Crossbreeding Effects of Native Baladi-Red and Acclimatized Californian Rabbits on Post-Weaning Body Weights

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Abstract: This study employed a crossbreeding plan experiment between Baladi-Red (BR) and the Acclimatized Californian (Cal) rabbits to assess the crossbreeding effects on post-weaning body weights from 4 through 15 Wk. of age. The estimated crossbreeding genetic factors of four phenotypes were direct additive, maternal additive effects, and direct heterotic effects. The general findings indicated that all fixed effects (*i.e.,* mating/breeding groups, sex, year of birth and litter size at birth as a covariate), except customarily parity and birth season were insignificant. Body weight heterotic percentages varied from 2.5% to 5.0%, and they were significant for the majority of body weight traits. Californian rabbits had considerable direct additive effects for body weight. All study traits showed positive sign of direct additive, with the exception of 14 Wk. body weight. The maternal additive (G^M) impact was negligible for all traits and showed a negative sign for body weight at 4, 5, 6, 10, and 11 Wk. of age. The latest findings suggest that crossbreeding these two rabbit breeds could be advantageous for developing plans to produce Egyptian crossbred broiler rabbits. This approach could help address the shortage of meat proteins and the economic challenges currently Egypt faces.

Keywords: native rabbits, acclimatized rabbits, crossbreeding, heterotic, maternal, direct additive effect

INTRODUCTION

Rabbits have a wide range of economic traits, including growth-related performances (e.g., gain in weight, growth rate, feed intake, and feed conversion). Therefore, by executing breed diversity and breeding programs, crossbred broiler rabbit performance can be quickly achieved **(Sakr *et al.,* 2020)**. Purebred and crossbred animals need to be assessed for the profitability and for previously listed economic attributes in order to run commercial operations **(Abdel-Azeem *et al.,* 2007)**.

Through crossbreeding experiments, genetic diversity is increased among some local breeds (Baladi-Red, White, and Black) and different standard exotic breeds introduced to Egypt (New Zealand White and Californian). Those genetic materials can be a precursor for subsequent improvements of many important rabbit traits (*e.g.* doe reproductive, milk production, post-weaning growth, carcass performance, and many other traits **(Piles *et al.,* 2004)**. To develop a successful rabbit crossbreeding program for meat production, purebred rabbits exhibiting desirable meat qualities are selected as parent stock and their crosses determine the productivity of the resultant meat-rabbits **(Hassanien and Baiomy 2011)**.

A quick tool available to breeders is crossbreeding. The resultant heterosis can be utilized to raise output and create superior crossings. **(Abdel-Kafy *et al.,* 2021)**. The development of heterosis has led to the emergence of premium crossed breeds, which are produced by combining different qualities, improving several traits, and establishing performance increases in farm animals **(Ali and El-Tarabany, 2013)**.

Californian rabbits that have been acclimatized to the climate of Egypt might have undergone certain modifications that make them more accustomed for the area. These sorts of adaptations may possibly include tolerance to heat, immunity to certain local illnesses and/or other survival skills **(Zhang *et al.,* 2016a)**. By exploiting these regional adaptations, it might be possible to create a new breed-strain (line) that is better-adapted, to the Egyptian environment, rabbit breeds through selection and breeding. Crossbreeding can, on the other hand, introduce genetic diversity into a population, which can be beneficial in terms of overall health and toughness. By combining the genetic material of the California rabbits and native improved rabbit breeds (e.g., Baladi-Red), it is expected that breeders can potentially extra-enhance the genetic diversity of the resulting offspring.

The purpose of this study is to evaluate the potential of the breeding group and the genetic and non-genetic fixed effects (*i.e.,* sex, season of birth, and parity) affecting rabbits' growth performance. Additionally, the heterotic effect of post weaning weight along with the crossbreeding effects (*i.e.,* direct additive and maternal additive) are evaluated.

MATERIALS AND METHODS

Ethical authorization:

The current study was conducted in accordance with the guidelines of the Rabbits Research Unit, Agricultural Research Farm (ARF), College of Agriculture; Suez Canal University; Egypt. The customary operating procedures for rabbit home management were followed in the raising of each and every rabbit.

Experimental Work:

During three consecutive years of production, experimental work was conducted in the Rabbit Farm of the Animal Production Department, Faculty of Agriculture, Suez Canal University; Ismailia, Egypt. The rabbits under study originated from one Acclimatized Standard-breed (Californian, Cal) and one Indigenous developed Native-breed, (Baladi-Red, BR). Same managerial, environmental, and veterinary surrounding settings were applied to the raising of all does and bucks of both Native and Standard rabbit breeds. Matings were organized in a 2 by 2, complete diallel crossbreeding scheme with more tendency to increase the numbers of Purebreds on the expense of crossbreds (Because of the Farm Policy).

Table 1 describes the coefficients used with different contrasts (linear function), made to estimate the various crossbreeding effects for different evaluated Breeding Groups (*i.e.,* Californian, Cal; Baladi-Red, BR; Cal X BR and BR X Cal). A semi-closed rabbitry was used to nurture all the rabbits. Bucks and does for breeding were kept apart in separate wire cages organized in single-tier batteries. Each doe was moved to the cage of its assigned buck in a rotational manner following the farm breeding plan. Following the apparently successful mating, does were put back in their own cages. Does were mated also directly after birth to avoid reproductive failure problems. A palpation was performed ten days later on each doe to assess pregnancy. The same mating buck was used to re-mate does that failed to conceive until they became pregnant. After 28 days of life, the newborn rabbits were weaned (kits were weaned 4 Wk. post-partum), sexed, and ear-tagged before being moved to different batteries to be kept in groups of three to four individuals in typical progeny wire cages attached with drinking nipples and feeding containers/vessels. Rabbits were fed on a pelleted commercial ration contained approximately 16% crude protein, 13% crude fibers, and 2.5% fat, which was given to the rabbits on an *ad libitum* basis.

Data and analysis models:

Utilizing the general linear model (GLM) method of (SAS, 2003), data for growth traits (*i.e.,* weaning and post-weaning body weights; designated as BW_i; i = 4, 6, 8, 10, 12, and 14 Wk. of age) were examined.

Mating/breeding groups (MG_i), sex (SEX_j), year $(Y)_k$ & season $(S)_l$ of birth, parity (P_m) as a fixed effect, and litter size at birth (LSB) as a covariate make up the analysis model. The mathematical model utilized was as follows:

$Y_{ijklmno} = \mu + MG_i + SEX_j + (Y)_k + (S)_l + P_m + \beta (LSB)_n + e_{ijklmno} \rightarrow$ (Model 1), where:

$Y_{ijklmno}$: is the observation of body weight; μ: an underlying overall least squares mean specific to each trait; MG_i = the fixed effect of the i^{th} Mating/breeding group; SEX_j = the fixed effect of the j^{th} Sex; $(Y)_k$: the fixed effect of the k^{th} Year of birth; $(S)_l$: the fixed effect of the l^{th} season of birth; P_m= the fixed effect of the m^{th} Parity; Besides litter size at birth (LSB) as a covariate, in addition to the random-deviation Errors ($e_{ijklmno}$), which are assumed to be independently; normally & randomly distributed with a mean equals zero and a variance equals σ^2_e [~NID; (0 & σ^2_e)]. The pursuing contrasts showed in Table 1 were made to estimate the various crossbreeding effects (linear function; values and significance using contrast& estimate statements of SAS, **(Abdel-Ghany *et al.,* 2000a & b)**.

RESULTS AND DISCUSSION

Table 2 presented the overall actual means, minimum, maximum, and standard error of the live body weights of the rabbit-crosses belonging to Cal, BR, and their offspring from the weaning weight up to 15 Wk. of age. At weaning, kits weighed on average 416, 377, 474, and 458 g. for Cal, BR, Cal X BR, and BR X Cal, respectively. At the marketing age (15 Wk. farm policy), their individual body weights had climbed to 1987, 2037, 2089, and 2094 g., respectively. The weaning weight data from the Baladi-Red released by **Abdel-Azeem *et al.* (2007), Attalah *et al.* (2007), Gharib (2008), and Mabrouk *et al.* (2008)** are largely equivalent to the preceding results. Also, in the previous studies, the weight of marketing for Baladi-Red rabbits varied based on each individual's age at marketing. For the Californian purebred weight, the body weight from weaning weight to marketing was somewhat less than that found by **Abdel-Hamid (2015) and Meky *et al.* (2023).**

Least squares analysis of variance (ANOVA):

Table (3) demonstrates the Least squares analysis of variance (LS-. ANOVA) for different effects influencing rabbits' body weights (g) from weaning at 4 *Wk.* up to marketing at 15 *Wk.* of age.

Results of Table (3) generally exposed that significance-results of various effects on body weight from 4 through 15 *Wk.* of age, differ from one age to another. However, most factors (Mating/breeding groups, BG; Sex; Year of Birth; and Litter Size at birth, LSB as a covariate) generally revealed significance, except for Season of Birth and Parity, which commonly failed to prove significant effects on body weight at many of the evaluated ages.

