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Genetic Resources and Optimal Utilization of Rabbits in Egypt

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ABSTRACT

During the period of 1955 – 2020 the population census in Egypt increased from 23,223,124 to 103, 023, 551, according to World meters Elaboration of the latest data of United Nations. This continues elevation in population will result in increasing the livestock demand. Therefore, the short-cycle animals such as rabbit are the best solution for the increasing demand of meat consumption.

In Egypt, small holders rear about 90% of the rabbit with small percent for the commercial farms. From the economical view, rabbits have superior advantages and unique physiological characterization such as; short gestation period, higher growth rate, early maturity and the does have higher productive and reproductive performance (each doe can produce eight progeny every month).

In spite of these advantages, rabbits did not receive the required attention and suffering from the limited resources in Egypt.

Specially that, the genetic diversity could play vital role in maximizing their productivity and adaptability to the environmental conditions. So, the Egyptian researches (at The Agriculture Research Center and Faculties of Agriculture at different Universities) success to develop new Egyptian rabbit lines (APRI, New Giza, Moshtohor, Alexandria) to support the native breeds, especially that, the commercials farms are depending on the imported breeds (New Zealand White, California, Rex and Buscat) with neglecting the local breeds. Therefore, the rabbit's industry is needing more efforts and attention to achieve the required benefits of these animals.

Keywords: Rabbit, Genetic diversity, reproductive & productive performance,

INTRODUCTION

The genetic resources for domestic animals play vital role in saving and provide sufficient food for people all over the World **Ligda and Zjalic (2011)**. Since a long time ago, agriculture is the major sector for the economic activities in Egypt. However, it is facing serious problems such as shortage of Nile water, providing required energy for development (manufacturing and transportation). This led to the urging of Ministry of Agriculture to design strategy of Sustainable Agriculture Development (SADA) 2030, which is working on achieving comprehensive economic and social development depending on the agricultural sector and reducing rural poverty **(FAO, 2013)**. The livestock is the one of the important sectors in agriculture, which represent 40% of the agricultural value **(FAO, 2017)**. The increasing in the Egyptian population is consider a serious problem, increased from 92 million in 2015 to 103, 023, 551 in 2020, and it will expect to be 151 million (Chart, 1) by 2050 according to the statics of **FAO (2017)**. This will result in elevation in livestock demand, and according to the scenario of SADS, it tended to increase the per capita share of animal protein to 4 g/ day by year 2030. It is expect that, the livestock demand will increase to be 400% for beef and 1100% for poultry (Chart, 2), according o the data of **FAO (2017)**. There is a challenge to face all these increases in animal protein demand, by elevating the share percentage of the commercial farms and large holder (they represent less than 10% of the poultry production sector and 21% for the large animals). While, small holders are accounting for 27% of livestock- keeping in Egypt (Chart, 3), they produce about 28% and 25% of egg and poultry.

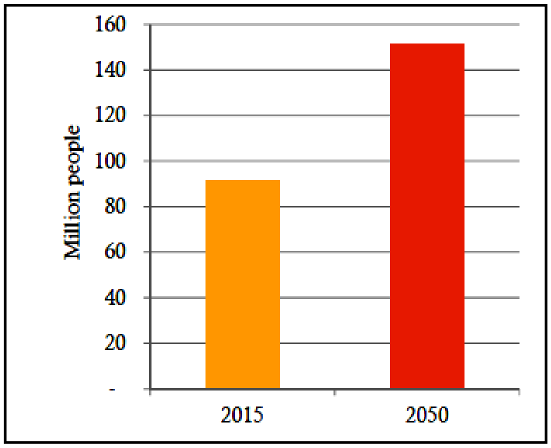


Chart 1. Egyptian population growth 2015-2050

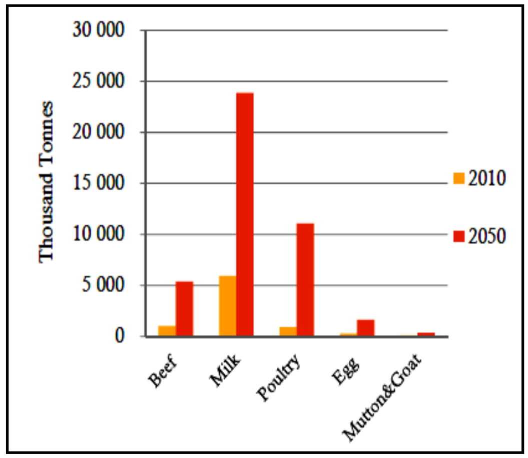


Chart 2 Livestock product demand 2010-2050

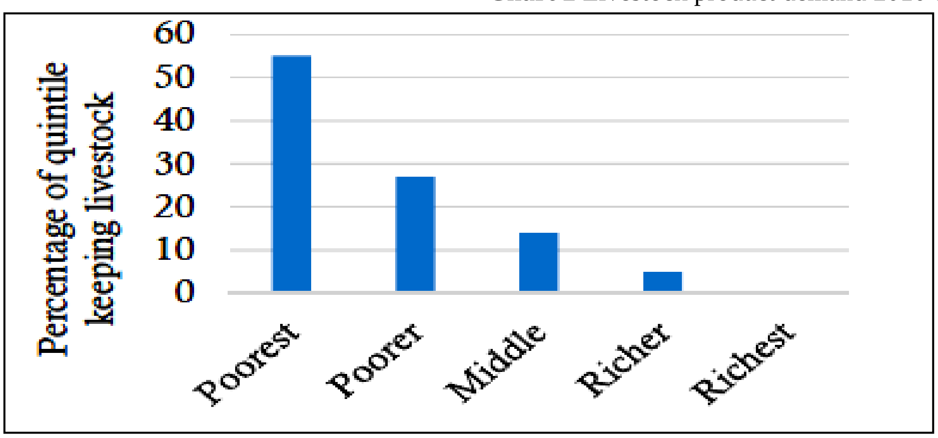


Chart 3 Percentage of livestock keepers by wealth, Egypt 2014

Therefore, the small holders will face the challenge in increasing and enhancing their productivity in order to achieve the expected increases in animal proteins demand **(FAO, 2017).** Additionally, increasing the animal production system should apply carefully. Because changing the production system may result in serious problems such as contamination of ground water, diseases, antimicrobial resistance. And this already happened in the Asian experience when they try to change their livestock production system. Especially that, the animal production has effects on public health and environment, and account as large part of the agriculture, which is the second largest methane emission producer in Egypt **(FAO, 2013)**. Therefore, in the upcoming period we need to draw attention to an important animal, which is rabbit. This short cycle animal can contribute significantly the increasing demand of animal protein and can surmount the shortages in meat production due to their varied and excellent features. Therefore, rabbit farming considered the vital industry in developing countries such as Egypt

From the economic view of meat production is how much can the animal convert plant protein to meat, and rabbits can achieve this point of view via converting about 20% of protein they eat to edible meat **(Lebas *et al*., 1997)**. In addition, their meat is characterized by low fat and cholesterol contents and higher protein percentage **(Ashour and Abdel-Rahman, 2019)**. Furthermore, their role in solving the unemployment problem **(Hamed *et al*., 2013)**.

2 Rabbit Development and Synthetics of New Lines in Egypt

In Egypt, the main sectors reared rabbits are the family in the rural areas (that represent 57% of rabbit production sectors). They reared small numbers of rabbits (less than 50), using cages or batteries **(Imam *et al*., 2020)**. These cages were used in Egypt since 1980s and developed before using the intensive system in rabbit breeding. Additionally, these cages were used by the breeder with higher income or getting financial support from the developing programs in rural areas **(Galal and Khalil,1994)**.

In the last decades, the rabbit farming achieved more advancement and started to distribute in Egypt and commercial farms started to be excited. For example, in Ismailia governorates a commercial farm used 15000 does. Also, in El-Sharkia governorate the imported breeds from Hungary such as; California and New Zealand White rabbits were presented, and began to distribute in the rural areas. With this separation of rabbit, small projects were found with 1200 does.

After that, new research flocks were found and represented the cooperation between Faculties of Agriculture and international projects. For example; Faculty of Agriculture - Ain Sham University cooperated with American colleagues and used modern techniques to introduce new line via crossbreeding between Flemish Giant and New Zealand White rabbits. Also, Faculty of Agriculture, Zagazig University created a project with the Egyptian Academy of Scientific Research and Technology, this project was aimed to distribute the exotic breeds New Zealand White and California rabbits to small holders [8].

Earlier, the Egyptian scientists were attempted (through selection and crossbreeding) to generate new lines of native breeds. Started in 1937 with Giza White **(El-Khishin *et al*., 1951)**. Additionally, **Mahmoud (1938)** referred to Gabali Rabbits, which reared in the Egyptian deserts (Sinai, eastern and western) and some places in Giza governorate **(Afifi, 2002)**. Recently, Animal Production Research Institute (APRI) developed in 2009 the native breed called NMER **(Abdel-Kafy *et al*., 2011).** In addition to local breeds that called, the Baladi Black and Baladi Red **(Abdel-Kafy *et al*., 2018)**, but few studies were carried out for these native breeds **(Abdel-Kafy *et al*., 2017)**, and they need more attention especially that they are more adapted to the Egyptian environment.

The International Conference of Rabbit Production in Hot Climates (held in 1994 in Egypt), pointed to the importance to give rabbits more attention and selections programs should be carried out to improve their productivity. Moreover, this industry needs more efforts from the scientific institutes to focus and find solutions for the constraints that facing rabbit industry. And, by overcoming all the problems that facing rabbit and understanding their reproductive biology, and build up a strong background of rabbit reproduction for the breeders, thus we have made fundamental step in rabbit farming **(Ashour *et al*., 2018).**

2.1 The Origin of Egyptian Rabbit Breeds

The native rabbits that reared by small holders are the most important genetic source characterizations of rabbits in Egypt. And these native rabbits must be protected from the threats of production system and from environmental factors. Generally, **Sandford (1996)** cleared that, classification of native rabbits is depending on; color coat, eye color, body dimensions and their origin.

2.1.1 .Giza White rabbits

Giza White rabbits (Photo, 1) has been originated since a long time ago. **El-Khishin *et al*. (1951)** stated that, in 1932 a breeding program for native breeds has been carried out in Department of Breeding – Faculty of Agriculture – Cairo University. This resulted in forming breed with different colors and body size, then black and albino colors were isolated. After that in 1937 a procedure of breeding steps took place to get breed with albino color, with special characteristics of higher growth rate and litter size **(Khalil, 2002).**

This medium sized breed has smooth fur with rounded hips and shoulders are connected with middle part of the body which extended the hind quarters in order to achieve the balance between parts of the body, and they are mainly used for meat production. Their body dimensions are illustrated in Table (1) on basis of **Khalil (2002)** data.

