the community level, it may involve local farmers, veterinary/extension service providers, and agricultural organizations engaged in the adaptation and effective use of AI technology. One of the approaches would be to host educational events to teach farmers about the benefits of AI, improved genetics, increased productivity (be it milk or meat), and better disease resistance [116]. On-farm demonstrations can be organized as practical demonstration to show the AI process, as well as the handling and care of cattle before and after insemination [117]. Partnerships and collaboration with local veterinarians to provide expert advice and hands-on training in AI techniques may add value to the community engagement. Equally, collaboration with agricultural extension services and cooperatives to reach a wider audience and leverage their networks for outreach is imperative [118].

Viable artificial insemination program ought to establish a support system for farmers, plus access to AI specialists who can provide guidance and troubleshoot issues. On financial assistance, information on funding opportunities or subsidies for purchasing AI equipment and services forms one of the useful support systems [119]. At this level, one way of resource development may include the development and distribution of brochures, videos, and other materials that explains the AI process, benefits and best practices. The other way is to create online resources such as webinars, forums, and informational websites to reach a broader audience and provide ongoing education; though it may not be very practical taking into consideration the nature and status of many African farmers [120]. Feedback and improvement at community level can be obtained by regularly gathering feedback from the community so as to understand their experiences, challenges, and areas where they need additional support [121]. The feedback received could be used to develop training programmes and support services to better meet the needs of the community.

Success stories and case studies could be attained by sharing success stories from local farmers who have benefited from AI, demonstrating tangible improvements in herd performance and profitability. Farmers who have successfully adopted AI should be encouraged to mentor others and share their experiences [122]. Community involvement would involve the identification and support to local champions who are enthusiastic about AI and can act as advocates within their communities in one way; and community members may be involved in the planning and decision-making processes related to AI programmes to ensure they are relevant and effective on the other.

Monitoring and evaluation

Monitoring and Evaluation (M and E) in artificial insemination is important for ensuring the effectiveness and efficiency of the process. Effective monitoring involves several key components: Heat detection, AI procedure, pregnancy diagnosis, reproductive health, semen quality, environment & management factors, data collection and analysis, and continuous improvement. Heat detection is a key factor in determining the reproductive success of a dairy/beef herd, and as a thumb rule, standing heat is the most sexually intensive period of the estrus cycle as cows stand to be mounted by other cows or move forward slightly with the weight of the mounting cow [123-125]. Failure to detect heat early in the breeding season or improper timing of insemination due to heat detection errors can result in extended time between calving and additional costs for semen and labour. Heat detection aids can save time and, in the long run, save money [126].

Although it is influenced by many factors (ovulation & conception rates, time of insemination, body condition/health, quality & quantity of semen, nutrition status of the cows, and others), pregnancy rate is another important aspect to be monitored after AI [127,128]. This involves a regular check of pregnancy rates resulting from artificial insemination in order to gauge the success of the process. The fertility potential of an artificial insemination dose is a function of the quality, quantity, and health status of the semen contained therein [129]. Semen quality attributes are many, but the volume, morphology, count or concentration, progressive motility, vitality and viability constitutes the most elements of sperm that should be checked before insemination [130,131].

The performance and skill level of artificial insemination technicians form another important aspect of AI that need to be regularly monitored. Hence, assessing technicians' profile and their insemination practices can be significant in improving AI success rate [124,132,133]. Investigation of other factors reflecting on health, environment and management (reproductive health, nutrition, bull factors) would further contribute to improving overall cow fertility following the artificial insemination. Evaluating the performance and skill level of the AITs will enable the arrangement for proper training and technique development that are critical for success. The establishment and maintenance of pregnancy to term are affected by several factors, including nutrition status of the animals; health; as well as environmental conditions [88,134-136]. These aspects need to monitored since they are equally essential for successful artificial insemination.

Regarding the evaluation, things like success rates, cost-effectiveness and genetic improvement should be keenly considered. Data on conception rates ought to be compared with those from the industry benchmarks or historical data, to evaluate the overall success of the AI program [137,138]. Several factors such as parity, season of AI, calving to first service interval, postpartum disorders (metritis, retained placenta, dystocia), and high milk production are reported to decrease the efficiency of first service conception. For cost effectiveness, it is recommended to assess the costs associated with artificial insemination (like semen procurement, labour, equipment, and transport) *versus* the benefits (in terms of improved herd genetics, increased productivity) to determine cost-effectiveness [139-141]. Relative to that from natural mating, artificial insemination can tremendously increase the rate of genetic improvement particularly in dairy cattle, due to the high intensity and accuracy of selection of bulls including cows. The impact of AI on genetic improvement within the herd such as increased milk production or enhanced disease resistance should regularly be evaluated [142-144].

CONCLUSION AND RECOMMENDATIONS

The most important reason of employing artificial insemination particularly in cattle was historically aimed at controlling venereal diseases such as *trichomonosis* and *campylobacteriosis* from *Trichomonas foetus* and *Campylobacter fetus* subsp. veneralis, respectively. Currently, the ever-growing world population has created a continuing demand on improving the level of livestock production. Artificial insemination technology maximizes animals' productivity and harvest individual sires with traits of superior quality through genetic improvement. The use of animal breeding technologies has become of great importance, particularly in tropical and subtropical areas where AI is the only alternative to introduce *Bos taurus* genetics into Zebu-based herds.

However, in spite of the efforts made to introduce large-scale AI breeding services in several developing countries, adoption of this technique and even growth in its use has generally not been very promising due to multiple factors: Poor detection of estrus, poor handling of semen, cost implication, remoteness from AI centres, and technical inability. The desired effect in terms of animal development has thus not been achieved. The current review has discussed ten key issues that merit an attention during the establishment and running of an efficient artificial insemination program in developing countries like Tanzania.

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CONFLICT OF INTEREST

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