Mating/breeding group:

Results of Table (3) revealed that different genotypes showed highly significant differences ($P \leq 0.001$) for almost all the variables evaluated. Almost all the time examined, crossbred rabbits had shown superiority for the post-weaning features compared with purebred. Results in Table (4) showed fluctuation of superiority between the two reciprocal crosses. For example, while the cross (Cal X BR) rabbits had the highest weight at most portrayed Wks. of age, the cross (BR X Cal) achieved the highest marketing weight at 15 Wk. of age. These outputs might not support the hypothesis that the supreme way to devolve locally produced broiler rabbits would be to use females from Californian rabbits and males from Baladi-Red rabbits. These findings could be due to the changes that happened during the decades of acclimatization process to the Californian rabbits.

The wide-ranging observed continuous increase of post-weaning body weight of the crossbreds could potentially be attributable to hybrid-vigor. Crossbreeding has a good effect on body weight at different ages and stages of growth compared with purebreds (**Hekil *et al.,* 2011, El-Bayomi, *et al.,* 2012, Nwakpu *et al.,* 2015, Mahran *et al.,* 2017** and **Shehab El-Din *et al.,* 2024**). These results correspond with the conclusions of **Abdel-Ghany *et al.* (2000a) and Nofal *et al.* (2000)** who made a comparison of crossbred rabbits with purebreds and revealed that hybrids created by crossing native Egyptian Baladi-Black rabbits exhibited superior marketing weight. The authors also mentioned the validity of employing the Baladi Black as a sire for most post-weaning traits. Furthermore, **Attalah *et al.* (2007)** revealed that the crossing between the buck of Baladi-

Red rabbits and the dam of Bauscat rabbits produced the highest weaning weight when compared to purebreds. Additionally, **Abdel-Azeem *et al.* (2007)** realized that the crossbreds' maximum weight was obtained throughout the fattening stage compared to the purebred when crossing Baladi-Red with French Giant Papillion rabbits. Conversely, **Afifi and Emara (1988)** established that crossing Bauscat, Giza white, white Flanders, and Baladi-Red decreased the BW of crossbred groups at 5 to 12 Wk. of age. Furthermore, **Abou Khadiga *et al.* (2008)** uncovered that throughout the post-weaning phase from 4 to 12 Wk. of age, the V-line purebred exhibited heavier weights than Baladi black and their crosses. Nonetheless, **Ali and El-Tarabany (2013)**, found that Gabali purebreds had the highest body weight values when compared to any of the reciprocal crosses between the Californian, Gabali, and New Zealand White.

Effect of Sex:

As shown in Table 3, sex significantly affected ($P \leq 0.01$ or $P \leq 0.001$) body weight of the tested rabbits at all evaluated post-weaning ages, except that at 4-Wks. (weaning). Results demonstrated that, on average, females do better than males at most investigated ages, with very little variation in their respective performances. This result aligns with the findings of **Abou Khadiga *et al.* (2008)**, who revealed that females were distinguished in terms of body weight from 4 to 12 Wk. Several authors, on the other hand, reported that sex had very little and insignificant effect (**Abdel-Ghany *et al.*, 2000b; Abdel-Azeem *et al.*, 2007 and Rabie *et al.*, 2019).**

Year of birth:

Year of birth was found to be a highly significant factor influencing differences in body weight ($P \leq 0.001$, Table 3). The body weight of kits at weaning was probably associated with increased milk yield, which is possibly resulted from the age-related weight increase of their dams, (Table 4). It also suggests that environmental factors (**Zhang *et al.*, 2016b** and **Huang *et al.*, 2020**) associated with specific years can have such substantial impact on growth and development. These environmental factors can feasibly be (Climate Variations; Disease Outbreaks and/or changes in management practices over time, such as feeding regimens, housing conditions, or veterinary care).

Season of birth:

The effect of birth-season on body weight was shown to be insignificant ($P > 0.05$, Table 3), at 4–12 Wk. of age, with the exception of that at the 6th Wk. The result in Table 4 showed that the winter-born rabbits had generally the highest weights, whereas the spring-born rabbits had the highest marketing weight. This is in contrast to the findings of **Rojan *et al.* (2013)** and **Al-Saffar *et al.* (2017)**, who found that during a period of 4 to 12 Wk. the season had a significant influence on post-weaning weight. Furthermore, the kits born in October through April were found to weigh the highest. **Desouky *et al.* (2021)** realized a substantial relationship between season and body weight with the springtime-born bunnies having the heaviest, while the summer-born had the lowest live body weights.

Parity:

Except that at the 6-Wk. BW, parity showed no appreciable impact ($P > 0.05$, Table 3) on body weight. The second parity gave the heaviest body weights, Table 4. These result's outcome differs from that of **Abdel-Ghany *et al.* (2000a)** who obtained a significant parity effect on BW of rabbits at most of age stages they examined, except that at 8, 14, and 16 Wk. of age. Furthermore, **Abou Khadiga *et al.* (2008)** ascertained that parity effect was significant ($P \leq 0.001$), for body weights from 4 to 12 Wk. with those born in the third parity performed the best. Moreover, **Desouky *et al.* (2021)** realized that the influence of parity revealed statistically significant variations on body weight of V-line rabbits across various age periods (from 4 to 12 Wk.). They also observed that the first parity was the lowest, while the third parity gained the heaviest. **Rabie *et al.* (2019)** observed that body weight fluctuated in response to increase in parity order.

Litter Size:

The results indicated that increased litter size at birth (LSB) caused a significant (Table 3 and 4; $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$) decrease in body weights at all estimated periods. These findings are highly consistent with those of **EL Kholya (2011)** who reported that post-weaning weight (28–70 days) was influenced by litter size. They concluded that a high litter size number would result in a decrease of post-weaning rabbits' weights. On the contrary; these findings are not in agreement with **Das (2022,** in India**)**, who realized that litter sizes significantly affected each litter's weight at weaning, but it had little effect on the rabbits' post-weaning growth.

Purebreds versus crossbreds:

Table (5) represents the linear functions (±SE) for various crossbreeding effects for the full diallel crossing between the Acclimatized Californian (Cal) and the Baladi-Red (BR) Rabbits from weaning (at 4 Wk.) till marketing (at 15 Wk.) of age.

Considering the hypothesis of preeminence of overall-heterosis over the med-parent value (purebreds vs. crossbreds) during the study period, results revealed that crossbreeding generally enhanced weight of crosses between Acclimatized Californian and Baladi-Red rabbits (Table 5). Nonetheless, outcomes displayed that crossbreeding effects were generally significant during the study period ($P \leq 0.001$ or $P \leq 0.01$). The negative sign of the linear function denotes that purebreds have significantly lower weights compared to crossbreds, which means that producing broiler rabbits would be visible using this crossbreeding plan. This is in agreement with the findings of **Abdel-Ghany *et al.* (2000a)**, who revealed that the cross between NZW and BR had a larger body weight from 6 to 16 Wk. compared with the pure-Breds.

Heterotic effect:

The direct heterosis (H^I; over med-parent value); ranged from (66.16 to 110.20 g.; and 3.63 to 17.54% as a percentage). Current findings showed that H^I was significantly positive at all evaluated ages ascertaining the last conclusion of the visibility of H^I in producing Egyptian broiler rabbits.

When considering overall heterosis over the Standard-Breed values [Acclimatized Californian rabbits, the higher-breed/superior-parent; [{Cal X BR) & (BR X Cal)} vs. (Cal X Cal)] during the same period of study, results displayed that crossbreeding generally enhanced the weight of crossbred-rabbits (with ranges from 46.39 to 98.24 g). However, Overall heterosis over the Native-Breed values [Baladi-Red, the lower-breed/inferior-parent; [(Cal X BR) & (BR X Cal)} vs. (BR X BR)] followed the same trend as that shown with the Californian rabbits. These results showed that the hybrid offspring surpasses the qualities of both parent breeds, ascertaining again the perceptibility of generating broiler Egyptian rabbits using those two available resources/breeds (with ranges from 46.51 to 138.46 g.).

Concerning the separate crosses heterosis over the Standard-Breed values [(Cal X BR) vs. (Cal X Cal)); (BR X Cal) vs. (Cal X Cal)] during the same study period, showed that crossbreeding of the two reciprocal crosses generally improved live body weight of crosses between Acclimatized Californian (Sires) and Baladi-Red Rabbits (with ranges from 54.99 to 93.71 g; while in case of Cal X BR crosses ranged from 37.80 to 102.77 g in case of BR X Cal -crosses).

When considering values of separate crosses heterosis over the Naive-Breed [(Cal X BR) vs. (BR X BR); (BR X Cal) vs. (BR X BR))] during the same study period, results revealed that live body weight of the two reciprocal crosses between Acclimatized Californian and Baladi-Red Rabbits generally has improved (with ranges from 41.98 to 138.46g in case of Cal X BR crosses and from 51.04 to 141.22g in case of BR X Cal crosses).

When comparing the two reciprocal crosses to each other, calculations uncovered that crosses sired by Acclimatized Californian rabbits (Cal X BR); fluctuated and did not differ significantly from those crosses sired by Baladi-Red native breed (BR X Cal) during the whole studied period until 14th Wk. of age.

