HERMAN OTTÓ INTÉZET
NONPROFIT KFT.

(Hungarian Journal of)
Animal Production

ÁLLATTENYÉSZTÉS és TAKARMÁNYOZÁS

2023. 72. 1

Alapítás éve: 1952

ÁLLATTENYÉSZTÉS – TARTÁS – TAKARMÁNYOZÁS

- Novel traits and breeding concerns in sheep, cattle and poultry
- Korszerű polimorfizmus vizsgálatok húshasznú galambokban
- Flow citometriás adatelemző szoftver alkalmazása
- Fermentált folyékony takarmányok szerepe a sertéshizlalásban
- Csökkentett nyersfehérjeszintű, probiotikummal kiegészített takarmányok etetése brojlercsirkékkel

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Címlap kép (Frontpage photograph)

Húsgalambok (Fotó: Dr. Bagi Zoltán)
Squab pigeons (Photo: Zoltán Bagi Dr.)

LIVESTOCK BREEDING FOR WELFARE, ADAPTATION AND SUSTAINABILITY: AN OVERVIEW OF THE NOVEL TRAITS AND BREEDING CONCERNS IN SHEEP, DAIRY, BEEF AND POULTRY

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SUMMARY

The principal goal of an animal breeder is to produce the next generation of progeny that has superior performance than the average of the parent population. Previously, genetic selection for traits to be improved emphasized functional traits of economic value. However, little attention was given to sustainability principles or breeding for sustainability (environmental sustainability, animal welfare, and consumer preferences). Thus, the current concerns on principles of sustainability have necessitated breeders to incorporate novel traits into the breeding program. Most of these novel traits have low heritability, and in some cases, they correlate with traits that compromise with the principle of breeding for sustainability. Therefore, using breeding techniques provides an opportunity for enhanced genetic gain in traits of interest as well as difficult to measure traits.This literature review provides an overview of sustainable animal breeding, strategies, and the current concerns by discussing market trends of livestock products, new considerations and traits for sustainable animal breeding or novel traits, new techniques in animal breeding, and genetic diversity in domestic animals focusing on selected animals including sheep, dairy, beef, and chicken breeding. Understanding animal breeding trends, the potential market structure for animal products, new technologies in animal breeding, and consumer concerns help in developing a sustainable farm animal breeding program to meet an ever-increasing food security demand.

ÖSSZEFOGLALÁS

Wanjala, G. – Astuti, P. K. – Bagi, Z. – Strausz, P. - Kusza, Sz.: ÁLLATTENYÉSZTÉS AZ ÁLLATJÓLÉT, AZ ADAPTÁCIÓ ÉS A FENNTARTHATÓSÁG ÉRDEKÉBEN: A JUH-, A TEJELŐ- ÉS HÚSMARHA, VALAMINT A BAROMFI ÁGAZAT ÚJ JELLEMZŐINEK ÉS TENYÉSZTÉSI VONATKOZÁSAINAK ÁTTEKINTÉSE

Az állattenyésztő fő célja, hogy a szülőpopuláció átlagánál jobb teljesítményű utódnemzedéket hozzon létre. Korábban a javítandó tulajdonságok genetikai szelekciója a gazdasági értékű funkcionális tulajdonságokat állította középpontba, és kevés figyelmet fordított a fenntarthatóság elveire (környezeti fenntarthatóság, állatjólét és fogyasztói preferenciák). A fenntarthatóság elveivel kapcsolatos jelenlegi aggályok azonban szükségessé teszik, hogy a tenyésztők új tulajdonságokat építsenek be a tenyésztési programokba. Az új tulajdonságok többsége alacsony örökölhetőséggel rendelkezik, és bizonyos esetekben olyan tulajdonságokkal korrelál, amelyek veszélyeztetik a fenntartható tenyésztés elvét. A korszerű tenyésztést támogató technológiák alkalmazása azonban lehetőséget ad az érdeklődésre számot tartó tulajdonságok esetében fokozottabb genetikai előrehaladásra, akár a nehezen mérhető tulajdonságok esetében is. Ez a szakirodalmi áttekintés a fenntartható állattenyésztésről, stratégiákról, az állattenyésztési termékek piaci trendjeivel kapcsolatos jelenlegi aggályokkal, valamint a fenntartható állattenyésztés új szempontjaival és jellemzőivel, továbbá az új tulajdonságokkal, az új állattenyésztési technológiákkal és a genetikai sokféleségggel foglalkozik, különös tekintettel a juh-, tejhasznú- és húsmarha, valamint és baromfi ágazatokra. Az állattenyésztési trendek, az állati termékek potenciális piaci szerkezetének, az új állattenyésztési technológiák és a velük kapcsolatos fogyasztói aggodalmak megértése segít egy fenntartható haszonállat-tenyésztési program kidolgozásában, amely megfelel az egyre növekvő élelmezés-biztonsági igényeknek is.

INTRODUCTION

Animal breeding involves selecting and mating genetically superior animals as parents of future generations. To do so, a breeding program is developed, clearly defining the traits of interest and a definite goal to be achieved. Nowadays, goals and selection objectives are set considering the customer's preference since breeding, in general, is a commercial activity. Previously, traits to be improved had to meet certain criteria including and not limited to 1) their economic value, 2) the existence of phenotypic and genetic variance, 3) they must be heritable, 4) they must be recordable 5) if possible, they correlate with other economically important traits (*Miglior et al*., 2017).