From the experiments that started from 1971 until 1990s, the productive performance of Giza White rabbits is lower than other exotic breeds such as Chinchilla and Giant Flander White and Grey **(Khalil, 2002)**. **Afifi and Khalil (1990)** created an experiment in Faculty of Agriculture – Benha University, Moshtohor, Benha, Egypt. They worked for one year, from 1978 to 1979 and created crossbreeding between Giza White and Grey Giant Flander rabbits. They get Giza White-Grey Giant Flander (GF) and Giant Flander – Giza White (FG). They found that, maternal ability of Giza White rabbit is not efficient as Giant Flander especially in post-natal period. So, the poor maternal ability in this study may explain the limited separation of this breed on large commercial scale. Additionally, kits produced from GF and FG is heavier in body weight at birth than the kits borne from Giza White rabbit does. They concluded that, crossbreeding between Giza White and Giant Flander success in producing kits with higher economic features (higher growth rate and lower mortality rate).

Table1 Body measurements of Giza White rabbits

Item	Body measurements (cm)
Body length	25
Chest circumference	11.5
Loin width	4.6
Thigh circumference	9

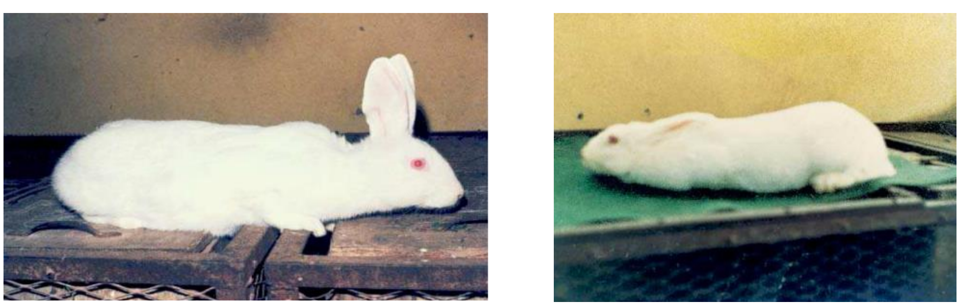


Photo 1 Male and female of Giza White rabbits

Moreover, this breed is more adapted to Egyptian climate conditions than the exotic breeds and have the ability to resist diseases. Although their milk production is lower than the foreign breeds, their milk components are much higher than other breeds **(Ibrahim, 1985)**. Also, they characterized with higher ovulation and conception rates in comparison with standard breeds in Egypt **(Khalil, 2002a).** As mentioned previously, this breed is used in meat production, but the carcass weight is lower than other breeds, and the animals can be slaughtered at 12 weeks of age **(El-Sayaad *et al*., 1990).**

2.1.2 . Baladi rabbits

The Baladi rabbit is an Egyptian rabbit that has been bred to cope with the Egyptian climate. These rabbits (Photo, 2) are medium sized and they used for meat production much like the Bauscat rabbit and as Giza White rabbits. Originated by using crossbreeding for several generations between native breeds and Flemish Giant in the Station of Ministry of Agriculture (Galal and Khalil,1994). The crossbreeding results in producing three colors; red, black and white. And all the Baladi rabbits have 1/8 of native breed and 7/8 of Flemish Giant (Imam *et al*., 2020 and El-Sayaad *et al*., 1990). The sequence of breeding adopted from Gala and Khalil (1994) are presented in the following diagram:

Baladi ×Baladi			
Selecting does with heavy weight and particular color			
	Red colored (R)	White colored (W)	Black colored (B)
Parents	♂G × R♀	♂G × W♀	♂G × B♀
F1	½ G ½ R	½ G ½ W	½ G ½ B
Parents of backcross	♂G ×½ G½ R♀	♂G ×½ G½ W♀	♂G ×½ G½ B♀
Backcross	¾ G ¼ R	¾ G ¼ W	¾ G ¼ B

These rabbits weight (in average) approximately 2.7 kg, the White Baladi rabbits have the lower body weight reaching to 2,250 kg, but both Black and Red Baldi have almost 2,850 kg. And a typical litter consists of 5-6 kits at birth. Their head is convex, eyes are black, ears are erect, feet and legs are medium in length, and their tails are short and straight. Baladi rabbits are docile and are adjusted to hot climates. They live in valleys that are about 15° to 35°C with relative humidity ranged between 25 to 75 %. All the rabbits have short fur and erect style ears **(Khalil, 2002b).** They are not recognized by the American Rabbit Breeders Association or the British Rabbit Council.

From this diagram, the heavy does of ¼ Flemish Giant and ¼ Baladi were upgraded, by mating them to pure Giant bucks for several generations and selection for pure color, Red, Black and White. Then the does of each strain were mated with buck from same strain and this operation continued for several generations until reaching to fixed colors and features **(Khalil, 2002b).** Concerning their reproductive performance, the three strains of Baladi rabbits are totally differed in their semen characteristics. The Baladi Red rabbit has the superiority in semen features **(Soliman, 1983)**. Their conception rate and general reproductive performance (Table 2) is lower than Giza White rabbits **(Afifi and Emara,1986).** Additionally, milk production and the ability to suckle their young are consider low. The total milk yield (3300g) is lower than foreign breeds like New Zealand White rabbits (7200g). But it is near to the milk production of Giza White rabbits (3700g). Unfortunately, their mother ability is week in comparison to exotic breeds as California and NZW rabbits **(Emara, 1982 and Youssef, 1992).**

All the aforementioned features could be a reason for lower litter size and weight, especially at weaning age and the increased mortality rate in Baladi Breed kits (Khalil, 2002b) The doe of Baladi rabbits has long breeding time (as Giza White rabbits), while their productivity per year is low **(Afifi and Emara,1986).**

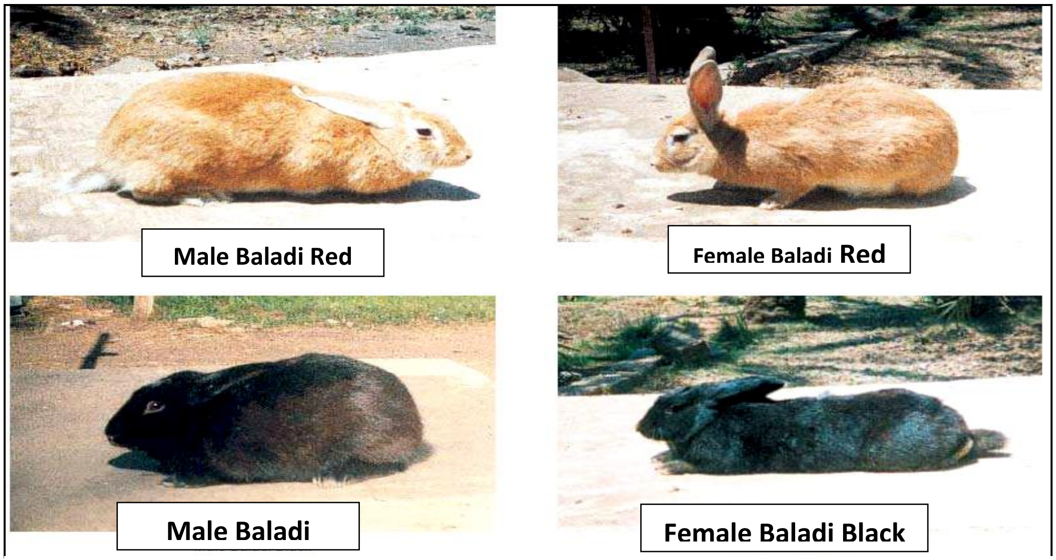


Photo 2. The Baladi Rabbits

Table 2 Reproductive performance of Giza White and Baldi rabbits

Parameters	Giza White rabbits	Baladi rabbits
Buck age at 1st service	6.2 – 8.5	6.2 – 8.2
Doe age at 1st service	6.5 – 10	6.5 – 9.5
Conception rate	65 – 80 %	42 – 85 %
Litter size at birth	5.6 – 8.2	5.4 – 6.2
Litter size at weaning (4 weeks)	3.8 – 6.4	3.2 – 6
Stillbirth	3.5 – 8.5 %	3 – 15 %

2.1.3 The Gabali rabbits

Most of Egyptian rabbit breeds are medium sized and have the ability to adapt with the climatic conditions in Egypt. The Gabali (Photo, 3) is a rare rabbit breed which originates in Egypt. It is primarily grey in color, having black or dark brown eyes, and was bred by Bedouins as meat producer. Their first identification was by **Mahmoud (1938)**, which defined as Egyptian native breed. There are two strains of Gabali, the first one is found in the northern coast and the second is living in Saini, which characterized with arid desert with two main seasons (both of them are dry seasons). The winter months started with November to March, and temperature during day light is worm while at night declined to 12°C **(Youssef *et al*., 2008)**. In Egypt, two projects were created to characterize Gabali rabbit features. First one, a project created by Desert Research Center (DRC) in 1992, and the second one (in 1994) represent cooperation between Ministry of Agriculture and Faculty of Agriculture – Benha University, in Moshtohor. The aim of this project was to clarify the genetic characteristics of Gabali rabbits and the possibility to crossbreed with New Zealand White rabbits **(Youssef *et al*., 2008).**

As mentioned previously, one of the most favorable features of Gabali rabbits, their ability to live in desert, they can tolerate air temperature until 35°C and to some extent can resist diseases **(Khalil, 2002c).** Their age at kindling is lower (7 months) than the Baladi rabbits (9 months), while it is close to Giza White kindling age (7.7 months) according to the data of **(Khalil, 1997 and Khalil, 2002c).** Actually, Gabali rabbit does have lower reproductive