The present findings are supported by **Meky *et al.* (2023)** experiments, they have uncovered a strong and positive direct heterosis on body weight at different stages except that in the 7th Wk. They also revealed that when crossing local Sinai-Gabali and California rabbits, the positive heterosis varied from 2.24 to 11.35%. Moreover, **Zaghloul *et al. (*2019)** reported that the crossing between APRI and Moshtohor, rabbit breeds, the direct heterosis ranged from 3.1 to 8.2%. Likewise, **Mahran *et al. (*2017)** revealed that the heterosis percentage varied from 3.15 to 3.55% for crossing between Chinchilla and Gabali, and from 4.18 to 8.79% when crossing New-Zealand White with Gabali.

The present results are substantiated by some other study that mentioned a robust and positive direct heterosis on body weight at most post weaning stage (4-12 Wk. of age), **Meky *et al. (*2023)** confirmed that the positive heterosis ranged from 2.24 to 11.35% when crossing California and local Sinai-Gabali rabbits. Additionally, **Zaghloul *et al. (*2019)** revealed that the direct heterosis varied from 3.1 to 8.2% for the crossing between APRI and Moshtohor line. On the other hand, **Mahran, *et al.* (2017)** established that the heterosis percentages when crossing Gabali with the New-Zealand White, they ranged from 3.15 to 3.55%, and from 4.18 to 8.79% when crossing with the Chinchilla. In addition, **Abdel-Hamid (2015)** showed that for the New Zealand White × Californian crossing, the percentage of the positive heterosis ranged from 9.20 to 20.24%, while for the Californian × Rex Crosses, it ranged from -3.61 to 12.05%. Also**, Hekil *et al.* (2011) i**ndicated positive heterosis for New Zealand White (NZW) X Californian (Cal) crosses ranged between 46.43 and 62.49% on body weight among 4 and 12 Wk. According to **Khalil and Al-Homidan (2014),** crossing the V-line with Saudi Arabia, showed a positive body weights heterosis of 4.5 to 5.4%.

The previous outcomes supported the hypothesis that the addition of Californian genes to native rabbit crossbreeding programs in hot climate countries (like Egypt) would improve post-weaning growth performance of the resultant crossbred rabbits.

This investigation took place to rationalize and substantiate the use of some of the acclimatized rabbit breeds to be crossed with some native breed, Baladi to produce Broiler rabbits with early reasonable growth. For instance, **Afifi *et al.* (1994)** reported that when crossing New Zealand White rabbits with Baladi-Red rabbits, the heterosis percentages for post-weaning body weights varied from 2.5 to 5.0%. Also**, Abou Khadiga *et al.* (2008)** revealed that when V-line, Egyptian Baladi Black, were crossed, the heterosis was positive and varied from 7 to 11.8%. Furthermore, **Abdel-Azeem *et al.* (2007)** suggested that the crosses between male Baladi-Reds and females of other breeds, including as Gigantea, Papillion, French Giant, and Chinchilla, have superior heterosis values. Contrariwise**, Nofal *et al.* (2000) and Abdel-Ghany *et al.* (2000a)**, reported that heterosis had no noticeable impact on their experimental flocks, post-weaning body weights (6 to 16 Wk.), and has even negative values at the 6, 8, and 12 Wk. of age. The last conclusion, of course, contradicted with the breeder's preference for their crosses between the Baladi-Black; BB or Baladi-Red; BR sires with NZW dams.

A dominance model would predict that genes with high heterosis in crossing would generally diverge from the mean gene frequency in opposite directions. The BR and CAL cross showed strong heterosis for post-weaning body weight because of the two breeds' lengthy histories of selection promoting variances in gene frequencies **(Abdel-Hamid, 2015)**. In the crossbreed progeny, this hybrid-vigor displays itself as better performing (e.g., faster growing or progressing, resistance to disease, and other desired fitness characteristics, **(Birchler *et al.*, 2006)**. Additionally, the heterotic effect can also be influenced by epigenetic changes like DNA methylation and histone alterations. The hybrid offspring may exhibit improved features because of these alterations, which may also affect gene expression patterns **(Chen, 2010)**.

Another alleged model is a Gene-Enzyme theory model which may be attributed to Heterosis. This theory delves into the intricate relationship between genetic diversity, enzyme function, and ultimately, superior phenotypes in hybrid organisms. The Gene-Enzyme Theory posits that multiple genes, each harboring slightly different versions (alleles), contribute to the production of a specific enzyme. These enzymes act as biological catalysts, accelerating crucial biochemical reactions within the organism **(Li *et al.,* 2008).** The key to understanding heterosis in this model lies in the concept of heterozygous advantage. When offspring inherit different alleles for these genes from each parent, they possess a wider variety of enzyme versions. These diverse enzymes can potentially lead to several advantages **(Li *et al.,* 2008)**. The presence of multiple enzyme variations can lead to a more efficient production of the targeted molecules within the metabolic pathway. This translates to faster reaction rates and potentially higher overall output **(Birchler *et al.,* 2003)**. The enzymes with slightly altered functions due to different alleles might create products with more desirable qualities. For example, an enzyme variant might lead to a stronger cell wall or a more nutritious seed composition **(Goodnight, 1984)**. The diverse enzymes within the same pathway could potentially work on a wider range of temperature, acidity and/or starting materials. This expands the organism's metabolic capabilities and allows for more efficient utilization of resources **(Goodnight, 1984)**. This finding offers a clear biological mechanism for heterosis by focusing on the impact of enzyme diversity on metabolic processes. This provides a testable framework for investigating the underlying causes of heterosis. Aligns well with the observation that heterosis is often most pronounced for quantitative traits (e.g., growth rate, yield ... etc.) heavily influenced by multiple genes and enzymes **(Birchler *et al.,* 2003)** It might be difficult to determine and measure exactly how much each unique variation in an enzyme contributes to heterosis. This makes it more difficult for the model to offer conclusive evidence in every situation. The model may not fully explain heterosis for complex traits influenced by factors beyond enzyme activity, such as gene regulation or protein-protein interactions **(Xu *et al.,* 2014)**. It complements other models for heterosis, such as over-dominance model: This model focuses on the advantage of heterozygous genotypes for specific genes, where both alleles contribute positively to the phenotype (**Falconer & Mackay, 1998)**. This model emphasizes the benefit of having more copies of beneficial genes, leading to increased production of essential proteins **(Charlesworth & Charlesworth, 1987)**. By understanding the interplay of these models, researchers can gain a more comprehensive picture of the intricate mechanisms driving heterosis. Generally, gene-enzyme theory provides a valuable perspective on heterosis by highlighting the potential benefits of genetic diversity in enzyme function. While limitations exist, it contributes significantly to the ongoing exploration of this intriguing biological phenomenon, enriching our understanding of hybrid vigor.

Superiority over sire or dam-breed:

As it was mentioned before that Heterosis, the phenomenon where offspring of genetically dissimilar parents do better than their straight Breds counterparts. These effects reported herein are to inspect if one of both the resultant reciprocal crosses significantly outperform any/both of their sire or dam-breed. The values of these contrasts are identical in values with those of [Separate cross heterosis Over Standard-Breed (Over Higher-parent value; Cal) and Separate cross heterosis Over Native/local-Breed (Over Lower-parent value; BR)]. The sign may change in some cases (mainly when compared to CAL, just because of the Superiority were for their counterpart straight Breds. The Interpretations herein are also the same as the aforementioned part pertaining to separate cross heterosis.

The superiority of crossbred rabbits over sire or dam breeds can be attributed to numerous factors. Crossbreeding rabbits can result in hybrid vigor, which is the phenomenon where the offspring of two different breeds exhibit superior traits compared to their parents. This can lead to increased growth rates, improved disease resistance, and overall better performance in cross-bred rabbits compared to purebred rabbits **(Hazel, 1943)**. Crossbreeding rabbits introduce new genetic material into the population, resulting in increasing genetic diversity. This can help reduce the risk of inherited diseases and improve overall health and vitality in crossbred rabbits **(Bishop *et al.,* 2011)**. Crossbreeding can be used to combine desirable traits from different breeds, such as meat quality, growth rate, or reproductive performance. This can result in cross-bred rabbits that are better suited for specific production purposes compared to purebred rabbits **(Lukefahr *et al.,* 2022)**. Cross-bred rabbits may exhibit increased adaptability to different environmental conditions compared to purebred rabbits. This can be particularly important for commercial rabbit production systems where animals are exposed to a variety of stressors **(Lukefahr *et al.,* 2022)**. Crossbreeding can help reduce the negative effects of inbreeding depression, which is a decline in fitness and health due to mating closely related individuals. By introducing new genetic material through crossbreeding, breeders can mitigate the negative effects of inbreeding and maintain healthy rabbit populations **(Bishop *et al.,* 2011).** On the whole, there are several reasons why cross-bred rabbits may exhibit superiority over sire- or dam-breeds, including hybrid vigor, increased genetic diversity, improved production traits, adaptability, and reduced inbreeding depression.

