The Role of Reproductive Biotechnologies in Addressing Food Sufficiency and Climate Change

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INTRODUCTION

Demographic and economic developments are the two major forces exerting tremendous pressures on earth’s natural resource base towards the end of the 20th and beginning of the 21st century. By 2050, human population is estimated to be 9.6 billion (UN, 2012), with more people drifting from rural areas to the urban areas. The global economy has also been growing dramatically, with a twenty-fold increase in global gross domestic products between 1970 to 2012 (World Bank, 2012) and is projected to quadruple by 2050, leading to significant increases in the demand for energy and natural resources (OECD, 2012).

The growing global population and the earth’s carrying capacity have been the subjects of major debates as early as the 18th century, following Malthus, and of late, Paul Elrich’s ‘Population Bomb’ theory. However, the world witnessed the growth in food production at a rate faster than the growth rate in human population. Indeed, there were registered increases in per capita food production in the past decades (FAO, 2006). The debate on increasing food production, food sufficiency and food security has been only complicated by the fact that there is so much unequal distribution of resource availability, income, technology and population growth between developed and developing countries (Bruinsma, 2012). Clearly, food access and distribution have been the major issues.

The production of animal-derived food is at the heart of world agriculture today owing to the increasing demand associated with fast growing urban population, increased income, and accompanying change in food preference. It contributes 40% of global agricultural domestic product, provides income and livelihood for more than 1.3 billion people (Thornton, 2010). Conversely, food animal production uses far more land and water resources than any other human activity. Ruminant grazing uses a quarter of earth’s terrestrial surface, while about a third of global arable land is currently used to grow feed for livestock, accounting for 40% of total cereal production (FAO, 2012). Livestock production also plays a major role in climate change, emitting an estimated 7.1 giga tonnes of CO2-eq per annum, representing 14.5% of all human-induced emissions (FAO, 2015). It becomes apparent that the major challenge today and in many years to come is how to produce more food, particularly of animal origin under finite, yet declining availability of land and water resources, and the increasing fragility of the environment.

Technological developments in genetic improvement in livestock, aided by reproductive and related biotechnologies in the past 50 years, have demonstrated the possibility of producing highly productive and efficient animals. The continuing development in these areas would allow further improvement in the way livestock will be produced in the coming decades in response to growing demand for animal-derived products and concerns about environmental footprints.

HUMAN POPULATION AND FOOD REQUIREMENTS

Human population growth

History of human development is relatively young considering that the earth was formed some 4.54 billion years ago, and that the first simple life forms appeared between 3.8 and 3.5 billion years ago (Ohmoto et al. 2013). Modern humans are believed to have originated only around 200,000 years ago (Gibbons, 2003), and only until around 1800 AD that global population reached its first billion. The second billion was recorded to have been reached 130 years later (1930) and now, world human population grows by 1 billion almost every 12 years. Today, global human population is 7,307,331,185.

Technological developments in the past, such as tool making, agricultural revolution and industrial revolution, coincided with the growth in human population. These developments contributed immensely to the ability of
humans to produce food. The agricultural and industrial revolutions increased food production through introduction of farm machineries that allowed opening of new lands, improved plant varieties, use of fertilizer and herbicides and better animal genetics, among others. On the other hand, development in medical sciences allowed humans to have better health and reduced mortality rate, live longer, and thus contributed to increase in population.

The United Nations (UN)-revised projections in 2008 indicated that world population can reach to 9.15 billion in 2050. But of interest is the fact the projected increase of 2.25 billion in the next 40 years is considerably lower than 3.2 billion accounted during the last 40 years. The global demographic growth rate over the period 2005/2007 to 2050 is estimated to be only 0.75% per year (Table 1), a decline from the recorded growth rate of 1.7% between 1961-2007 (Alexandratos and Bruinsma, 2012), and this therefore translates in reduced growth rate in projected food consumption. It is important to consider, however, that the overall decline in demographic growth rate constitutes a continuing increase in some countries and a slowing down in others. In most of the sub-Saharan Africa, population growth rate of 2.8% is projected to decline to 1.9% per year between 2007-2050 while the rest of the world declines from 1.6% to only 0.55% per year. Unfortunately, majority of the countries with expected fast growth rate in population are also those with registered inadequate food consumption and undernutrition. These are the countries where semi-arid agriculture is predominant and have limited import capacity.

Livestock production and demand

The growing human population is central to the debate about food sufficiency and food security. Food sufficiency is a generic term and it involves addressing level of production sufficient to meet the requirements, both in quality and in quantity. Food security is a far more complex issue as it encompasses availability, access as well as sustainability. The theory behind the “population bomb” was proven wrong as the overall food production globally during the past decades has grown substantially and surpassed the global food requirements. The main issue is that there are regions of the world whose population has per capita consumption way above the recommended nutritional level, yet there are substantial numbers of countries with food consumption per capita way below the standard. Based on statistics of the Food and Agriculture Organization (FAO), the world average per capita availability of food for direct human consumption, after allowing for waste, animal-feed and non-food uses, reached 2,770 kcal/person/day in 2005/2007, implying that in principle that there is sufficient global aggregate food consumption for everyone to be well-fed (Alexandratos and Bruinsma, 2012). The reality on the ground was that some 0.5 billion people are in countries with less than 2000 kcal, some 2.3 billion live in countries with under 2500 kcal, and 1.9 billion are in countries that consumed more than 3000 kcal. Food distribution and access appear to be the main issues.

This paper will not exhaust discussion on food security. Suffice it to recognise that in the livestock sector, the contribution of the smallholders system is very significant where producers regard the animals more than just a mere source of income. It is this sub-sector where producers have low income and animal production efficiency is relatively lower. On the other hand, there is the intensive commercial sector where livestock production is for profit and where increases in production efficiencies are readily noted. The intensive system of animal production cannot be regarded as a realistic means of providing food security to the rural poor (Lukefahrd and Preston, 1999). But the intensive production system is a more technologically developed sub-sector and certainly can address the growing food requirements of animal origin of urban populations. (Neeteson et al., 2014).

The World Bank (2010) estimated that to meet the growing demand for food from 2005-2050, agricultural productivity will need to rise by 64% under the assumptions of “business as usual”, and further to 80% to offset the projected stresses arising from climate change.

