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Crossbreeding experiments of rabbits in Egypt: Synthesis of results and overview

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SUMMARY - Crossbreeding between different breeds of rabbits (local and exotic) under the Egyptian conditions was generally associated with an improvement in most economic traits in rabbits (e.g. litter size and weight, mortality, litter gain, mean young weight per litter, postweaning body weights and gain, etc...). Heterotic effects on litter traits (e.g. litter size & litter weight) were more pronounced at weaning rather than at birth. Breed of doe was more important than breed of buck in influencing crossbred litters. Local breeds (e.g. Giza White & Baladi Red and White) are superior in prenatal abilities while foreign breeds (e.g. New Zealand White, Californian, Bouscat, etc...) are superior in post natal maternal abilities. Double crossbred litters or rabbits (i.e. crossbred litters or rabbits produced by crossbred dams) were superior in performance than those of single crossbreds (i.e. crossbred litters or rabbits produced by purebred dams) or purebreds. This encourages the commercial rabbit breeders in Egypt to use crossbred dams instead of pure ones. Crossbred litters and rabbits resulting from mating bucks of local breeds (e.g. Giza White, Baladi Red and White) with does of exotic breeds (e.g., New Zealand White, Californian, Chinchilla, etc...) showed considerable positive heterosis for most economic traits in rabbits, while crossbred litters and rabbits mothered by does of local breeds showed negative heterosis in most cases.

Key Words: Rabbits, crossbreeding, litter traits, body weight, combining & maternal abilities.

RESUME - "Essais de croisement chez les lapins en Egypte : Synthèse et discussion des résultats obtenus". Les croisements entre races différentes de lapins (locales et exotiques) sous les conditions de l'Egypte ont en général débouché sur une amélioration de la plupart des caractères d'importance économique chez cette espèce (par exemple, la taille et le poids de la portée, la mortalité, l'augmentation de la portée, le poids moyen des lapereaux par portée, le poids corporel et le gain moyen quotidien au sevrage, etc.). Les effets d'hétérosis sur les caractères de la portée (par exemple taille et poids de la portée) ont été plus marqués au sevrage qu'à la naissance. La race de la femelle avait plus d'influence pour les portées croisées, que la race du mâle. Les races locales (par exemple Giza White et Baladi Rouge et Blanc) sont meilleures pour les qualités pré-naissance tandis que les races étrangères (par exemple Néo-Zélandaise Blanche, Californienne, Bouscat, etc...) sont supérieures en ce qui concerne les qualités maternelles post-naissance. Les portées ou lapins doublement croisés (c'est-à-dire les portées ou lapins croisés provenant de femelles croisées) avaient des performances supérieures à ceux croisés simples (c'est-à-dire des portées croisées, ou des lapins provenant de femelles de race pure) ou de race pure. Ce fait encourage les sélectionneurs cunicoles privés, en Egypte, à utiliser des femelles croisées plutôt qie de race pure. Les portées et lapins croisés provenant de mâles de races locales (par exemple Giza White, Baladi Rouge et Blanc) avec des femelles de races exotiques (par exemple, Néo-Zélandaise Blanche, Californienne, Chinchilla, etc...) ont montré un effet positif d'hétérosis considérable pour la plupart des caractères d'importance économique chez le lapin, tandis que les portées et lapins croisés dont les mères appartenaient aux races locales montraient une hétérosis négative dans la plupart des cas.

Mots-clés: *Lapin, croisement, caractères de la portée, poids corporel, aptitude à la combinaison et maternelle.*

Introduction

The domestic rabbit when compared with other livestock animals is characterized by early sexual maturity, high prolificacy, relatively short gestation length, short generation interval, high productive potential (number of progeny produced per doe per annum), rapid growth, relatively high meat production, good ability to utilize forages and fibrous plant materials and agricultural by-products (i.e. it does not need a lot of concentrate in its diet), more efficient in feed conversion, low cost per breeding female and by its profitability for small-scale systems of production and in backyards (Cook, 1977; Rao *et al.*, 1977; Hunt, 1980; Taylor, 1980; Lebas, 1981 & 1983; Schlolaut, 1981 & 1982). Also, the rabbit meat is pearly white, fine-grained, palatable, mildly flavoured, high in good quality protein content, low in fat and caloric content, it contains a higher percent of minerals than other meats, is nearly of the same nutritive value as beef meat and comparable to that of broiler chicken and of good meat-to-bone ratio and is acceptable to the general consumer in Egypt and other countries (Butterfield, 1953; Casady *et al.*, 1971; Rao *et al.*, 1977 & 1978; Reddy *et al.*, 1977; Maff, 1978; Hunt, 1980; Schlolaut, 1981 & 1982; others). Therefore, rabbit production might play a considerable role in solving the problem of meat shortage in Egypt.

Crossbreeding experiments carried out in countries other than Egypt were found to be generally associated with improvement in doe performance for litter size and weight at birth and/or at weaning (Wilson and Dudley, 1952; Rollins and Casady, 1964; Terentjeva, 1966; Barsukov, 1967; Zelink and Granat, 1972; Partridge *et al.,* 1981; Lukefahr *et al.,* 1983a&b&c; others). Also, it was proved that crossbred rabbits recorded a lower mortality rate than purebreds during the suckling period (Johansson and Venge,1953; Rollins and Casady, 1964; Mach and Trojan, 1979; Carregal, 1980; Carregal and Lui, 1984; Lukefahr *et al.*, 1983c; Lukefahr *et al.*, 1984). Conclusions of Yao and Eaton (1954), Kaszowski *et al.* (1965) and Kawinska *et al.* (1969) showed that body weight of the crossbred rabbits at different ages was intermediate between those of their parental breeds and therefore crossbreeding was an effective method for improving rabbit stock.

The Egyptian literature (Kheireldin, 1950; El-Khishin *et al.,* 1951; Shawer, 1963; Shawer and El-Ibiary, 1963a&b; El-Bendary, 1967; others) revealed that the local breeds of rabbits (e.g. Giza White, Baladi Red and others) showed, in general, lower performance than exotic standard breeds (e.g. Bouscat, Chinchilla, White Giant Flander, Grey Giant Flander and others) for different productive traits. Recently, new standard breeds (e.g. New Zealand White and Californian) were introduced in Egypt and were used in crossbreeding experiments with local breeds. Results of some of these experiments are available and some others are as yet unobtained (Oudah, 1990).

