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Evaluate pure Breeding and Crossbreeding Strategy for Better Carcass and non-carcass Traits of Awassi, Chios, and their Reciprocal Crossbred Lambs

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ABSTRACT

In Jordan, crossing local sheep with the exotic breed has an acceptable sound by farmers but needs scientific proof for planned-ahead crossing and introgression. This work aimed to find the best mating strategy on economic carcass and non-carcass traits of produced lambs under an intensive production system in Jordan. The mating strategy among Awassi and Chios for two years was designed to obtain different pure- and cross-bred lambs. They were pure Awassi, pure Chios, and reciprocal crosses of Awassi-Chios and Chios-Awassi lambs for two years. The studied factors included sex of lamb, breed, lamb birth type, age at slaughtering, and their two-way interactions. The lamb sex significantly affected ($P < 0.001$) most carcass and non-carcass traits of economic importance. Similarly, the effect of age was notable ($P < 0.05$) on all carcass and non-carcass traits. The breeds were significantly different ($P < 0.05$) for the hot carcass, tail, and internal organs weights. Therefore, the use of Awassi sire as a paternal contributor for producing meat over one year in crossbreeding can be implemented for increasing carcass weights. The heterosis effect had only significant for tail weight. Significant differences for the liver with and without a trachea, kidney with and without fat, heart with and without fat, and lung between reciprocal crosses for heterosis percentages always favored the reciprocal cross of Awassi female parent. Interaction effects of age with sex were detected on body weight, carcass length, and kidney, while interaction effect of birth type with sex was significant for body weight and some internal organs. finally, significant interaction effects of the breed with both sex and birth type were significant for the cold carcass, tail, and some organs weights. In the present study, sheep producers might be benefited better if Awassi sire is used as a paternal contributor for producing meat over one year in crossbreeding strategy with Chios for increasing carcass weights.

Keywords: sheep, crossbreeding, carcass and non-carcass traits, heterosis.

INTRODUCTION

Systems of lamb meat production are needed to be profitable and provide products to meet consumer demands. Therefore, it is essential to provide necessary information on the best use of available breeds considering the effect of factors such as sex, breed, birth type, and age on lamb carcass composition and growth. Furthermore, lamb producers needed to be aware of such factors in their production systems to produce lamb's meat while providing a high growth rate and profitability in marketing. Body and carcass traits were reported to be influenced by the sex of lamb, birth type, age, and breed (Fogarty *et al*, 2000; Hassen *et al.*, 2004; Momani Shaker *et al.*, 2010b; Ulutas *et al.*, 2010; Esmailizadeh *et al.*,

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2011). Furthermore, significant interactions of some factors, for example, breed-sex, were observed for birth, slaughter, and carcass weights (Glimp, 1971).

In Jordan and the neighboring countries, Awassi is a native breed and is a fat-tailed, while Chios is a native breed of Cyprus and Greece and is a thin-tailed breed. The fat-tail is regarded as an adaptive response of animals to a hazardous environment and is a valuable energy reserve for the animal during migration and winter. The size of the fat-tail varies between breeds. The fat deposited in the body or tail is laid down at a much higher cost in terms of feed energy than lean meat (Kashan et al., 2005). It is hypothesized that the size of the fat-tail in progeny from Awassi x Chios crosses would be smaller than that of the Awassi pure breed. Therefore, crossing with thin-tail breeds like Chios could lead to improvement in production efficiency and carcass characteristics. Lowering fat content can be achieved by docking the fat tail or crossing with thin-tailed breeds (Kashan et al., 2005). The consumers in many instances show an increasing preference for lean meat.

On the other hand, the best breeding strategy is also needed by lamb producers for available sheep breeds. Producers in Jordan tended to slaughter their lambs at early ages to get a better price for their lambs. Such practice reduces the productivity of sheep in Jordan. Many strategies for the improvement of lamb production and the growth performance of lambs have been practiced. One such strategy is the production of commercial crossbred slaughter lambs (Doloksaribu *et al.*, 2000; Fogarty *et al.*, 2000; Freking *et al.*, 2000). In general, breeds evaluation as the first step provides necessary information on the use of breeds in crossbreeding systems that exploit effects of heterosis and complementarily to meet specific production and marketing objectives. A common practice of crossbreeding is to have two-breed crossing in order to improve market lamb production. In consequence, crossbred lambs' production was mostly practiced by lamb producers in order to produce heavier and faster-growing lambs, both before and after weaning until slaughtering than either purebred group (Mavrogenis, 1995).

Such a strategy has been applied in Jordan where the only sheep breed, fat-tailed sheep named Awassi, is crossed with different exotic breeds such as Charollais and Romanov (Momani Shaker *et al.*, 2010a) and Chios (Abdulla & Tabbaa, 2011). Due to its high milk-producing potential under harsh conditions of the Middle East, the Awassi breed can be used as a sire breed in many indigenous Asiatic, European and African breeds. On the other hand, the Chios sheep breed was crossed in many attempts and for different purposes with Awassi sheep (Mavrogenis, 1995). In Jordan, crossing Awassi with any other breed has acceptable sound by farmers but not scientifically proven so far. In addition to the carcass, Jordanian people use many non-carcass organs on their lunch and dinner meals. This would include the head, feet, fat-tail, liver, spleen, heart, lungs, kidney, and digestive tract. These parts are preferable, important, and have an economic value for people in many Middle Eastern countries.