The economic value has been a driving force for selection (*Miglior et al.*, 2017). Candidate traits were considered for selection if they are marketable and can improve the value of the current trait and/or if its improvement resulted in reduced production cost, e.g., in dairy (*Schmidtmann et al.*, 2021), sheep (*Medrado et al.*, 2021) and poultry (*Fathi et al.,* 2021). Emphasis on economic traits, which were highly correlated with higher productivity and/ or high yield, led to the compromise of overall fitness traits and other non-additive traits (*Alves et al.,* 2020).

The efficiency of selection depends on the amount of genetic and phenotypic variation of that trait in the population (*Guinguina,* 2020; *Nogues et al.*, 2020). The rate of genetic gain from generation to generation depends on *inter alia* heritability of the trait (*Wolc et al.,* 2021). Heritability is defined as the proportion of the phenotypic variation that is attributable to the genetic influence as opposed to environmental influence (*Visscher et al*., 2008). Performance recording (*Chagunda et al*., 2006) has played a key role in the success of animal breeding, and thus recordability of the trait has been vital. In some instances, a high correlation between easy-to-measure and difficult-to-measure traits has been observed (*Miglior et al.,* 2017), easing selection for difficult to measure traits by use of indicative traits. And thus it is worth stating that continuous and success in performance recording provided more opportunities in identification of important traits and their relationship for genetic evaluation (*Miglior et al.,* 2017).

Several criteria were used to implement genetic selection; multiple traits, independent culling, and sequential selection indices (*Hazel et al.*, 1994). The multiple trait index has been pivotal and widely used in the selection of multiple traits simultaneously (*Hazel et al*., 1994).

Even in cases of success in performance recording and selection in animal breeding, data generated have been marred with inaccuracies and a slow rate of genetic gain. To improve the rate of genetic gain, several techniques have been used, most important and extensively used are assisted reproductive techniques (ART) and genomic assisted selection (discussed later).

Continuous selection for functional traits of economic value led to an overall performance improvement in animal breeding. However, some improvements were associated with a compromised natural state and integrity of the animal, raising a welfare concern. Moreover, environmental sustainability has also become a global concern globally, especially the role of livestock industry in the contribution of greenhouse gas emissions e.g., methane. In response, breeders are now obligated to include traits associated with animal welfare, as well as product quality in the breeding program and selection index while considering the impact of the selected traits on the environment.

Therefore, this paper will briefly discuss farm animal breeding for sustainability and where necessary suggests materials for further reading. Issues discussed in the present paper include market trends of animal products, new considerations and traits for sustainable breeding, new techniques in animal breeding, genetic diversity in domestic animals, and animal welfare issue in animal breeding.

DISCUSSION

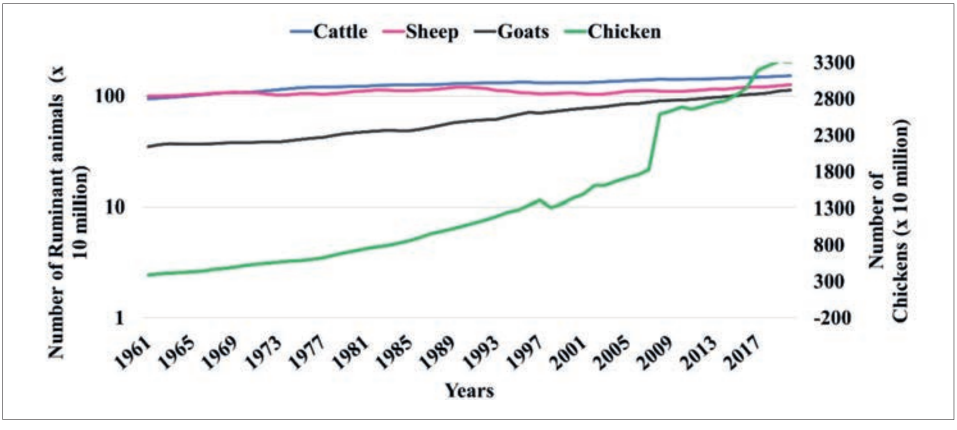
Market trends of animal products

Livestock population and their trend

According to *Faostat* (2021), there has been a registered increase in global livestock populations from 1960 to 2018 suggesting a sustained increased demand for livestock products. Figure one shows the population growth of selected livestock species from 1960 to 2018.

To reach 852 metric tons (Mt), global milk output increased by 1.3% in 2019 compared to 2018. However increased production did not significantly impact milk trade as India trades only marginal quantities of milk and dairy products. The major milk-producing countries EU, New Zealand, and the United States, registered only a slight increase in 2019 (*OECD-FAO*, 2020). World milk production volumes are projected to grow by 1.6% to 997 Mt by 2029. Moreover, the cowherd is also projected to increase by 0.8%. Over the same period, milk volumes from developing counties are projected to increase more than in developed countries, with India and Pakistan being the main contributors by 30% (*OECD-FAO,* 2020).

