Introduction

The rabbit meat production could represent a valuable source of proteins for developing or less developed countries due to the sustainable efficiency of this species in prolificacy and capacity to use local feedstuffs or agro-industrial by-products. To reduce the animal protein shortage of the population and to promote this new agricultural production, some of these countries decided to develop this kind of production in small or medium-scale units. The failure of some rabbits projects, based on the importation of exotic breeds (Lukefahr 2004; Oseni 2008a) led the producers to consider more sustainable projects. This paper will review and analyze some of these projects, focusing on their genetic aspects in terms of: (1) genetic improvement programs; (2) estimation of selection responses; (3) direct and maternal heterotic effects obtained from crossbreeding; (4) attempts to identify specific genetic markers. The other aspects such as management, sanitary conditions, feedstuff availability are as well important (see for example Lukefahr, S.D. 2004; Samkol, P. and Lukefahr, S.D. 2008).

Sustainable genetic improvement programs in developing countries

The sustainable genetic improvement program must take into account the following economical, sociological and ecological aspects:

- Are the local genetic resources of interest and/or they are endangered?
- What are the kinds of production the producers they encourage: small, medium or large-scale units?
- Are the farmers able to buy initial and replacement bucks and does?
- Is there a technical training to help the farmers and what is the political strategy to support this production?
- What are the outlets of rabbit meat for familial consumption, small markets, restaurants, large scale distribution channels,…?

Sustainable genetic improvement is mainly based on selection and/or crossbreeding. Selection allows to have an accumulative additive genetic progress, while the main interest of the crossbreeding is to get profits from breed complementarity and the effect of heterosis (Bidanel J.P. 1992). The first way to establish a sustainable genetic improvement program in rabbits is using three-way crossing. As a result of this concept, some specialized strains are selected in Europe to produce F1 females, which are crossed with a sire of another strain to produce a terminal product. This concept has the advantage to exploit the entirety of the effect of heterosis at each generation (direct and maternal), but this concept requires a complex scheme, basing on the maintenance and selection of the pure stocks and the multiplication and diffusion of the crossbred females. This is the reason why these turnkey programs are rarely used in developing countries, except in some large scale private units.
The second way to establish a genetic improvement program in developing countries is to create a synthetic line by crossing females of a local population or breed, well adapted to the environment, with imported males or semen from a selected strain to produce $F_1$ population and this population will be bred without selection for few generations (avoiding consanguinity, and constituting a nucleus population submitted to selection). This trend makes possible to provide farmers with improved animals, while ensuring their independence. It lets the farmers to adapt their strategy of renewal of their herd by: (1) practicing self-replacement without loss of the genetic level, (2) buying males or the two sexes to the nucleus, and (3) getting permanently or punctually profits from the genetic progress carried out. The third way is to select pure breeds, either from local or imported populations. This solution is less used, for different reasons: local populations performances are usually very low, even if they are well adapted, while imported breeds often do not adapt to poor environments and, in both case, complementarity and heterosis are not exploited.

**In Asia.** In Saudi Arabia, a national project of rabbit production was established to detect the possibilities of producing meat rabbit under industrialized and hot conditions (Khalil M.H., Al-Sobayel K., Hermes I.H. et al, 2002; Khalil M.H., García, M.L., Al-Dobaib, S.N. et al 2005). For this reason, special emphases were paid to construct a genetic improvement programme to develop new lines of meat rabbits convenient for this developing hot country. Accordingly, V-line rabbits were imported in 2000 from the university of Valencia (Spain) and were crossed with desert Saudi rabbits (Gabali). This program was based on an evidence stating that V-line rabbits and their crosses could produce efficiently under hot climatic conditions (Khalil M.H., Al-Sobayel K., Hermes I.H. et al. 2002; Al-Sobayil, K. and Khalil, M. H. 2002). From this program, two synthetic lines (Saudi-2 as a maternal line with the structure of $((\frac{3}{4}V\frac{1}{4}S)^2)^2$ and Saudi-3 as a paternal line with the structure of $((\frac{3}{4}S\frac{1}{4}V)^2)^2$) were developed from crossing Saudi Gabali with V-line rabbits, both selected for litter weight at weaning and individual weight at 84 d (Tables 1 and 2). Details concerning the development of these new lines were presented by Khalil M.H., García, M.L., Al-Dobaib, S.N. et al (2005) and Al-Saef, A.M., Khalil M.H., Al-Homidan A.H. et al. (2008).