Most sheep growth studies are focusing on live weight overtime the period. For example, birth weight and weaning weight (Hassen *et al.*, 2004). Relationship information of different factors with bodyweight at slaughtering time is important for selection purposes given their association with other traits. Therefore, in this study, an attempt was made by crossbreeding Awassi with Chios to improve meat productivity sheep under intensive conditions in Jordan. Therefore, this research work is aiming to evaluate the effects of different factors and heterosis (hybrid vigor) on carcass and non-carcass traits under pure breeding and crossbreeding of Awassi and Chios at different ages under intensive production in Jordan.

Materials and methods

The study was carried out on 152 lambs of a sheep flock belonging to the Agriculture Research Station at the University of Jordan. Mating among Awassi and Chios for two years was designed to obtain different pure- and cross-bred lambs. They were pure Awassi and Chios lambs and reciprocal crosses of Awassi-Chios and Chios-Awassi lambs (Table 1). The lambs were 64 Awassi, 38 Chios, 36 Awassi*Chios (Awassi sired), and 14 Chios*Awassi (Chios sired). At birth, lambs were ear-tagged and recorded till the time of slaughtering (at 3, 6, ,9, and 12 months of age). Lambs were allowed to suckle their dams until weaning time which averaged 73.6±7.5 days of age. Creep feeding was provided to lambs during the suckling period. After weaning, each lamb was provided with 0.25 kg of a ration consisting of barley 68%, wheat bran 15%, soy soybean limestone 1.5%, and table salt 0.5%, in addition to 1.5kg/ton of vitamin-mineral premix. The ration amount was increased up to 0.6 kg when lambs reached 6-month-old. Older lambs were supplied with 1.2 kg/day from the same ration. Wheat straw, mineral blocks, and water were offered ad libitum to lambs inside semi-open sheds. Furthermore, lambs were allowed to graze pasture during spring times (January to April) with an estimated intake of energy from the pasture of 18 MJ ME/day.

Bodyweight was taken just before slaughtering at 3, 6, 9, and 12 months of age. The hot carcasses were weighed immediately after dressing and offal removed. Carcasses were chilled overnight and then weighed to determine cold carcass weight. Dressing percentage was calculated as cold carcass weight divided by live body weight. Non-carcass components such as head, skin, feet, omental, mesenteric, kidney, and pelvic fats, empty alimentary tract, liver, spleen, heart, kidneys, lung, trachea empty reticulo-rumen, and intestines were weighed immediately after slaughter. The studied factors were the sex of lamb (male or female), breed of sire and dam (Awassi or Chios), lamb birth type (single or twin), age at slaughtering and, their two-way interactions. The least-square analyses of variance were performed to study the effect of different fixed effects of the studied factors on measurements under investigation at the different slaughtering ages for the 152 lambs. The General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1994) was utilized for this purpose. The least-square means were calculated for all factors levels. In addition, means were separated using Fisher protected LSD test at $P<0.05$ for all significant effects. Heterosis was calculated for all measurements as the percentage difference between crossbred and purebred measurement divided by the purebred measurement.

Results and Discussion

Some carcass and non-carcass measurements at slaughtering of Awassi, Chios, and their reciprocal crossbred lambs were influenced by breed, sex, birth type, and slaughtering age (Table 1-4). The significant two-way interaction effects of the above-mentioned factors were also observed (Figure 1-5). The effect of sex was significant ($P<0.001$) on body weight at slaughter, hot and cold carcass weight, carcass length, head weight, front feet weight, skin weight (Table 1 and 2). It was also significant on weights of the liver with trachea, liver, heart, lung, kidney without fat, a heart without fat, small intestine empty, and large intestine empty (Table 3 and 4). Several authors confirmed the effect of sex on growth parameters (Said *et al.*, 2000; Dawson *et al.*, 2002; Momani Shaker *et al.*, 2010a). For example, Said *et al.* (2000) reported that Awassi males had heavier bodyweight, weaning weight,t and daily gain than females. Epstein (1985) reported that the 140-day weight of males and females of Awassi, Chios, and crossbred was 35.9, 32.3 and 38.6 and 33.6, 30.2, and 31.4 kg, respectively. Although numerically singles had higher values than twins, there was no significant per se effect of birth type on any traits measured. These findings are in contrast to other previous reports by Ozcan *et al.* (2001), Hassen *et al.* (2004), and Momani Shaker *et al.* (2010b). All weights of studied traits were significantly affected by age at slaughtering (Table 1-4). Most studied traits were highly significantly (P<0.001) affected by age at slaughter. Such findings are in accordance with many previous studies considering weights of different ages at weaning and slaughtering (Ozcan *et al.*, 2001; Hassen *et al.*, 2004; Momani Shaker *et al.*, 2010b). It is important to stress out that the dressing percentage at six months of age was nearly similar to those of nine months old. This is important, from the economical point of view, and influences strongly the net income that more profit for market weight at a younger age of six months instead of nine months (Table 1).