Straight-Bred differences:

In this respect, the straight Breds difference (Cal X Cal vs. BR X BR) indicated slight but still significant superiority of the Acclimatized Californian rabbits over the Baladi-Red Native breed. That difference faded with the advancement of age till the 14th Wk. of age, where it is Turned/Converted in favor of/towards Baladi-Red. It seems that during the acclimatization process, which lasted for many decades, it seems that Californian rabbits failed to demonstrate their reported growth performing preeminence except for early growth. Under the pressure of the Egyptian environment which differed greatly from the environment they had been selected-in they had to withdraw their eminence for genes of adaptability. However, this apparently does not mean that they have lost all of their superior genes, on the contrary, they have got a combination of alleles (through natural selection) that enable them to face that new environment they have been introduced to. Yet, it appears that those Acclimatized Californian rabbits, did not lose all the genetic distance with the improved local breed (Baladi-

Red), since the crossbreeding between them was still meaningfully successful ($P \leq 0.001$ or $P \leq 0.01$) as to what was mentioned before. These results are generally in agreement with those reported by **Abou Khadiga *et al.* (2008)** who demonstrated that purebred differences were found to be significantly better favored the standard breed (V-line) rabbits than that for Baladi-Black ones.

Direct additive effect (G^I):

The crossbreeding direct additive effect (G^I) refers to the average genetic contribution of a specific breed to the performance of its crossbred offspring. It is calculated as the deviation of a breed's average performance from the overall average performance of all breeds involved in the crossbreeding program **(Dickerson, 1969; Cunningham, 1997 and Dekkers, 2004)**.

In this particular, direct additive effect (Cal-G^I), was moderate and significant ($P < 0.05$) indicating superiority of the Cal rabbits contributions, over BR Native breed, at early growth till the 7th Wk. of age. Conversely, it turned to be none-significant ($P > 0.05$) thereafter, till the end of the assessment period. However, direct additive effects can be significant if the target trait has relatively high heritability estimates (*e.g.,* body weights, daily weight gain …etc.). In the context of crossbreeding, high heritability for a trait suggests that the genetic differences between the breeds being crossed will have a more significant impact on the offspring's performance for that trait, **Dekkers (2004)**. This is because the additive genetic effects from each breed will be more pronounced.

G^I ranged from -30.40 to 31.61 g. during the experimental period. Similar findings were made by **Abdel-Ghany *et al.* (2000a& b)**, who ascertained that crossing NZW with either Baladi-Red or Baladi Black, the produced direct additive effects of NZW were consistently superior to either breed for post-weaning body weights. Likewise, **Youssef *et al.* (2009)** recognized a substantial difference in the direct additive effects generally favors the V-Line rabbits over Baladi-Red on post-weaning weight during the period from 4 to 12 Wk. of age.

Maternal additive effect (G^m):

Maternal-additive influences are the effects on the offspring's phenotype due to the mothering ability genes and the environment provided by the mother during gestation and lactation. In crossbreeding, it refers to the influence of the dam's breed, regardless of its genetic contribution (direct additive effects, G^I) to the offspring's traits **(Dickerson, 1969; Cunningham, 1997 and Dekkers, 2004)**.

For all studied qualities, the maternal-additive influences were found to be negligible and non-significant ($P > 0.05$). Reasons for potential insignificancy maternal additive, G^m, effects are A. Limited uterine environment effects. Some traits might be less influenced by the in-utero or milk quantity, or composition provided by the mother (e.g., fur color might be primarily determined by the offspring's quantity, with minimal impact from the maternal environment). B. Similar Maternal Abilities of the crossed breeds, if both the standard (especially acclimatized ones) and native breeds have comparable lactation performance, milk composition, and nesting behavior, their maternal contributions to the offspring's development might be statistically similar. C. Short Gestation and Weaning periods (especially in intensive Production-Systems), Rabbits have a relatively short gestation period (around 30 days) and weaning time (around 4-6 Wk.). Rabbit maternal environmental influences on certain traits may be restricted compared to species with longer gestation or maternal care periods. Therefore, the significance of maternal additive effects in crossbreeding with rabbits depends on the specific traits being studied and the breed characteristics of the dam.

Despite the fact, they might not be a major factor for some traits, they can be very crucial for others, particularly those influenced by the maternal environment during early development **(Ouyed *et al.,* 2011)**.

The study's estimates of the Maternal-additive influences (G^m) for the considered growth characteristics revealed that across the evaluated early post-weaning period, the distribution of positive and negative estimates was relatively equal in the investigated Californian rabbit. Apart from significance, G^m estimates of Californian on kits' body weight at 7, 8, 9, 12, 13, 14, and 15 were positive and ranged from 0.05 to 9.26 g. whereas the trait in the other Wks. were negative with values ranged from -0.23 to-17.19 g. Therefore, motherhood outcomes were not in favorable of Cal or BR dam.

Corresponding to this, **Piles *et al.* (2004)** revealed no significant maternal effects on post-weaning development aspects when Californian and New Zealand White rabbits were used, along with their crossing. Additionally, **Ouyed and Brun (2008)** established that the genetic effects of Californian dams have a negative impact on body weights at 35 to 63 of age. Also, **Abdel-Hamid (2015)** established that, except for that at four Wks., the majority of post-weaning features in Californian rabbits showed a negative estimate of the maternal influence. However, **Abou Khadiga *et al.* (2008)** ascertained that maternal additive effects (G^m) were much more favorable to V-Line dams than Baladi Black for body weights at 8 and 12 Wk. of age. Furthermore, **Iraqi *et al.* (2008)** realized that when it came to maternal influence on body weights at 8 and 12 Wk. of age, the Gabali breed performed better than the V-Line. Additionally, **Abd El-Ghany *et al.* (2000a)** revealed that New Zealand White rabbits of all ages favored the maternal additive effects on body weights over the Baladi Black rabbits.

The acclimatized breeds of rabbits may show lower weights than their original breeds due to a variety of factors, including discontinue of genetic selection, environmental adaptation, and nutritional modifications. Acclimatized breeds of rabbits are often bred for specific traits that are desirable in their new environment, such as disease resistance or heat tolerance. This selective breeding may result in changes to the genetic makeup of the rabbits, including alterations in growth rates and body size. For example, a study on rabbit breeds in Nigeria established that acclimatized breeds had different growth patterns, body sizes and lower body weights compared to their European counterparts due to genetic selection for adaptation to local conditions **(Oseni and Lukefahr, 2014)**.For instance, a study on rabbit breeds in China realized that acclimatized rabbits had lower body weights than imported breeds due to adaptations to the local climate and feed resources **(Zhang *et al.*, 2016a)**.

A crossbreed's response to complementarity effect and crossbreeding among breeds can vary greatly depending on how well the purebreds participate in the crossbreeding-plan and reproductively perform and in terms of outputs. Each breed's additive maternal and cytoplasmic inheritance is referenced by these variations in maternal impact.

CONCLUSIONS

Positive& highly significant heterotic effects support the use of crossbreeding techniques to produce broiler rabbits in Egypt. A successful synthetic line that would succeed in Egypt might be produced by combining acclimatized Californian rabbits with the locally adapted genetic resource “Baladi Red”. Moreover, traits related to body weight are more influenced by direct genetic impacts than by maternal genetic effects.

Table (1). The coefficients used with different contrasts made to estimate the various crossbreeding effects (linear function), of Body weights (from weaning at 4-Wks till marketing at 15-Wks of age) for different evaluated Breeding Groups (*i.e.*, Cal; BR; Cal X BR and BR X Cal).

Contrast	Cal X Cal	Cal X BR	BR X Cal	BR X BR
Californian *vs.* Baladi-Red (**Straight Breds differences**).	1	0	0	-1
Straight Bredss *vs.* crosses (**Overall Heterosis**).	1	-1	-1	1
Direct heterosis.				
{(Cal X BR) & (BR X Cal)) *vs.* {(Cal X Cal) & (BR X BR)}	-0.5	0.5	0.5	-0.5
Separate/single-cross heterosis (over med-parent value) **Divergence of reciprocal crosses over med-parent value**.				
(Cal X BR) *vs.* {(Cal X Cal) & (BR X BR)}	-0.5	1	0	-0.5
(BR X Cal) *vs.* {(Cal X Cal) & (BR X BR)}	-0.5	0	1	-0.5
Overall-Heterosis, versus the standard breed (Californian).				
{(Cal X BR) & (BR X Cal)} *vs.* (Cal X Cal)	-1	0.5	0.5	0
Separate-cross heterosis, versus the standard breed (Californian).				
(Cal X BR) *vs.* (Cal X Cal)	-1	1	0	0
(BR X Cal) *vs.* (Cal X Cal)	-1	0	1	0
Overall heterosis, versus local/native (Baladi-Red).				
{(Cal X BR) & (BR X Cal)} *vs.* (BR X BR).	0	0.5	0.5	-1
Separate-Cross heterosis, versus local/native (Baladi-Red).				
(Cal X BR) *vs.* (BR X BR)	0	1	0	-1
(BR X Cal) *vs.* (BR X BR)	0	0	1	-1
Testing-crosses versus each other.				
(Cal X BR) *vs.* (BR X Cal)	0	1	-1	0
Sire-Breed Californian.				
(Cal X BR) *vs.* (Cal X Cal).	1	-1	0	0
Sire-Breed Baladi-Red.				
(BR X Cal) *vs.* (BR X BR).	0	0	1	-1
Dam-Breed Californian.				
(BR X Cal) *vs.* (Cal X Cal).	1	0	-1	0
Dam-Breed Baladi-Red.				
(Cal X BR) *vs.* (BR X BR).	0	1	0	-1
Californian maternal additive (G^M).	0	-1	1	0
Californian direct additive (G^I).	0.5	0.5	-0.5	-0.5

Table (2): Qualitative Statistics (*i.e.,* Numbers, N; Minimum, Min; Maximum, Max; Actual means and standard errors, SE) of Body weights (from weaning at 4 *Wk.* till marketing at 15 *Wk.* of age) for different evaluated Breeding Groups (*i.e.,* Cal; BR; Cal X BR and BR X Cal).