Figure 1. *A population trend for cattle, chickens, goats, and sheep from 1960 to 2018 (faostat.fao.org)*



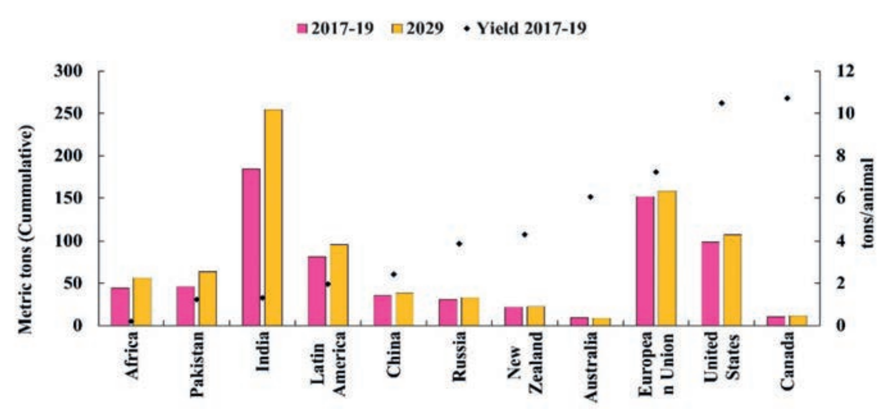
1. ábra A szarvasmarha, házityúk, kecske és juh populációs trendje 1960 és 2018 között (faostat.fao.org.)

kérődző állatok száma (x 10 millió) (1); évek (2); házityúkok száma (x 10 millió) (3); szarvasmarha (4); juh (5); kecske (6); házityúk (7)

Milk production of the three major dairy exporters, New Zealand, the European Union, and the United States, increased only slightly. As domestic consumption of dairy products in these three countries is stable, the availability of fresh dairy and processed products for export increased. In the People's Republic of China, the world's largest importer of dairy products, milk production increased by 3.6% in 2019. Her dairy imports, especially whole milk powder (WMP) and skim milk powder (SMP), nevertheless increased in 2019 due to increasing demand. *Figure 2* shows milk production yields and projected in selected countries (*OECD-FAO*, 2020). Although the chicken trend population remained lower than other species shown in *Figure 1*, *OECD* (2020) reported that poultry remained the fastest growing sector globally.

The outbreak of the African swine fever (ASF) in China caused a decrease in world meat production to 325 Mt in 2019, although there was a registered increase in production volumes of other meats. An increase in productivity was the main factor for the increase in meat production in many countries where meat production increased (*OECD-FAO*, 2020). The European Union (EU) production of all meat categories is projected to increase. Furthermore, meat exports increased globally by 4% from 2018 to 2019 which is attributed to increased imports by China due to ASF-related losses. For instance, the import of meat increased by 62% in China in 2019. On the other hand, exports also increased especially in Argentina, Canada, the EU, the US, and Thailand. It is also projected that meat consumption growth will increase by 12% by 2029 (*OECD-FAO, 2020)*.

Figure 2. *Milk production and projected yield in selected countries (OECD-FAO, 2020)*



2. ábra Tejtermelés és várható hozam a kiválasztott országokban (OECD-FAO, 2020)

hozam 2017-2019 (1); metrikus tonna (halmozott) (2); tonna/állat (3); Afrika (4); Pakisztán (5); India (6); Latin-Amerika (7); Kína (8); Oroszország (9); Új-Zéland (10); Ausztrália (11); Európai Unió (12); Amerikai Egyesült Államok (13); Kanada (14)

Livestock breeding for welfare and environmental sustainability
Sheep breeding for sustainability

Sheep and goats are thought to be hardy and adapted to the environment they are produced in. A larger percentage of these species is produced under an extensive system where selection is seldom made for meat-producing breeds. However, for specialized meat, milk, and wool-producing breeds, several selection criteria are applied. But, it is more profitable to combine traits in one selection index to produce a multi-product breed (*Galal,* 1986). Under multi-product selection, traits for meat and wool, or meat and milk are considered in a breeding program besides adaptation and other traits of economic importance. The most important traits in sheep selection are traits associated with the economics of production efficiency for the product and/or products under consideration (*Bradford and Meyer,* 1986) and thus the necessity of including the following traits in a breeding program.

Reproductive traits

Reproductive traits in sheep have a vital economic value in sheep breeding. They include fertility, fecundity, and prolificacy. Fertility in simple terms is the number of lambing per year, prolificacy defines the litter size determined by ovulation rate whereas fecundity is the number of lambs produced per year (*Abdoli et al.,* 2016). According to *Snowder* (2002), it is advisable to improve meat production by increasing the biological and economic value of sheep breeds. In so doing, selection for improved reproductive efficiency was suggested. However, the heritability of reproductive traits is estimated to range between low and medium (*Rao*, 1997; *Abdoli et al*., 2016). Another hindrance facing genetic progress in reproductive efficiency in sheep breeding is the fact that this trait is affected by many genes and a mutation on a major gene. Luckily, the possibility of utilizing genomic tools in selection provides an opportunity of increasing the accuracy of selecting for reproductive efficiency.

Growth and meat traits

Growth and meat traits are also crucial in the economic viability of a sheep breeder. The increasing economic value of mutton relative to wool has further enhanced the desire for improved meat traits (*Rao*, 1997). Some of the growth traits include pre-slaughter weight, dressing weight, growth rate post-lambing to weaning and post-weaning to slaughter, and mature weight (*Jafari et al*., 2012) while meat traits include dressing weight percentage, carcass tissue depth at GR site, fat depth at C site, eye muscle depth, width, muscles pH among others (*Corazzin et al*., 2019).