The breed or genotype effect was studied considering parent breeds; sire alone and dam alone of both Awassi and Chios. In addition, lamb breeds or genotypes were pure Awassi, pure Chios, and crossbred of Awassi*Chios and Chios*Awassi. The results of all these effects are reported in Table 1-4. Sire breed significantly (P<0.05) affected only hot carcass weight out of all carcass traits (Table 1). In addition, the sire breed significantly affected tail weight (Table 2), liver and kidney weights (Table 3). It seems that the breed of sire affected a few traits out of the twenty-two studied traits. Of all affected traits only hot carcass weight is of economic importance and make difference on a business of large scale. The most notable result was that the hot carcass weight of lambs sired by Awassi was heavier (17.897 kg) than those (15.675 kg) sired by Chios (Table 1). Chios breed is a high milk-producing and prolific breed (Fahmy, 1996) while Awassi is a dual-purpose breed for meat and milk (Epstein, 1985). For this reason, it is expected that F1 crossbreds would have growth parameters as similar as those of exotic mutton breeds (Dawson *et al.*, 2002). In this regard, better growth parameters of the crossbreds were reported as a result of the sire breed (Momani Shaker *et al.*, 2010a). This might be due to the heterosis effect. However, lambs sired by Awassi sires were heavier which is in contrast to results of previous reports on exotic breed sired lambs that had faster growth and heavier live weights (Dawson *et al.*, 2002; Momani Shaker *et al.*, 2010a). This might be plausible as Awassi, a dual-purpose breed, and Chios, mainly dairy breed, are not meat breeds. In contrast, Fogarty and Mulholland (2012) reported no difference between Dorset, Hyfe, and Suffolk sire breeds for lamb growth traits.

Dam breed significantly (P<0.001) affected skin and tail weights (Table 2). Though, in other studies, the effect of the dam was observed for economically important traits such as weaning weight, 105-day weight, and pre-weaning daily gain of reciprocal crossbreds (Mavrogenis, 1996). Lamb breed affected the following internal organs weights; liver with trachea, liver, kidney, heart, lung, kidney without fat, and heart without fat (Table 3). The major effect was the heavier weight of liver, kidney, heart for Awassi purebred lambs, whereas the weights of the rest traits were the heaviest for Chios purebred lambs. In a similar study of crossing Awassi with Chios in Cyprus, Mavrogenis (1996) found that Awassi lambs were heavier and had faster growth than that for Chios lambs. Crossbred lambs were mostly heavier and had faster growth before and after weaning than purebreds. In addition, Momani Shaker *et al.* (2010a) found that crossbred lambs of Charollais and Romanov breeds were heavier growth parameters compared with pure Awassi lambs. In contrast, Hassen *et al.* (2004) reported that Awassi lambs consistently weighted more than Ethiopian indigenous lambs breeds and their crossbreds. In addition, Abdullah *et al.* (2011) reported an influence of breed on the fattening performance of male lambs of Jordanian Awassi, Charollais-Awassi, and Romanov-Awassi; the Charollais-Awassi genotype was heavier than other genotypes. Furthermore, hot and cold carcass weights and dressing percentages differed significantly with the Charollais-Awassi genotype having greater values than Awassi.

One purpose of the present study was to determine the heterosis effects in reciprocal crossbred of Awassi and Chios on traits at slaughtering. First, the heterosis effect on carcass traits was shown in Table (1). Negative effects were found for all traits except carcass length (0.45) in Awassi-Chios breed and dressing out percentage (0.79) in Chios*Awassi breed. Awassi sheep are traditionally raised on an extensive system for its multi-purpose products of meat and milk, whereas Chios sheep breed is widely raised on the intensive system for its high milk production and prolificacy (Hatziminaoglu *et al.*, 1996). Generally, both breeds are better for milk production than meat production. However, crossbreeding of Awassi with Chios has been performed under experimental conditions and is expected to exhibit heterosis for carcass traits. These effects, as a reflection of heterosis, might be higher for carcass length (0.45) when it is of direct effect and higher for dressing out percentage (0.79) when it is the maternal effect with regards to Awassi breed (Table 1). Positive effects of heterosis estimates on lamb growth traits have been previously reported (Mavrogenis, 1981). On the other hand, the estimated individual heterosis in average and non-carcass traits was negative except for front and rear feet weights in average and Awassi-Chios breed and for skin weight for Chios-Awassi breed (Table 2). The positive effects were also noticed for small and large intestine empty weight in both crossbreeds and for the average (Table 3-4). Similarly, crossbreds of Kivircik and Black-headed Mutton with Chios exhibited better growth performance up to weaning (Ozcan *et al.*, 2001). Furthermore, Mavrogenis (1996) reported that all estimates of individual heterosis for lamb traits exhibited positive heterosis effects of crossbreeding, whereas they were for ewe reproductive and production traits negative except for total lamb weight at weaning. The estimated heterosis values were positive; however, the more important is to consider the gain due to heterosis for a specific trait in each cross. For example, in the Chios-Awassi breed, the positive effect for dressing percentage suggests considering Chios-Awassi lambs to be an improved meat breed, whereas the positive effect for skin weights suggests considering Chios-Awassi lambs as good wool producers. Although the heterosis for non-carcass traits was negative, such as internal organs and gut traits (Table 3 and 4), they are important to producers being so because it means lower weights for low-priced internal organs. For example, the negative effect on mesenteric fat would be preferred assuming a low amount of fat produced in the lamb meat industry. Many studies of crossing Awassi with Chios provided recommendations of better purebred and crossbred use. Mavrogenis (1996) reported that Chios ewes were significantly more prolific than Awassi and their crossbred ewes. On the other hand, Awassi ewes had a higher milk production compared with all other breed groups. Defiantly, their crossbred lambs were mostly heavier and had a faster growth rate, both before and after weaning than either purebred group. In general, Shrestha (2010) reported that estimates of heterosis were either positive or negative for a particular trait in a wide range of traits from many previously reported crossbreeding studies. Lamb progeny from the different sire- and dam-breeds combinations had little loss of hybrid vigor for growth traits since hybrid vigor values for birth weight were higher than that for weaning and older ages weights (Fogarty & Mulholland, 2012).