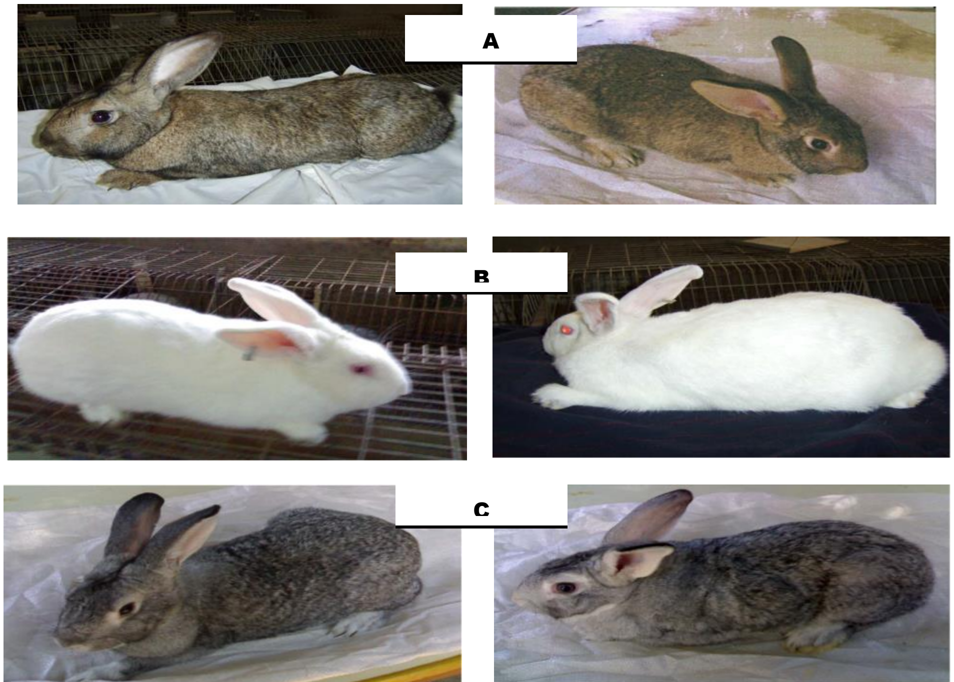


Photo 3. Male and female of Gabali rabbits

Photo 4 Male and female of Moshtohor breed. A= Yellowish color, B= White color C= Grey color (**Iraqi *et al*., 2010**).

performance, because they have longer kindling interval, ranged between 48-66 days. This is longer than the other Egyptian breeds (Giza White and Baladi breeds) as reported by **Khalil (1996 and 1999).** The litter size at birth and weaning is ranged between 5.7 – 7.2 and 3.6 – 5.8, respectively. Which to an extent is close to Giza White breed and Baladi rabbits. Their litter weight at birth is 372 g and at weaning age is 3083 g **(El-Sherbiny, 1987 & Afifi, 1997 and 1999)** In addition, their milk production is slightly lower (produce 2176 g in 4 weeks) than the exotic breeds (NZW and California rabbits) and the local breeds (Giza White and Baladi breeds).

Despite of foregoing, these rabbits are superior in semen characteristics. The sperm concentration (362 10^6/ml) and volume of ejaculation (0.68 ml). Are higher than reported in New Zealand White rabbits (329 10^6/ml and 0.60 ml, respectively) and that found in Giza White (282 10^6/ml and 0.38 ml, respectively). In addition, they have low percentage (20%) of sperm abnormalities, which is lower than that found in New Zealand White (NZW) rabbits (22%), but higher than the sperm abnormalities in Giza White (17%), according to the data of **El-Sherbiny (1987) and Afifi (1997).** Concerning meat production, these rabbits are slaughtered at age 12-14 weeks, and they have moderate dressing percentage and hot carcass weight **(Khalil, 2002c).** Many authors by **Khalil (1996) and Abdel-Aziz (1998),** illustrated the positivity of crossbreeding between Gabali and New Zealand White rabbits. Their results revealed improvement in litter size, litter weight, semen characteristics and lower mortality rate. Same results were recorded when Gabali crossbred with California rabbits.

2.1.4 Moshtohor rabbits

This new breed was created in 2006, in the Rabbitry Farm, Faculty of Agriculture – Benha University in Moshtohor (**Iraqi *et al*., 2010).** By mating does of V-Line with bucks of Saini Gabali (50×50), this crossbreeding lasted for three generations. After that, the new line was selected for increasing litter weight at weaning period. The color of this line (Photo, 4) is varied between yellowish brown, the most abundant color (56%), white (34%) and 10% for grey color (**Iraqi *et al*., 2010).**

The buck age at first service is ranged between 4 to 5 months and the same for does. With average of body weight 3114 g for male and 2865 for female, with kindling age of 5-6 months, which is lower than the kindling age of Gabali (7 months) and Baladi (9 months). As for semen characteristics, average of ejaculate volume is higher (1.6 ml) than that reported in NZW and Gabali and Giza White rabbits. The percentage of live sperm is 82% and have low sperm abnormalities (2-13%) in comparison with exotic (California and NZW) and local (Giza White and Gabali) breeds (Table, 3).

In addition, the age of slaughtering is 84 days with average of body weight 2290 g and the hot carcass weight is 1345 with dressing percent 58.9%. All the aforementioned data is on the basis of **(Iraqi *et al*., 2010)** with no more available data on the description of Moshtohor rabbits. Additionally, does conception rate is 79%, kindling interval is 38.9 days, litter size at birth and weaning is 6.94 and 5.77, respectively. And have lower abortion rate (0.6 %) and the percent of stillbirth is 3.2%. Moreover, total milk yield at day 21 is 2400, and at the day 28 of lactation the average of total milk produced is 3415 g (higher than the amount of produced milk by Giza White breed during 4 weeks of lactation).

2.1.5 APRI Line

The origin of the new line APRI was established in 2009 at Animal Production Research Institute (APRI) – Agricultural Research Center (ARC), Giza, Egypt. By crossbreeding between Red Baladi bucks with dose of V-line to get the first generation (F1). The procedure continued to get the other generations, F2 and F3. After F3, the rabbits were named with APRI line. This line, consisting of 50% from V-line and 50% from Red Baladi genes. The V-line rabbits are found at the stations of Sakha – in the Kafr El-Sheik Governorates and Gemmeza – in El Gharbia governorate, and selected for litter weight at weaning. The Institute also keeps the APRI line at Sakha Station **(Youssef *et al*., 2008)**.

Ashour *et al*. (2016) compared the productive performance of APRI line with other genotypes, NZW and Baladi Black rabbits, under Egyptian environmental conditions. They found that, litter size at birth was higher in the line of APRI than the two other breeds. While, litter weight in APRI and NZ W rabbits were almost equal (51.37 and 51.42 g, respectively) and

Table 3 Comparison between Moshtohor, Giza White and Gabali breeds

Parameters	Giza White	Moshtohor	Gabali
Buck age at 1st service (month)	6.2 – 8.5	4-5	5-7
Doe age at 1st service(month)	6.5 – 10	4-5	4.5 – 6.5
Conception rate (%)	76	79	-
Kindling age (month)	8-12	5-6	6 – 8
Ejaculate volume (ml)	0.38	1.6	0.6
Sperm abnormalities (%)	17	2-13	20
Litter size at birth	5.6 – 8.2	6.94	5.7 – 7.2
Litter size at weaning (4 weeks)	3.8 – 6.4	5.77	3.6 – 5.8
Total milk yield in 4 weeks (g)	2640	3415	2176 (at day 21)

Reference data**; Khalil (2002 a,b, c and Iraqi *et al.* (2010).**

higher than recoded in Baladi Black (48.22g) kits. The same result was recorded for litter weight at weaning. But, milk yield in Baladi Black does was higher (113.8g) than that in NZW (91.15g) and APRI does (98.69 g).

Unfortunately, there was not a specific description (for body length, eye color,…etc.) for APRI line as that found for other breeds (Giza White, Baladi and Gabali breeds), may due to few studies that concerning about the morphological features of native breeds in Egypt. Most of studies were described their productive and reproductive performance.

2.1.6 NMER Rabbits

The NMER name is the abbreviation of Native Middle Egypt Rabbit. This breed was collected from three Egyptian governorates (Map, 1); 1- Menia (Bani –Mazar, Samalot and Mghagha), 2- Fayoum (Ebshawi, Fayum and Beba), 3- Beni- Suif (Fashn and Bani-Suif). Until 2010, there were no studies that concerning about the NMER rabbits. These rabbits are reared in rural areas for the purpose of meat production. Their statics is 6600 rabbit divided into 5280 and 1320 for male and female rabbits, respectively. The total number of young kits is 15840, according to the data of **Abdel-Kafy *et al*. (2016).** The authors also described these rabbits morphologically, these rabbits have small to medium head with small neck. And their eyes is large with black color, red and dark grey colors. Additionally, the color coat is varied between grey, brown and red and in some body parts (the upper part) black or pale grey colors are found (Photo, 6)

The NMER average body weight is 1995 g with body length 33.2 cm, the abdominal girth is 28.4 cm. The ear is thin with length 8.5 cm covered by well fur, and its width is 4.4 cm. On Genetic basis, the authors found higher genetic differentiations (ranged from 0.026 to 1.743) between rabbits from Menia and Fayoum. They attributed these differences to the distance between two governorates and the natural barriers.

Moreover, **Abdel-Kafy *et al*. (2018)** continued their studies on NMER rabbits that collected from the same previous mentioned Governorates. They found that, average of heavier body weight was for rabbits from Menia (2062 g), followed by Fayoum rabbits (1691 g) and 1538 g for Beni-Suif rabbits. These rabbits almost having equal body length, 32.5 and 32.8 cm for rabbits from Beni-Suif and Fayoum, while body length in Menia rabbit was 35.2 cm. The same was for chest circumference, which was 24.2 and 23.0 and 27.4 cm for Fayoum, Beni-Suif and Menia rabbits, respectively.

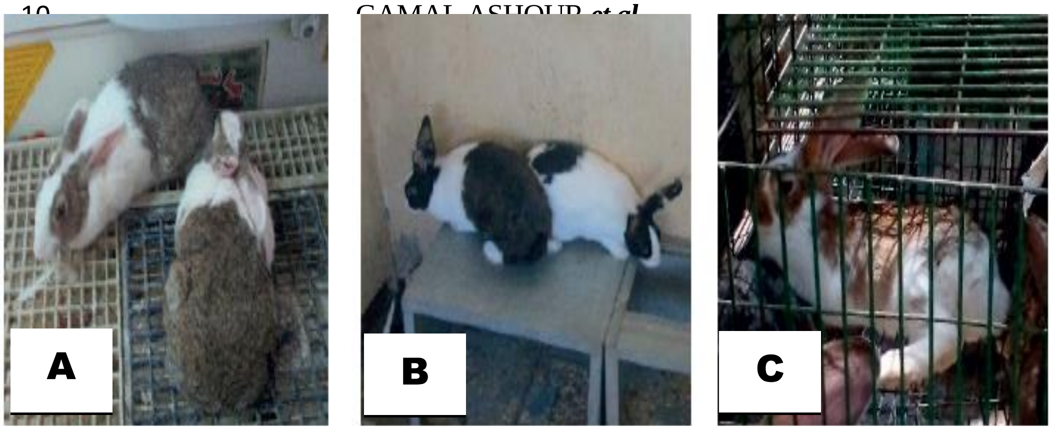


Photo 6 NMER rabbits. A= from Fayoum, B= Beni-Suif, C= Menia

Map1 Location of Egyptian Governorates

Photo 7. Alexandris rabbits. Source: El-Sabrout; El-Raffa

First description of genetic diversity was done by **Abdel-Kafy *et al.* (2018)** who stated that, native rabbits that collected from 3 different governorates almost having same ancestor. But, rabbits from Menia and Beni-Suif were genetically close to each other more than rabbits from Fayoum. And the authors suggested for more genetic studies and conservation programs for these native breeds, and they need more attention as confirmed by **Emam *et al.* (2016).**

2.1.7 Alexandria Rabbits

The Alexandria rabbits (Photo,7) were originated in 1996 at the Unit of Rabbit Breeding belongs to Faculty of Agriculture – Alexandria University. Through crossing between two breeds, V-line (87.50%) and Baladi Black rabbit (12.5%). It has erected ears, and its fur can be found in brown, tan, or a red agouti (**El-Sabrout and Aggag, 2014**). **El-Sabrout and El-Raffa (2015)** studied the genetic variations between Alexandria rabbits and the exotic breeds New Zealand White, V-Line and California rabbits using random amplified polymorphism DNA (10 primer of RAPD). They found the polymorphism between these different breeds were about 41.03% and there is a genetic variation between these genotypes.