Disease resistance

The pressure to develop sustainable production systems and low cost of production inspires breeders to select for disease resistance. Of importance is the emergence and development of zoonotic diseases and pathogen resistance to drugs or vaccines (*Raadsma et al*., 1998; *Bishop et al*., 2002; *Bishop and Morris*, 2007). Furthermore, antibiotic resistance is also an issue of concern, and therefore production with a minimum requirement for veterinary attention is necessary. It is also worth noting that, one of the challenges brought forth by climate change is the emergence of new diseases, pests, and parasites. So, selection for disease resistance provides an opportunity for mitigating future epidemiological risks.

Dairy cattle breeding for sustainability

Intensive selection for productive, economically viable, and highly heritable traits has been reported to correlate with some negative traits that compromise animal welfare, health, and environmental sustainability. To address these, breeders now include novel traits in the breeding program or selection index emphasizing environmental sustainability, animal welfare, and economic efficiency (*Miglior et al*., 2017). Among other traits, feed efficiency, methane emission, heat stress, hoof health, immune response, milk composition, and reproductive traits are used to calculate the selection index in dairy.

Feed efficiency

Depending on the locality and availability of animal feeds, especially fiber, feed constitutes a major proportion of total dairy production cost. Feed efficiency can be described as a change in the unit of output per unit change in the animal's energy intake. The output unit is measured in terms of the amount of milk, protein, and fat content, and/or net income (*Korver,* 1988; *Miglior et al.*, 2017; *Guinguina,* 2020). Increased feed efficiency is relevant and vital since animals with higher feed efficiency will have high returns at a lower cost of production with fewer traces of environmental degradability or ecological footprints (*Guinguina,* 2020). Energy efficiencies differ between breeds, hence the importance of selection to improve this trait (*Korver,* 1988).

Methane emission

Climate change is a global challenge that poses the greatest threat to the existence of humanity. Several factors contribute to the rate at which climate is changing and the possible severity of its impact on humanity. Greenhouse gas emission has been identified as the greatest cause of global warming. Among other emitters, the livestock sector has been listed as one of the major contributors to greenhouse gas specifically methane emission. And of significance is the dairy sector. Genetic selection has been proposed to mitigate enteric methane emissions by the dairy herd. Several studies reported genetic variability of this trait among individuals in the dairy population and a possibility of inclusion of methane emission in the breeding goal as well as selection index (*Zhang et al.*, 2019; *González-Recio et al.,* 2020*; Richardson et al.,* 2021). Recently, studies reported a correlation between certain phenotypes with methane emission. For example phenotypes like feed intake, milk spectral data, and rumen microbial communities have been extensively reviewed by *de Haas et al*. (2017). The authors further infer that some traits associated with low methane emission are costly and difficult to evaluate. Luckily, with the advent of genomic selection, it has been made easier for genetic evaluation as well as selection. Similar thoughts are also addressed in a literature review by *Hayes et al*. (2013) in which the authors discussed how whole genome sequencing would accelerate the selection of difficult to measure traits.

Heat stress

As discussed previously, climate change comes with several impacts that threaten the existence of humans and other organisms on the earth. One of the greatest challenges caused by climate change is heat stress. It is predicted that global warming will continue and that the average global temperature increase is projected to be 2°C (*Molina and Abadal,* 2021). Increased greenhouse gas emissions such as methane as discussed in the preceding section, are among the contributors to increased global warming (*Hayes et al*., 2013). Heat stress directly impacts cattle productivity, animal welfare, and cattle immunity (*Dahl et al.*, 2020). Recently *Sammad et al.* (2020) proposed artificial cooling to mitigate the impact of heat stress on the reproduction of dairy herds notwithstanding the costs associated. Several studies have averred selection possibilities for heat stress resilience because of the existing genetic component (*Ravagnolo et al.*, 2000). For example, a model of genetic evaluation of growth heat tolerance in the Angus breed was developed by *Bradford et al*. (2016). Quantitative and population geneticists are in concurrence that indigenous cattle breeds despite having a low productive potential harbor the genetic potential for heat stress resistance (*Mwai et al*., 2015). Selection for heat stress tolerance has been facilitated by the genomic revolution (*Bagnato and Rosati,* 2012). And thus many studies have embraced genomic markers to unravel genomic regions underpinning adaptations and heat tolerance (*Hayes et al.,* 2013; *Ponsart et al*., 2014; *Nguyen et al.,* 2016).

Breeding for heat stress tolerance will provide an opportunity for improved animal welfare and feed efficiency hence reducing methane emission and production costs thereby increasing net income from dairy while at the same time ensuring a sustainable supply of animal proteins in the future under the climate change and global human population increase scenarios.

Hoof health

Body conformation is a vital trait in dairy and its preference and emphasis in dairy farms are high e.g. in the United Kingdom (*Leach et al.*, 2010). Lameness in dairy cattle negatively affects milk yield, reproductive efficiency, longevity, and increases the cost of production (*Ring et al.*, 2018). Moreso, lameness has recently become an animal welfare concern that affects consumer perspective toward agriculture (*Ring et al.*, 2018). Although lameness is caused by several non-genetic factors including management practices, conformation, diet, hygiene and housing system among others, the genetic influence cannot be underestimated (*Bergsten*, 2001). According to *Ring et al*. (2018), the efficiency of selection against lameness can be done by the use of phenotypic indicators like hoof health, hoof lesions, and morphological conformation score. The same authors still assert that the heritability of lameness-related traits like hoof types and lesions is very low and thus improvement of the trait by farmer recorded traits could be hampered. For instance, a study comparing the heritability of infectious hoof lesions under pedigree-based and genomic single-step analysis suggested a heritability of 0.08 (±0.05) for pedigree-based as compared to 0.12 (±0.08) for genomic-based in United State Holstein Friesian cattle. Despite low heritability, selection against lameness indicators is possible and breeders must adhere to welfare concerns.