Significant interaction effects of age with sire breed on kidney weight ($P<0.05$), and with dam breed on carcass length ($P<0.05$), tail weight ($P<0.01$) was presented in Figure (1A). Moreover, there were some significant two-way interaction effects on some of the studied traits (Figure 1-4). The Interaction effect of age and sex on the head ($P<0.001$), rear feet, and skin ($P<0.01$) weights were significant (Figure 1B). Other traits such as body and carcass weights were not affected by such interactions. In accordance, results of interaction between age and sex were not significant for birth weight, weaning weight, and dressing out percentage (Ruttle, 1971). Another interaction effect was birth type and sex which was significantly affected the liver with trachea weight; heart weight and lung weight (Figure 2). Male of both breeds had heavier internal organs weights, being male Awassi lambs the heaviest. In contrast, Ruttle (1971) reported no significant interaction between type of birth and sex on birth weight, weaning weight, and dressing percentage. The interaction effect of sire breed and sex was significant on tail weight and large intestine empty weight (Figure 3). As expected, the ail weight of male Awassi lamb was the heaviest followed in a consequence by female Awassi lamb, male Chios lamb, and then female Chios lamb (Table 1). The last affected trait was the weight of the empty large intestine which was the heaviest for male Chios lamb compared to both sexes of Awassi lambs while it was the lightest for female Chios lamb. On the other hand, the interaction of dam breed and sex was only significantly affected the empty large intestine weights ($P < 0.01$) (Figure 3). The heaviest weight of this trait was found for male Awassi lamb which followed by both male and female Chios and then female Awassi lamb. The last significant interaction effect was sire breed with birth type on each of liver with trachea, liver, heart, lung, kidney, and kidney without fat weights (Figure 4)., It was important to note that the resulted interaction effects were similar to interaction effect of the breed with sex and type of birth as well as age with type of birth on different body weights of crossbred lambs of D'man and Saradi breed for five generations (Boujenane *et al.*, 1999). Significant effects of sire breed and dam breed interaction were recently reported for age at the slaughter of crossbred lambs reared in Australia (Fogarty & Mulholland, 2012).

Overall, introducing the crossbreeding of exotic meat sheep breed to local Awassi sheep breed could not prove valuable for improving meat production on farms that crossbred lambs under intensive production system. Contrary to other research, introducing crossbreed sheep production proveda successful in improving meat performance under intensive and extensive production systems (Gavojdianab et al., 2013).

Conclusion

The lamb sex affected body weight and carcass weight and length traits of economic importance. Similarly, the effect of age was notable on all traits. However, the birth type had no effect on carcass and non-carcass traits. The sire breed, dam breed, and lamb breed differences were generally significant for hot carcass weight, tail weight, and internal organs, respectively. Heterosis for carcass traits and external organs weights was not notified except tail weight in both reciprocal crosses. Significant differences for internal organs between reciprocal crosses for percent heterosis always favored the reciprocal cross in which Awassi female parent had a low estimate for the maternal component. Finally, interaction effects of age with sex were detected for carcass length and some internal and external organs. While interaction effects of birth type with sex were significant on some internal organs. The last significant interaction effects of the breed with sex and with the type of birth were significant on tail weight and some internal organs. In the present study, sheep producers might be benefited better if Awassi sire is used as a paternal contributor to lamb production in crossbreeding strategy for increasing carcass weights. Nonetheless, further information is needed on these crossbreeds' performance under an extensive production system.

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Table 1. Effect of sex of lamb, sire breed, dam breed, birth type, and age at slaughter on body weight at slaughter, hot and cold carcass weights, and dressing percentage.

Effect	N	Bodyweight at slaughter (kg)	Hot carcass weight (kg)	Cold carcass weight (kg)	Dressing percentage (%)	Carcass length (cm)
Sex		***	***	***		***
Female	69	30.1±1.1^{b}	15.1±0.6^{b}	14.7±0.6^{b}	49.4±1.2	110.9±1.118^{b}
Male	83	35.7±1.0^{a}	18.4±0.6^{a}	18.0±0.6^{a}	51.1±1.4	115.9±1.071^{a}
Birth type						
Single	73	33.6±1.1	17.2±0.6	16.7±0.6	50.2±1.5	114.9±1.174
Twin	79	32.2±1.1	16.3±0.6	16.0±0.6	50.3±1.3	112.0±1.128
Age (in month)		***	***	***	**	***
3	27	20.2±1.8^{d}	8.3±1.1^{d}	8.4±1.1^{c}	46.1±2.2^{c}	99.3±1.92^{c}
6	72	28.7±0.9^{c}	14.8±0.6^{c}	14.2±0.6^{b}	50.8±1.3^{b}	112.2±1.18^{b}
9	23	34.3±1.8^{b}	17.2±1.0^{b}	16.6±1.1^{b}	49.1±2.0^{bc}	114.3±1.87^{b}
12	30	48.3±1.4^{a}	26.7±0.8^{a}	26.2±0.8^{a}	55.0±1.3^{a}	128.0±1.53^{a}
Sire breed			*			
Awassi	100	34.4±0.9	17.8±0.5^{a}	17.2±0.5	50.4±1.1	112.8±0.975
Chios	52	31.3±1.3	15.6±0.7^{b}	15.5±0.8	50.1±1.5	114.1±1.38
Dam breed						
Awassi	78	34.1±1.2	17.4±0.7	17.2±0.7	51.0±1.5	111.9±1.32