Rabbit population in Egypt

In recent years there has been increased awareness of the advantages of rabbit projects in developing countries as a mean to alleviate world food shortages. This is largely attributable to the rabbit's reproductive and productive features. On the continents level, during the period 2000-2019 Asia success to be the first continent in rabbit stock, its contain 84.5% (Chart, 4). Followed by Europe 7.7%, Africa (8.5%) and Americans (1.9%) o of total rabbit number according to the data of **FAO (2020).**

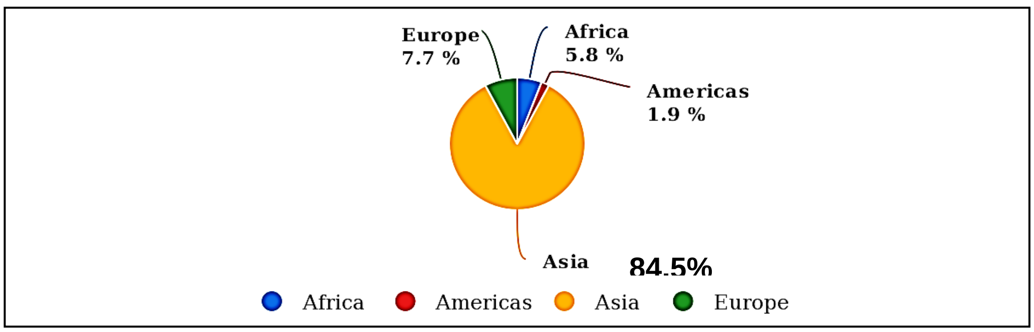


Chart 4 Rabbit stock by region during the period 2000-2019

Unfortunately, the level of people poverty in Sub-Saharan Africa is in continues increase, elevated in rural area from 200 – 220 million during the period 1993 – 2002 according to report of World Bank (2008). So, it should find tools that could use as a key to solve and prevent continues increase of poverty. Such investments in short cycle animals, such as rabbit could be helpful vehicle for those people. Based on numerous reports; **Lukefahr et al. (2000), Kpodekon et al. (2004), Owen et al. (2005) and Kaplan-Pasternak and Lukefahr (2011),** rabbit production have several economic benefits such as; 1- reducing mitigation from rural to urban areas such as in Egypt, confirmed by **Kamel and Lukfahr (1990),** 2- declining poverty level, 3- solving the unemployment of youth and 4- rabbit production is successful project, due to low investment with early and quick revenue. In addition, **Finzi (2000)** listed the benefits of rabbit breeding for small holders which are; a- can rear small numbers in the backyard, b- preparing their cages from local materials, c- can feed them on food wastes or fresh forage, d- the labor are from family itself. Therefore, in developing countries, rabbit production is an important economic project especially at small holder level (Colin and Lebas, 1996). Despite all the aforementioned advantages, rabbit production has long term contribution in reducing poverty in African countries **(Oseni and Lukefahr, 2014).**

3. 1 Rabbit Stock and Production in Egypt

The first introducing of rabbits in African countries such as Egypt was from more than 100 years ago by European colonists **(Lukefahr, 2000).**

The total number of rabbits in Egypt is 7.6 million head based on Economic Affairs Sector Ministry of Agriculture and Land Reclamation (2017). Almost 57% of people in Egypt are living in rural area and have great contribution in the field of agriculture (**World Bank, 2018**). In rural arears, small holders are rearing rabbits in lower numbers (less than 50). And usually using one buck with 8 to 10 does **(Imam *et al*., 2020).** Most of (83.4%) rabbit farming is presented in Lower Egypt. Meanwhile, 2.9% of them were localized in Upper Egypt **(Imam *et al.*, 2020).** Moreover, the production capacity (the number of kits per does) shown to be higher in Lower of Egypt followed by the Middle area (57.1 and 44.2 %, respectively), according to the data adopted from the Economic Affairs Sector of Agriculture and Land Reclamation (2017). Since 1990 until 2010, Egypt success in elevating rabbit production that increased from 15 to 41 % based on the report of **FAO (2011**) And during 1990-2010, rabbit does number elevated from 6591 to 7300 doe (Chart, 5), respectively (**FAO, 2011**). Egypt considers the largest African country in does number in comparison with Algeria, Kenya, Rwanda and Cameron. The same was for rabbit meat production, which gradually increased from 49020 in 1990 to 54600 tons in 2010 (**FAO, 2011**). Due to increased awareness of the high potential of meat rabbit production in making a positive impact on family welfare. At global level, rabbit meat production increased from 1998 to 2017 by 85%. In 1998, Egypt ranked the 4th country in meat production, produced 54000 thousand tones with share percent (6.7%) comparing with Italy, Germany, Ukraine and Korea. After that, in 2017, Egypt continued in keeping the same position in meat production, but with lower share percent (3.8%). Because, countries such as China and Korea increased their production level especially Korea (Chart, 6), increased from 13.000 to 154.000 tons of rabbit meat during 1998-2017, respectively **(FAO, 2019).**

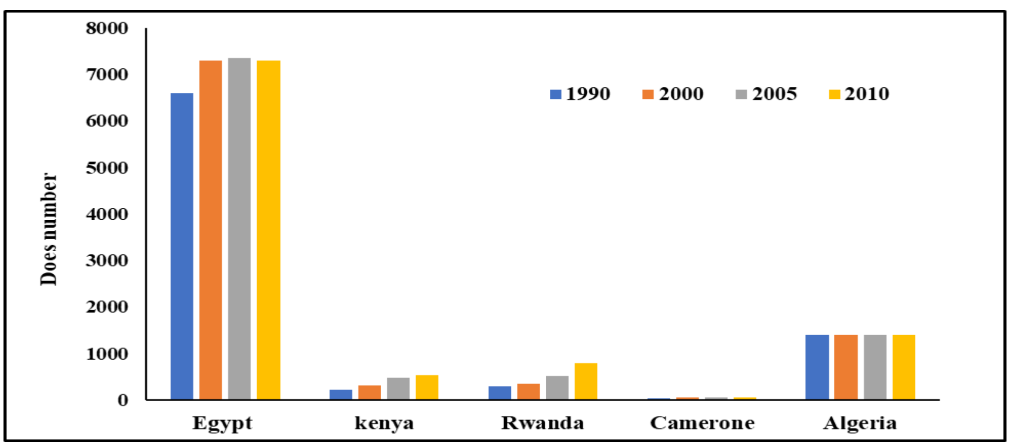
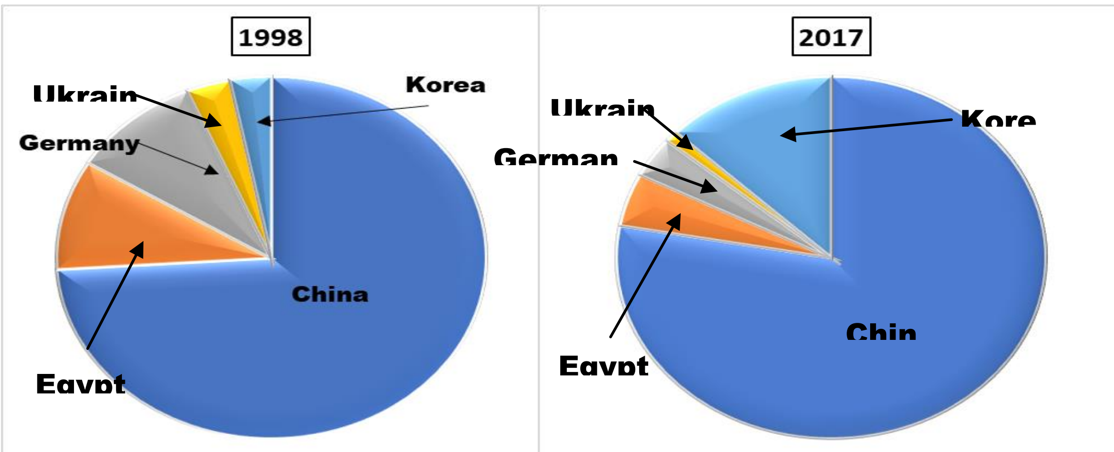


Chart 5 Development of rabbit does number in Egypt and other African countries over 20 years ago

Despite of numerous of nutritive values of rabbit meat (low fat and cholesterol content, good source of vitamin B and rich in sodium and phosphorus) its consumption comparing with other meat source is minor. At continents level, in 1998 Europe ranked the first rabbit meat producer, contributing 48% of total amount of produced meat. Followed by Asia (40%), Africa

(9%) and Americas (3%). While, in 2017, Asia success in elevating its production level and shared with 73% of total meat production, but Europe declined its production level reached to 28% from 1998 to 2017. Africa share meat production with 6% and the lowest was for Americas, recorded 1% of total produced meat (**Trocino *et al.*, 2019**).

Chart 6 Share percent of rabbit meat production in Egypt at global level during 1998-2017



Beside rabbit meat production, there are by-products from rabbits such as; fur, pelt and shorn hair that removed from skin and skin that could use as fertilizer. Unfortunately, rabbit coat under Egyptian conditions did not well study until recent time. In general, rabbit fur uses in industry is limited and their skin is not suitable for manufacturing, because of cutting into two parts and limitation of tanneries for rabbit skin **(Imam *et al.*, 2020).**

In addition, rabbit manure is another source of rabbit wastes, it used in garden and crop fertilization, and it is cheaper than other manures. Before using rabbit manure, it should apply some procedure such as; 1- using water to remove extra salts, 2- mixing feces with material have higher content of carbon. Because, rabbit feces contain higher level of nitrogen with low content of carbon and when rabbit feces mix with their urine it become toxic, so rabbit manure should well prepared before using**. Abdraboo and Fara (2008)** added 6% of organic rabbit manure to three different media; the first one peat moss with perlite, the second is sand with churched husk of peanut and sand with rice hell. To study its impact of growing and productivity of pepper and eggplant in Egypt. They found that, this treatment enhanced growth of these two plants and increased their productivity.