Immunity response trait

Climate change is linked with the emergence of new diseases and the enhanced pathogenicity of pathogens. These diseases may enhance the immune suppression associated with heat stress (*Bagath et al.*, 2019). In dairy cattle breeding, selection for enhanced immunity is intended to improve the health status of the herd. Frequent occurrence of diseases on the farm increases losses and a higher likelihood of using drugs for treatment, consequently resulting in traces of drug elements in milk e.g., antibiotics (*Kurjogi et al*., 2019). In cattle and other species, the use of antibody-mediated and cell-mediated immune response as an adaptive indicator has demonstrated that individuals can be identified based on low or high immune response profiles (*Dahl et al.,* 2020). Furthermore, the heritability of immune response in dairy cattle is estimated to be between low and average implying the possible slow genetic gain through generations (*Berry et al.*, 2019) but can be enhanced by embracing genomic selection.

Beef cattle breeding for sustainability

Although the literature on the novel traits for selection in beef is scanty, the available suggest welfare-related traits as being favored during selection. However, because most beef production is done under an extensive production system, welfare issues are well addressed. Nevertheless, the industry must meet the commercial value of the investors and the consumer expectations. Some of the traits in consideration for selection in beef cattle breeding correspond to those in dairy, as discussed above, besides, traditional traits that have been under selection over a long period. However, the main consumer preferences driving beef breeding are discussed below.

Carcass and meat traits

In this context, meat quality involves both intrinsic and extrinsic considerations that occasionally are shaped to make the product more desirable and acceptable to consumers (*Font-i-Furnols and Guerrero,* 2014). And since consumers are the ultimate target in any commercial venture, the industry is obliged to satisfy their wishes and maintain a viable business as well. For example, a recent study by *Liu et al.* (2020) revealed that beef flavor likeness and tenderness were the most favored sensory traits explaining the progress in meat tenderness over time.

While carcasses and meat quality are influenced by both genetic and non-genetic factors, this paper will dwell on the genetically influenced characteristics. Carcass traits can only be recorded after the animal has been slaughtered. In this case, genetic gain for such traits is slow as it takes longer for the animal to reach the right age for trait recording to be done. Among the carcass traits currently included in the beef selection index are longissimus muscle area, backfat thickness, and rump thickness (*Brito Lopes et al*., 2016).

Due to the advancement of technology, it is now possible to perform the genetic evaluation for beef carcass traits. For example, literature has suggested that ultrasound can be used to select sire within the breed to increase marbling score or tenderness (*Bertrand et al*., 2001).

Longevity

This is another trait in beef farming with a high economic value (*Rogers et al.*, 2004). The longer the female cow remains productive in the beef herd, the more profitable it is for the farmer. This reduces the cost of replacement as well as the cost associated with challenges befalling the first calvers like difficulty in calving, low birth and winning weights, etc. However, the late expression of longevity in the life of a female beef cattle hampers its genetic evaluation. For instance, it will take a considerable amount of time for the sire to be selected for longevity after all his daughters under the progeny testing program are culled (*Rogers et al*., 2004). This is costly and time-consuming. Unlike other difficult-to-measure traits that could be selected for using other indicators, longevity is a stand-alone trait. Another setback for quick genetic progress is its low heritability (*Rogers et al.*, 2004; *Forabosco et al*., 2006). This makes it difficult to do early selection to get fast genetic improvement. Mathematical and statistical modeling methods have been used to evaluate longevity for sires' genetic evaluation. Most commonly used are the survival analysis technique (*Rogers et al*., 2004; *Forabosco et al*., 2006), and the linear model (*Forabosco et al*., 2006). However, with the advent of genomics-assisted selection, it is now possible to select for this trait early in life (*Hamidi Hay and Roberts*, 2017).

Temperament

There is also increased concern about the handle-ability of beef cattle now that most of the beef cattle production system is extensive. In general, the interaction between beef cattle and human beings is rare. This means that beef cattle do not get used to being handled by herders in their productive life unless handled during veterinary attention. It is hypothesized that; animals may become violent and temperamental during handling when the need arises. It is, therefore, necessary to select for ease to handle cattle.

Temperament is scored from docility to aggressiveness toward humans (*Hoppe et al*., 2010). Other scores like flight time (*Kadel et al*., 2006; *Piovezan et al*., 2013) have been suggested to be important in beef cattle. Flight time is described as the time taken by the animals to cross a distance of 2 m after the weighing scale (*Piovezan et al*., 2013). Genetic evaluation has suggested a medium heritability ranging between 0.2 to 0.4 (*Haskell et al*., 2014). More details on the genetic selection for temperament traits have been extensively reviewed by *Haskell et al.* (2014).