All these previous findings encouraged the research workers to perform different crossbreeding experiments in Egypt using different local and acclimatized exotic breeds of rabbits. These experiments were started and carried out by Afifi and some of his colleagues (Khalil, 1980; Emara, 1982), since 1971 up to 1990. Moreover, other crossbreeding experiments were carried out by other Egyptian investigators (Tag El-Din, 1979; Soliman, 1983; Sallam and Hafez, 1984; Kosba *et al.*, 1985; El-Sayed, 1988; El-Qen, 1988; Oudah, 1990).

The objectives of the present article are (1) to survey the crossbreeding experiments carried out in Egypt and (2) to give some conclusions on synthesis of results and overview. Future research needed is also presented.

Material, experimental work and breeding plans

EXPERIMENT OF AFIFI (1971)

The crossbreeding experiment was practised using Bouscat (B), Chinchilla (C) and Giza White (G) breeds in a diallel crossbreeding program at the experimental rabbitry of the Faculty of Agriculture, Ain Shams University at Shoubra Al-Khaima, Cairo. This experiment was carried out for two consecutive years of production (1966/67 & 1967/68). The year of production in conventional systems of production (i.e. in the non-commercial farms) that prevails in Egypt usually starts in September or October and ends in April or May (i.e. about eight months). The breeding plan (Table 1) permitted the production of purebred and crossbred progeny in each year and for all possible combinations in each litter (i.e. three purebred groups & six crossbred groups). In addition to the breeding plan described above, two double crossbred groups were obtained by using does and bucks of two single crossbred groups (Chinchilla X Bouscat and Giza White X Bouscat) born in the first year in a reciprocal mating (CB x GB & GB x CB). Matings occurred and progeny produced are presented in Table 2. Results reported by El-Tawil *et al.* (1971) and Afifi *et al.* (1973, 1975, 1976a&b) were based on results of the same crossbreeding experiment.

EXPERIMENT OF TAG EL-DIN (1979) AND DORA (1979)

For one year of production (1977/78), Bouscat (B) and Baladi White (W) rabbits were used to produce purebred B and W progeny in addition to the crossbreds resulting from the reciprocal crossbreeding between does and bucks of the two breeds. This experiment was carried out in the experimental farm of the Faculty of Agriculture, Mansoura University at El-Mansoura, in the north- east of the Nile Delta. Matings and the resulting breed groups are illustrated in Table 3.

EXPERIMENT OF KHALIL (1980)

A crossbreeding experiment was practised for one year of production (1978/79) by using Giza White (G) and Grey Giant Flander (Fg) rabbits in the experimental rabbitry of the Faculty of Agriculture at Moshtohor (30 Km. north of Cairo), Zagazig University, Banha Branch. The breeding plan (Table 4) consisting in producing the progeny of G and Fg rabbits as well as that resulting from their reciprocal crossing (i.e. G Bucks X Fg does, and Fg bucks X G does). Findings of Afifi and Khalil (1989) were based on data of this experiment.

EXPERIMENT OF EMARA (1982)

A diallel crossbreeding program was followed for three consecutive years (1976/77, 1977/78, 1978/79) using Bouscat (B), Giza White (G), White Flander (Fw) and Baladi Red (R) rabbits of the flock raised at the experimental station of the Animal Production Research Institute, Ministry of Agriculture at Dokki, Cairo. The breeding plan of that work was similar to that followed by Afifi (1971), but the difference was that Emara (1982) used four breeds instead of three breeds (table 5). Matings applied and progeny produced are illustrated in Table 6. Results reported by Afifi and Emara (1984a&b, 1985, 1987, 1988, 1989a&b) and Afifi *et al.* (1987) were based on data obtained from that experiment.

EXPERIMENT OF SOLIMAN (1983)

For two years of production (1980/81 and 1981/82), a crossbreeding study was conducted in the farm of the Faculty of Agriculture, Alexandria University, using Chinchilla (C), Bouscat (B), Baladi Grey (Bg) and Baladi Yellow (By) rabbits. Mating plan for this experiment is illustrated in Table 7. Results of Kosba *et al.* (1985) were based on data of this study.

EXPERIMENT OF SALLAM AND HAFEZ (1984)

A crossbreeding experiment was performed in the rabbit farm of the Faculty of Agriculture, El-Minia University at El-Minia (Middle Egypt) using Baladi Red (R), Bouscat (B), Chinchilla (C) and Flemish Giant (Gf) rabbits. Matings of this study and progeny produced are shown in Table 8.

EXPERIMENT OF EL-SAYED (1988)

Purebred progeny of New Zealand White (Nz) and Californian (Ca) rabbits in addition to those resulting from mating Ca bucks to Nz does were produced in the rabbitry of the Faculty of Agriculture, Zagazig University, during one year of production (1986/87).

EXPERIMENT OF EL-QEN (1988)

A crossbreeding program was carried out in the farm of the Faculty of Agriculture, Tanta University at Kafer El-Sheikh during two years of production (1985/86 and 1986/87). Matings and progeny obtained in the two years are presented in Table 9.

EXPERIMENT OF OUDAH (1990)

New Zealand White (Nz), Californian (Ca) and local Baladi (Ba) rabbits were used in a crossbreeding study during 1988/89 in a private farm at Talka city near El-Mansoura under the supervision of the Animal production Department, Faculty of Agriculture, Mansoura University. Purebred and crossbred progeny resulting from all possible combinations are shown in Table 10.

Synthesis of results and overview

LITTER SIZE

Reviewed estimates of heterosis for litter size of crossbred rabbits raised in Egypt are given in Table 11.