Traits	N	Min	Max	Mean	SE	N	Min	Max	Mean	SE
	Californian (Cal)					**Baladi-Red (BR)**				
WW4	877	210	750	416.67	2.90	729	155	750	377.19	3.38
BW 5	835	330	860	541.26	3.23	700	230	950	487.1	3.99
BW 6	800	380	1000	677.00	3.68	678	300	1090	615	4.84
BW 7	777	410	1210	815.07	4.10	630	350	1280	751.94	5.59
BW 8	758	550	1370	960.04	4.40	601	440	1580	912.23	7.44
BW 9	744	450	1520	1106.02	4.74	579	440	1880	1071.4	8.38
BW 10	729	650	1670	1255.34	4.76	554	650	2150	1224.51	9.46
BW 11	727	710	1850	1399.6	4.98	550	770	2310	1372.95	10.38
BW 12	725	760	2030	1547.34	5.21	548	900	2530	1519.98	11.23
BW 13	724	1270	2190	1695.77	5.28	540	1000	2630	1663.84	11.57
BW 14	724	1400	2400	1840.87	5.42	529	1250	2810	1807.57	11.82
BW 15	724	1550	2700	1987.68	5.69	218	1400	3080	2037.98	23.35
	Cal X BR[†]					**BR X Cal**				
WW	77	300	800	474.94	12.95	84	320	870	458.21	11.14
BW 5	76	390	950	609.47	13.95	82	410	990	600.85	12
BW 6	73	510	1110	754.52	15.15	81	480	1860	754.57	19.07
BW 7	73	570	1270	894.25	16.34	77	560	1300	896.88	14.46
BW 8	71	630	1430	1040.7	17.48	77	730	1460	1044.94	15.05
BW 9	70	860	1600	1196.14	16.99	76	860	1620	1196.84	15
BW 10	70	1000	1750	1346.71	17.39	76	1000	1760	1342.89	15.31
BW 11	70	1130	1900	1496.43	18.16	76	1130	1910	1492.63	15.52
BW 12	70	1270	2050	1644	18.38	76	1270	2060	1641.84	15.84
BW 13	70	1400	2200	1790.43	19.04	76	1400	2210	1791.45	16.27
BW 14	70	1530	2350	1938.57	19.59	76	1530	2360	1942.63	16.75
BW 15	70	1670	2510	2089.43	20.75	76	1670	2510	2094.21	16.91

†: Sire-breed is denoted first

Table (3): Least squares analysis of variance (ANOVA) for different effects influencing rabbits' body weights (g) from weaning at 4 Wk. up to 15 Wk. of age.

Source of variance	BWW			BW5			BW6		
	df	SS	Prob.	df	SS	Prob.	df	SS	Prob.
Mating/breeding groups, BG	3	1187292	<.0001	3	2098279.31	<.0001	3	2749792.92	<.0001
Sex	1	16754.13	0.142	1	87512.83	0.0024	1	101158.13	0.0057
Year of Birth	2	528766.9	<.0001	2	727182.32	<.0001	2	928698.28	<.0001
Season of Birth	3	52148.48	0.0819	3	47453.37	0.1725	3	30239.90	**0.515**
Parity	4	62874.88	0.0885	4	78872.82	0.0816	4	187829.49	0.0068
Litter Size at birth, LSB	1	71119.24	0.0025	1	100832.52	0.0011	1	205345.83	<.0001
Experimental Error	1722	13368673		1648	15653555		1588	20987500	

Source of variance	BW7			BW8			BW9		
	df	SS	Prob.	df	SS	Prob.		SS	Prob.
Mating/breeding groups, BG	3	2773453.39	<.0001	3	1964562.65	<.0001	3	1619678.37	<.0001
Sex	1	252082.08	<.0001	1	268945.81	0.0004	1	439406.41	<.0001
Year of Birth	2	1002100.49	<.0001	2	1275263.24	<.0001	2	1268188.83	<.0001
Season of Birth	3	12344.54	0.8435	3	104331.77	0.1763	3	88160.99	0.3148
Parity	4	255562.00	0.0019	4	299381.72	0.0069	4	279553.06	0.0242
Litter Size at birth, LSB	1	224791.78	0.0001	1	348984.95	<.0001	1	310910.96	0.0004
Error	1514	22652181		1478	35646592		1427	35444618	

Source of variance	BW10			BW11			BW12		
	df	SS	Prob.	df	SS	Prob.		SS	Prob.
Mating/breeding groups, BG	3	1483164.87	<.0001	3	1478221.14	<.0001	3	1520523.09	<.0001
Sex	1	554862.74	<.0001	1	794249.48	<.0001	1	974982.10	<.0001
Year of Birth	2	1057552.41	<.0001	2	1013659.73	<.0001	2	1160610.70	<.0001
Season of Birth	3	66671.70	0.5015	3	63822.45	0.5826	3	57094.47	0.6739
Parity	4	268338.62	0.0504	4	234724.36	0.1274	4	243687.06	0.1618
Litter Size at birth, LSB	1	261630.83	0.0024	1	228491.14	0.0083	1	267214.04	0.0074
Error	1387	39197630		1381	45154769		1377	51156593	

Source of variance	BW13			BW14			BW15		
	df	SS	Prob.	df	SS	Prob.		SS	Prob.
Mating/breeding groups, BG	3	1613113	<.0001	3	1723896	<.0001	3	1364950	<.0001
Sex	1	1255579	<.0001	1	1506830	<.0001	1	2119082	<.0001
Year of Birth	2	1286954	<.0001	2	1372104	<.0001	2	639006.1	0.0003
Season of Birth	3	32745.08	0.836	3	40789.6	0.7917	3	61075	0.6703
Parity	4	297510.8	0.1007	4	318361.4	0.0882	4	220581.3	0.2313
Litter Size at birth, LSB	1	345833.3	0.0027	1	221744.6	0.0176	1	193050.4	0.027
Error	1368	52321485		1358	53288457		1067	41979884	

BWW = body weights at Weaning (4 Wk.); BW5 to BW15 refer to BW at 5 to 15 Wk. of age. Litter Size at birth, (LSB) was incorporated in the model as a covariate.

Table (4): Least squares means (+SE, in grams) of different factors affecting body weight. From weaning at 4 Wk. till marketing at 15 Wk. of age) in California (Cal); Baladi-Red (BR) rabbits and their single reciprocal crosses