Alexandratos and Bruinsma (2012) projected that overall demand for agricultural products will grow at 1.1% per year from 2005/2007 to 2050, down from 2.2% per year in the past four decades. The main drivers of this projection are the growth in population, increase in per capita consumption, and changes in diets leading to the consumption of more animal-derived products. It is concluded that the per capita meat consumption in developing countries is likely to grow at a much slower rates than in the past, estimated to be only half of that noted the last 30 years. In developed countries, there shall be relatively modest increase till 2050, combined with the declining human population. Further, the growth in feed grain is projected to be lower than the growth in livestock sector due to estimated decline in feed grain usage, owing to more efficient conversion of feed to meat,
and also due to expected shift from ruminant production to swine and poultry production, particularly in Asia. There is also a possible increase in conversion of feed grain to cereal-based biofuels in the future (FAO, 2012).

The average production growth rate per annum for the last 46 years (1961-2007) for all meat was 2.9% with the greater growth recorded in poultry and swine meat, 5.2% and 3.1% per annum, respectively. It was projected that growth rate in consumption, which theoretically corresponds to production will dramatically decline from 2.9% in 1961-2007 to only 1.3% per year in 2007-2050. Interestingly, growth rate in production is projected to significantly drop in poultry and swine meat, from 5.2% per annum down to 1.8% per annum and 3.1% down to 0.8% p.a., respectively.

In developing countries, the 1961-2007 consumption/production growth rates were recorded higher than the world average for all meat. A large percentage of the growth during the period has been associated with record high growth in China and Brazil. But even then, the projected growth rate for all meat in developing countries is 1.7% p.a., down from 4.8% p.a.. Growth rate in consumption/production of poultry, meat and pork in 1961-2007 were 7.4% p.a. and 5.7% p.a.. The high growth rates in these commodities are projected to decrease to 2.4% p.a. and 1.1 % p.a. for poultry and swine meat, respectively (Table 1).

Table 1. Human population and meat production growth rates, 1961-2007 and projected growth rates 2007-2050

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Human Population</td>
<td>1.7</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>World</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bovine</td>
<td>63.2</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Ovine</td>
<td>12.8</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Pork</td>
<td>99.9</td>
<td>3.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Poultry</td>
<td>81.9</td>
<td>5.2</td>
<td>1.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>258.3</td>
<td>2.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Developing Countries</td>
<td></td>
<td></td>
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<tr>
<td>Bovine</td>
<td>34.1</td>
<td>2.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Ovine</td>
<td>9.4</td>
<td>3.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Pork</td>
<td>60.4</td>
<td>5.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Poultry</td>
<td>44.8</td>
<td>7.4</td>
<td>2.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>148.9</td>
<td>4.8</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Sources: Alexandratos and Bruinsma, 2012; FAO 2012
Concerns have been raised recently about agricultural sector’s ability to respond to increased food production of the growing human population at levels needed for a healthy and active life due to environmental degradation, loss of biodiversity and ecosystem services as well as climate change (Godfray et al, 2010, Foresigth, 2011; UNEP, 2012; Place and Meybeck 2013). Resource scarcities and production increases are difficult to reconcile. Ensuring more efficient and sustainable use of natural resources is key to ensuring food sufficiency and security globally. Under these conditions, it is essential to design better practices and technologies, aiming not only for more physical production and also taking into account the sustainability of resource use. Another element which could possibly impact on food security is large-scale biofuel and bioenergy production as this will require land and feedstocks (Place and Meybeck, 2013).

Historical changes in the production response in various production systems have been associated with science and technology as well as an increase in number of animals (Thornton, 2010). In the future, production will increasingly be affected by competition for natural resources, essentially land and water, competition between food and feed, and by the need to operate in a carbon-constrained economy. Being so, livestock production will be increasingly affected by carbon constraints and environmental and animal welfare legislations. On the other hand, demand for animal-derived products in the future could be significantly affected by socio-economic forces, such as human health concerns and changing socio-cultural values (Thornton, 2010).

**LIVESTOCK PRODUCTION AND CLIMATE CHANGE**

**Climate change**

Climate change affects agricultural production through its effects on the timing, intensity and variability of rainfalls and shifts in temperatures and carbon dioxide concentrations, which singly or collectively, can have direct effect on plant and animal growth, and indirect effects on production through potential changes in pest and disease patterns. Based on climate change models with six different emission scenarios, the IPCC estimated that the global temperatures are likely to rise between 1.1°C and 6.4°C by 2100. A rise of over 2°C above the pre-industrial average temperature is considered the level at which dangerous climate challenge possess a risk to all, not just the most vulnerable. Worldwide, increased frequency and intensity of floods, droughts and other extreme weather events will expose hundreds of millions of people to various risks. It is thus estimated that billions of people will be at risk from adverse impacts on food and water security and changing patterns of diseases.

At the global scale, IPCC (2007) summarised the greenhouse gases emitted by human activities to include a) carbon dioxide (CO₂), primarily from fossil fuel (57%) and those from activities related to deforestation (17%), b) methane (CH₄) from agricultural activities such as livestock production (14%), c) nitrous oxide (N₂O) coming mostly from fertiliser usage for crop production (8%), and d) fluorinated gasses coming from industrial processes, refrigeration and other consumer products (1%). The GHG by source is summarised in Table 2.

<table>
<thead>
<tr>
<th>Source</th>
<th>Percent share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy supply</td>
<td>26</td>
</tr>
<tr>
<td>Industry</td>
<td>19</td>
</tr>
<tr>
<td>Forestry</td>
<td>17</td>
</tr>
<tr>
<td>Agriculture</td>
<td>14</td>
</tr>
<tr>
<td>Transport</td>
<td>13</td>
</tr>
<tr>
<td>Residential and commercial buildings</td>
<td>8</td>
</tr>
<tr>
<td>Water and waste water</td>
<td>3</td>
</tr>
</tbody>
</table>
The over-exploitation of the natural resources by countries that started industrializing early has in fact resulted in global warming, and it is ironic that the fallout shall be primarily on the developing countries, much of which are still poor and have low per capita emissions (Das Gupta, 2013). In effect, these countries will be the first to experience decline in agricultural output, disruption in rainfall patterns and frequent natural disasters.

In 2010, the global GHG emission was estimated to be 50.1G tonnes CO$_2$-eq. Taking into account the GHG emissions from 1850-2010 period, about 52% of the emissions came from developed countries and 48% from developing countries (denElzen et al., 2013). Taking the GHG emission on a per capita basis, emission in developed countries in 2010 is estimated to be 21.24 tonnes CO2-eq/capita, whereas it was only 4.25 tonnes CO$_2$-eq/capita in developing countries, thus developed countries emit 4.94-fold more GHG per capita. More of the future growth in GHG emissions is expected to come from the developing countries and that by 2020, the share of the developing countries may be about 51%, in view of the increasing economic activities as well as the increasing population, and considering that the developed countries have reached their peaks.