3.2 Efforts to Support Rabbit Production in Egypt

As mentioned previously, rabbit production in Egypt did not receive the required attention before 1980. After that, the scientific institutions started to cooperate with other institutions to support rabbit production in rural areas**. Oseni and Lukfahr (2014)** stated that there was cooperation between the National Development Agriculture Bank of Egypt and United Agency for International Development (USAID) in order to spread and increasing rabbit production in Egypt. Additionally**, Kamel and Lukfahr (1990)** created a project in the region of Esbet Badr, funded by Near East Foundation. Moreover, during the period 2003 – 2006, The International Fund for Agriculture Development provided 330 job chance for women in rural areas including supply them with rabbit batteries to encourage them to rear rabbits, according to their report **IFAD (2017).**

A cooperation between Egypt, Saudi Arabia and Spain have been created to study the adaptability of each breed used in the study and enhance their response to local environmental conditions to increase meat production. The used breeds were, V–line, Alexanderia, APRI line, Moshtohor, Saini Gabali and Saudi Gabali. The authors, **Youssef *et al.* (2008)** found the synthetic lines from V-line have good performance under hot conditions in Egypt and Saudi Arabia. And they can be used as pure breed for meat production and spread them in Delta regions, Upper Egypt (hotter than Delta) and reclaimed areas. In addition, in 2014 a project titled by; QTL and candidate genes for economic traits in rabbit with synthetic line in Egypt and Tunisia, the Animal Production Research Institute (APRI) represents Egypt in this project. Which aimed to improve the productivity of rabbits and synthesis new lines to increase rabbit production.

3. 3 Rabbit Situation on Basis of Scientific Publications

Trocino *et al.* (2019) used electronic search to clarify number of published research paper (listed in Scopus site) that are interested in rabbit production and biology. They found that, Egypt did not publish any scientific paper in journals belongs to Scopus from 1998 to 2012. Meanwhile, from 2013 to 2018, Egypt was the 6th country at global level in publishing research paper in rabbit field (Chart, 7). Actually, the Egyptian researcher in Faculties Agriculture and Institutions are working on increasing awareness of rabbit production through training courses and awareness campaigns in the rural areas. And applying different methods to increase rabbit productivity and reproductive performance.

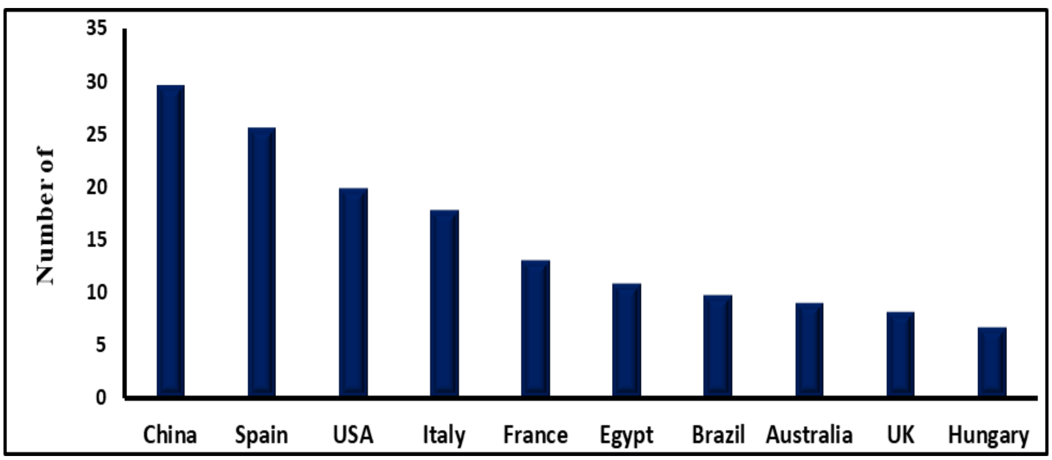


Chart 7 Egypt's world ranking in international publishing (in the field of rabbit science) during the period 2013-2018

3.4 Constrains of Rabbit Production in Egypt

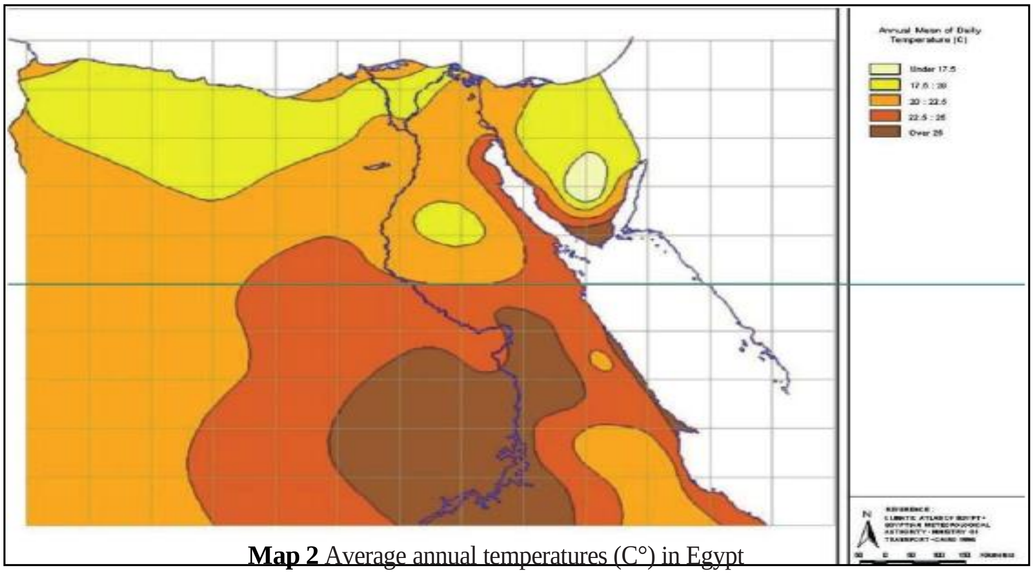
Almost there is no specific market for rabbit meat only in Egypt or limited. This problem can largely be prevented by conducting market research and evaluation in the economic feasibility. The limited market leads to low consumer demand, insufficient promotion, erratic product supply, unreasonable prices, competition from other meats, lack of product diversification and poorly developed marketing channels (**Lukefahr and Goldman, 1985 & Bondoc *et al.*, 1986).** In addition, heat stress is the main factor in limiting rabbit production in Egypt and leading to shortage of breeding season. **El-Rafaa (2004)** discussed all the negative impact of heat stress on rabbit performance. Causing infertility, decreased feed intake, lower growth rate, increased kit mortality rate, and it will discuss in details later. Studying the biology of rabbit reproductive performance need more studies which help in knowing the accurate way in rabbit breeding (**Ashour and Abdel-Rahman, 2019**). Finally, to increase rabbit production system it needs deep studies on socio-economic aspects to identify well the major constrains that limited their production system and what are the suitable solutions that can be applied.

4. ***Climate Change and Rabbit Production in Egypt***

Climate is the average weather conditions experienced in a particular place over a long period. Weather is the state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity and barometric pressure for short period of time. Climate can be divided in to two types; microclimate and macroclimate. Microclimate is the climate of a very small or restricted area, especially when this differs from the climate of the surrounding area. Macroclimate is the climate prevailing over a large area i.e. country, continent or the planet (**Padodara and Ninan, 2013**). Egypt could be characterized as arid area because most of it is a desert area, so its climate is hot and dry (Map, 2). Since the period of 1961 till 2000, the average of air temperature in Egypt increased about 0.34/ decade. **Domroes and El-Tantawi (2005)** reported that Egypt gets a wormer trend in the south areas during the period 1941 to 2000 but cooler in the northern part. Meanwhile, in the year 1971 till 2000 the worming trend presented in all stations. Wherefore, Egypt is one of the most vulnerable countries that face the impact and risks of climate change as described by United Nations Framework Convention on Climate Change (EEAA, 2010). In the same manner, **Nardone *et al.* (2010)** stated that by year 2100 mean global temperature may be 1.1-6.4°C wormer than 2010.

Changes in the climate (which is associated with increasing global temperature) are caused by humans, mainly due to greenhouse gases resulting from burning of fossil fuels which lead to the production of CO_2 and methane (**Padodara and Ninan, 2013**). Egypt sharing less than 1% from the global greenhouse gas emission, where the first national communication record 116 million tons of carbon dioxide equivalence for the base year 1990 rose to 193 million tons in year of 2000. Also, deforestation reduces the capacity to store carbon, and the carbon is released in the atmosphere. The gases, especially CO_2, act like a blanket and restrict the rate at which earth's surface can radiate heat to space resulting in global warming (increases the temperature and humidity). The increased temperature affects both plants and animals, in grazing plants the characteristics of these plants are changed through increases lignification's of plant tissues and therefore reduces the digestibility (**Padodara and Ninan, 2013**). In animals, when the environmental temperature becomes near the body temperature, high ambient relative humidity percentage (RH%) reduces evaporation, overwhelms the cooling capability, and the body temperature rises. This is due to the negative effects of high RH% on dissipation of body heat, because of the decline in effectiveness of radiation, conduction and convection. In addition to the decline in the efficiency of evaporative cooling needed to maintain the heat balance (**West, 1993**).

High temperatures, as encountered in Egypt and in many other countries during the summer, is a major constraint factor for rabbit production. Rabbits are very sensitive to heat stress since they have few functional sweat glands which means they have difficulties in eliminating excess body heat when the environmental temperature is high (**Marai *et al*., 2002**).
Rabbit is homoeothermic animal they can regulate their body temperature through several process including; physical, behavioral, biochemical and morphological process (**Marai and Habeeb, 1994**). The thermo-neutral zone (TNZ) temperature in rabbits is around 18–21 °C ((**Marai and Habeeb, 1994 & Habeeb *et al*., 1998)**.