**North Africa.**

*In Algeria,* an attempt to introduce selected strains and to develop rabbit meat production (between 1985 and 1988) was failed because of many factors, among which the lack of knowledge of rabbit production, the absence of an adapted industrial feedstuff, the absence of a prophylactic program. Afterwards, the strategy to develop this species was based on using and upgrading the local populations. Since 1990, the Institut Technique de l'Elevage (ITELV) and some universities, especially that of Tizi Ouzou, setting up the programs of characterization for these populations and to control their productive performances. They highlighted the defects of these populations in terms of prolificacy and adult weight, but they were looking for goodness of adaptation to the local climatic conditions, without any loss of productivity in summer (Lakabi, D., Zerrouki, N., Lebas, F. et al 2004; Zerrouki N., Bolet G., Berchiche M. et al 2005a; Zerrouki N., Kadi S.A., Berchiche M. et al 2005b). To provide the farmers with more productive animals, ITELV collaborated with INRA to create a synthetic line by crossing the local population with INRA 2666 strain (Gacem M. and Bolet G. 2005). After 4 generations of homogenization, this synthetic line was compared to two local populations in the same conditions for a period of 18 months. Does of this synthetic line were heavier in weight (+200 to 420 g) with observed
superiority in litter size (+1.9 to 2.5 born alive). There was no genotype x season interactions which it means that the synthetic line is well adapted to local climatic conditions and much more productive than the local populations. This comparison confirms the fact that this synthetic line was used to develop rabbit production in Algeria and it is now selected for litter size and weight at slaughter age with a BLUP index including direct and maternal effects and disseminated by ITELV for cooperative and multiplicative farms (Gacem, M., Zerrouki, N., Lebas, F. et al, 2008; Gacem, M., Zerrouki, N., Lebas, F. et al, 2009; Lebas, F., Gacem, M., Meflah I. et al 2010).

In Egypt, great efforts have been made since 1998 to select for one exotic maternal line under local conditions and to develop and select lines based partially on local breeds. An Egyptian-Spanish program was established involving Alexandria University, Animal Production Research Institute (APRI, Cairo) and Benha University. V-line rabbits were imported in 1998 from Spain and various selection experiments were practiced. The first line was developed from crossing Baladi Red with V-line and this maternal line named APRI was selected for litter weight at weaning (Youssef, Y.K., Iraqi, M.M., El-Raffa, A.M. et al 2008; Table 1). A synthetic paternal line named Alexandria was originated in Alexandria University from crossing V line with Baladi Black and selection was practiced for daily weight gain during 28-63 days of age (El-Raffa, A.M. 2007; Table 2). In 2003, a selection program was started to produce a synthetic multi-purpose line named Moshtohor resulting from crossing Sinai Gabali with V-line and selection was practiced for litter weight at weaning and live weight at 56 days (Iraqi, M.M., Shenana, M.E. and Baselga, M.. 2007; Gacem, M., Zerrouki, N., Lebas, F. et al, 2008; Table 3).

In Tunisia, local populations of the South West (Tozeur and Gafsa oases) have been characterized (Ben Larbi, M., Haddad, B. and Allalout, S. 2008) and very poor performances have been evidenced. On the other hand, European strains have been imported about 20 years ago and are maintained in some farms with a limited selection (Lebas, F. and Bolet G 2008). At that time, there was strong political willing to develop rabbit meat production in medium-sized units. A team from Ministry of Agriculture and INRA were collaborated to develop farms with data recording system to characterize these strains; afterwards programs of selection and diffusion were implemented (Bouslama et al. unpublished data).

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<tr>
<th>Synthetic line and origin</th>
<th>Founder breeds</th>
<th>Selection criteria</th>
<th>Selection methodology</th>
<th>Number of generations</th>
<th>Selection response per generation</th>
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<tr>
<td>Saudi-2, Saudi Arabia (Khalil et al, 2005)</td>
<td>V line and Saudi Gabali</td>
<td>LSB + LSW</td>
<td>BLUP animal-repeatability model</td>
<td>11</td>
<td>LSB= 0.18 kit/litter; LSW= 0.16 kit/litter; LWW= 62g/litter; WW= 8.6g/kit</td>
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LSB = litter size at birth; LSW = litter size at weaning; LWW= litter weight at weaning; WW = weaning weight; W12= weight at 12 weeks.