Effect	N	Bodyweight at slaughter (kg)	Hot carcass weight (kg)	Cold carcass weight (kg)	Dressing percentage (%)	Carcass length (cm)
Chios	74	31.6±1.0	16.0±0.6	15.5±0.6	49.5±1.4	115.0±1.12
Lamb Breed						
Awassi*Awasi	64	35.9±1.0	19.1±0.6	18.6±0.6	51.3±1.2	111.4±1.11
Chios* Chios	38	30.2±1.3	15.5±0.8	15.2±0.8	49.5±1.8	115.8±1.45
Awassi*Chios	36	32.9±1.5	16.6±0.9	15.8±0.9	49.5±1.7	114.1±1.62
Chios*Awassi	14	32.3±2.2	15.8±1.3	15.9±1.4	50.8±2.6	112.3±2.46
Hybrid vigor (%)						
Awassi*Chios	36	-0.38	-4.20	-6.40	-1.78	0.45
Chios*Awassi	14	-2.21	-8.92	-6.06	0.79	-1.15
Average		-1.30	-6.56	-6.23	-0.49	-0.35

* (P < 0.05), ** (P < 0.01), *** (P < 0.001).
lamb means with different superscripts at the same column are different (P < 0.05).
Dressing percentage was calculated as cold carcass weight divided by live body weight.
Hybrid vigor was calculated as the percentage difference between crossbred and purebred measurements divided by the purebred measurement.

Table 2. Effect of sex of lamb, sire breed, dam breed, birth type, and age at slaughter on head, feet and skin weights.

Effect	N	Head weight (kg)	Front feet weight (kg)	Rear feet weight (kg)	Skin weight (kg)	Tail weight (kg)
Sex		***	***		***	
Female	69	1.8±0.10^{b}	0.45±0.02^{b}	0.45±0.021	3.09±0.14^{b}	1.12±0.10
Male	83	2.8±0.10^{a}	0.55±0.02^{a}	0.49±0.020	3.86±0.14^{a}	1.35±0.10
Birth type						
Single	73	2.3±0.12	0.52±0.02	0.48±0.022	3.43±0.14	1.24±0.10
Twin	79	2.3±0.11	0.48±0.02	0.45±0.021	3.52±0.15	1.24±0.10
Age (in month)		***	***	***	***	***
3	27	0.56±0.19^{c}	0.16±0.03^{c}	0.17±0.035^{c}	1.71±0.21^{c}	0.49±0.18^{b}
6	72	2.07±0.13^{b}	0.48±0.02^{b}	0.46±0.025^{b}	3.22±0.18^{b}	1.06±0.10^{ab}
9	23	3.21±0.12^{a}	0.66±0.03^{a}	0.60±0.033^{a}	3.69±0.24^{b}	1.21±0.17^{ab}
12	30	3.62±0.15^{a}	0.69±0.02^{a}	0.65±0.027^{a}	5.29±0.14^{a}	2.19±0.13^{a}
Sire breed						**
Awassi	100	2.47±0.09	0.51±0.01	0.48±0.017	3.57±0.12	1.45±0.08^{a}
Chios	52	2.26±0.11	0.49±0.02	0.45±0.026	3.39±0.16	1.02±0.12^{b}
Dam breed					***	***
Awassi	78	2.34±0.18	0.50±0.02	0.46±0.025	3.85±0.17^{a}	1.71±0.12^{a}
Chios	74	2.39±0.11	0.50±0.01	0.47±0.021	3.10±0.14^{b}	0.76±0.10^{b}
Lamb Breed						*
Awassi*Awasi	64	2.53±0.10	0.50±0.01	0.48±0.020	3.81±0.16	2.10±0.10^{a}
Chios* Chios	38	2.37±0.12	0.49±0.02	0.46±0.026	2.87±0.19	0.72±0.13^{c}
Awassi*Chios	36	2.41±0.16	0.52±0.02	0.49±0.029	3.33±0.19	0.81±0.14^{bc}

Effect	N	Head weight (kg)	Front feet weight (kg)	Rear feet weight (kg)	Skin weight (kg)	Tail weight (kg)
Chios*Awassi	14	2.14±0.24	0.49±0.04	0.45±0.047	3.90±0.29	1.32±0.22^{ab}
Hybrid vigor (%)						
Awassi*Chios	36	-1.486	4.313	4.66	-0.35	-42.59
Chios*Awassi	14	-12.645	-0.702	-3.39	16.83	-6.53
Average		-7.066	1.805	0.63	8.23	-24.56

* (P < 0.05), ** (P < 0.01), *** (P < 0.001).
^{a,b} means with different superscripts at the same column are different (P < 0.05).
Hybrid vigor was calculated as the percentage difference between crossbred and purebred measurements divided by the purebred measurement.