Single crossing and individual heterosis

Results of Afifi (1971) and Afifi *et al.* (1976b) revealed that some of crossbred combinations showed superiority for litter size at birth and at weaning over that of either parental breed, some others manifested intermediacy between the parental breeds and a few of them exhibited inferior performance in this respect. Afifi (1971) reported that the average of means of litter size in all crossbred combinations excelled that of all the purebred ones at birth (6.43 vs 5.8 young) and at weaning (4.39 vs 3.98 young). The same author found that heterosis percentages, not for all but for most crossbred combinations, showed positive value (Table 11) which ranged from 2.15 to 14.68 % for litter size at birth and from 0.25 to 46.34 % for litter size at weaning, i.e. not all crossbred groups obtained showed hybrid vigour. The same conclusion was also detected by Khalil (1980) and Afifi and Khalil (1989). They found that crossbreeding between G and Fg rabbits was associated with the presence of heterotic effects on litter size either at birth or at weaning with the exception of litter size at birth in FgG litters (Table 11). Similarly, Emara (1982) and Afifi and Emara (1987) found that heterotic effects were evident in most of the possible single crossbred combinations either at birth or at weaning (Table 11). They also noted that the average of means of litter size in the crossbred groups was superior to the average of all the parental pure breeds at birth (6.43 vs 5.87 young) and at weaning (4.37 vs 3.98 young). Also, the same superiority was detected when comparing the crossbred and purebred litters of each of the 4 breeds at birth and at weaning. Soliman (1983) observed that Bg-By and Bg-B crossbred groups excelled either of their parental breeds, while some groups showed intermediate performance between their two parental breeds and others showed inferior performance in this respect. The general mean of litter size for all crossbred combinations was not significantly higher than that of all the purebreds (5.31 vs 5.25 young). El Qen (1988) gave a general evidence for the presence of heterotic effects on litter size at birth and at weaning (Table 11).

All these previous findings may lead to conclude that crossbreeding in rabbits (local and exotic) raised in Egypt is generally associated with an improvement in litter size. Comparison of percentages of heterosis for litter size at birth and at weaning (Table 11) showed that heterotic effects on litter size were more pronounced at weaning than at birth in most cases (Afifi, 1971). This is thought to be due to the fact that heterosis might play a greater role in postnatal viability of the rabbits and this would be due to high fitness and ability of crossbred young to suckle their dams more than purebred ones.

Breed of dam

Afifi (1971) observed that G does produced purebred and crossbred litters with larger size at birth than both B and C does. This may be due to the fact that G does ranked first in prenatal maternal ability when compared with B and C does. Khalil (1980) found that G bucks when mated to Fg does produced litters with larger sizes than when mated to G does. This may refer to the importance of the breed of dam in crossbreeding programmes and to the lower performance of G does (for prenatal maternal ability) when compared to Fg does. This lower maternal ability may have masked the effect of crossbreeding on FgG litters. Means of the twelve crossbred groups reported by Afifi and Emara (1987) showed that BR crosses were the best performing crossbred group for litter size at birth and at weaning (8.38 and 5.83 young, respectively). This group excelled significantly its two parental breeds for litter size at birth. In this respect, Tag El-Din (1979) found that each of the two crossbred combinations produced (BW & WB) surpassed their parental breeds for litter size at birth and at weaning except WB at weaning which showed intermediate performance between its parental breeds (Table 11). Oudah (1990) found that the best crossbred combination for litter size at birth, 4, 6 and 10 weeks of age was the one resulting from mating Ba bucks to Nz does, and that this combination was the sole one which showed considerable positive heterosis percentages at the four ages of this study (Table 11). Also, crossbred litters mothered by Ba does showed always negative heterosis.

Double crossing and maternal heterosis

Afifi (1971) observed that litters produced by double crossbred combinations (GB X CB and CB X GB) exceeded those of single crossbred combinations in litter size at birth and at weaning. This confirms the superiority of the crossbred dams over the purebred ones in kindling and weaning of crossbred litters with larger size. The same author explained this superiority as a result of heterotic effect of crossbred dams on ovulation rate, intra-uterine environment (the dam provides during prenatal stage) and on her mothering or rearing ability (i.e. her maternal effects).

El-Qen (1988) noticed that litters of F2 produced by mating of BF and FB rabbits showed the highest performance and also the highest heterosis percent among all crossbred litters obtained. He also observed that back-crossbred B-BF and F-FB litters recorded larger sizes than BF and FB ones. The increase of litter size in F2 and backcrosses indicates the superiority of the crossbred mothers in producing larger litters than the purebred ones. This could be attributed to the positive and important role of maternal effects of crossbred dams compared to purebred ones in determining litter size, i.e. crossbred dams showed better efficiency in producing more young per litter and in rearing them more efficiently than purebred ones.

WEIGHT AND GAIN IN LITTER AND MEAN BUNNY WEIGHT PER LITTER

Single crossing and individual heterosis

Afifi (1971), Afifi *et al.* (1973), Afifi *et al.* (1975) and Afifi *et al.* (1976a) noticed that most of the single crossbred combinations recorded superior or intermediate performance in relation to their respective parental breeds, i.e. most crossbred combinations showed evidence of the presence of heterotic effects on litter weight (at birth and at weaning), gain in weight of litter during the suckling period and on mean bunny weight per litter. They found that most of the crossbred combinations obtained showed positive heterosis which ranged from 0.78 to 16.05 % for litter weight at birth, from 7.76 to 42.25 % for litter weight at weaning, from

12.89 to 55.03 % for gain in weight of litter and from 1.45 to 10.48 % for mean bunny weight per litter (Table 12). Afifi *et al.* (1975) noted that the presence of heterosis in most of the crossbred groups of single crossbred litters may indicate the presence of some nicking ability in the crosses. Tag El-Din (1979) reported that single reciprocal crossbred groups obtained in his experiment showed intermediate performance between their two parental breeds for litter weight at weaning. Findings of Emara (1982) and Afifi and Emara (1984a) indicated that most of the crossbred combinations had heavier litters than their parental purebred groups. They concluded that crossbreeding among B, G, Fw and R rabbits was generally associated with an increase in litter weight at birth and at weaning and with the presence of heterotic effects in such traits.

Bearing all this in mind, the above mentioned findings and those reported by Khalil (1980), Afifi and Emara (1984a) and Afifi and Khalil (1989) lead to state that crossbreeding between different breeds of rabbits under the Egyptian conditions was associated with the presence of heterotic effects on litter weight at birth and at weaning and preweaning gain in weight of litter and on mean bunny weight per litter at kindling. The superiority of the single crossbred groups over their parental purebred ones (i.e. positive heterosis) may refer to the presence of inter-breed non-additive genetic effects (Afifi, 1971).