New traits in poultry selection

The demand for high-quality proteins, white meat, environmental sustainability, consumer health, and welfare are increasing globally. Also, there is an increase in the consumption of chicken products, meat, and eggs (*OECD-FAO*, 2020). This new development has exerted pressure on the need to improve the genetic makeup of the poultry sector, from high producing genotypes to improved efficiency in feed utilization. In order to improve economic performance in laying chicken, breeders will need to incorporate several traits in the selection index including disease resistance, pre and post molt performance, the persistence of lay, temperament, percent of solid and lipids in the eggs, egg inclusions (blood and meat spots), albumen height, shell strength, shell color, feed conversion, residual feed consumption, body weight, egg weight, livability in the growing and laying house and age at first laying *(Arthur and Albers*, 2003; *Parmar et al.*, 2006; *Fulton,* 2012).

Similarly, in broiler chicken breeding, the number of days from hatch to slaughter and feed efficiency are among the vital traits in consideration as this reduces the feed required to raise the birds. In addition, breeding for welfare is vital in this sector, examples of welfare-related traits include leg disorders, cardiovascular diseases, and the high mortality rate of chicks (*Dawkins and Layton*, 2012; *Siegel et al.*, 2019).

New techniques in animal genetics improvements

Since the agrarian revolution, genetic selection has played a key role in improving animal genetic potential. However, in some species and traits as well, the efficiency of genetic selection and gain has been set back by inaccuracy in performance recording, low heritability, inbreeding, long generation interval, and high cost of recording some traits which need progeny testing as well as the sacrifice of animals before some traits are recorded.

At present, improved technology has hastened the recording and selection processes. Here some technologies used in animal breeding are discussed.

Assisted Reproductive Techniques (ART)

The increased demand for animal proteins resulting from increased human population and improved social status in developing countries has necessitated innovations in the field of animal breeding. The use of biotechnology has become vital in the quest for enhanced genetic gain between generations. Furthermore, the conservation of genes for future use has also been made possible by biotechnology. Moreover, gene transfer has also been eased, however, this has contributed to the global loss of genetic diversity within species. Some of the ART techniques commonly used are discussed below. As fate would have it, not all technologies, no matter how useful they are, will be without their drawbacks. One ART treatment that has been linked to serious side effects is the in vitro fertilization. *Urrego et al.* (2014) and *Rivera* (2020) have comprehensively reviewed the negative effects of ART.

Artificial insemination

Artificial insemination (AI) involves a manual collection of semen from males and transferring it to the female reproductive system (*Webb*, 1992). This technology is widely and successfully applied in cattle breeding especially dairy (*Robertson and Rendel*, 1950). Other species like sheep (*Cognie*, 1990), poultry (*Getachew,* 2016), goats (*Williams et al.*, 1998), and many others, are nowadays being bred by artificial insemination. The use of artificial insemination opened a window for successful use of other reproductive-assisted techniques like synchronization, embryo transfer, multiple ovulations, cloning, sexing of semen and embryo, oocyte or embryo cryopreservation, and in-vitro fertilization (*Verma et al.*, 2012). Artificial insemination is particularly vital in genetic improvement from the elite male animal. For more information on AI see *(Anderson,* 1945; *Foote,* 2010; *Ombelet & Van Robays,* 2015)”author”:[{“dropping-particle”:””,”family”:”Ombelet”,”given”:”W”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Robays”,”given”:”J”,”non-dropping-particle”:”Van”,”parse-names”:false,”suffix”:””}],”container-title”:”Facts, views & vision in ObGyn”,”id”:”ITEM-3”,”issue”:”2”,”issued”:{“date-parts”:[[“2015”]]},”language”:”eng”,”page”:”137-143”,”title”:”Artificial insemination history: hurdles and milestones.”,”type”:”article-journal”,”volume”:”7”},”uris”:[“http://www.mendeley.com/documents/?uuid=229aaf1f-d05f-440e-85d4-7154b8d4d8d4”]}],”mendeley”:{“formattedCitation”:”(Anderson, 1945; Foote, 2010; Ombelet & Van Robays, 2015 and on statistics of AI see (*Thibier and Wagner*, 2002).

Sperm sexing

Breeders always desire to have certain gender of offspring of the species they are breeding. In the process of sperm sexing, X and Y sperms are effectively sorted, therefore breeders can breed for the preferred gender. This process has been widely used in the dairy sector. Less documentation for other species is available. Generally, the whole process of sperm sorting could result in low sperm viability and needs a lot of care. For more information on the use of sexed semen, see (*Seidel Jr*, 2007). We shall make a specific mention of poultry sperm sorting in this section. Similar to mammals, in birds, females are heterogametic (ZW) and males are homogametic (ZZ). So, although it’s uncommon, it is conceivable to sort sperm in chickens by swiftly isolating, visually classifying, pooling, and storing the gonads by sex. After being sexed and refrigerated, the components are thawed, separated, and then injected into sterile chicken embryos. You may read more about sperm sexing in poultry here (*Ballantyne et al.,* 2021; *Hu et al.,* 2022).

Multiple ovulation and embryo transfer (MOET)

Although not new, this technology is currently gaining popularity due to its importance in breed improvement from the maternal line. It is commonly used in sheep and cattle breeding. The technique remains expensive due to the required skills expertise and infrastructure, but economically viable at the selection breeding level, where breeding is done for commercial purposes (*Smith*, 1988). “In the recent past, the recovery of embryos required anesthesia-induced surgical operations, which had several adverse effects, including endangering the health of the animals. *Fonseca et al*. (2016) went into a detailed discussion about the advantages and disadvantages of recovering embryos surgically as well as non-surgically from small ruminants. The use of embryo transfer in cattle has not been generally accepted; certain breeders, as reported by *Vázquez-Mosquera et al.* (2022), have widely accepted the technology while others indicated a preference against the technology, as recorded by *Clasen et al.* (2021).