Table 3. Effect of sex of lamb, sire breed, dam breed, birth type, and age at slaughter on weights of internal organs.

Effect	N	Liver with trachea (kg)	Liver (kg)	Spleen (kg)	Heart (kg)	Heart without fat (kg)	Lung (kg)	Kidney (kg)	Kidney without fat (kg)
Sex		***	***		***	***	***		***
Female	69	1.32±0.04^{b}	0.41±0.016^{b}	0.05±0.006	0.16±0.07^{b}	0.15±0.01^{b}	0.38±0.02^{b}	0.202±0.01	0.09±0.004^{b}
Male	83	1.56±0.04^{a}	0.54±0.015^{a}	0.05±0.005	0.19±0.07^{a}	0.18±0.01^{a}	0.47±0.02^{a}	0.182±0.01	0.12±0.004^{a}
Birth type									
Single	73	1.47±0.04	0.49±0.01	0.06±0.006	0.18±0.01	0.17±0.01	0.43±0.02	0.20±0.01	0.10±0.004
Twin	79	1.42±0.04	0.47±0.01	0.05±0.006	0.17±0.01	0.17±0.01	0.42±0.02	0.19±0.01	0.10±0.004
Age(month)		**	***	*	***	***	***	***	***
3	27	1.19±0.07^{b}	0.38±0.02^{c}	0.04±0.011^{b}	0.12±0.01^{c}		0.28±0.03^{c}	0.08±0.02^{d}	
6	72	1.20±0.04^{b}	0.43±0.01^{b}	0.05±0.006^{b}	0.16±0.01^{b}	0.13±0.01^{b}	0.39±0.02^{b}	0.15±0.01^{c}	0.09±0.004^{c}
9	23	1.33±0.07^{b}	0.47±0.02^{b}	0.05±0.010^{b}	0.17±0.01^{b}	0.15±0.01^{b}	0.44±0.03^{b}	0.20±0.02^{b}	0.10±0.006^{b}
12	30	2.05±0.06^{a}	0.62±0.02^{a}	0.08±0.008^{a}	0.25±0.01^{a}	0.22±0.01^{a}	0.58±0.03^{a}	0.34±0.01^{a}	0.12±0.005^{a}
Sire breed			*					**	
Awassi	100	1.47±0.03	0.50±0.01^{a}	0.06±0.005	0.18±0.01	0.17±0.01	0.44±0.01	0.21±0.01^{a}	0.11±0.004
Chios	52	1.41±0.05	0.45±0.01^{b}	0.05±0.007	0.16±0.01	0.16±0.01	0.41±0.02	0.17±0.01^{b}	0.10±0.004
Dam breed									
Awassi	78	1.39±0.04	0.47±0.01	0.05±0.007	0.16±0.01	0.16±0.09	0.40±0.02	0.20±0.01	0.10±0.004
Chios	74	1.49±0.04	0.48±0.01	0.05±0.006	0.18±0.01	0.18±0.01	0.45±0.02	0.19±0.01	0.11±0.005
Lamb breed		*	*		*	*	**	**	**
Awassi*Awasi	64	1.50±0.04^{a}	0.52±0.01^{a}	0.06±0.006	0.19±0.01^{a}	0.17±0.01^{ab}	0.45±0.02^{a}	0.24±0.01^{a}	0.11±0.004^{a}
Chios* Chios	38	1.55±0.05^{a}	0.49±0.02^{ab}	0.05±0.007	0.18±0.01^{a}	0.18±0.01^{a}	0.48±0.02^{a}	0.20±0.01^{b}	0.11±0.006^{a}
Awassi*Chios	36	1.44±0.06^{ab}	0.48±0.02^{ab}	0.06±0.008	0.18±0.01^{a}	0.16±0.01^{ab}	0.42±0.02^{ab}	0.20±0.01^{b}	0.10±0.006^{ab}
Chios*Awassi	14	1.28±0.09^{b}	0.41±0.03^{b}	0.044±0.012	0.14±0.02^{b}	0.15±0.01^{b}	0.35±0.04^{b}	0.15±0.02^{b}	0.09±0.007^{b}
Hybrid vigor (%)									
Awassi*Chios	36	-5.3	-5.01	-2.6	-4.0	-6.5	-9.8	-12.2	-7.6
Chios*Awassi	14	-16.2	-17.8	-22.1	-24.3	-16.7	-25.3	-28.0	-21.8

Average	-10.7	-11.4	-12.4	-14.1	-11.6	-17.6	-20.1	-14.4

* (P < 0.05), ** (P < 0.01), *** (P < 0.001).
[a,b] means with different superscripts at the same column are different (P < 0.05).
Hybrid vigor was calculated as the percentage difference between crossbred and purebred measurements divided by the purebred measurement.

Table 4. Effect of sex of lamb, sire breed, dam breed, birth type, and age at slaughter on weights of different parts of digestive system.