Breed of dam

Results of Afifi (1971) on purebred and crossbred litters produced by B, C and G does indicate the superiority of G does for litter weight at birth while B does were superior in litter weight at weaning, i.e. G does are superior in pre-natal abilities while B does are superior in post-natal maternal abilities. Khalil (1980) found that litters resulting from mating G bucks to Fg does (GFg) were heavier than those of either of the parental breeds at birth and at weaning while litters of the reciprocal crossbred combination (FgG) showed intermediate performance between their parental breeds (Table 12). These results may suggest that Fg does have better prenatal maternal abilities than G ones and G does have better postnatal maternal abilities (i.e. more ability to produce milk and to suckle and care for their young more efficiently) than Fg does.

Results of Afifi (1971) referred to the importance of breed of doe, more relevant than breed of buck in influencing litter weight and mean bunny weight per litter at kindling of crossbred combinations. On the other hand, findings of Khalil (1980) showed that breed-of-doe effects were more important than breed of buck in influencing litter weight at birth and weaning of the crossbred combinations.

Double crossing and maternal heterosis

Afifi (1971) and Afifi *et al.* (1976a) observed that litters of the double crossbred combinations (CB-GB and GB-CB) were heavier than those of either single crossbreds or purebreds at birth and at weaning. The superiority exhibited by the crossbred litters produced by crossbred does compared with those of the crossbred litters produced by purebred does might be an indication for the presence of heterotic effects on the pre-and post-natal maternal abilities of the crossbred does. Also, preweaning mean bunny weight of double crossbred litters produced by crossbred does was superior than that of crossbred and purebred litters produced by purebred does and bucks as shown by Afifi (1971) and Afifi *et al.* (1973 & 1975).

PRE-WEANING LITTER MORTALITY AND VIABILITY

Influence of crossbreeding on mortality or viability up to weaning was studied in Egypt by some investigators. Some of these investigators (e.g. Khalil, 1980; Soliman, 1983; EL-Qen, 1988; Afifi and Khalil, 1989) evidenced that crossbreeding was associated with a reduction in the pre-weaning mortality (i.e. an improvement in pre-weaning viability) and a reverse trend was reported by others (Afifi, 1971; Tag EL-Din,1979; Emara, 1982; Afifi and Emara, 1984b).

Single crossing and individual heterosis

Khalil (1980) and Afifi and Khalil (1989) found that the reduction in pre-weaning litter mortality caused by crossbreeding was more pronounced in GFg litters than in FgG ones. Also, Soliman (1983) reported that viability of BBg crossbred litters (88.8%) exhibited better pre-weaning viability than other crossbred litters. Similarly, EL-Qen (1988) found that crossbreeding improved viability of rabbits up to 30 days (weaning) and that FB litters presented better pre-weaning viability than the reciprocal BF crossbred ones.

Double crossing and maternal heterosis

Findings of Afifi (1971) showed that pre-weaning litter mortality for crossbred litters produced by crossbred does was lower than that of crossbred litters given by purebred does. Similarly, EL-Qen (1988) reported that viability up to weaning for crossbred rabbits produced by crossbred does (83.05, 80.01, 76.64%) was higher than that of crossbred rabbits produced by purebred does (73.37 & 75.28%), i.e. the role of crossbred does is more important than that of their crossbred litters or progeny.

BODY WEIGHT AND GAIN

Reviewed estimates of heterosis in body weights and gains obtained from crossbreeding experiments are given in Tables 13 & 14. Most crossbreeding experiments carried out in Egypt (Afifi, 1971; Tag EL-Din, 1979; Dora, 1979; Soliman, 1983; Kosba *et al.*, 1985; Sallam and Hafez, 1984; EL-Sayed, 1988; Oudah, 1990) indicated the presence of positive heterotic effects on body weights and weight gains of rabbits at different ages of growth. This may have resulted from inter-breed non-additive genetic effects. Other crossbreeding experiments carried out by Khalil (1980) and EL-Qen (1988) showed that crossbreeding was of little importance in improving body weights and weight gains in rabbits.

Breed of dam

Among the six single crossbred groups obtained by Afifi (1971), BC and CB rabbits recorded the heaviest weight and gain at different ages from four (weaning) to 24 weeks of age (Table 14), i.e. rabbits with B or C mothers were the heaviest for body weight and gain from 4 to 24 weeks of age. He attributed these results to the superiority of B or C does in the genetic make-up for postnatal maternal abilities (i.e. high milking and nursing ability of such does). These results indicated the importance of breed-of-dam effect on body weight and gain of crossbred rabbits. This effect may remain existent up to 24 weeks of age. Tag El-Din (1979) and Dora (1979) found that the average weights of WB crossbred rabbits from 30 to 105 days of age excelled in general those of BW crossbred rabbits. Findings of Emara (1982) on B, G, Fw and R rabbits and their crosses gave evidence that heterosis percentages for body weights and gains of crossbred rabbits mothered by B does were higher than for other crossbred rabbits obtained (Tables 13 & 14). Sallam and Hafez (1984) showed that 2-breed crossbred rabbits resulting from mating either B or C bucks to R does (BR and CR) excelled R ones.

Recently and with the most common standard breeds, El-Sayed (1988) found that the superiority of CaNz crossbred rabbits over their maternal, paternal and mid-parental breeds for body weight may be attributed to better milking and mothering abilities of Nz does than Ca ones. El-Qen (1988) showed that body weight of BF crossbred group excelled that of B, F and FB groups at 4, 8 and 12 weeks of age. Findings of Oudah (1990) on body weight at 4, 6, and 10 weeks of age indicated that all crossbred groups mothered by Nz and Ca does showed positive heterosis while those mothered by Ba does (Table 13) showed negative heterosis.

Crossbred dam and maternal heterosis

Afifi (1971) indicated that double crossbred rabbits (CB-GB and GB-CB) excelled their contemporary single crossbred and purebred rabbits in body weight at 4 (weaning), 12 and 24 weeks of age as well as in gain in weight from 4 to 24 weeks of age. Sallam and Hafez (1984) found that body weights and gains of 3-breed crossbred rabbits resulting from mating Gf bucks to either BR or CR does (Gf-BR) surpassed those of the 2-breed crossbred groups at the different ages studied. These findings gave an evidence for the superiority of crossbred dams in producing rabbits with heavier body weight and gain than purebred ones.

Better performance of crossbred rabbits produced by crossbred does (relative to crossbred rabbits produced by purebred does) may be attributed to heterotic effects of crossbred does on pre-natal and post-natal maternal abilities and to high fitness of crossbred bunnies produced. The maternal abilities of the crossbred doe seems to be a reflection of the additive contribution from each of the parental breeds to the make-up of the doe plus some of the non-additive effects.