Map 2 Average annual temperatures (C°) in Egypt

Thus, when rabbits are exposed to elevated ambient temperatures (Ta) imbalances are induced in their body temperature (**Marai *et al*., 1996 & Habeeb *et al*., 1999**), which adversely affect their growth and reproductive traits (**Habeeb *et al*., 1996, Marai *et al*., 2001, Okab AB, El-Banna, 2003 and Okab *et al*., 2008).** Adult rabbits were better able to respond to hyperthermia conditions and to adapt themselves to conditions of decreased ventilation and evaporation, compared with young rabbits which responded more sensitively to elevate temperature (**Ayyat and Marai, 1997).**

4.1 Rabbit Thermoregulation

Generally, diurnal changes in rabbit's body temperature is not affected by the changes in air temperature during the day (changed in a very short range, 0.2-0.3°C) which revealing a high efficiency of body heat regulation in rabbits, but it is highly affected by monthly air temperature changes (**Shafie *et al*., 1970**). Rabbits can live safely at 21°C [79], the ideal environmental temperature range for rabbits should be 16-21ºC for does and 12-16ºC for bucks which is known as comfort zone (Fig., 1) and rabbit tolerant to low temperature than the higher one (**Lebas and Matheron, 1982**). In cold conditions, when environmental temperature is below 10°C rabbits are curl up to minimize the total area of losing heat and lower their ear temperature. Also, rabbits consumed more feed to maintain body temperature and poorer feed conversion occurs. So, it very important to provide extra feed in these conditions. But, it must be noticed that the sudden drop in temperature triggers an increase in feed intake could cause carbohydrate overload, proliferation of pathogens in gut with the production of lethal toxin.

With increasing environment temperature rabbits stretch out to lose as much heat as possible by radiation and convection and step up their ear temperature (**Lebas *et al*., 1986).** The average body temperature of rabbits is about 39.5°C, respiration and pulse rates per minute are 168 and 235, respectively in NZW rabbits **(Lee *et al*., 1976).** While, White Egyptian Giza rabbits, the respective values are; 39.4°C, 85 and 137 cpm under summer conditions of Egypt (**Shafie *et al*., 1982**). When air temperature increased two folds from winter to summer, respiration rate increased by 70% than in winter **(Shafie *et al*., 1982**). Meanwhile, NZW rabbits increased by triple when air temperature doubled and ear lobe temperature increased at summer by 70% of its value of winter (15°C difference). So, respiration, pulse and ear lobe rates are

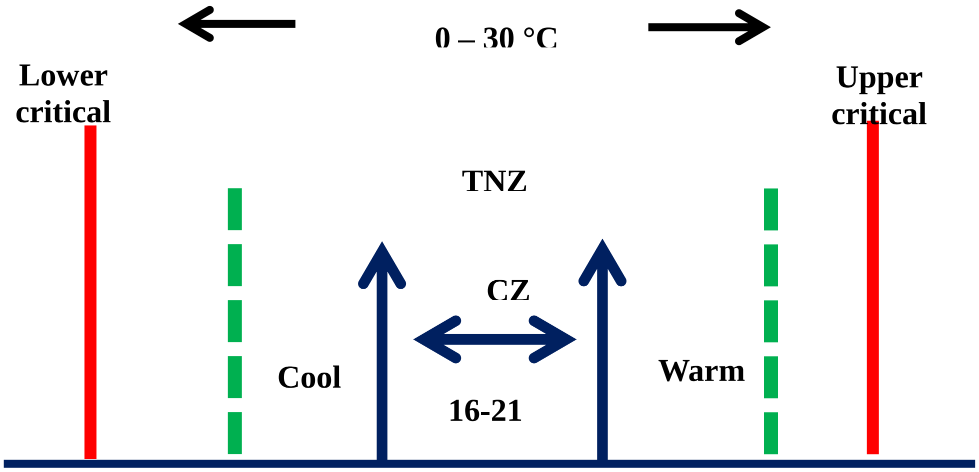


Fig. 1 The thermal nutria zone (TNZ) in rabbits

highly affected by monthly air temperature changes **(Shafie *et al.*, 1970).** In addition, **Marai and Habeeb (1994)** stated that in nonfunctional sweating gland like rabbits, respiration rate goes up by 5-6 for each 1°C increases in air temperature (to accelerate evaporative cooling) and slight change in pulse rate due to variation in air temperature probably a counter mechanism to vasodilatation in ear lobe, indicating that, particularly, the two reaction; respiration rate and ear lobe temperature and the major physiological process, that regulate body temperature against any environmental changes. Above 35°C rabbits can no longer regulate their internal temperature (**Lebas *et al.*, 1986).** At 40°C considerable panting and salivation occurred and concentration of hormones and enzymes decreased significantly as a function of heat stress in an attempt by animals to diminish heat production to counteract the increased heat load **(Shafie *et al.*, 1982).**

4.2 Implications of Heat Stress on Rabbit Reproductive Performance

Generally, Stress is revealed by the inability of an animal to cope with its environment, which resulting a failure in growth rate, milk production and fertility (**Dobson and Smith, 2000).** Reproductive efficiency is the major factor affecting profitability in many livestock production systems. Inefficient reproduction may be caused by numerous factors, which include environmental stressors such as temperature extremes or changes in photoperiod (day and night cycles), light intensity, humidity, rainfall and wind speed (**Etim *et al.*, 2013). Lewis *et al.* (2006)** also, reported that flock reproductive efficiency is an integrated measure of; age at puberty, capacity to produce and deliver adequate numbers of fertile spermatozoa, ovulation rate, ovum fertilization rate, embryo and fetal survival to weaning, interval between pregnancies, reproductive lifespan, and ability to cope with a variety of environmental stressors.

4.2.1 In Rabbit Bucks

Generally, heat stress has negative effects on sexual behavior semen volume, concentration and mass activity of semen samples and measurements of both tests and scrotal (**Chnadra *et al.*, 2015**). In previous studies, it was observed that high temperature levels altered the performance of growing rabbit and their plasma androgen and thyroid hormone profile (**Boiti *et al.*, 1992). Chandra *et al.* (2015)** cleared that, heat stress has negative impact on spermatogenesis by eliminating permatogonial germ cells in seminiferous tubules and degeneration of Sertoli and Lydig cells.

Also, decreases spermatozoa storage in oviduct results in fewer spermatozoa cells available to bind, penetrate and fertilize the egg. Also, heat stress is causing oxidative stress which results in DNA damage and apoptosis in germ cells. **Chiericato *et al.* (1996**) found that environmental temperature resulting in a decrease in testosterone level in growing rabbits. It must be focused on the positive effect of nutrition level on plasma androgen concentrations. Probably, as a consequence of higher intensive feeding plan adopted, the rabbits reached sexual maturity earlier (**Chiericato, 1984**). Testosterone is the main circulating androgen of testicular origin, it is vital in maintaining libido, body fat, maintaining muscle mass, bone density and the regulation of blood sugar (**Yahaya and Ajuogu, 2014**). Both, **Brownlee *et al.* (2005) and Khalil *et al.* (2015**) stated that, there was negative correlation between level of plasma cortisol (stress hormone) and plasma testosterone. The hormone of cortisol (its metabolism is shown in Fig., 2) produced from the zonal fasciculate of the adrenal cortex and is needed in times of stress to maintain blood glucose levels and prevent shock. Cortisol regulates its own secretion by a negative feedback effect on the hypothalamic-pituitary-adrenal axis (**Burtis, 2006**). It has been shown that temperature is an important factor in the regulation of its release **(Squires, 2003). Kalaba (2012), Tanchev *et al.* (2014) and Khalil *et al.* (2015**) recorded that, growing rabbit that exposed to short term heat stress leads to an increase in the levels of ACTH and cortisol in blood of California rabbits.

4.2 *2 In Rabbit Does*

In Egypt, the reproductive efficiency of rabbit does during summer season is declined for many reasons mainly, increased the ambient temperature and poor management through low plane of nutrition (**Shafie *et al*., 1984**). This cause a limitation in breeding season for rabbits which begins in September and ends in May. Many studies have been reported that, the conception rate in rabbit does decreased during summer season. **Shafie *et al*. (1984)** recorded (**Hahn and Gabler, 1971**) that; conception rate declined from 66% to 33% when rabbit does exposed to highly environmental temperature (35°C). In the same manner, thermal stress causes reduction in ovulation rate (and percentage of corpora lutea associated with the number of

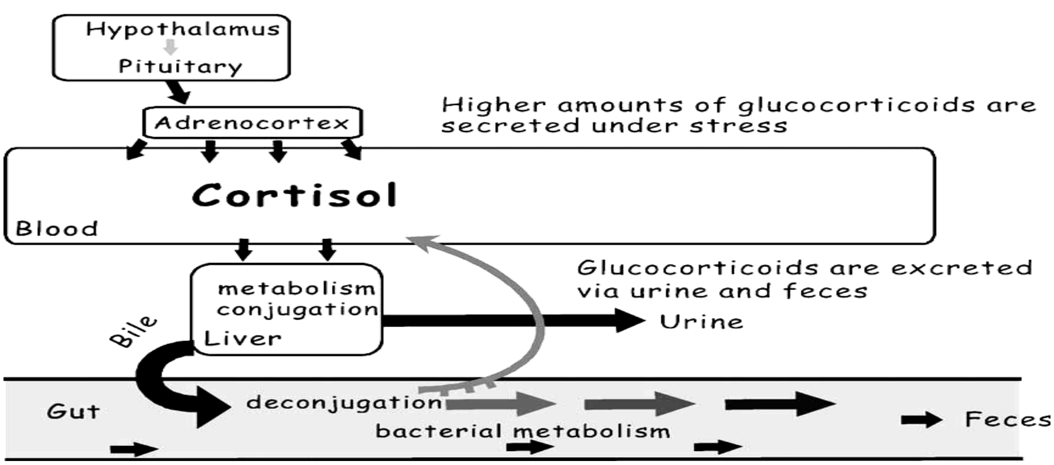


Fig. 2 Scheme of the secretion, metabolism and excretion of glucocorticoids (**Möstl and Palme, 2002)**

implantation sites/ doe and number of viable embryos per doe. **Yassien *et al.* (2008)** stated that, high environmental temperature affects the development of mature ovarian follicle thus reducing conception rate in rabbit does by 37.5% in control group compared to treated groups with Vit. C and cooled water. Also, they stated that, number of oocyte and number of oocyte per ovary decreased in rabbits exposed to environmental temperature ranged between 27-35°C which was 71 and 7, respectively in control group. Meanwhile, in group of Vit. C and cooled water the values were 83, 8.2, 79 and 7.9, respectively. It is important to know that, the preovulatory follicle is a key component of reproductive system and when animal exposed to thermal stress this leads to an impairment of its function thus affects the other reproductive events such as, secretions of gonadotropin, progesterone (P4), which decreased when animal exposed to chronic heat stress not the acute one. So, P4 still high when animal exposed to acute stress because of elevated adrenal secretion of P4, estradiol (E2) and subsequently the development of corpus letuem (CL) and embryo (**Chandra *et al.*, 2015**)

The impact of heat stress on the follicles development could be explained according to **Chandra *et al.*(2015**) who stated that, thermal stress caused a reduction in glucose and IGF-I concentrations, both are important for the follicle development and quality of oocytes. Also, they mentioned that, heat stress causes the development of non-ovulatory or cysts follicles through its effects on the secretion of LH and E2 and therefore a reduction of follicular dominance and the secretion of inhibin from granulose cell decreased, thus alters the FSH. Moreover, they mentioned that, the early stage of pregnancy is very sensitive to the thermal stress thus increases the percentage of apportion.