Parameters	BWW	BW5	BW6	BW7	BW8	BW9	BW10	BW11	BW12	BW13	BW14	BW15
Breeds												
Cal X Cal	407.01±4.11	529.21±4.68	663.39±5.66	799.10±6.11	943.63±7.46	1090.55±8.18	1241.65±8.90	1384.53±9.60	1532.61±10.25	1681.64±10.41	1823.13±10.56	1970.67±11.33
Br X Br	368.07±4.13	474.70±4.72	600.90±5.71	735.72±6.21	896.59±7.65	1056.18±8.43	1211.72±9.30	1359.59±10.03	1507.35±10.71	1652.82±10.94	1795.07±11.16	2022.41±15.65
Cal X BR	462.60±10.49	594.37±11.72	736.09±14.18	874.18±15.10	1017.74±18.23	1172.77±19.92	1327.05±21.30	1474.94±22.91	1623.76±24.43	1770.63±24.79	1916.45±25.12	2064.39±25.49
BR X Cal	445.41±10.05	585.65±11.25	735.86±13.40	876.95±14.57	1024.59±17.37	1176.05±18.99	1325.51±20.31	1473.83±21.85	1623.82±23.30	1774.79±23.64	1922.14±23.95	2073.45±24.34
Sex												
Male	417.80±5.02	538.69±5.66	676.07±6.86	808.56±7.40	957.07±8.95	1106.31±9.79	1256.46±10.57	1399.21±11.37	1545.24±12.13	1689.64±12.32	1830.85±12.50	1988.10±13.68
Female	424.05±5.03	553.28±5.68	692.05±6.87	834.42±7.38	984.21±9.00	1141.47±9.87	1296.50±10.71	1447.24±11.54	1598.53±12.31	1750.30±12.53	1897.55±12.71	2077.36±13.86
Parity												
1st	425.19±5.42	554.84±6.11	695.20±7.30	836.38±7.90	976.90±9.54	1129.81±10.43	1282.58±11.20	1430.35±12.05	1579.87±12.88	1731.29±13.07	1879.07±13.29	2047.17±14.36
2nd	430.09±4.90	554.70±5.51	698.01±6.61	839.83±7.20	991.64±8.64	1144.53±9.50	1292.13±10.18	1440.27±10.96	1587.81±11.70	1734.44±11.89	1882.43±12.06	2054.72±13.02
3rd	413.82±6.29	537.45±7.07	669.89±8.52	806.05±9.21	953.03±11.06	1106.75±12.10	1257.32±13.03	1406.64±14.03	1555.78±14.98	1703.07±15.29	1849.30±15.53	2021.36±17.35
4th	417.22±7.21	542.97±8.21	675.81±9.77	819.39±10.59	959.24±12.74	1112.91±13.96	1259.04±15.06	1409.36±16.25	1554.01±17.32	1695.68±17.61	1841.41±17.94	2017.31±20.03
5th	418.30±12.22	539.97±14.01	681.37±17.40	805.79±18.55	972.38±23.19	1125.45±25.44	1291.35±28.13	1429.49±30.27	1581.95±32.27	1735.37±32.75	1868.78±33.18	2023.09±37.85
Season of Birth												
Autumn	425.27±5.79	552.65±6.55	691.94±7.89	826.27±8.51	986.61±10.33	1138.70±11.34	1288.82±12.25	1434.22±13.20	1583.34±14.08	1728.08±14.29	1871.61±14.52	2032.01±15.87
Spring	411.40±5.88	538.14±6.61	678.55±8.02	817.26±8.66	963.15±10.46	1120.48±11.47	1277.25±12.37	1426.44±13.31	1572.54±14.20	1721.17±14.42	1868.88±14.64	2046.43±15.91
Summer	420.77±7.88	542.12±8.89	681.35±10.69	820.83±11.61	961.97±14.02	1117.02±15.33	1265.87±16.52	1411.63±17.83	1563.20±19.09	1714.77±19.50	1856.04±19.81	2026.34±22.31
Winter	426.25±5.38	551.03±6.11	684.39±7.39	821.59±7.97	970.81±9.67	1119.36±10.58	1273.99±11.48	1420.59±12.35	1568.46±13.17	1715.86±13.39	1860.26±13.58	2026.13±15.02
Year of Birth												
1st	387.15±7.00	505.56±7.95	636.98±9.55	772.40±10.33	914.23±12.55	1067.05±13.78	1223.26±14.99	1371.20±16.16	1516.61±17.25	1662.17±17.55	1804.13±17.83	1984.95±19.76
2nd	432.92±4.92	559.16±5.53	703.76±6.66	836.94±7.16	988.25±8.66	1141.25±9.49	1293.84±10.26	1439.47±11.04	1587.81±11.79	1735.36±11.98	1880.64±12.15	2051.83±13.27
3rd	442.70±5.18	573.24±5.84	711.43±7.11	855.13±7.70	1009.44±9.33	1163.37±10.19	1312.35±10.98	1459.00±11.82	1611.24±12.60	1762.38±12.80	1907.82±12.98	2061.41±14.16

Table (5): Linear function, mm. (±SE) of purebred differences and crossbreeding effects of live body weight (BW) from 4 to 15 Wk. of age in Californian (Cal); Baladi-Red (BR) rabbits and their reciprocal crosses.

Crossbreeding Effect	BW4	BW5	BW6	BW7	BW8	BW9
Pure *vs.* Cross	-132.323***± 14.72	-176.10***±16.46	-207.66***±19.71	-216.30***±21.24	-202.11***±25.43	-202.1***±27.81
Direct heterosis						
Crossing *vs.* pure H^{I} †	66.16***± 7.36	88.05***±8.23	103.83***±9.85	108.15***±10.62	101.06***±12.72	101.1***±13.91
Heterosis (H^{I} %)	17.07	17.54	16.43	14.09	10.98	9.42
Separate/Single-Cross heterosis (Over med-parent value) Divergence of reciprocal crosses over med-parent value						
CAL*BR *vs.* pure	74.76***± 10.39	92.41***±11.59	103.95***±13.95	106.77***±14.87	97.63***±17.91	99.41***±19.57
BR* CAL *vs.* pure	57.57***± 9.91	83.69***±11.10	103.71***±13.18	109.53***±14.38	104.48***±17.09	102.69***±18.68
Heterosis Over Standard-Breed (Over Higher-parent value; Cal).						
Crossing *vs.* CAL* CAL	46.39***±7.63	60.80***±8.53	72.59***±10.22	76.46***±11.00	77.53***±13.17	83.86***±14.40
Separate cross heterosis Over Standard-Breed; Cal); Divergence of reciprocal crosses over Higher-parent value						
CAL*BR *vs.* CAL* CAL	54.99***±10.58	65.15***±11.80	72.70***±14.20	75.08***±15.13	74.10***±18.22	82.22***±19.91
BR* CAL *vs.* CAL* CAL	37.80**±10.11	56.44***±11.33	72.47***±13.47	77.84***±14.68	80.96***±17.45	85.50***±19.07
Heterosis Over Native/local-Breed (Over Lower-parent value; BR).						
Crossing *vs.* BR* BR	85.93***±7.78	115.31***±8.70	135.07***±10.42	139.84***±11.27	124.58***±13.52	118.23***±14.81
Separate cross heterosis Over Native/local-Breed; Divergence of reciprocal crosses over Lower -parent value						
CAL*BR *vs.* BR* BR	94.52***±10.22	119.66***±11.93	135.19***±14.37	138.46***±15.35	121.15***±18.50	116.59***±20.24
BR* CAL *vs.* BR* BR	77.34***±10.22	110.95***±11.44	134.96***±13.60	141.22***±14.86	128.01***±17.69	119.87***±19.35
Divergence of reciprocal crosses versus each-other.						
CAL*BR *vs* BR* CAL	17.19±13.98	8.72±15.61	0.23±18.67	-2.76±20.11	-6.86±24.06	-3.28±26.28
Superiority of reciprocal crosses Over Sire-Breed.						
CAL*BR *vs.* CAL Sire	-54.99***±10.58	-65.15***±11.80	-72.70***±14.20	-75.08***±15.13	-74.10***±18.22	-82.22***±19.91
BR* CAL *vs.* BR Sire	77.34***±10.22	110.95***±11.44	134.96***±13.60	141.22***±14.86	128.01***±17.69	119.87***±19.35
Superiority of reciprocal crosses Over Dam-Breed.						
CAL*BR *vs.* CAL Dam	94.52***±10.69	119.66***±11.93	135.19***±14.37	138.46***±15.35	121.15***±18.50	116.59***±20.24
BR* CAL *vs.* BR Dam	-37.80**±10.11	-56.44***±11.33	-72.47***±13.47	-77.84***±14.68	-80.96***±17.45	-85.50***±19.07
Straight Breds difference:						
Cal Pure vs. Baladi Pure	39.54***±4.51	54.51***±5.10	62.49***±6.13	63.38***±6.71	47.04***±8.12	34.37***±8.95
Californian direct additive	28.36***±7.35	31.61***±8.22	31.36**±9.84	30.31**±10.62	20.09±12.71	15.55±13.90
Californian maternal additive	-17.19±13.98	-8.72±15.61	-0.23±18.67	2.76±20.11	6.86±24.06	3.28±26.28