Opposite trends for maternal heterosis were observed by Soliman (1983), Kosba *et al.* (1985) and El-Qen (1988). Soliman (1983) and Kosba *et al.* (1985) with 2-way and 3-way crossing between C, B, By and Bg breeds noted that the 3-way crosses surpassed the 2-way crosses in body weight at different ages from 30 (weaning) to 60 days. Their results were not able to give a clear evidence for improving body weight (at the ages studied) through crossbreeding among these breeds. El Qen (1988) found that body weights and gains from 4 to 16 weeks of age for F1 crosses (BF & FB) was found to excel those of F2 crosses (F1xF1) and two backcross groups (B-BF and F-FB).

POST-WEANING VIABILITY

Single crossing and individual heterosis

Results of Afifi (1971) showed that some single crossbred groups outperformed their parental breeds from 4 to 12 and from 4 to 24 weeks of age, some of them exhibited intermediate performance while others showed inferiority to both parental breeds. He also noted that means or heterosis percentages of individual viability of crossbred rabbits from 4 to 12 and from 4 to 24 weeks of age were slightly higher than those of the purebred groups in each of the two years of crossbreeding (Table 15). Tag El-Din (1979) found that WB crossbred rabbits recorded lower mortality than either of their parental breeds from weaning to 90 days while the reverse was observed for BW group (post-weaning mortality up to 90 days recorded 16.0, 21.6, 14.0 and 25.8 % for W, B, WB and BW rabbits, respectively). Results of Soliman (1983) showed that some of the crossbred groups (BgC, CBg, BgB, BBg and ByB) excelled their parental breeds, some of them recorded intermediate performance (CB and BgBy) while others (CBg, ByC, BC and BBy) showed inferiority to both parental breeds.

Afifi and Emara (1988) observed that heterotic effects on post-weaning viability from 5 (weaning) to 6, 8 and 12 weeks of age were not evident since most of the single crossbred groups among B, G, Fw and R rabbits showed negative heterosis percentages, i.e. crossbreeding was not associated with an increase in postweaning viability. Similarly, results of Oudah (1990) did not give a clear evidence for the presence of heterotic effects for post-weaning viability from 4 (weaning) to 10 weeks of age.

Breed of dam

Afifi (1971) reported that average of means for individual viability of purebred and crossbred rabbits produced by B, C and G does gave evidence that the highest viability was recorded by rabbits kindled by C does in the first year of crossbreeding and by B does in the second year. Data of Soliman (1983) revealed that purebred and crossbred rabbits produced by Bg and B does were more viable from weaning at 30 to 58 days of age (85.13 and 83.30 %) than those born by C or By does (36.50 and 67.32 %, respectively), i.e. better maternal abilities for Bg and B does over C and By does were observed. Findings of Afifi (1971) and Soliman (1983) may refer to the importance of breed of dam in the crossbreeding programs for improving post-weaning viability of rabbits.

Double crossing and maternal heterosis

Afifi (1971) showed that crossbred rabbits produced by crossbred dams survived better than those crossbreds produced by purebred dams and were also more viable than purebred ones. The superiority of crossbred rabbits kindled by crossbred dams relative to crossbred rabbits born by purebred dams is a reflection of heterotic effects on mothering ability traits of the crossbred dams. Superiority of the crossbred rabbits produced by crossbred dams over purebred rabbits is due to heterotic effects on both crossbred rabbits and on their crossbred dams.

MISCELLANEOUS

Findings of Afifi (1971), Tag El-Din (1979), Soliman (1983), Afifi and Emara (1985) and Oudah (1990) showed that crossbreeding did not considerably influence gestation length. Crossbreeding, in general, was found to improve feed efficiency (Dora, 1979; Soliman 1983; El-Qen 1988) and dressing percentage (El-Sayed, 1988; El-Qen, 1988). Effects of crossbreeding on feed efficiency and dressing percentage under the Egyptian conditions needs more investigation.

Crossbreeding analysis

HETEROSIS

Heterotic effects were evident for litter size and weight at birth and at weaning and post-weaning body weights according to some investigators (Afifi, 1971; Afifi and Emara, 1989). On the other hand, the absence of heterotic effects for pre-weaning litter mortality and post-weaning body weight was reported by Emara (1982). Results of Afifi (1971) and Afifi and Emara (1989) reported higher heterotic effects on litter size and weight at weaning than at birth. Sucha higher degree of heterotic effects on litter size and weight at weaning than at birth could be explained by higher survival rate up to weaning among the crossbred litters. However, the existence of heterotic effects may refer to the presence of non-additive variance due to epistasis, dominance and over-dominance.

GENERAL COMBINING ABILITY (GCA)

Reviewed studies in Egypt reported that breed differences in GCA for litter size at birth and at weaning and preweaning mortality were limited and non-significant (Table 16). For litter weight at weaning, Afifi (1971) and Emara (1982) reported highly significant ($P<0.01$) differences in GCA among breeds of their experiments.

Results of Afifi (1971) on GCA showed that breeds of his study (B, C and G) ranked differently for litter weight at birth and at weaning and that G and C rabbits were the best in GCA at birth and at weaning, respectively. Emara (1982) with B, G, Fw and R breeds found that B breed was the best in GCA for litter weight at birth and at weaning and pre-weaning litter mortality. Afifi (1971) observed that the best performing breed for body weight in his crossbreeding experiment was B breed at 4 and 12 weeks of age and C breed at 24 weeks of age. With four breeds of rabbits and their crosses, Emara (1982) found that the ranking of the breeds in GCA was not the same at all ages studied.

MATERNAL ABILITY (MA)

Emara (1982) and Afifi and Emara (1989) found that variation in litter size and weight at birth and pre-weaning mortality among B, G, Fw and R breeds due to MA was non-significant, while significant variation in litter size and weight at weaning and in body weights at different ages was observed (Table 16). These findings indicate that MA was important at weaning and thereafter but not so at birth. Contrary to the previous results, Afifi (1971) reported that MA effects on litter weight at birth and body weights at 4, 12 and 24 weeks of age varied slightly and insignificantly among B, C and G breeds.