Kolbert (2014) considered the human-induced climate change, of which modern agriculture and a rapidly growing human population are major contributors, if not managed well could lead to the “sixth extinction”. By warming the planet, introducing invasive species to different areas, and encouraging the spread of contained fungi and viruses, people are killing the life around us. It was further articulated that no creature has ever altered life on the planet in this way before, and yet other comparable events have occurred. In the distant past, the planet has undergone change so wrenching that the diversity of life plummeted. Five of these ancient events were catastrophic enough that they are called the “Big Five”. What seems to be happening now is that people are causing another one, this time potentially the “sixth extinction”.

Recently, a study concluded that while the rest of the world wrestles with the political and technological complexities of reducing emissions, family planning programs offer the poorest countries a simple and effective means to improve their circumstances (Das Gupta, 2013). Family planning programs are effective means of helping lower fertility and are highly pro-poor in impact as those who benefit are mostly poor, uneducated women that live in rural areas. Fisher and Newman (2011), however, pointed out that it is essential that any efforts to link population and climate change should fully acknowledge and respond to the many associated complexities and sensitivities, and advocate clearly that coercive family planning programs have no place in international development programs.

Livestock production and climate change

The link between livestock production and anthropogenic GHG emissions has been known earlier, but the FAO publication ‘Livestock’s Long Shadow’ (Steinfeld et al., 2006) catalyses more discussions on the issue of climate change and sustainability of livestock production.

The report noted that livestock is estimated to produce 7,516 million metric tons/year of CO$_2$-eq, representing 14.5% of worldwide GFG emissions (FAO 2006). Beef cattle and dairy cattle production account for the majority of emissions, representing 41% and 19% of the sector's emissions, respectively. Pig and poultry (meat and egg) contribute 9% and 8%, respectively. The main sources of emissions are feed production (45%) of which a large percentage has been attributed to expansion of pastureland, enteric fermentation from ruminants (39%) and manure decomposition (10%). In a review of the same subject, it was reported that the correct estimate of GHG emissions from livestock should be 32,564 million tons, not only 7,516 million tons of CO$_2$-eq/year, representing 51% of annual worldwide GHG emissions (Goodland and Anhang, 2009).

Greenhouse gas emission intensities in livestock production expressed as CO$_2$-eq/kg of product is shown in Table 2. Among the animal products, milk from cattle and buffalo have the lowest GHG intensities of 2.8 and 3.4 CO$_2$-eq/ kg of fat and protein corrected milk (FPCM), FAO, 2010, whereas beef from cattle and buffalo have the highest GHG intensities of 46.2 and 53.4 C0$_2$-eq (FAO, 2013). Producing poultry meat has 8.5-fold less and pork has 7.5-fold less intensity than beef (Table 3).
Table 3. Greenhouse gas emission intensities of livestock production

<table>
<thead>
<tr>
<th>Species</th>
<th>CO$_2$–eq/kg Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td></td>
</tr>
<tr>
<td>Cattle</td>
<td>2.8</td>
</tr>
<tr>
<td>Buffalo</td>
<td>3.4</td>
</tr>
<tr>
<td>SR</td>
<td>6.5</td>
</tr>
<tr>
<td>Beef</td>
<td></td>
</tr>
<tr>
<td>Cattle</td>
<td>46.2</td>
</tr>
<tr>
<td>Buffalo</td>
<td>53.4</td>
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<tr>
<td>SR</td>
<td>23.4</td>
</tr>
<tr>
<td>Pig</td>
<td></td>
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<tr>
<td></td>
<td>6.1</td>
</tr>
<tr>
<td>Poultry</td>
<td></td>
</tr>
<tr>
<td>Meat</td>
<td>5.4</td>
</tr>
<tr>
<td>Egg</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Another aspect of concern about ruminant production is related to water usage as global demand for fresh water is rising rapidly. For example, it would require only 650 liters of water to produce a kilogram of corn, 1600 liters for a kilogram of rice, and 2000 liters for a kilogram of soybeans, whereas it is estimated that some 43,000 liters of water is required to produce a kilogram of beef, and 51,000 liters of water per kilogram of sheep meat (Pimentel and Pimentel, 2003).

Development of animals with high productivity and efficiency

In view of the projected increase in demand for animal-derived products, animal production is seen as directly competing for resources such as land, water and fertiliser with human food and fuel production. Garnett (2010) suggested that increasing further food production, particularly of animal origin, may reach the limit of the earth’s carrying capacity, and thus it was suggested that the option is to reduce consumption of animal-derived food products. FAO (2012) estimated that there will be only limited land for further expansion and this can only represent some 20% of the projected increases in food production, the rest should be coming from increased productivity. The animal components of such needed increased productivity can possibly be addressed by breeding animals with higher productivity and efficiency rate to greatly ease the food-feed-fuel competition for limited land and other natural resources.

Long-term genetic improvement of livestock, involving increased productivity, feed efficiency, and tolerance to high temperature and diseases can be done, with limitations set by many external forces (Neeteson et al. 2014). Among beef cattle, heritability for feed conversion ratio is 0.32 and even higher for dressing % (0.39). Milk yield
is equally heritable (0.39) although there is a very high negative correlation with fat% (0.58) and protein % (0.62) Simm (2010). Enhanced resistance to disease is stable under natural selection and therefore deliberate selection for disease resistance should also be stable and sustainable (Stear et al, 2001). The heritability of traits associated with resistance to many important diseases is often high and considerable variations among animals exist. However, the desirability of breeding for disease resistance depends upon whether there are trade-offs with other economically important traits (Stear et al, 2001).

The impact on production and environmental foot print is exemplified by the genetic improvements in poultry carried out in the last decades. For example, given the global consumption of poultry meat in 2010 at 86.5 million tonnes and a conservative estimate of the global commercial field improvement in feed conversion ratio (FCR) of -0.015 kg/year, there is a cumulative savings of about 1.85 million tonnes of feeds. At the wheat yield of 466 tonnes per sq kilometer per year, the increases in FCR translate into freeing some 4000 sq kilometres of arable land (Neeteson et al, 2014a). Furthermore, genetic improvement in FCR has the greatest potential to reduce the environmental impact when compared to body weight, liveability and carcass yield in broiler. A cumulative genetic improvement of -0.03 kg feed /kg product /year in 15 years could reduce global warming potential of poultry meat production by 19%, and eutrophication and acidification potential by over 30 % (Neeteson at al. 2014a).