Concerning the other reproductive merits of rabbit's doe, **Ashour *et al.* (1995**) compared the reproductive performance of 27 rabbit does at two different environmental conditions; artificial heat stress (HS) 35±2°C and natural winter thermal (WT) condition for 4 months. They found that weight of ovary, uterus and number of embryos decreased in heat stressed rabbits but number of corpora lutea did not affected by HS. Also, they recorded that, P4 level decreased during first and second parities in HS group in comparison with WT. Meanwhile, in third gestation the decline in P4 is less (7%); this is due to sort of adaptation. The same results obtained by **Gad *et al*. (1995)** they recorded elevation in P4 level in winter season than the summer in both New Zealand Whit rabbits (NZW) and Egyptian Baladi Red rabbits (BR). Additionally, litter size (LS) decreased due to the negative of heat stress as found by **Ashour *et al*. (1995)** recorded a reduction in LS at birth (10%) in heat stressed group (35±2°C) during the first and second parities.

Additionally, Mortality rate (MR) increased by heat stress as recorded by **Shafie *et al.* (1984)** which was 31.8% under Egyptian summer condition compared to winter condition (17.2%). The same was confirmed by **Ashour *et al*. (1995)** recorded increases in MR from birth till weaning by 23% in the first parity but lower in the second one; this could be attributed to increased mother ability and its fewer drops in milk production. The MR in rabbit breeds during summer heat stress is differ as found by **Gad *et al.* (1995**) who stated that during the first and second parities in summer season the MR was 45 and 31%, respectively. Meanwhile, lower MR was recorded in BR rabbits (8 and 15% during first and second parities), and that cleared the ability of Egyptian native breeds are more adapted to Egyptian environmental conditions than the exotic one. As for the daily milk production (DMP), above 20°C, DMP declined by 7.7% with every increase in air temperature by 1°C and expected decline will be observed in the 3rd week of lactation (Rafai and Pappu, 1984) This was previously confirmed by **Ashour *et al* (1995)** reported a decline in DMP by 20% in the third week of lactation during the first and second parities. They attributed this decline to the negative effect of HS on hypothalamus then on the pituitary gland. Thus affects the doe appetite resulting in less consumed feed and consequently affects milk production. The same finding was recorded by **Gad *et al.* (1995)** especially in the first parity but they found that in the second party DMP affected by heat stress at the 4th week of lactation; this is due to the better mother ability and more mammary gland growth.

4.3 Climate Change and Rabbit Meat Production

Due to numerous characteristics of rabbits, higher growth rate, short production cycle and their superiority in conversion efficiency. They considered the best animal for meat production (**Jiang et al., 2020**). Unfortunately, their meat consumption is facing such problems, perceived as pets and from economic view rabbit meat prices is not competitive with beef cattle. Rabbit meat has addition advantages via producing little amount of greenhouse gases. **Vayssieres *et al.* (2010**), calculated the amount of greenhouse gases that produced from 1 kg rabbit meat in comparison with beef, dairy cattle and ham. They found that, total emission of CO_2 was 83.2 kg CO_2 – eqkg^{-1} protein, while beef cattle produced 239.7 kg CO_2 – eqkg^{-1} protein. Additionally, the amount of enteric methane produced from rabbit meat was lower (2.3%) than beef and dairy cattle (65.5% and 26.2%, respectively) and ham (6.1%). Also, rabbits are economic animals, they can convert 20% of protein into meat. They are efficient in energy use (EU), they use energy less than cattle. Rabbits use 0.15 kg crude energy/ kg fossil energy. While beef cattle use 0.37 kg crude energy/ kg fossil energy. As mentioned previously, rabbits are sensitive to heat stress, which affects negatively on their body weight, feed intake, changing in feed consumption, impaired appetite and impaired feed conversion therefore rabbit meat production will be affected (**Cesari *et al*., 2018**)

So, to mitigate or reduce the impact of heat stress suitable strategies should be applied:

1. Using efficient and high producer breeds, for example; in meat production the heavy with medium size breed are recommend in intensive system and search in carful way for the suitable productive breed (**El-Raffa, 2004**)
2. Good experience in providing management for rabbits, especially during heat stress
3. Providing hygiene programs, to limit medications usage and the costs of it. Because all the drugs are considered as poison and may not work correctly and the animal may die, and must use according to special instructions. Thereby, hygiene is a key for successful rabbit breeding **(El-Raffa, 2004**). Additionally, rabbit must keep away from noise, strangers, cat and dogs. It should be noticed that, team work is considered as a vector disease for rabbits and may transfer contaminates from outer environment to rabbit house. The workers in rabbit farm must change their clothes before entering to rabbits and wearing footgear (**El-Raffa, 2004**).
4. Using suitable feeding system; **Cesari *et al* (2018)** stated that, it could replace some of soybean meal with protein alternatives such sunflower meal during hot season
5. Suitable house and design and providing good ventilation, and protect them from heat load, rain, and rodents (El-Raffa, 2004). In Egypt, **AboZaher *et al*. (2020)** stated that, one of most important factors to control heat stress is design rabbit house to be comfortable during this critical period. The authors used evaporative cooling fan pad, depending on water supply with pump (373W). They put this cooling system in the Southern wall and calculated temperature humidity index (THI) and house heat balance (HB). The HB was calculated according to equation of **Field and Long (2018);** ± heat (kW) = total heat gain – total heat loss. They found the inner temperature of rabbit house was 26.85°C and relative humidity was 67.83%. Thereby, this system success to provide the required environment for rabbit during summer season.
6. Providing sufficient water (clean, fresh and cooled water).
7. Providing comfortable cages, keep enough space for each rabbit for breeding and rearing. The cages should be clean and avoid any feces traces that stuck on cages wire. And provide ice sacs inside cages (**El-Raffa, 2004**)

8. In case of meat production, according to **Cullere and Dalle Zotte (2018**), most of rabbits are semi-automatic, so applying automation for rabbit may help in reducing impact of heat stress.
9. Planning carefully for reproduction system that will apply during hot season to maximize doe productivity (number of kits produced from each doe per unit of time). It depends on production system (intensive, semi-intensive or extensive). To maximize doe productivity, the non-productive period (the period between kindling to mating interval should be declined (**El-Raffa, 2004**). In some studies, recommend 33 days cycle is suitable to increase rabbit productivity. But, during hot season the 42 days cycle is recommended strongly to save rabbit productivity in this period (El-Raffa, 2004). And when rabbits are extremely stressed it should stop mating to prevent new stress on them
10. It recommends to spray the outer wall and roof of rabbit house with water.
11. Keep rabbits away from direct ventilation to prevent respiratory diseases.
12. Inject kits with vitamins such as D, E especially during hot season.
13. Avoid and separate any rabbit that suffer from illness.

4. Rabbit reproduction

According to the **FAO guidelines (2007**) most rabbit breeds have been included in the national programs of genetic resources conservation. Native rabbit breeds by smallholder under low-input systems consider as important genetic resources because of their adaptation to harsh environmental conditions and their tolerance to a wide range of diseases**,** specially that the role of rabbit breeds selected for meat production, has dramatically decreased **(Jochová *et al*., 2017**)**.** Accordingly, local breeds should be protected against any threat factors as a priority of sustainable management **(Nyamushamba *et al*., 2017**) Genetic resource banks (GRB) are a valuable tool for maintaining genetic variability and preserving breeds from pathogens or catastrophe, enabling us to assess and correct breeding schemes, minimizing the impact of genetic drift and facilitating diffusion, Our study demonstrated that our GRB of embryos vitrified 15 years ago is a successful strategy to re-establish rabbit populations to continue the breeding program **(Marco-Jime´nez *et al*.**, **2018).**

From the reproductive point of view, **El-Ratel (2012)** stated that, the high reproductive efficiency of rabbits allowed their usage as a model in basic and applied reproductive technologies such as artificial insemination (AI), in vitro fertilization (IVF), intra-cytoplasmic sperm injection (ICSI), embryo transfer (ET) and cloning by somatic cell nuclear transfer. Improving the genetic selection and reproductive management increased commercial rabbit breeder profitability.

5.1 Seasonality in Egyptian Rabbit Breeds

In Egypt, the environmental temperature is considered to be high during the period from end of March to mid of October, with slight decrease in December to March. In summer season, the surrounding temperature increases, causing negative effects on rabbits productivity. Heat stress is one of the most serious problems facing rabbit production in Egypt; it influences each of animal welfare, performance, yield and quality of products (**Barakat, 2000 Khalil *et al.,* 2006 and El-aaser, 2007**). Although the productivity is drastically affected by high temperature, but also the reproductive performance of both bucks and does is also affected, **El-Sayed *et al.* (2016)** noted that in Gabali rabbits the effects of season had a significant impact on reaction time, individual motility %, live spermatozoa %, sperm abnormalities % for total, primary and secondary abnormalities and sperm cell concentration. On the other hand, a non-significant effect was observed on ejaculate volume due to season. They concluded that, male Sinai Gabali rabbits have good reproductive performance during winter months under conditions of Egypt and more adapted in winter months than summer months. Rabbit does are also affected with the surrounding environmental conditions, **Daader *et al*. (2016)** stated that, heat stress, occurring in hot regions, alters several aspects of reproductive functions in female rabbits such as hormonal secretions of the hypothalamo-pituitary-gonadal axis leading to infertility. It also depresses appetite resulting in negative energy balance. Later, **Khalil (2018)** reported that gestation period significantly (P<0.05) varied according to the environmental conditions, as well as, litter size and litter weight (gm) at the different season studied were significantly (P<0.05 and 0.01) higher during the mild conditions than the hot season.

5.2 *Effect of management and breeds in relation to rabbit reproductive performance in Egypt*

Since environmental factors had severe effects on productive and reproductive performance of farm animals (**Attia *et al.,* 2013**), animal management seems to be a very important topic to tolerate animals saving their high or at least their normal productivity. The surrounding environment includes temperature, lighting periods, feeding and watering system …..*ect*. In this regard, **Attia *et al.* (2015)** reported that well water and poor water quality induced a significant decrease in semen quality and hence fertility of males**.** Whereas magnetic treatment improved water quality and in turn semen quality, blood picture and antioxidant status and hence buck fertility. **Gado *et al.* (2015)** revealed that, animals fed *ad libitum* on a basal diet supplemented with a multi-enzyme complex (EZ, including cellulases, xylanases, protease and α-amylase) increased (*P*<0.05) sperm transit in estrus doe cervical mucus, as it improve both semen characteristics and sexual drive.