Afifi and Emara (1989) reported that the best MA for litter size was shown by Fw and R rabbits at birth and at weaning, respectively, while the poorest MA was shown by B rabbits at both ages. Afifi (1971) reported that since MA differences among breeds for litter weight at birth were not evident, it appears that the highly significant MA differences among breeds at weaning may possibly be due to breed differences in milking ability and in the ability of the doe to care for her young during the suckling period i.e. post-natal maternal ability. Results of Afifi (1971) confirmed the superiority of B rabbits in MA while those of Emara (1982) did not show any consistent trend in this respect. Emara (1982) concluded that MA effects were important in determining body weight of rabbits.

SPECIFIC COMBINING ABILITY (SCA)

Results of Emara (1982) and Afifi and Emara (1989) showed that effects of SCA on litter size at birth and at weaning, litter weight at weaning, preweaning mortality and body weights (at 12 and 16 weeks of age) were not significantly evidenced. On the other hand, litter weight at birth and body weights at 5 and 8 weeks (i.e. at early stage of growth) were found by Emara (1982) to be significantly affected by SCA (Table 16).

SEX-LINKAGE OR RECIPROCAL EFFECT (SL)

Emara (1982) and Afifi and Emara (1989) reported that most economic traits in rabbits (e.g. litter size and weight, preweaning mortality and body weight) were found to be non-significantly influenced by sex-linkage (reciprocal) effects, i.e. differences between reciprocal crosses seemed to be non-existent.

Future research needs

— Reproductive traits (e.g. age at first kindling, kindling to first service interval, insemination period, days open, ovulation rate, embryonic mortality, kindling interval, etc...) in crossbreeding experiments were not investigated deeply and therefore more future investigations are needed.

— Under the Egyptian conditions, heterotic effects on lactation traits (e.g. milk, fat and protein yields and lactation length and curve) were not investigated and consequently an intensive research for lactation aspects is urgently needed.

— Coat characteristics in crossbred rabbits were not investigated under the Egyptian local conditions. Therefore, fiber diameter, length, thickness and density need to be determined in different crossbred combinations of rabbits. Also, aspects of coat and pelt processing for different crossbreds require deeper knowledge.

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Table 1. Breeding plan used by Afifi (1971) to obtain the purebred and crossbred progeny in all possible combinations in each litter.

Breed of doe+	Subclass of doe	Breed of Service buck +			
		1st litter	2nd litter	3rd litter	4th litter
B	1	B	C	G	B
B	2	C	G	B	C
B	3	G	B	C	G
C	1	C	G	B	C
C	2	G	B	C	G
C	3	B	C	G	B
G	1	G	B	C	G
G	2	B	C	G	B
G	3	C	G	B	C

+ B= Bouscat, C= Chinchilla, G= Giza White.

Table 2. Matings and progeny produced by Afifi (1971) for different systems of breeding.

Purebreeding		Crossbreeding			
		Single crossing		Double crossing	
Mating+	Progeny	Mating+	Progeny	Mating+	Progeny
BXB	B	BXC	BC	CBXGB	CB-GB
CXC	C	CXB	CB	GBXCB	GB-CB
GXG	G	BXG	BG		
		GXB	GB		
		CXG	CG		
		GXC	GC		

+ B= Bouscat, C= Chinchilla, G= Giza White; buck breed group listed first.

Table 3. Mating plan and progeny produced by Tag El-Din (1979) and Dora (1979).

Purebreeding		Crossbreeding	
Mating+	Progeny	Mating+	Progeny+
BXB	B	BXW	BW
WXW	W	WXB	WB

+ B= Bouscat, W= Baladi White; buck breed group listed first.

Table 4. Breeding plan used by Knalil (1980) to obtain purebred and crossbred progeny.

Breed of doe+	Subclass of doe	Breed of buck+	Purebred and crossbred progeny++
G	1	G	G
G	2	Fg	FgG
Fg	1	Fg	Fg
Fg	2	G	GFg

+G= Giza White, Fg= Grey Giant Flander
++ buck breed group listed first.

Table 5. Breeding plan used by Emara (1982) to obtain purebred and crossbred progeny in all possible combinations in each litter (Emara, 1982).

Breed of doe+	subclass of doe	Breed of service buck+			
		1st litter	2nd litter	3rd litter	4th litter
B	1	B	G	Fw	R
B	2	G	Fw	R	B
B	3	Fw	R	B	G
B	4	R	B	G	Fw
G	1	G	Fw	R	B
G	2	Fw	R	B	G
G	3	R	B	G	Fw
G	4	B	G	Fw	R
Fw	1	Fw	R	B	G
Fw	2	R	B	G	Fw
Fw	3	B	G	Fw	R
Fw	4	G	Fw	R	B
R	1	R	B	G	Fw
R	2	B	G	Fw	R
R	3	G	Fw	R	B
R	4	Fw	R	B	G

+ B= Bouscat, G= Giza White, Fw= White Flander, R= Baladi Red.

Table 6. Matings and progeny produced in purebreeding and crossbreeding programme applied by Emara (1982).

Purebreeding		Crossbreeding	
Mating+	Progeny+	Mating+	Progeny+
BXB	B	BXG	BG
GXG	G	GXB	GB
FwXFw	Fw	BXFw	BFw
RXR	R	FwXB	FwB
		BXR	BR
		RXB	RB
		GXFw	GFw
		FwXG	FwG
		GXR	GR
		RXG	RG
		FwXR	FwR
		RXFw	RFw

+ B= Bouscat, G= Giza White, Fw= White Flander, R= Baladi Red; buck breed group listed first.

Table 7. Matings and progeny of different breeding systems reported by Soliman (1983).

Purebreeding		2-way crossbreeding		3-way crossbreeding	
Mating+	Progeny+	Mating+	Progeny+	Mating+	Progeny+
CXC	C	CXB	CB	ByXBC	By-BC
BXB	B	BXC	BC	ByXCBg	By-CBg
BgXBg	Bg	CXBg	CBg	BXByBg	B-ByBg
ByXBy	By	BgXC	BgC	BXBgC	B-BgC
		CXBy	CBy		
		ByXC	ByC		
		BXBg	BBg		
		BgXB	BgB		
		BXBy	BBy		
		ByXB	ByB		
		BgXBy	BgBy		
		ByXBg	—		

+C= Chinchilla, B= Bouscat, Bg= Baladi Grey, By= Baladi Yellow; buck breed group listed first.