In layers, the improvement in production efficiencies and environmental footprints were analysed for systems in 1960 versus 2010. Results revealed that 2010 laying hens have 26% less daily feed use (9.03 versus 12.23 kg) per 100 hens, 42% better feed conversion (1.98 versus 3.44 kg) per kg of egg, 32% less direct water use per dozen eggs produced. Further, it has 65% lower acidifying emissions, 71% lower eutrophying emissions, and 71% lower GHG emissions (2.1 versus 7.2 kg CO₂-e). Therefore, using the 1960 technologies to produce the egg supply for 2010 would require raising more 27% (78 million) more hens, growing 72% (0.53 million ha) more corn, and growing 72% more (0.73 M ha) soybean (EIC, 2013).

Likewise, the US pork industry has been very successful in significantly reducing its environmental impact and use of natural resources by nearly 50% per 1,000 of pork produced. Based on their 1959 baseline, a 35% decrease in carbon footprint, a 41% reduction in water usage and a 78% drop in land needed to produce a pound of pork has been reported (Cunningham, 2012). Similarly, lean growth improvement in swine carried out for 35 years reduced nitrogen excretion by 25% per annum and by 31% per kilogram of protein produced (Knap, 2011).

In Australian dairy cattle, between 1980-2010, milk yield per cow has almost doubled and the stocking rate has increased by 50% and thus the production per hectare has increased by 192% from an estimated 2,878 lit/ha in 1980 to 8,419 lit/ha in 2010 (DEPI, 2015). Similar improvements in milk yield per cow have been noted among US dairy cattle (Oltenacu and Broom, 2010). However, caution should be observed in designing breeding program on just increasing yield alone. The case in dairy cattle is a good example: while production more than doubled in the last 40 years, there is a marked reduction in fertility and deterioration in health among high yielding dairy cows (Oltenacu and Broom, 2010).

The main logical question along this approach is whether genetic improvement can continue at all over a long time and that the basis of expected improvement, which is genetic variation, may run out and thus improvement can stop. To show that this may not be the case, data obtained from 47 generations of chicken breeding show no signs of plateauing and is indicative that genetic variations have not been exhausted (Neeteson et al, 2014). Furthermore, new mutations have been suggested to provide the needed genetic variability and contribute to the perceived lack of selection plateau. In this process, new alleles are being created all the time, although at a very slow rate (Hill, 2008). On the basis of this data, there is no reason to expect cessation of responses to selection.

ROLE OF REPRODUCTIVE AND RELATED BIOTECHNIQUES

The two related technologies which can have major impact on rates of genetic improvement are the reproductive technologies and the molecular genetic technologies. Selective breeding, aided by assisted reproductive technologies, has led to the development of increasingly specialised breeds that produce very high yields. Breeding companies continue to pursue improvement in genetic gains in many economically important traits such as growth rate, feed conversion efficiency, and quality of meat, milk and eggs.
The various reproductive and related biotechniques and their role in the quest for more productive and efficient livestock are briefly discussed below.

**Artificial Insemination**

Artificial Insemination is the oldest of the assisted reproductive technologies and has the greatest impact on the livestock industry worldwide. Its development started as early as 1678 when low magnification microscope was developed, and was followed almost after 100 years by successful AI in dog by Spallanzani in 1784 (Foote, 2001). After another century, Heape (1897) and many others reported successful AI in other animal species. Following these reports, semen extenders were developed, followed by the discovery of glycerol as cryoprotectant that paved the way to production of frozen semen and allowed the change in storage of frozen semen from solid carbon dioxide (-79°C) to liquid nitrogen (-196°C.)

This technology allowed the use of superior sire to thousands of females and permit international transport of germplasm at less cost and safely, meeting the phytosanitary measures that prevent spread of diseases. AI allows much higher selection intensities among males than those from natural mating, added to the possibility that the desired number of progenies can be produced at shorter time. This therefore shortens the male generation interval. AI can also contribute to a more accurate evaluation of genetic merit as well as the possibility of large scale progeny testing in many herds. In fact, with the use of AI, it was possible to carry out multi-country semen exchange program and thus allow the evaluation of best bull under a given environment.

The experience in Holstein dairy cattle is an example and is on this basis that an international semen exchange program to hasten the genetic improvement of water buffalo has been proposed recently (Cruz et al, 2015). Progress can be particularly high if AI is coupled with accurate techniques for predicting breeding value (Simm, 2010).

In the dairy sector, for example, AI combined with organised and extensive recording, testing, selection and analysis of milk production traits has resulted in substantial increases in milk yield per cow. Among Holstein animals, the estimated breeding values increased by 3670 kg in just 50 years (1960-2010). In many countries, the yield per cow has more than doubled in the last 40 years (Oltenau and Broom, 2010). Currently, more than 60% of US dairy cows are bred through AI (NIFA, 2015) and 70-75% of US commercial swine producers. AI has not made much impact in beef cattle and sheep industry as it has in dairy cattle owing to the fact that extensive production system applied in beef and sheep herds make it difficult to detect estrus. This limitation, however, can be resolved by the availability of practical estrus synchronising programs.

AI also has very important role in the production of "tropicalized dairy cattle" as a way of increasing milk production in hot and humid tropic. In New Zealand and Australia, crossbreeds between a tropical breed, Sahiwal, and Holstein are produced by inseminating Sahiwal semen in the Holstein cows. The crossbreeds are exported to many countries in Asia, such as the Philippines, Indonesia, Thailand, Malaysia and China during the past years. In the same manner, composite breed such as Girolando is now the dairy animal in most of the tropical part of Brazil, able to harness the heat and disease tolerance of tropical breed and the productivity of the Holstein breed.