Effect	N	Empty rumen (kg)	Empty small intestine (kg)	Empty large intestine (kg)	Mesenteric fat (kg)
Sex			***	*	
Female	69	1.18±0.1	0.52±0.02^{b}	0.34±0.04^{b}	0.65±0.132
Male	83	1.29±0.1	0.65±0.02^{a}	0.44±0.04^{a}	0.44±0.150
Birth type					
Single	73	1.29±0.1	0.60±0.02	0.40±0.04	0.60±0.140
Twin	79	1.19±0.1	0.57±0.02	0.40±0.04	0.49±0.148
Age (month)		***	*	***	***
3	27	0.91±0.2^{b}	0.57±0.05^{ab}		
6	72	0.97±0.1^{b}	0.55±0.03^{b}	0.50±0.04^{a}	0.37±0.124^{b}
9	23	1.13±0.1^{b}	0.57±0.04^{ab}	0.50±0.06^{a}	0.30±0.200^{b}
12	30	1.95±0.1^{a}	0.66±0.03^{a}	0.22±0.04^{b}	0.97±0.146^{a}
Sire breed					
Awassi	100	1.26±0.1	0.58±0.02	0.39±0.04	0.63±0.150
Chios	52	1.22±0.1	0.60±0.03	0.39±0.05	0.46±0.138
Dam breed					
Awassi	78	1.26±0.1	0.57±0.03	0.34±0.04	0.64±0.142
Chios	74	1.22±0.1	0.60±0.02	0.44±0.05	0.45±0.148
Lamb breed					
Awassi*Awasi	64	1.32±0.1	0.53±0.02	0.28±0.04	0.77±0.180
Chios* Chios	38	1.22±0.1	0.58±0.03	0.40±0.06	0.41±0.179
Awassi*Chios	36	1.21±0.4	0.63±0.03	0.50±0.06	0.49±0.176
Chios*Awassi	14	1.21±0.2	0.62±0.05	0.39±0.07	0.51±0.170
Hybrid vigor (%)					
Awassi*Chios	36	-5.031	12.7	45.7	-16.5
Chios*Awassi	14	-4.796	10.3	15.5	-12.6
Average		-4.914	11.5	30.6	-14.6

* (P < 0.05), ** (P < 0.01), *** (P < 0.001).
[a,b] means with different superscripts at the same column are different (P < 0.05).
Hybrid vigor was calculated as the percentage difference between crossbred and purebred measurements divided by the purebred measurement.