Table 8. Matings and progeny produced through purebreeding and two types of crossbreeding (Sallam and Hafez, 1984)

Purebreeding		Crossbreeding			
		2-breed crossing		3-breed crossing	
Mating+	Progeny+	Mating+	Progeny+	Mating+	Progeny+
RXR	R	BXR	BR	GfXBR	Gf-BR
		CXR	CR	CfXCR	Gf-CR

+ R= Baladi Red, B= Bouscat, C= Chinchilla, Gf= Flemish Giant; buck breed group listed first.

Table 9. Matings and progeny produced by El-Qen (1988) in the two years of his study.

Year of production	Mating+	Progeny+
1985/86	BXB	B
	FXF	F
	BXF	BF
	FXB	FB
1986/87	BXB	B
	FXF	F
	BXF	BF (F1)
	FXB	FB (F1)
	F1XF1	F2
	BXBF (backcross)	B-BF
	FXFB (backcross)	F-FB

+B= Bouscat, F= Flander, F1= crossbred rabbits resulting from mating BF with the reciprocal cross of FB; buck breed group listed first.

Table 10. Mating and progeny produced by Oudah (1990).

Purebreeding		Crossbreeding	
Mating+	Progeny+	Mating+	Progeny+
NzXNz	Nz	NzXCa	NzCa
CaXCa	Ca	CaXNz	CaNz
BaXBa	Ba	NzXBa	NzBa
		BaXNz	BaNz
		CaXBa	CaBa
		BaXCa	BaCa

+Nz= New Zealand White, Ca= California, Ba= Local Baladi, buck breed group listed first.

Table 11. Reviewed estimates of heterosis and reciprocal effect percentages for litter size at birth and weaning.

Crossbred combination	Heterosis (%) for litter size at: Birth	Weaning
Afifi et al (1966)+:		
BC	6.98(-7.29)	0.25(-6.97)
CB	2.15(-8.55)	14.11(0.48)
BG	-1.50(4.69)	9.48(19.41)
GB	3.99(-15.0)	46.34(9.02)
CG	14.68(5.13)	21.63(6.96)
GC	6.60(-4.80)	14.11(-24.7)
CB-GB	— (-0.33)	— (15.61)
GB-CB	— (1.34)	— (22.44)
Tag El-Din (1979):		
BW	20.70	20.25
WB	22.10	5.64
Khalil (1980) & Afifi and Khalil (1989)		
FgG	-7.4	3.3
GFg	10.0	7.0
Emara (1982):		
BG	-0.3	20.92
GB	3.39	-0.73
BFw	17.55	-10.97
FwB	2.53	10.72
BR	50.72	57.78
RB	9.35	27.47
GFw	14.66	6.94
FwG	-6.07	6.71
GR	-6.17	-0.63
RG	2.16	15.39
FwR	3.88	-18.59
RFw	28.46	-9.41
Afifi and Emara (1987):		
B-G	1.5	10.1
B-Fw	10.0	-0.1
B-R	30.0	42.6
G-Fw	2.8	6.8
F-R	-2.0	7.5
Fw-R	16.1	-13.1
El-Qen (1988)+:		
BF	7.31(8.21)	-1.37(6.24)
FB	-5.85(-8.76)	-1.74(-7.78)
BF-FB (as F2)	0.73(21.85)	-1.56(35.16)
B-BF	(5.65)	(11.80)
F-FB	(-0.44)	(1.70)
Oudah (1990):		
Nz Ca	1.4	0.0
Ca Nz	0.0	-3.2
Nz Ba	-6.6	-5.0
Ba Nz	15.3	10.0
Ca Ba	-9.2	-8.2
Ba Ca	2.1	3.3

+Estimates of heterosis for the 2nd year of the study are given in parentheses adjacent to the estimates of the 1st year.

Table 12. Heterosis and reciprocal effects (%) for litter weight at birth (BLW), litter weight at weaning (WLW), preweaning gain in weight of litter (GLW) and mean bunny weight per litter (MBW).

Crossbred combination	Heterosis percentages for			
	BLW	WLW	GLW	MBW
Afifi (1971)+				
BC	2.25 (1.95)	-5.49 (10.13)	-2.28(17.93)	-2.32(2.94)
CB	6.17 (20.75)	0.78 (13.51)	29.71(18.40)	7.37(3.36)
BG	3.08 (7.76)	5.12 (15.03)	-14.62(19.05)	5.33(3.10)
GB	3.91 (42.25)	-11.31 (7.95)	55.03(14.17)	2.46(3.31)
CG	9.65 (23.85)	14.00 (-2.44)	34.94(-4.42)	1.45(9.71)
GC	16.05 (9.45)	-6.64 (-29.9)	12.84(-35.0)	10.48(-2.9)
CB-GB		12.10 (22.94)	(27.44)	(12.1)
GB-CB		4.68 (12.94)	(17.15)	(3.12)
Tag El-Din(1979):				
WB	—	7.3		
BW	—	0.0		
Khalil (1980):				
GFg	6.3	1.1		
FgG	13.5	1.8		
Emara (1982):				
BG	12.72	25.04		
GB	17.12	9.65		
BFw	17.91	-6.17		
FB	10.71	9.54		
BR	61.37	44.92		
RB	15.57	18.73		
GF	20.31	16.16		
FwG	-0.64	7.18		
GR	17.24	-8.52		
RG	4.52	1.27		
FwR	13.40	-11.48		
RFw	22.89	-10.9		
Afifi and Emara (1984a):				
BG	14.9	17.3		
BFw	16.0	1.7		
BR	38.5	31.8		
GFw	9.8	11.7		
GR	10.9	-3.6		
Fw-R	18.1	-11.2		

+Estimates of heterosis for the 2nd year of production are given in parentheses adjacent to the estimates of the 1st year.

Table 13. Heterosis and reciprocal effect percentages reported by different Egyptian investigators for body weight of crossbred rabbits at different ages.