The technique for cryopreservation of semen in the early 1949 (cited by Foote, 2002) allowed the expansion of the use of AI, and permitted transport of frozen semen across continents. In cattle, the recorded pregnancy rate achieved from frozen semen is similar with those of natural mating (Lima et al, 2009), while in other species, the success rate from the use of frozen semen remains less optimal as in pig (Johson et al, 2000), small ruminants (Barbas and Mascarenhas, 2009). In boars where use of frozen semen remains less successful, the use of extended semen in liquid state can result in high pregnancy rate (Flowers and Alhusen, 1992). There is a continuing search for improving processing of frozen semen to improve fertilising capability, This includes the addition of antioxidant to semen extender (Zhang et al, 2012), glutathione to improve post-thaw motility and acrosomal integrity (Perumal et al, 2011). Addition of seminal plasma before freezing has been reported to improve sperm survival rate in bull, boar, ram and stallion (Caballero et al, 2012; Robinson et al, 2011) and thus improve pregnancy rates among inseminated animals.

In the early period, the wide-scale use of AI has been constrained by the correct estrus detection since the occurrence of silent estrus is very common in some species. The problems have been resolved by the use of estrus synchronisation procedures following the development of the luteolytic compound, prostaglandin F 2 alpha, and long-acting progestagen preparations, used singly or in combination. Synchronization of ovulation with the use of GnRH or E2 or in combination before AI is normally carried out among high-producing lactating
dairy cows as they are noted to have reduced estrus behaviour. The procedure also optimizes luteolysis, follicular growth and ovulation, and has completely eliminated the need for oestrous detection, permitted timed AI and could improve pregnancy among treated animals (Wiltbank et al., 2011; Baruselli et al., 2013).

The development of the flow cytometric techniques to separate x-bearing from the y-bearing sperm in 1980 added much power to AI as a tool in livestock development. Since then, the cytometric technique has been improved and live births have been reported in pigs, horses, elk, human and dolphins (Garner and Seidel, 2008; O’Brien et al., 2009). Sexed semen was introduced for commercial use in cattle in the USA as early as 2005, and by 2008 about 17.8% of the recorded breedings in Holstein heifers and about 0.4% of recorded breeding in Holstein cows (Norman et al., 2010). In large-scale studies in cattle using X-sorted semen, the reported female calves ranged from 89-91% (DeJarnette et al., 2009; Norman et al., 2010).

A study on AI involving 93,481 Holstein heifers using sex-sorted and non-sorted semen was reported and indicated that conception rate was 56% when bred with conventional semen and 45% for those bred with sex-semen (DeJarnette et al., 2009). In the following year, Norman et al (2010) analysed 1.3 million breeding of Holstein heifers and 10.8 million Holstein cows, and reported that for heifers, conception rate obtained from the use of sex-sorted semen was 39% and from conventional semen 56%. For cows, the conception was 30% from the conventional semen and 25% from the sex-sorted semen. Based on these large-scale analyses, there is a need to improve the process of sex sorting of semen through the cytometric technique. The likelihood of identifying proteins distinctive of X- and Y- containing sperm seems very small, however, there is a hope for other options as sex chromosomes become condensed and transcriptionally inactive during meiosis (De Vries et al, 2012).

Sex-sorted semen has also been successfully used for the production of in vitro embryos with success rate similar with those obtained from non-sorted semen (Underwood et al, 2010). In this manner, it is possible to obtain many high genetics embryos from a straw of sex-sorted semen. The integrity and development competence of embryos produced through this scheme has been reported to be equal to that from the non-sorted semen (Rasmussen et al, 2013).

For practical industry application, sex-sorted semen can be capitalised by the beef industry to produce all-male calves, which tend to have higher body weights and higher feed efficiency compared to female calves when placed under feedlot conditions. In contrast, the dairy industry prefers heifer calves, which ultimately will be replacement heifers to produce milk.

**Embryo Technology**

Embryo transfer has been regarded as the female equivalent of AI in females - a method to increase genetic selection by increasing the number of offspring from genetically elite females. Compared to AI, however, the number of offspring from a single cow in a most intensive embryo transfer program is only in the hundreds while that from AI from a single bull can be hundreds of thousands. One limitation in ET is the lower accuracy in selecting genetically elite female, owing to the disparity in number of performance records from offspring (Hansen, 2014). The improvements on genotyping for the genomic prediction of important traits have greatly addressed this limitation, and thus accuracy of selection of elite females is higher.

Applications of embryo technology for genetic improvement can be classified into the following: a) with-in breed improvement program, b) international trading of genetic materials, c) accelerating breed substitution by multiplication of the newly introduced breed, d) conservation of genetic materials by freezing embryos, and e) as a platform for other related technologies, such as cloning and production of transgenic animals with desired traits.

Embryo transfer (ET) was performed first in 1890 in rabbit by Walter Heape (Mapleton, 2013). ET in farm animals began in 1930 in sheep and goats, and only in 1950 when ET was applied commercially in cattle and pigs in England and in US (Willett et al, 1951). As the technology gets wide-scale acceptance, the International Embryo Transfer Society (IETS) was formed in 1972 by Rowson, and then 10 years later, the American Embryo Transfer Association (AETA) was formed, followed by the Canadian Embryo Transfer Association (CETA) and in 1985, the Brazilian Embryo Transfer Society (SBTE) Rubin (2005) cited by Mapleton (2013). The past decades have seen the development of more reliable procedures for super-ovulation, embryo recovery, embryo freezing and transfer. One important development in the early years of ET is the move from surgical embryo transfer in 1970 to non-surgical method in 1976 (Drost et al., 1976; Rowe et al, 1976). Also, the issue on the use of natural
FSH for super ovulation treatment that necessitated multiple injections has been solved with the use of FSH analogue (Tribulo et al., 2011). A combination of embryo transfer using proven cows inseminated with semen from proven bulls, appear to be the most common use of bovine embryo transfer.

There are two modes to derive embryos, the first and most common is the in vivo route, and the second is through in vitro method. The single major limitation on in vivo embryo production is the characteristics of superovulation response. For almost a decade the reported average number of in vivo embryos per superovulatory regimen has not changed dramatically, the average in vivo embryos/collection improved from 5.54/collection in 1997 to only 6.67/collection in 2012 (Hasler et al., 1983; Hasler, 2014).

ET has been in commercial use, mostly in beef and dairy animals. The reported number of transferrable in-vivo embryos in bovine from 1998-2012 started at 528,688/year and peaked to as much as 789,972 in 2005. Thereafter, the reported collected in vivo-derived bovine embryos declined to a level of 699,586 in 2012. The extent of ET use in various regions of the world in 2012 is presented in Table 4.