Table 2: Programs used to create synthetic paternal lines in developing countries

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<td></td>
<td>Norfolk English line</td>
<td>Weaning litter + ADG (28-70 d)</td>
<td>Selection index</td>
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<td>Sinai Gabali, line V</td>
<td>LWW+ 56-d weight</td>
<td>Two-stage selection using BLUP</td>
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LSB = litter size at birth; LWW = litter weight at weaning; ADG: average daily gain; W12: weight at 12 weeks.

Table 3: Programs used to create synthetic multi-purpose paternal lines in developing countries

Sub-Saharan Africa.

In Benin, a nucleus from local populations of rabbits in South Benin has been implemented in CECURI of University of Abomey-Calavi (Kpodekon, T.M. and Coudert, P. 1993) and after many years of sanitary efforts, a selection program has been recently initiated (Akpo, Y., Kpodekon, T.M., Taninomo, E. et al. 2008). With the help of INRA, a new project of crossing was performed between this local population with INRA strain to create a synthetic line and this program is in progress.

In Nigeria, Oseni, S.O. (2008) emphasized the lack of applied research for rabbit production; Abu, O.A., Onifade, A.A., Abanikannna, O.T.F. et al (2008) and Oseni, S.O., Ajayi, B.A., Komolafe, S.O. et al (2008) characterized these traditional systems. Oseni, S.O. (2008) recently proposed a genetic improvement program with a strategy: (1) to exploit locally available heterogeneous populations, (2) to create a closed nucleus, (3) to define the breeding goals and selection criteria, and (4) to provide backyard small units with improved animals.

Latin America.
In Brazil, a multi-purpose selection program was initiated in 1992 to develop a multipurpose line named Botucatu, using a selection index including litter size and weight at weaning and post-weaning growth traits (Moura, A.S., Costa, A. and Polastre R. 2001; Table 3).

In Mexico, a strategy of providing "Family packages" began many years ago to promote the production and consumption of rabbit meat and seems to continue (Mendoza et al. 2008), but no information is available concerning the origin and selection of bucks and does.

Selection responses:

In selection experiments carried out in developing countries, definite methodologies have been proposed to estimate selection responses. One of them is based on regressing the estimates of the breeding values on generations and this approach depends on the genetic parameters and the model used (Moura, A.S., Costa, A. and Polastre R. 2001). The other methodologies were based on using the control population which could be an unselected population (Khalil M.H., Al-Sobayel K., Hermes I.H. et al 2002; Khalil M.H., Garcia, M.L., Al-Dobaib, S.N. et al, 2005), or using a divergently selected population (Moura, A.S., Kaps, M., Vogt, D.W. et al 1997).

As presented in Table 1, genetic responses obtained from long-term selection experiments for litter size and other litter traits were found to be moderate. Selection experiments for growth rate show successful responses in most experiments carried out in Brazil (Moura, A.S., Kaps, M., Vogt, D.W. et al 1997). Khalil, M.H. and Al-Saef, A.M. (2008) stated that does selected for litter size at weaning presented significant responses in feed intake (3%) and milk yield (6%). A response of 62 g per litter was recorded when selecting for litter weight at weaning. Estimates of direct selection responses per generation were moderate and ranged from 8.7 to 12.6 g for weaning weight, 18 to 68 g for marketing weight, 0.45 to 1.73 g/day for weight gain from weaning to marketing. Selection for growth rate had little or rather moderate effects on carcass characteristics and meat quality when the rabbits were selected at the same stage of maturity. Selection for litter weight at weaning achieved considerable responses in growth rate while maintaining high litter components and feed conversion.