Habeeb *et al* (2008), concluded that the high quality and quantity of semen were found in the groups exposed to normal day light under winter season. Meanwhile, the short daylight during summer season seemed to be affecting adversely semen quality traits. Finally, the overall results of this study clearly indicated that the highest permitted level of photoperiod for buck rabbits under Egyptian conditions should be around 12-13h daily during the whole year. **Mousa-Balabel and Mohamed (2011**) results revealed that exposure of rabbits to long photoperiods (14 and 16 h light) or treatment with melatonin improved the quantity and quality of ejaculate traits and buck sexual activity as well as doe's sexual receptivity, feed intake, litter size, weight at birth and time-to-weaning. On the other hand, gestation period and pre-weaning mortality percentage decreased. Application of long photoperiods is beneficial to rabbit producers and 14 h light combined with 10 h dark is optimal for satisfying the physiological requirements of the rabbits.

Finally, from an economic point of view, the light schedules are cheap and easy to apply and can be used as biostimulation instead of melatonin. More recent, **Daader *et al.* (2016**) declared that daily lighting period control favorably affects doe reproduction performance.).**Badawi and El-Aasar (2018**) noted that conditioning rabbitry significantly (P≤0.05) improved improved net revenue and relative economic efficiency as compared to un-conditioning group.

The results also indicated that, scrotal circumference, testicular index and mating activity, as well as, female and male sexual hormones were significantly (P ≤ 0.05) higher in conditioning rabbitry than un-conditioning ones. Also libido and physical semen quality of bucks, and fertility traits of does mated naturally or inseminated artificially were significantly (P ≤ 0.05) improved by conditioning the rabbitry, in different investigated breeds, although **Khalil *et al*. (2014**) previously reported that libido and semen characteristics in Balady red (BR) bucks seems to be better than those recorded by the NZW bucks. However, productive and reproductive efficiency in NZW does appears to be higher than those obtained from BR breed, under the same managerial conditions.

5.3 Rabbits' Semen Manipulation

To date, in rabbit farms AI is performed with fresh or cooled semen rather than frozen semen because of the poor fertility results after thawing (**Mocé and Vicente, 2009 and Lavara et al., 2017**). Rabbit semen freezing protocols have been studied by many authors for creation of rabbit semen cryo-banks (**Iaffaldano *et al.*, 2012, Kuliková *et al.*, 2014, Di Iorio *et al.*, 2018 and 2020)**. Many studies have been performed to find out what the appropriate sperm dose is when using frozen semen for artificial insemination. However, the optimal number of frozen spermatozoa, in order to reach effective reproductive performances, is highly variable because it largely relates to the experimental conditions and the physiological status of the does at the moment of the insemination. In addition to the improvement of semen diluents for semen preservation. **T-Allah *et al.* (2016)** declared that the use of artificial insemination technique in rabbits with recommendation of using second ejaculate semen sample and egg yolk citrate as diluent leads to significant increase.

Recently, **Abdelnour *et al.* (2020)** noted that the addition of curcumin and its nanoparticles to the tris yolk fructose (TYF) diluent can improve the post-thawed quality of rabbit sperm, namely the progressive motility, viability, membrane integrity and sperm ultrastructure of post-thawed rabbit semen.

5.4 Artificial Insemination in Rabbits

The AI of rabbit does appear on European farms in the late 1980's (Theau-Clement, 2007). Later the technology was extensively used in the rabbit's industry in both small farms and in the wide scale rabbitries (**El-Gaafary and Marai,1994**). Although, Soliman and **El-Sabrout (2020**) reviewed factors affecting the success of AI application in rabbits, in term of semen collection, dilution degree, protocol of hormone injection date, equipment, duration of semen storage, technical of AI procedure, as well as the costs of these steps. This may suggest the need for private companies for rabbit semen collection, dilution, conservation and AI application in small farms. But still the application of AI help maximizing the financial profit of the rabbitry by reducing the number of pen-raised bucks and, consequently, the number of non-productive cages (**Seleem and Riad, 2005**). When AI is applied in a rabbitry, it is estimated that one single buck may affect the fertility and prolificacy of about one hundred does (**Seleem, 2005**). For smallholders Soliman and **El-Sabrout (2020**) assumed that **a**rtificial insemination in developing countries for rabbits could be difficult for the smallholder of rabbit farms especially that they depend on small rabbit flocks. Meanwhile, **T-Allah *et al.* (2016**) studied the effect of mating technique (natural mating and artificial insemination) on the productive and reproductive traits of different breeds**.** They reported that the use of artificial insemination technique in rabbits leads to significant increase in litter size and decrease in number of service/conception but on the other hand it affects the daily weight gain which is a disadvantage can be avoided by fostering.

5.5 Hormonal Manipulation of Female Rabbits

Ovulation and fertilization rates in rabbits are the most important traits which affect directly the viability of their young and litter size at birth (**El-Ratel *et al.*, 2017**). In the rabbit doe, ovulation does not occur spontaneously, but it has to be induced through a neurohormonal reflex, which is initiated during mating. When using AI, in the absence of a male, ovulation has to be induced by artificial hormonal stimulation. The ovulation inducing methods most frequent used is an intramuscular application of GnRH. Most frequent method is an intramuscular administration of gonadotropin-releasing hormone (GnRH) or its synthetic analogues (**Quintela *et al*., 2004**). However, some of the exogenous hormonal substances used for this purpose may negatively affect rabbit welfare and cause fertility disorders in does (**Zapletal and Pavlik, 2008**). **Dimitrova *et al.* (2009**) showed that, the scheme of hormonal stimulation using only GnRH application – 0.2 ml intramuscularly at the moment of insemination was more effective for insemination of both nulliparous and multiparous rabbit does. Later, **Zhang and Qin (2012**) confirmed that inclusion of the GnRH analogue leuprorelin in the seminal dose induced doe ovulation, and led to the same reproductive performance obtained with the intramuscular method. More recent, **Munari *et al* (2019**) studied the effect of possible alternative methods for ovulation induction in rabbit does by the GnRH analogue lecirelin acetate could be administered by inclusion in the seminal dose during insemination rather than intramascular injection to reduce stress on animals they figured up that that the incorporation of GnRH in a seminal dose could be used for ovulation induction in rabbit does. In rabbits, ovulation could be induced by hormonal treatment as GnRH agonist, which had a direct effect on the ovary (**Mobarak *et al*., 2015**). The GnRH analogue had efficiency of about 15 times stronger than that of natural GnRH (**Tarlatzis and Kolibianakis, 2007**). Injection of GnRH or its analogue could improve fertilization and Conception Rate (CR) by increasing level of plasma LH and FSH in rabbits **(Zhang and Shang,2009).** The GnRH can be repeatedly injected without eliciting antibody formation. **El-Ratel *et al.* (2017**) study concluded that rabbit does injected with GnRH analogue (Receptal) at a level of 0.25 mL doe at mating on day 10 post-mating resulted in remarkable improvement in in vivo reproductive performance in terms of higher kindling rate, litter size and kid viability rate at birth and weaning.

Recently, **Boudour *et al*. (2019)** stated that rabbits' receptivity is influenced by the mode of ovulation induction. Indeed, the rabbits in which ovulation is induced by GnRH have a significantly greater receptivity and fertility rates and prolificacy compared to females for which PMSG and the infertile male have been used. It is also concluded that in rabbit does having low reproductive performance which may be output due to increase plasma progesterone concentration or/and advance age, the PGF2α could be effective in removing the progesterone block and improving the most of reproductive parameters studied (**Abdel-Azeem *et al*., 2011**). However, further researches are needed in order to not/minimize future use of hormones (PMSG and GnRH) for AI in rabbits, either for the availability of bio-stimulation methods to synchronize rabbit doe estrus or natural substances in seminal plasma for rabbit ovulation, as **Daader *et al.* (2016)** reported that using hormones in rabbit reproduction technology management becomes unfavorable from the welfare point of view. Bio-stimulation methods are natural and are an alternative to hormonal treatments. These methods include doe-litter separation (DLS), lighting control and male proximity.

5.6 Embryos Manipulation in Rabbits

The rabbit has been an important animal in the study of reproductive biology, for example, Sexing of X- and Y-chromosome bearing sperm based on the difference in DNA content is the most reliable and repeatable method to produce sex-preselected animals. Since the first report by **Johnson *et al.* (1989**) in rabbits, flow cytometric sexing technology has been shown to be efficacious in several species.

Expanding knowledge on the embryology of the rabbit, the effective cryopreservation of embryos and the reproductive particularities of the rabbit allowed the development of embryo reproductive techniques. The first successful embryo transfer experiment in rabbits about 100 years ago (**Biggers and WalterHeap,1991**). Since then, these techniques have been successfully applied in the rabbit industry and have been extrapolated to other species. There are clear advantages in the use of rabbit for embryo studies. Since the 1970's, rabbit embryos can be cryopreserved and stored with optimal efficiency (**Banks and Maurer,1974**). Several protocols have been developed for embryo vitrification, providing a survival rate 60% after transfer (**Kasai *et al*., 1992, López-Bejar *et al.*, 2002, Mocé and Vicente, 2009 Silvestre *et al*., 2003**). Garcia-Ximenez et al. (1991) described a method for transferring embryos into the uterus by laparoscopy. They transferred on average 10.8 embryos to twelve lactating recipients. All twelve does became pregnant and showed an embryo survival rate of 47%, which is comparable with our results. **Techakumphu *et al* (1987)** transferred by laparotomy two cells, 16-32 cells and late morulae in each case into the Fallopian tube of five recipients. However, these authors observed implantation rates of 68%, 62% and 63%, respectively. **Daniel and Renard (2015)** stated that embryo transfer in this species requires a high degree of synchrony between the physiological status of the recipient doe and the developmental stage of the embryo at the time of transfer.

In some cases, however, especially after in vitro culture of reconstructed embryos or after an extended culture period (*e.g.* overnight), the pregnancy rate obtained after embryo transfer into asynchronous recipients can be increased relative to synchronous transfers. The efficiency of embryonic verification to produce offspring ranged between 25–65%, depending on the genetic breed and whether the embryo transfer was from a single donor or a pool of different donors (**Garcıa´ and Baselga, 2002, Marco-Jime´nez *et al*., 2013 and 2016).**

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