### Table 4. Bovine in vivo-derived (IVD) embryo collection and transfer, 2012

<table>
<thead>
<tr>
<th>Region</th>
<th>Embryo Collected</th>
<th>Embryo Transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transferrable</td>
<td>Fresh</td>
</tr>
<tr>
<td>Africa</td>
<td>7609</td>
<td>3272</td>
</tr>
<tr>
<td>Asia</td>
<td>100558</td>
<td>20436</td>
</tr>
<tr>
<td>Central America</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Europe</td>
<td>135517</td>
<td>40174</td>
</tr>
<tr>
<td>North America</td>
<td>355866</td>
<td>100354</td>
</tr>
<tr>
<td>Oceania</td>
<td>15338</td>
<td>6959</td>
</tr>
<tr>
<td>South America</td>
<td>87798</td>
<td>37876</td>
</tr>
<tr>
<td>TOTAL</td>
<td>699586</td>
<td>209071</td>
</tr>
</tbody>
</table>

Source: IETS, 2013

The second mode of embryo production is through in vitro technique, the more traditional method is collection of oocytes from slaughtered animals, and of recent development is the collection of oocytes from live donors. One major limitation in the slaughter-obtained oocytes is the inability to decipher the genetic quality of the sources of ovaries plus the fact that aspiration of oocytes from each ovary can be done only once. On the other hand, ovum pickup (OPU) allows the chance to select the oocyte donors plus the advantage of being able to collect oocytes from the same donor for several times. Efficiencies of production of transferable embryos in both modes are summarized in Table 5. It appears that based on large-scale data, OPU-IVF has an efficiency of 35.7% versus 2.25% in abattoir-derived oocytes. The added advantage of the system is the ability to use very efficiently sexed semen from elite sire for fertilization in vitro.

### Table 5. Production efficiency of IVF-derived bovine embryos, 2012

<table>
<thead>
<tr>
<th>ITEM</th>
<th>OPU-IVF</th>
<th>ABATTOIR-IVF</th>
</tr>
</thead>
</table>

10
OPU has several advantages over the system that recovers oocytes from slaughterhouse animals. In this system, purebred animals of high genetic merit can be used as donor, so the technique is of potential benefit for genetic improvement and not just in genetic dissemination. It is also possible to plan well the oocyte recovery and thus embryo production as compared to the post-mortem oocyte recovery. Very interesting is the possibility of aspiration of oocytes from relatively young donors, thus it is possible to produce offspring from donors long before it reaches its actual reproductive maturity. And since aspiration of oocytes can be done twice a week, the technique permits the production of hundreds of embryos from a single top genetic donor. Increasing the number of embryos in this way could have a major impact on the rate of gain achievable from MOET breeding schemes, possibly allowing rates of gain up to 34% above those in conventional progeny testing scheme (Lohuis, 1993 as cited by Simm, 2010).

Repeated collection of oocytes through laparoscopic method was done in cattle as early as 1983 (Lambert et al., 1983) and the ultrasound guided aspiration of follicular oocytes through the sacrociatic ligaments was reported in 1987 (Callesen et al., 1987). The transvaginal ultrasound-guided follicle aspiration was first established in cattle by a Dutch team (Pieterse et al., 1988). This procedure has been demonstrated to be possible, aspirating twice a week and carried out for a five months period without deleterious effect (Kruip et al., 1994). OPU can be applied irrespective of reproductive status of the animals, such as in acyclic or in pregnant animals (Kruip et al., 1994; Merton et al., 2009; Takuma et al., 2010; Cseh et al., 2012), or in animals that are less sensitive to superovulatory treatments. To date, OPU technique did not show significant improvements in terms of number of oocytes recovered. However, the number of transferable embryos from the OPU-derived oocytes significantly increased due to improvement in the IVEP technology (Boni, 2012). The only limitations in the current technology is the lower conception rate following the transfer of in vitro-produced embryos compared to the in-vivo-derived embryos.

In South America, the use of in vivo-derived embryos has been on the decline due to the acceptance of the IVF technology (Table 6). Data on IVF embryos were first recorded in 1997 and despite the increase in IVF-derived embryos, there seems to be no international trade so far. This may be ascribed to the fact that most IVF-derived embryos are transferred fresh as success rate in frozen thawed IVF embryos are far less, IVF embryos being more sensitive to cryopreservation owing to the high content of lipid (Stewart et al., 2011).

Another interesting area in in vitro embryo technology that has received some attention is the in vitro culture of pre-antral follicles. This is because the potential of harnessing the thousands of oocytes in the ovary of pre-pubertal female calves is enormous. When technology is fully developed to allow these pools of antral follicles to mature and fertilise, then this can maximise the production of superior high-performing animals (Araujo et al., 2014). More interestingly, this technique facilitates embryonic and somatic cloning, creating transgenic individuals, their cloning and also creating chimeras.

<table>
<thead>
<tr>
<th>N</th>
<th>96,672</th>
<th>31,772</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oocytes/donor</td>
<td>13.0</td>
<td>19.4</td>
</tr>
<tr>
<td>Oocytes to produce an embryo</td>
<td>2.8</td>
<td>44.3</td>
</tr>
<tr>
<td>Embryo/donor</td>
<td>4.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Source: IETS, 2013

Table 6. In vitro bovine embryo transfers, 2012

<table>
<thead>
<tr>
<th>Region</th>
<th>In vitro-derived</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OPU-IVF</td>
<td>Abattoir-IVF</td>
<td>Total IVF</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>fresh</td>
<td>frozen</td>
<td>total</td>
<td>fresh</td>
<td>frozen</td>
</tr>
<tr>
<td>Africa</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Somatic bulls can be produced via IVF that allows the number of offspring to be greatly increased. Several reorganizations and transfers of bull germplasm from MOET programs have been made, and SNP chips have been used in this testing. Successful use of genomic information for the prediction of breeding values in dairy cattle has been demonstrated in France. It started in 2001 and has evolved into a national consortium that initiated large marker-assisted programs for pre-selection of young bulls before progeny testing. With the availability of high-throughput SNP chips, the evaluation model was upgraded with genome-wide information. In 2009, genomic evaluation was made official, allowing the use of young bulls without waiting for progeny test results. Because of this, progeny testing programs have been stopped and genomic selection and reproductive technologies have been associated (Patry and Ducrocq, 2013).

Genomic selection applied to embryos has gained interest recently (Seidel, 2010) with the availability of commercial chips containing 800,000 SNPs. Several ET/ reproductive biotech companies are currently working towards introducing genomic analysis of embryos to cattle breeders and is expected to result in major reorganization in ET business interested to offer such services (Hasler, 2014). Selection of embryos early in life is expected to shorten generation interval plus reduce the cost of producing and rearing large number of bulls for multi-character selection. Pregnancy rates following transfer of fresh biopsied in vivo-produced embryos were shown to be over 60% (Lacaze et al. 2008).