Direct and maternal heterotic effects

For litter and lactation traits, different crossbreeding experiments carried out in Egypt indicated that direct heterotic effects were evidenced for litter size, litter weight, and milk yield in most of the possible crossbred does obtained (Khalil, M.H., Afifi, E.A., Youssef, Y.M.K. et al 1995; Khalil, M.H. and Afifi, E.A. 2000; Abd El-Aziz, M.M., Afifi, E.A., Bedier, N. et al. 2002; Iraqi, M.M., Shenana, M.E. and Baselga, M. 2007; Youssef, Y.K., Baselga, M., Khalil, M.H. et al 2009). Consequently, both producers and processors in this area could potentially benefit economically through using crossbred does. Also, estimated maternal heterosis were favorable and indicate that crossbred dams had considerable maternal heterotic effects in terms of larger litter size, heavier litter weight at birth and weaning, favorable feed conversion ratio, and efficient milk to litter gain conversion ratio than their crossbred daughters (Khalil M.H., Garcia, M.L., Al-Dobaib, S.N. et al. 2005). Khalil, M.H. and Afifi, E.A. (2000) and Abd El-Aziz, M.M., Afifi, E.A., Bedier, N. et al. (2002) reported that crossing Gabali rabbits with New Zealand White in Egypt was associated with negative low non-significant heterotic effects on milk yields during the first 21 days of suckling and the whole period of lactation (0.12 to 2.4%).

For postweaning growth, estimates of direct heterosis for body weights raised in hot countries
were mainly positive and ranging from 1.3 to 14.5 %, but the estimates for maternal heterosis were mainly negative and ranging from 0.2 to 5.3 %. Abdel-Ghany, A. M., Ahmed, E. G., Hassan, N. S. (2000) and Afifi, E.A., Khalil, M.H., Khadr, A.F. et al. (1994) found that heterosis percentages ranged from 2.7 to 9.5% for post-weaning body weights and gains by crossing New Zealand White with Baladi Black or Baladi Red in Egypt.

For carcass traits, Afifi E.A., Khalil, M.H., Khadr, A.F. et al. (1994) found that direct heterosis percentages from crossing New Zealand White X Baladi Red in Egypt ranged from 1.0 to 4.7. In Saudi Arabia, Al-Saef, A.M., Khalil M.H., Al-Homidan A.H. et al (2008) showed non-favorable negative estimates of maternal heterosis of -65.5 g, -6.7 g, -5.3 g and -12.2 g for hot carcass, offal, fat and bone weights, respectively. For meat quality traits, neither individual heterosis, nor maternal heterosis was significant.

For semen parameters, direct heterosis given by Khalil, M.H., Al-Sobayl, K.A., Al-Saef, A.M. et al (2007) indicated that crossbred bucks were associated with heterotic effects in some semen parameters. Such crossing was associated with an increase in ejaculate volume (11.6%; P<0.05), sperm concentration (10.5 %; P<0.05), percentages of motile (9.8%) and living sperms, and libido of bucks (P<0.05) along with a reduction in percentages of abnormal (-10.8%) and dead sperms (-23.5%; P<0.05). Reviewed estimates of maternal heterosis for semen characteristics were favorable and moderate (Khalil, M.H., Al-Sobayl, K.A., Al-Saef, A.M. et al. 2007). Consequently, crossbred dams could produce crossbred bucks characterized by higher volume of ejaculate, higher semen quality with more concentration and motile sperms, along with lesser percentages of abnormal sperms and dead sperms than their crossbred daughters.

QTL analyses in developing countries

Till now, marker-assisted selection (MAS) is not used in current rabbits' selection programs in developing countries and the recent molecular technologies were used only in these countries to detect the associations between phenotypic traits and genetic markers. Khalil, M.H., Motawei, M.I., Al-Saef, A.M. et al. (2008) used RAPD markers to search for the linkage between markers and quantitative traits. From a total of 40 primers used in their study, five were polymorphic, and only three of them showed significant associations with phenotypic traits. El-Zarei, M.F. (2010) detected five markers to differentiate between individuals and to study the association between these markers and some carcass, tissues composition traits and meat quality traits.

Conclusions

1) In developing countries, the most efficient strategy used is the development of synthetic lines, resulting from crossing local populations or breeds with selected European strains. These strains were provided essentially from University of Valencia (Spain) and the INRA (France). These lines can be used as specialized maternal or paternal lines, or multi-purpose lines. This strategy allows to get profits from the complementarity between local populations (well adapted to the environment) and the selected strains. It allows also to get benefits from half of the heterosis.

2) The favorable estimates of direct and maternal heterosis reviewed for reproduction, lactation, growth and carcass traits and heat-stress physiological parameters would be an encouraging factor for the rabbit producers in hot climate countries to use such lines.

3) Till now, marker-assisted selection (MAS) is not generally used in current rabbits' selection
programs in developing countries and the recent molecular technologies were used only in these countries to look for associations between phenotypic traits and genetic markers.

References