Marker-assisted selection (MAS)

Marker-assisted selection uses genomic information in addition to phenotypic information to improve selection response in animal breeding (*Haley and Visscher,* 1998). Traditionally, animal breeding involved selection for functional traits influenced by a genomic region with multiple loci that contribute to the variation of the phenotype within the population. The genomic region is referred to as quantitative trait loci (QTL) (*Soller,* 1994). The use of molecular markers has provided an opportunity to build genetic linkage maps (Linkage disequilibrium), physical maps of candidate genes, and comparative maps of different farm animals (*Wakchaure et al.*, 2015). Furthermore, the genomic revolution i.e., ease access to genomic information of many species, low cost of genotyping and/or genome scan, made masker-assisted selection easy. Genomic selection refers to the process of estimating breeding value and subsequent selection by using variants from the whole genome scan. Genomic selection slightly differs from MAS in that the former uses all relevant variations throughout the genome, whereas the latter uses a specific genomic region (QTL). Important markers include microsatellites, single nucleotide polymorphism (SNP), restricted fragment length polymorphism (RFLP) among others. SNPs are widely preferred because their abundance and denser nature provide more information than other markers (*Wakchaure et al.*, 2015). And since most of the economically valuable phenotypes are controlled by multiple genes with an environmental influence, the main goal would be mapping out and characterizing genes that determine the QTL. Candidate gene association studies and whole-genome scans (Genotype or sequencing) are two major methodologies of identifying QTL (*Soller,* 1994*; Haley and Visscher,* 1998; *Williams*, 2005, *Wakchaure et al.*, 2015). Genomic-assisted selection has also been embraced in current breeding strategies. By applying whole-genome sequencing, breeders use bioinformatics tools to map out genes underpinning traits of interest. The procedure is very useful for difficult-to-measure traits like traits for adaptation. Once outlier putative genomic regions are detected, a gene-phenotype association study is conducted mainly referred to as a genome-wide association study (GWAS) e.g. (*Smołucha et al.*, 2021; *Stegemiller et al.*, 2021; *Tao et al.*, 2021) to infer the role of identified genes on the associated phenotype. Gene annotation and pathway analysis could be necessary to better understand the physiological functions of these genes.

Genetic engineering

Genetic engineering refers to the manipulation of an organism's genome by the introduction or deletion of hereditary material. In other words, the process is referred to as genome editing. New heritable material is formed by using recombinant nucleic acid (DNA or RNA) and then incorporated into the genome either directly through micro-injection, macro-injection, or micro-encapsulation and or indirectly through a vector (*Montaldo*, 2006). The author also enumerates some of the applications of genetic engineering in animal breeding including the production of transgenic animals that are resistant to diseases, production of high-yielding animals, the technique is also used in vaccine production. To learn more about this technology see *Montaldo* (2006).

Currently, genome editing tools that are commonly used include zinc-finger nucleases (SFNs), transcription activator-like effector nucleases (TALENS), and cluster regularly interspace short palindromic repeats/associated nucleases Cas9 (CRISPR/Cas9) (*Ruan et al.*, 2017). CRISPR is widely used due to its ease to use, robustness, efficiency, and cost-effectiveness. More details on genome editing have been discussed by *Ruan et al.* (2017).

Welfare concerns in animal breeding

Animal welfare has become a topic of concern in the current socio-economy. Consumers perceive that animal welfare compliance is strongly correlated with human health consequences due to the impact the production process has on the environment (*Goldberg*, 2016). Animal welfare is defined differently by different animal welfare promoters, however, definitions have been widely involve in the ability of the animals to display their natural behavior, subjective experience, and biological functioning (*Dwyer and Lawrence*, 2008).

Previously, animal breeding was driven by the desires of the breeders and producers themselves, breeders made the selection to satisfy producers' demands, this trend disregarded consumers' preferences. For instance, in the US, there was a contest between breeding dairy cattle that produce more milk against breeding good looking cattle that produce milk. Farmers demanded good-looking cattle that produce milk, and hence selection for body conformation (*Miglior et al.*, 2017). This trend now has changed, and consumer preferences are being considered in breeding programs. The concept of "breeding for sustainability" (*Gamborg and Sandøe*, 2005) has taken control of animal breeding. Furthermore, the use of some techniques has also raised concerns and some of the welfare concerns are discussed below.

In dairy, breeding for high-yielding cows is associated with a declined reproductive efficiency. To improve the reproduction ability of the cow, a breeder/farmer will need to artificially manipulate ovulation by the use of hormones, which is against the ethics and welfare standards (*Farstad,* 2018).

In beef breeding, the cardinal objective of selection is to increase the growth rate. By so doing, some breeds might develop traits that compromise the animal welfare standards especially when associated with compromised health. A typical example is the Belgium blue breed with the double muscling trait, a mutation on the myostatin gene. This breed is highly associated with dystocia, higher numbers of cesarean sections, problems with deformation of jaws, and over enlarged tongue which affects the calf's ability to suckle. Other negative traits associated with this breed are respiratory and heart problems as well as reproductive efficiency (*Farstad*, 2018). So artificial insemination using semen from this breed is discouraged.