The use of embryo-based biotechnologies in carrying out the genomic selection is becoming important. This is so because the most important feature of the new selection procedures will be to considerably increase the number of candidates submitted to genomic selection to maximize the chances of getting interesting individuals that will be positively evaluated for a large number of traits (Humblot, 2010). In this context, AI alone may be inadequate to generate sufficient animals in a given period of time, and in this regard, efficient MOET and OPU-IVF may provide these large numbers of animals to be genotyped. With the use of OPU-IVF, repeated sessions can potentially produce about 70 calves/per donor per year. Additional advantage can be obtained if different bulls are used for different OPU sessions (Humblot, 2010).

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<table>
<thead>
<tr>
<th></th>
<th>N America</th>
<th>Europe</th>
<th>Asia</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
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<td>5291</td>
<td>465</td>
<td>348238</td>
</tr>
<tr>
<td>S America</td>
<td>307201</td>
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<td>0</td>
<td>36761</td>
</tr>
<tr>
<td>Oceania</td>
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<td>665</td>
<td>384999</td>
</tr>
<tr>
<td>N America</td>
<td>28793</td>
<td>665</td>
<td>5912</td>
<td>6311</td>
</tr>
<tr>
<td>Europe</td>
<td>7636</td>
<td>2345</td>
<td>5897</td>
<td>7452</td>
</tr>
<tr>
<td>Asia</td>
<td>35281</td>
<td>5291</td>
<td>465</td>
<td>348238</td>
</tr>
<tr>
<td>TOTAL</td>
<td>348238</td>
<td>36761</td>
<td>384999</td>
<td>6311</td>
</tr>
</tbody>
</table>

Source: IETS, 201

MOET and genomic selection

In the late 1970s and early 1980s nucleus breeding scheme using multiple ovulation and embryo transfer (MOET) and sib testing were proposed as an alternative to progeny testing. Production records from bull's siblings are available much sooner than those from its offspring. In the process, there is expected substantial reduction in generation interval compared to those possible in progeny testing. However, in this scheme there seems to be a reduced accuracy in selection for males, but in sum, the gains in shorter generation intervals outweigh the losses from reduced accuracy, and thus the scheme is predicted to give higher rates of genetic gain (Simm, 1998). There are also benefits from progeny testing scheme integrated with MOET as the nucleus herd can provide unbiased and more accurate assessment of potential dams of young bulls for progeny testing and also provide valuable direct source of young bulls for progeny testing.

Successful use of molecular information for the prediction of breeding values in dairy cattle has been demonstrated in France. It started in 2001 and this evolved to a national consortium that initiated large marker-assisted program for pre-selection of young bulls before progeny test. With the availability of high-throughput SNP chips, the evaluation model was upgraded with genome-wide information. In 2009, genomic evaluation was made official, allowing the use of young bulls without waiting for progeny test results. Because of this, progeny testing programs have been stopped and genomic selection and reproductive technologies have been associated (Patry and Ducrocq, 2013).

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Somatic Cell Nuclear Cloning
The major use of SCNT is genetic duplication of elite animals. In theory, SCNT can improve rates of genetic selection as a result of increase in selection intensity and because the accuracy of selection can be improved by recording performance of specific genotypes under a variety of environments (Dematawewa and Beger, 1998).

Cloning technology is already being used commercially in some parts of the world for the replication of elite breeding animals, mostly cattle, which are used for improving commercial herds’ production efficiency. In some cases, elite bulls are cloned to maximize the production of semen used for artificial insemination. Elite females are likewise cloned and are usually utilised as source of young bulls. Following the FDA decision to allow products from cloned animals to freely enter the market (FDA, 2008), products from offspring of cloned animals have already entered the human food chain in the US and elsewhere (Weiss, 2008; Plume, 2009). In fact many US companies offer cloning services to the livestock breeding industry, mostly to cattle and pigs (Viage, 2009; TransOva Genetics, 2009; Cyagra, 2009; Bovance, 2009) cited by Hasler (2014).

Cloning is also used in the production of genetically modified animals used for food production or for biomedical as well as research purposes. Although SCNT process is still less efficient than desired, the technology is the choice for creating transgenic animals by microinjection of foreign DNA (Vajta and Gjerris, 2006). The use of cloning technology is therefore facilitating the development and commercialization of genetically modified animals for food production purposes.

Cloning could be of use to help preserve rare indigenous breeds of livestock or individual within a breed which possess unique characteristics (Westhusin et al., 2007) in order to prevent the loss of unique traits, such as adaptability to local environment, from the global gene pool. If scientists will be able to dramatically increase the efficiency of cloning, then the technology can be very helpful in rescuing wild and endangered species with stored DNA.

Concerns have been raised about the effect of cloning on genetic diversity, that while it does not appear to have direct effect in that no new genetic modification are introduced in the cloned animals, the indirect effect due to over use of a limited number of animal in inbreeding program, increasing homogeneity of a genotype within the population may increase the susceptibility of an animal population to infection and other risk factors (CIWF, 2010).

To have dramatic improvement in the genetic base of a cow herd, it will require 10-20 years using the natural service. By incorporating AI, these improvements can be achieved in 7-8 years, and if combined with aggressive ET program, this change is accelerated to 4-5 years. Recently, a report combining in-vitro embryo production and ET, genomic selection and SCNT to produce high genetic merit calves has been successful in cattle, and in the process reduced the generation interval by approximately seven months (Kasinathan et al., 2015).

Transgenics Technologies

Success in somatic cell nuclear transfer is considered a significant advancement that has made obsolete the need for using embryonic stem cells to conduct cell-mediated genome engineering. This is so because site-specific genetic modifications can be conducted in bovine somatic cells via DNA homologous recombination and whereby genetically engineered cattle can be subsequently produced through animal cloning from the genetically modified cells (Wang, 2015). Examples of such animal is the production of genetically engineered cattle with improved disease resistance (Donovan et al, 2005), and cattle with increased meat production (Proudfoot et al, 2014).