Crossbreeding Effect	BW10	BW11	BW12	BW13	BW14	BW15
Pure *vs.* Cross	-199.19***±29.71	-204.65***±31.97	-207.63***±34.08	-210.96***±34.59	-220.40***±35.06	-144.75***±36.60
Direct heterosis						
Crossing *vs.* pure H^{I} †	99.59***±14.86	102.32***±15.98	103.81***±17.04	105.48***±17.30	110.20***±17.53	72.38***±25.20
Heterosis (H^{I} %)	8.12	7.46	6.83	6.33	6.09	3.63
Separate/Single-Cross heterosis (Over med-parent value) Divergence of reciprocal crosses over med-parent value						
CAL*BR *vs.* pure	100.370***±20.90	102.88***±22.48	103.79***±23.96	103.40***±24.32	107.35***±24.64	67.85*±24.14
BR* CAL *vs.* pure	98.82***±19.95	101.77***±21.46	103.84***±22.88	107.56***±23.22	113.04***±23.53	76.91**±16.56
Heterosis Over Standard-Breed (Over Higher-parent value; Cal).						
Crossing *vs.* CAL* CAL	84.63***±15.38	89.85***±16.55	91.19***±17.64	91.07***±17.90	96.17***±18.14	98.24***±18.18
Separate cross heterosis Over Standard-Breed; Divergence of reciprocal crosses over Higher-parent value						
CAL*BR *vs.* CAL*CL	85.40***±21.26	90.41***±22.87	91.16***±24.38	88.99**±24.74	93.32**±25.06	93.71**±25.11
BR* CAL *vs.* CAL*CL	83.85***±20.36	89.30***±21.90	91.21**±23.35	93.15***±23.69	99.01***±24.00	102.77***±24.06
Heterosis Over Native/local-Breed (Over Lower-parent value; BR).						
Crossing *vs.*BR* BR	114.56***±15.87	114.80***±17.09	116.44***±18.22	119.89***±18.51	124.23***±18.79	46.51*±21.45
Separate cross heterosis Over Native/local-Breed; BR); Divergence of reciprocal crosses over Lower-parent value						
CAL*BR *vs.* BR* BR	115.34***±21.64	115.35***±23.29	116.41***±24.83	117.81***±25.21	121.39***±25.57	41.98±27.59
BR* CAL *vs.* BR* BR	113.79***±20.70	114.24***±22.27	116.47***±23.75	121.97***±24.12	127.07***±24.46	51.04±26.61
Divergence of reciprocal crosses versus each-other.						
CAL*BR *vs* BR* CAL	1.55±28.04	1.11±30.16	-0.05±32.15	-4.16±32.62	-5.69±33.04	-9.06±33.12
Superiority of reciprocal crosses Over Sire-Breed.						
CAL*BR *vs.* CAL Sire	-85.40***±21.26	-90.41***±22.87	-91.16**±24.38	-88.99**±24.74	-93.32**±25.06	-93.71**±25.11
BR* CAL *vs.* BR Sire	113.79***±20.70	114.24***±22.27	116.47***±23.75	121.97***±24.12	127.07***±24.46	51.04*±26.61
Superiority of reciprocal crosses Over Dam-Breed.						
CAL*BR *vs.* CAL Dam	115.34***±21.64	115.35***±23.29	116.41***±24.83	117.81***±25.21	121.39***±25.57	41.98±27.59
BR* CAL *vs.* BR Dam	-83.85***±20.36	-89.30***±21.90	-91.21***±23.35	-93.15***±23.69	-99.01***±24.00	-102.77***±24.06
Straight Breds difference:						
Cal Pure *vs.* Baladi pure	29.93**±9.71	24.94*±10.47	25.26*±11.18	28.83*±11.39	28.06*±11.61	-51.74**±15.56
Californian direct additive	15.74±14.86	13.03±15.99	12.60±17.05	12.33±17.30	11.19±17.54	-30.40±18.31
Californian maternal additive	-1.55±28.04	-1.11±30.16	0.05±32.15	4.16±32.62	5.69±33.04	9.06±33.12

* = Significant ($P< 0.05$); ** = Significant ($P< 0.01$); *** = Significant ($P< 0.001$).

REFERENCES

Abdel-Azeem, A.S., Abdel-Azim A.M., Darwish, A.A. and Omar, E.M. (2007). Some Growth Performance Traits of the Present Pure Breeds of Rabbits and Their Crosses under Egyptian Environmental Conditions. The 5th Inter. Con. on Rabbit Prod. In Hot Clim. Hurghada, Egypt, 53-65.

Abdel-Ghany, A.M., Ahmed, E.G. and Hassan, N.S. (2000a). Crossbreeding genetic parameters of post-weaning growth traits of the Egyptian acclimatized New Zealand White and native Baladi Black rabbits. 7th World Rabbit Congr. Valencia, (Spain), vol. A, pp. 317-323.

Abdel-Ghany, A.M., Hassan, N.S. and Amin, A.A. (2000b). Heterosis, direct and maternal abilities of post-weaning daily gain in weight traits of two Egyptian native breeds on account of crossing with New Zealand White rabbits. 7th World Rabbit Congr., Valencia, (Spain), vol. A, pp. 325-331.

Abdel-Hamid, T.M., (2015). Crossbreeding Parameters for Growth Traits in a Complete Three Breeds Diallel Cross Design of Rabbits in Egypt. J. Adv. Vet. Anim. Res., 2(2): 120-127.

Abdel-Kafy, E.S., S. El-Deighadi, A., M. Shabaan, H., H. A. Ali, W., A. Sabra, Z. E.-A., and Farid, A. (2021). Genetic evaluation for growth traits in new synthetic rabbit line in Egypt. Open Journal of Agricultural Research, 1(2).

Abou Khadiga, G., Saleh, K., Nofal, R. and Baselga, M. (2008). Genetic evaluation of growth traits in a crossbreeding experiment involving line V and Baladi Black rabbits in Egypt. 9th World Rabbit Congress-June 10-13, Verona- Italy, pp 23-27.

Afifi, E A., Khalil, M. H., Khadr, A. F. and Youssef, Y.M. K. (1994). Heterosis, maternal and direct genetic effects for post weaning growth traits and carcass performance in rabbits crosses. J. Animal Breed. Genet. 111(1): 138-147.

Afifi, E.A. and Emara, M.E., (1988). Post-weaning viability of purebred and crossbred rabbits under Egyptian conditions. J. Appl. Rabbit Res. 1 (1). 38-40.

Ali, M.A and El-Tarabany, M.S. (2013). Economic and productive comparison among three rabbit breeds and their crosses under Egyptian conditions. Suez Canal Veterinary Medical Journal, XVIII (1)

Attalah, G.E.Y., Farid, A. and Gharib, M.G., (2007). Estimation of crossbreeding effects for doe traits in crossing of Bauscat and Baladi-Red rabbits. J. Agric. Sci. Mansoura Univ., 32 (2): 869-877.

Birchler, E.A., Auger, D.L. and Riddle, P.M. (2003). In search of the molecular basis of heterosis. Plant Cell, 15(10), 2236-2239.

Birchler, J.A., Yao, H., and Chudalayi, S. (2006). Unraveling the genetic basis of hybrid vigor. Proceedings of the National Academy of Sciences, 103(35), 12957-12958. DOI: 10.1073/pnas.0604630103.

Bishop, S.C., Axford R.F.E., Nicholas F.W. and Owen J.B. (2011). Breeding for disease resistance in farm animals. 3rd ed. Wallingford: CAB International; p. 251-76.

Charlesworth, D., and Charlesworth, B. (1987). Inbreeding depression and heterosis: Kinds of fitness effects and their genetic basis. Evolution, 41(6), 1067-1079.

Chen, Z.J. (2010). Molecular mechanisms of polyploidy and hybrid vigor. Trends in Plant Science, 15(2), 57-71. DOI: 10.1016/j.tplants. 12.003.

Das, S.K. (2022). Effect of litter size at birth on litter traits and growth of broiler rabbit in sub temperate climate of India. Acta Scientific Veterinary Sciences 4.2: 61-64.

Desouky, A.T., EL-Gendi, G.M. Iraqi, M.M and Rashad, S.A. (2021). Influence of Genotypes, Season of Birth, Parity Order and the Interactions between Them on Litter Traits and Body Weight Measurements of Rabbits. Annals of Agric. Sci., Moshtohor, Vol. 59 (2).

Elkholya, S.Z. (2011). Effect of litter size on post weaning ingestive behaviour, mortality rate and productive performance of rabbit's kits. BVMJ, 22(2): 161-168.

El-Bayomi, Kh. M., El-Tarabany, M.S. and Abdel-Hamid., T.M. (2012). Estimation of heterosis and combining ability for some weaning and post-weaning traits rabbits with Hyla strain: growth and reproductive performance in the first generation. Options Mediterrannens Serie. A, Seminaries Mediterrannens. No. 8: 103-108.

Al-Saffar, A.H., Al-Mousawi, A.H. and Al-Khafaji, A.A. (2017). Effect of breeding season on growth performance of rabbits. Iraqi Journal of Veterinary Sciences, 31(2): 113-120.

Cunningham, P.J. (1997). Heterosis and breed complementarity in crossbreeding systems. Animal Science 64: 255-267.

Dekkers, J.C.M. (2004). Quantitative genetics of crossbreeding. Journal of Animal Science 82: 1888-1897. Falconer, D.S. and Mackay, T.F.C. (1998). Introduction to quantitative genetics (4th Ed.). Longman.

Dickerson, G.E. (1969). Experimental approaches in utilizing breed differences and heterosis in swine. In: Pig Breeding (ed. J.L. Lush), pp. 169-194. Iowa State University Press, Ames, Iowa, USA.

Gharib, M.G. (2008). A study of some productive and reproductive traits and growth rates in Baladi-Red and Bauscat rabbits and their crosses. M.Sc. Thesis, Faculty of Agriculture, Al-Azhar University, Nasr-City, Cairo, Egypt.

Goodnight, C.J. (1984). Epistasis and the effect of genetic uniformity on developmental stability. Genetics, 108(3), 441-450.

Hassanien, H. and Baiomy A. (2011). Effect of breed and parity on growth performance, litter size, litter weight, conception rate and semen characteristics of medium size rabbits in hot climates. Egypt Poultry Sci.31-45.

Hazel, L.N. (1943). The genetic basis for constructing selection indexes. Genetics 28, 476-490.