(1) Experiment of Afifi (1971)

Breed group	4-wk weight	12-wk weight	24-wk weight
BC	1.93(13.99)	10.19(3.85)	10.92(12.57)
CB	8.73(12.07)	5.91(5.62)	10.84(15.79)
BG	-7.35(01.55)	-11.23(1.63)	-5.08(-3.28)
GB	0.16(04.00)	-9.08(-3.16)	-1.04(-1.80)
CG	4.08(-06.79)	-3.74(-0.37)	6.44(17.08)
GC	-8.49(-12.36)	-6.43(5.24)	12.63(6.75)
CB-GB	(16.51)	(12.44)	(15.85)
GB-CB	(05.47)	(8.87)	(14.77)

(2) Experiment of Tag El-Din (1979) & Dora (1979)

Breed group	4-wk weight	6-wk weight	8-wk weight	10-wk weight	12-wk weight	14-wk weight
BW	-10.3	4.4	1.4	-7.96	1.3	2.4
WB	-4.8	10.8	11.0	-4.50	14.4	17.4

(3) Experiment of Khalil (1980)

Breed group	5-wk	6-wk	8-wk	10-wk	12-wk	14-wk	16-wk
FgG	6.2	3.7	-6.9	-12.9	-16.8	-12.5	-12.8
GFg	-4.2	2.1	-7.5	-10.9	-8.5	-1.1	-6.6

(4) Experiment of Emara (1982)

Breed group	5-wk weight	6-wk weight	8-wk weight	12-wk weight	16-wk weight
BG	9.51	7.31	3.91	2.56	3.62
GB	10.55	8.31	13.42	13.35	8.90
BFw	10.91	6.17	-0.70	-3.21	-5:59
FwB	1.81	2.45	1.64	1.51	2.53
BR	11.27	9.08	6.87	7.78	7.48
RB	7.37	3.52	2.68	5.00	7.90
GFw	5.23	9.08	2.91	7.32	7.55
FwG	-2.91	2.09	-3.93	3.36	2.07
GR	-12.66	-11.14	-3.79	5.96	5.30
RG	-10.47	-13.52	-9.45	-3.39	-3.56
FwR	-3.87	-5.61	-4.61	-3.61	-1.49
RFw	4.56	-0.56	2.01	0.64	-2.72

(5) Experiment of EL-Qen (1988)

Breed group	4-wk weight	8-wk weight	12-wk weight	16-wk weight
BF	-7.9(9.9)	3.7(-2.7)	5.7(-4.6)	(-2.4)
FB	-7.4(5.8)	-0.1(2.9)	-3.3(0.6)	(-5.7)
F2+	(-13.3)	(-21.1)	(-16.5)	(-18.9)
B-BF	(-0.8)	(-2.7)	(-4.1)	(-5.3)
F-FB	(-2.2)	(-4.9)	(0.6)	(-5.6)

(6) Experiment of Oudah (1990)

Breed group	4-wk weight	6-wk weight	10-wk weight
NzCa	4.7	7.7	6.4
CaNz	3.9	3.1	7.1
NzBa	-4.5	-3.2	3.4
BaNz	3.3	5.8	6.5
CaBa	-4.3	-5.8	-5.2
BaCa	2.8	8.5	6.6

+Where F2 was BF-FB or FB-BF.

Table 14. Reviewed estimates of heterosis and reciprocal effect percentages for gain in body weight during different age intervals.

(1) Experiment of Afifi (1971)		(2) Experiment of EL-Qen (1988)			
Breed group	4-24 weeks	Breed group	4-8 weeks	8-12 weeks	12-16 weeks
BC	15.95(13.31)	BF	-15.59	-8.13	-2.07
CB	14.80(18.06)	FB	-0.06	3.56	-28.71
BG	-02.15(-02.37)	F2	-30.28	7.68	-18.28
GB	01.12(-01.65)	B-BF	-4.69	-6.05	-5.73
CG	09.45(17.36)	F-FB	-7.53	10.89	-24.50
GC	17.24(12.23)				
CB-GB	(16.40)				
GB-CB	(15.61)				

Table 15. Reviewed estimates of heterosis and reciprocal effect percentages for post-weaning viability.

(1) Experiment of Afifi (1971)

Breed group	4-12 weeks	4-24 weeks
BC	30.43(8.51)	57.89(16.36)
CB	-8.70(34.04)	0.00(52.73)
BG	-25.37(-9.80)	-26.47(11.11)
GB	34.33(5.88)	23.53(-13.9)
CG	12.36(-20.4)	7.69(-67.2)
GC	-5.62(8.16)	-15.38(11.48)
CB-GB	(22.45)	(28.12)
GB-CB	(2.04)	(-21.9)

(2) Experiment of Afifi and Emara (1988)

Breed group	5-6 weeks	5-8 weeks	5-12 weeks	5-16 weeks
BG	-3.5	-11.6	-10.7	-10.9
BFw	-0.2	-10.6	-9.9	-9.8
BR	0.0	0.3	-0.3	0.6
GFw	0.4	-4.1	-5.7	-5.6
GR	-0.8	-0.8	-5.6	-5.7
FwR	-0.8	2.8	-7.2	-7.6

Table 16. Tests of significance for heterotic and genetic effects on some economic traits as reported in crossbreeding experiments in Egypt+.

Trait & reference	Genetic parameters++				
	H	GCA	MA	SCA	SL
Litter size at birth Afifi and Emara (1989)	**	ns	ns	ns	ns
Litter size at weaning Afifi and Emara (1989)	**	ns	*	ns	ns
Litter weight at birth Afifi (1971) Emara (1982)	ns **	ns **	ns ns	— **	— **
Litter weight at weaning Afifi (1971) Emara (1982)	** **	** ns	** **	— ns	— ns
Pre-weaning mortality Emara (1982)	ns	ns	ns	ns	ns
Body weight at 4 weeks (weaning) Afifi (1971)	ns	**	ns	—	—
Body weight at 5 weeks (weaning) Emara (1982)	ns	ns	*	*	ns
Body weight at 8 weeks Emara (1982)	**	ns	**	**	ns
Body weight at 12 weeks Afifi (1971) Emara (1982)	ns ns	ns **	ns **	— ns	— ns
Body weight at 16 weeks Emara (1982)	ns	ns	**	ns	ns
Body weight at 24 weeks Afifi (1971)	*	ns	ns	—	—

+ Breeds used by Afifi (1971) were B, C and G while breeds used by Emara (1982) and Afifi and Emara (1989) were B, G, Fw and R.

++ Where H= heterosis, GCA= general combining ability,
MA= maternal ability, SCA= specific combining ability and
SL= sex-linkage.