Cloning also has raised some concerns. It is reported that compared to success rates obtained in vivo after insemination and embryo transfers, the cloning success rate is lower. Besides, a significant proportion of successful implantation that survives to term develop disorders like oversized organs, increased or decreased overall growth, respiratory failures, and limb malformations (*Farstad,* 2018). In general, the enlarged abnormal phenotypes are referred to as large offspring syndrome (*Young et al.*, 1998; *Farstad*, 2018).

The welfare concern in chicken breeding is also on the rise. For instance, breeders believe that featherless broiler birds are resource-efficient, however, others view chicken having feathers as their natural characteristic and therefore breeding featherless chickens lowers the integrity of the breed. Further, in layer chicken breeding, cockerels are viewed as by-products and they are slaughtered prematurely which lowers the intrinsic value of chicken (*Farstad,* 2018).

Genetic diversity in domestic animals

Selection in animal breeding is expected to maintain adequate genetic diversity within the breeds and among breeds. By so doing, production needs tend to adhere to environmental requirements (*Notter*, 1999). Further genetic improvement within the breed is also sustained and high productivity under the changing environmental conditions is assured. However, under intensive selection where few males are used for breeding e.g. in dairy cattle and in poultry where distinct lines are used for breeding large populations, genetic diversity is compromised (*Notter*, 1999). However, in some cases, breeders have opted to crossbreed to take advantage of the potential of hybrid vigor (heterosis).

Heterosis in animal breeding

Heterosis or hybrid vigor is attained when offspring are crossbred or are from parents of different genetic lines. These offsprings then perform better than the average performance of both parents (*Wakchaure et al.*, 2015). The phenotypes that are mostly targeted for hybrid vigor include growth rate, disease resistance, higher productivity. Heterosis is caused by non-additive gene interaction (Over-dominance, epistasis, and dominance), and traits with low heritability exhibit the greatest heterosis and it is least in traits with high heritability (*Wakchaure et al.*, 2015). An example of traits with low heritability is reproductive traits. It is important to note that additive gene action does not result in heterosis (*Wakchaure et al.*, 2015). Heterosis has been used widely in sheep breeding to improve reproductive traits, and in other animals as well. For example, many breeds have been cross-bred with Booroola Merino breed to take advantage of fecB genes that influence multiple ovulations. For instance, recently a new multiparous mutton sheep breed called Huang-huai sheep was developed in China, resulting from a crossbreed between Dorper sheep as a sire and Small-tailed Han sheep as a dam (*Quan et al.*, 2021). In dairy breeds, heterosis has been recorded on milk production traits in first lactation cattle in the Danish dairy herd (*Kargo et al.*, 2021). Besides, a recent review by *Sørensen et al*. (2008) on crossbreeding in dairy cattle, the Danish perspective intimated a 10% heterosis for total merit particularly increased longevity and improved functional traits. A varied rate of recombination has been reported in systematic crossbreeding programs (*Johnston et al*., 2016; *Shen et al*., 2018).

Loss of genetic diversity in domestic animals

Continuous selection for particular qualities has an effect on allele frequencies in subsequent generations. As a result, directional selection favors the frequency of favored alleles while reducing the frequency of undesirable alleles (*Goszczynski et al.*, 2018). As a result, more animals will be homozygous for alleles that impact the traits of interest, reducing genetic diversity within the population (*Goszczynski et al.*, 2018). It is recommended that breeders consider maintaining genetic diversity as one of the goals in a breeding program development. Loss of genetic diversity has been exacerbated by the advent of assisted reproductive technologies and in particular AI. This has led to an intensive selection of male animals and the global use of semen from the few selected elite males leading to widespread inbreeding.

Loss of genetic diversity is detrimental to the performance and survival of the species in the future. Gene diversity can be caused by inbreeding, intensive selection, genetic drift, and mutation among other factors. Inbred animals suffer from inbreeding depression, a decrease in performance although it is hypothesized that not all inbreedings are equally harmful e.g. ancient inbreeding is less harmful than the recent ones (*Doekes et al*., 2019).

Traditionally, evaluation of inbreeding, co-ancestry, and inbreeding depression is performed using pedigree information alongside performance records. However, the availability of genomic markers has made it possible to achieve more accurate and precise estimates particularly when pedigree information is missing (*Granado-Tajada et al.*, 2020).

Levels of inbreeding within the populations are estimated using several methodologies including pedigree information and molecular analysis. Molecular analysis is more precise especially in breeds that do not have pedigree information. Molecular approaches include estimations of effective population size, use of runs of homozygosity, and estimation of inbreeding coefficients using algorithms among others.(*Eydivandi et al.*, 2020; *Nosrati et al.,* 2021; *Ocampo et al.*, 2021).

CONCLUSION

Due to the increased awareness of consumer preferences, the importance of environmental sustainability as well as animal welfare, breeding has shifted towards satisfying the demands of various stakeholders in the livestock sector. Therefore, the development of animal breeding programs involves not only selection for traits that have positive net economic returns (additive traits) but also animal welfare-associated traits. The pain challenge hampering genetic improvement for these non-additive traits is their low heritability and difficulties in their selection. Luckily, most of them are associated with other traits, and/or with the advent of biotechnology, it is possible to improve accuracy in their selection. In the long term, breeders will consider consumer preferences since, in commercial ventures, the ultimate target is the consumer.

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Érkezett: 2022. március

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