Hekil, A.M, Gebriel G.M, Enab A.A., Hamoda I.A. and Abdou F.H. (2011). Genetic studies on some economic traits in rabbits. 2- Post-weaning body weight and growth rate. Egyptian Journal of Agriculture Research, 89: 345-360.

Huang, L., Zhang, Q. and Wang, Z. (2020). Genetic and phenotypic analysis of growth traits in rabbits. Journal of Animal Science and Biotechnology, 11(1): 1-9.

Iraqi, M., Afifi, E., Baselga, M., Khalil, M. and García, M. (2008). Additive and heterotic components for post-weaning growth traits in a crossing project of V-Line with Gabali rabbits in Egypt. Proc. 9th World Rabbit Congress, Verona, Italy, 131-136.

Khalil, M. and Al-Homidan, A. (2014). Genetic evaluation for growth traits and thermos-tolerance parameters in synthesizing program of new rabbits. 2nd International Conference on Biotechnology Applications in Agriculture, Benha University, Moshtohor and Hurghada, 8- 11 April 2014, Egypt, 1-9.

Li, J.B., Zhao, Z.F. and Si, H.Z. (2008). Heterosis in rice: Genetic variation and dominance. Journal of Genetics and Genomics, 35(12), 751-762.

Lukefahr, S.D., McNitt, J.I., Cheeke, P.R. and Patton, N.M. (2022). Rabbit production 10th edition. Wallingford, Oxfordshire; Boston, MA: CAB International

Mabrouk, M.M., Abul-Hussan, M.A. Attalah, G.E.Y. Farid A. and Gharib, M.G. (2008). Evaluation of crossbreeding effects for some litter traits in crossing of Californian with Egyptian Baladi-Red rabbits. Egyptian Journal of Rabbit Science, 2: 153-144.

Mahran, M.D., Nasr A.E., Peris S.I. and Alzohairy A.M. (2017). Productive and reproductive traits improvement of the Egyptian local strain rabbits by the crossing with two foreign strains. Zagazig J. Agric. Res., Vol. 44 No., (6B).

Meky, M.A, Yonis H.H, EL-Tahawy W.S, Ragab M. and El-Speiy M.E. (2023). Effect of crossing California with Gabali rabbits on litter weight, litter size and milk production. J. Agric. and Env. Sci., (Damanhour University). 22 (2): 224-237.

Nofal, R.Y., Abdel-Ghany, A.M., Hassan, N.S. and Ahmed, E.G. (2000). Crossbreeding components for growth performance of the Egyptian Baladi Red rabbits crossed with the acclimatized New Zealand White. In: Proc. 3rd All Africa Conference Anima of Agric. and 11th Conference Egyptian Society Animal Production, 6-9 Nov., Alexandria, Egypt, 579-586.

Nwakpu, P.E., Ogbu C.C. and Ugwu S.O.C. (2015). Heterosis of early growth performance in three breeds of rabbits (*Oryctolagus cuniculus*), International Journal of Agriculture Innovations and Research Volume 3, Issue 6, ISSN (Online). 2319-1473.

Oseni, S. and Lukefahr, S. (2014). Rabbit production in low input systems in Africa: Situation, knowledge and perspectives–A review. World Rabbit Sci.22, 147-160.

Ouyed A. and Brun J.M. (2008). Heterosis, direct and maternal additive effects on rabbit growth and carcass characteristics. In: Proceedings 9th World Rabbit Congress-June 10-13, Verona–Italy. pp: 195-199.

Ouyed, A., Rivest, J. and Brun, J.M. (2011). Heterosis, direct and maternal additive effects on rabbit growth and carcass traits from a Canadian experiment. World Rabbit Sci. 2011, 19: 31-41.

Piles, M., Rafel, O., Ramón, J. and Gómez, E.A. (2004). Crossbreeding parameters of some productive traits in meat rabbits. World Rabbit Science, 7: 59-64.

Rabie, T.S.K., Nowier, A.M, Abou-Zeid, A.E. and Khattab, A.S. (2019). Impact of crossing between Gabali and V-line rabbits on the pre-weaning traits by using tridiagonal and genetic merit methods. Egypt. Poultry. Sci. Vol., (39). (II): p 519-536.

Rojan, P.M., Bindu, K.A. and Raja, T.V. (2013). Effect of genetic and non-genetic factors on post-weaning body weight in rabbits. Glob. J. Anim. Breed. Genet. Vol. 1 (1), pp. 016-019.

Sakr, S. Radwan, H., El-Desoky, A., Darwish, R. and Fouda, M. (2020). Impact of crossbreeding on performance traits in two breeds of rabbit under Egyptian conditions. Mansoura Veterinary Medical Journal 21(2), P19-24

SAS (2003). Statistical Analysis System. Users Guide Statistical Analysis. Inst. Inc. Cary, North Carolina.

Shehab El-Din, M.I., Ramzy, A.A. and El-Komy, E.M. (2024). Assessing the Genetic Response of Crossing on Post-Weaning Growth Traits in Rabbits. Egypt. J. Vet. Sci. Vol. 55, No. 5, pp. 1327-1335.

Xu, S., Li, J., Zeng, J., Gao, Y. and He, Y. (2014). Dominant and over-dominant QTL effects contribute to heterosis for yield and related traits in rice. Frontiers in Plant Science, 8, 1264.

Youssef, Y.K., Baselga, M., Khalil, M.H., Omara, M.E. and Garcia, M.L. (2009). Crossbreeding Effects for Post Weaning Growth Traits in a Project of Spanish V-line with Baladi-Red Rabbits in Egypt. Livestock Science, Vol. 122 No. 2 pp. 302- 307.

Zaghloul, A.R., Khalil, M.H., Iraqi, M.M, Ramadan, Sh. and EL-Nagar, A.G. (2019). Crossbreeding effects and polymorphic associations of genotypes of GH gene with growth traits in rabbits. Egyptian Journal of Rabbit Science, 29 (2): 235- 255.

Zhang, S., Lu, F., Liu, Q., Liu, Y., Guan, X., Wei, Y., Tan, S. and Shi, D. (2016a). Efficient generation of sFat-1 transgenic rabbits rich in n-3 polyunsaturated fatty acids by intracytoplasmic sperm injection. Reprod. Fertil. Dev. 28, 310–318.

Zhang, Y., Zhu, H. and Wang, J. (2016b). Genetic parameters for growth traits in rabbits. Journal of Animal Science, 94(12), 5639-5647.

تأثيرات التهجين التبادلى بين سلالة الأرانب البلدي الاحمر والأرانب الكاليفورنيا (المتكيفة على الظروف المصرية) على أوزان الجسم لنسلها بعد الفطام

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طبقت فى هذه الدراسة خطة تهجين تبادلى بين سلالتى الأرانب البلدية الحمراء (BR) والكاليفورنيا (CAL) لتقييم تأثيرات التهجين التبادلى على أوزان الجسم بعد الفطام في الفترة من 4 إلى 15 أسبوعًا من العمر. وقد شمل التقييم الوراثي للتهجين التبادلى -والمقدرة لصفات النمو التأثيرات المباشرة المضيفة والأمية، وكذا قوة الهجين المباشرة. أشارت النتائج العامة إلى أن جميع المتغيرات الثابتة المدروسة، باستثناء العمر عند الولادة وترتيب الولادة كانت معنوية، هذا بينما كانت تأثيرات مجموعات التربية/التزاوج، الجنس، سنة الولادة، وكذا حجم الخلفة عند الولادة (كمتغير تابع)، كانت جميعها غير معنوية. تباينت نسب تأثير قوة الهجين على أوزان الجسم بين 2.5% إلى 5.0%، وكانت معنوية بالنسبة لمعظم صفات وزن الجسم. كانت للأرانب الكاليفورنيا تأثير مضيف مباشر معنويا على أوزان الجسم في الفترة من 4 إلى 7 أسابيع. أظهرت جميع الصفات الدراسية أثر موجب للتأثير المضيف المباشر (باستثناء ذلك عند الأسبوع 14 من العمر). كان التأثير الأمى المضيف لأرانب الكاليفورنيا ضئيلًا –وغير معنوى- على جميع صفات وزن الجسم المدروسة، بل وكان هذا التأثير سالبا على أوزان الجسم عند 4 و5 و6 و10 و11 أسبوع من العمر. يمكن مما سبق استنتاج أن استخدام قوة الهجين باتباع التهجين التبادلى بين هاتين السلالتين من الأرانب يمكن أن يكون مفيدًا في أي خطة مستقبلية لإنتاج أرانب اللحم (بريلرز) المصرية، دون وضع اعتبار للسلالة المستخدمة كأم (Half-Diallel)، كوسيلة مفيدة دعم الأسر في ظل الظروف المصرية الحالية والتى تتلخص فى المعاناة من نقص بروتينات اللحوم والأزمات الاقتصادية المتتالية.

الكلمات المفتاحية (الرئيسية): الأرانب الأصيلة والمصرية، الأرانب القياسية المتكيفة، التهجين التبادلي ،التأثيرات الأمية المباشر