The possibility of utilizing transgenic technology in order to enhance desirable traits, such as high reproductive efficiency, has been of interest almost 20 years ago (McEvoy et al., 1992) but progress in the practical aspects of transgenic technology has been rather slow due to technical, regulatory and ethical considerations (Xavier and Ashworth, 2013; Fahrenkrug et al, 2010). Recent development of the novel technologies such as Zinc finger nucleases (ZFNs) (Cathomen and Keith, 2008) allowing greater precision and control will likely permit the use of transgenic technologies in animal reproduction (Xavier and Ashworth, 2013). Improving fertility in farm animals is very important in the face of persistent decrease in livestock fertility associated with modern farming systems, most notably observed among high-producing dairy cattle, pig and chicken (Lucy, 2001; Young et al, 2010; Julian (2005). The loss in fertility can be reversed as shown in dairy cattle without compromising productivity through genome-wide multiple traits selection (Coleman et al. 2009) but the desired output through this approach may take decades. As an option, transgenic technology can be used to induce modifications in
selected genes followed by conventional breeding and selection, particularly in species with long generation interval, such as cattle and buffalo. These could be aimed at improving fertility directly, removing genes that naturally suppress ovulation or indirectly by improving energy utilisation by reproductive tissues or inserting reporter genes that would facilitate estrus detection or early pregnancy diagnosis (Xavier and Ashworth, 2013). In order to achieve this, gene-knocking or knockout approaches to modify whole genes or large portion or use ZFN technology for targeted or untargeted gene mutagenesis to modify gene function in animals can be made (Cui et al., 2011; Whyte et al., 2011; Yang et al., 2011). Among the genes that could be targeted to increase fertility in livestock, certain members of the BMP family meet all the criteria for optimum target, particularly BMP15, GDF9 and BMP receptor type 1B (McNatty et al., 2005; Souza et al., 2004). For example, BMP15 (bone morphogenetic protein 15), which restricts maturation-promoting effects of gonadotropins, preventing development of excessive number of pre-ovulatory follicles and early luteinization/ovulation can be transgenically altered to address the relative deficiency in gonadotropin levels during early postpartum period.

The current project of ILRI is the development of transgenic cattle containing genomic locus of baboon APOL 1 that will render the african cattle resistant to Trypanosomiasis, a disease that reduces the output of meat and milk by at least 50%.

**Related cell-based biotechnologies**

For assisted reproduction, cell-based technologies offer a myriad of possibilities. For example, breakthrough in stem cells research may soon make it possible to use stem cells to produce gametes of either sex (Hansen, 2014). Pluripotent stem cells such as embryonic stem cells (from inner cell mass of preimplantation embryos), embryonic germ cells (from primordial germ cells) and iPS cells, are those that can give rise to virtually any cell type (exclusive of embryonic membranes). Of particular interest in this respect are the spermatogonial stem cells (SSC) in the testis that give rise to spermatogonia as described by Oatley and Brinster (2012) and oogonial stem cells (OSC) as reported by Hutt and Albertini (2006) and Woods and Tilly (2012). Production of sperm from transplanted testicular cells in semen has been reported in cattle (Stockwell et al, 2009). In fact live births were reported from sperm-derived testicular cell transplant in goats (Honaramooz et al, 2003). This technology can possibly contribute to produce spermatozoon of a given superior genotype for use in artificial insemination or as an important vehicle for introducing transgenics into population of livestock as shown in mice (Nagano et al, 2001).

On the other hand, offspring have been produced in mice following production of oocytes from OSC transplanted in ovaries of infertile mice (Zou et al, 2009). Perhaps, if these technologies can be applied in livestock, it can expand the production of embryos through IVF.

Hansen (2014) suggested that stem cell technologies may also be useful in modifying males so that all spermatozoa carry X chromosome. This could be achieved if SSCs-derived genetic females (ES cells, iPS cells, or OSC) were transplanted into the testis.

**SUMMARY AND FUTURE OUTLOOK**

The potential values of the various reproductive biotechniques in genetic improvement and in genetic dissemination are summarized below (Table 7).

<table>
<thead>
<tr>
<th>Reproductive technology</th>
<th>Value in genetic improvement program</th>
<th>Value in dissemination of improvement to commercial herd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial insemination</td>
<td>★★★★</td>
<td>★★★★</td>
</tr>
</tbody>
</table>
The currently available and emerging technologies in reproduction and related areas have the potential to increase livestock productivity, increase nutritional efficiency, reduce herd size without compromising the yield, and minimize the environmental footprints in the process. Many of the new technologies in current use are as yet inefficient for application in commercial scale as was noted in AI some 75 years ago. But the developments in science appear to have much faster pace today than before. For example, the genome sequencing in human required three years of intensive efforts and collaborations among many scientists and laboratories and at an estimated cost of 1.0B USD. Currently, high-throughput sequencing of a single genome may take only a week at an approximate cost of 18,000 USD (Murphy, 2012). Nanotechnology brings further sophistication as it is expected to reveal an entire genome sequence in just 15 minutes (Pennisi, 2012).

Advances in stem cell technology can also be expected, such as in vitro production of gametes or embryos from stem cell. This will allow rapid genetic gain in livestock, particularly for those species with relatively long generation intervals (Murphy 2012). We can also anticipate improvements in transgenic technology in farm animals so that it will be practical to insert genes of economic interest to produce animals with more efficient feed conversion ratio, tolerant to high temperature and tolerant to diseases, among other important traits.

The development and refinement of technologies take a relatively long time, and in the process have encountered social and ethical constraints, as in the case of objections against artificial insemination in the 1920s and 1930s, about cloning in recent years as well as apprehensions about the emerging cell-based technologies. For those technologies that have created impact on the livestock sector worldwide, such as AI and embryo transfer, science has sent a clear message. To what extent the new and emerging technologies in reproduction are able to respond to the growing challenge of increasing population and climate change is bringing more pressure to scientists. Perhaps one of the constraints to rapid advance is the narrowness of our training and skill sets.

<table>
<thead>
<tr>
<th>Technology</th>
<th>★★★★</th>
<th>★</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple ovulation and embryo transfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In vitro production of embryos</td>
<td>★★★★</td>
<td>★★★</td>
</tr>
<tr>
<td>Sexing of semen and embryos</td>
<td>★★</td>
<td>★★★</td>
</tr>
<tr>
<td>Cloning of embryos</td>
<td>★★</td>
<td>★★★★</td>
</tr>
<tr>
<td>Transgenesis</td>
<td>★★★★</td>
<td></td>
</tr>
</tbody>
</table>

Modified from Simm, 2010  * = low value  **** = high value
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