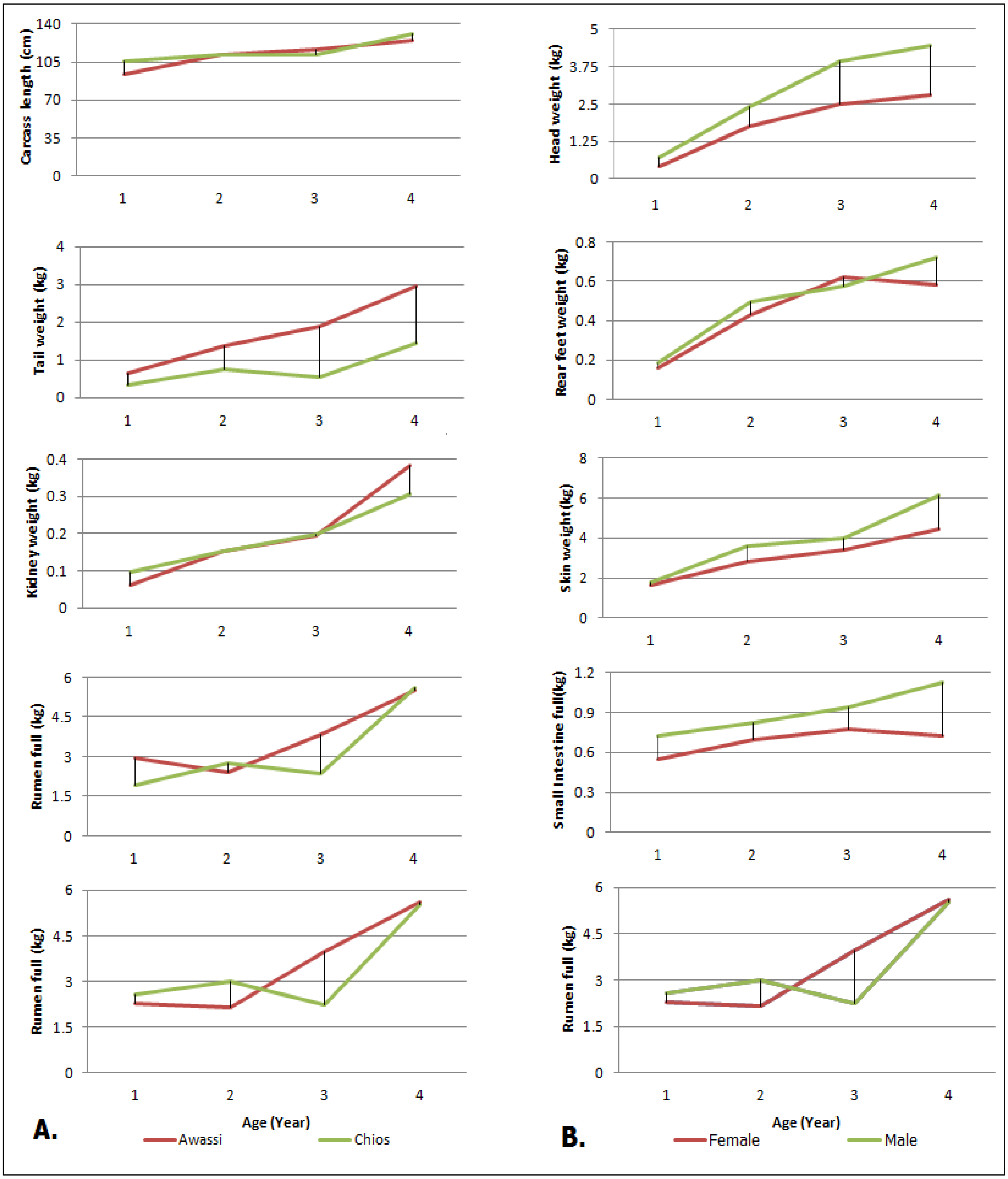

Figure 1. A. Interaction effect of age with dam breed on carcass length (P<0.05); Interaction effect of age with dam breed on tail lenth (P<0.01); Interaction effect of age and sire breed on kidney weight (P<0.05); Interaction effect of age and sire breed on rumen full (P<0.05); Interaction effect of age and dam breed on rumen full (P<0.01). B. Interaction effect of age and sex on head weight (P<0.001), rear feet weight (P<0.05), skin weight (P<0.01), small intestine full (P<0.01) and Rumen full weight (P<0.01).

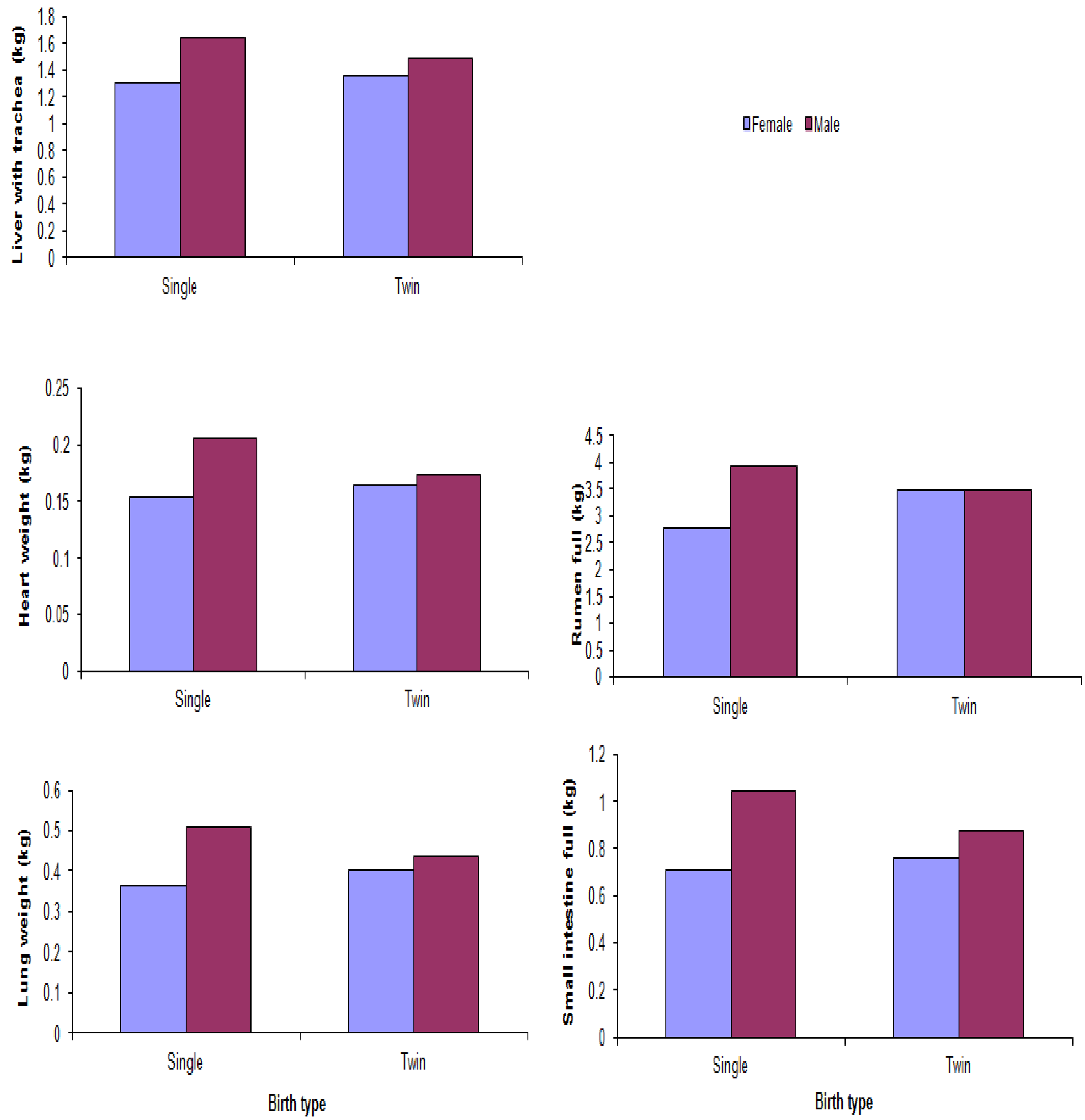

Figure 2. Interaction effect of birth type and sex on liver with trachea w, heart, lung weights (P<0.05) and rumen full, small intestine full (P<0.01).

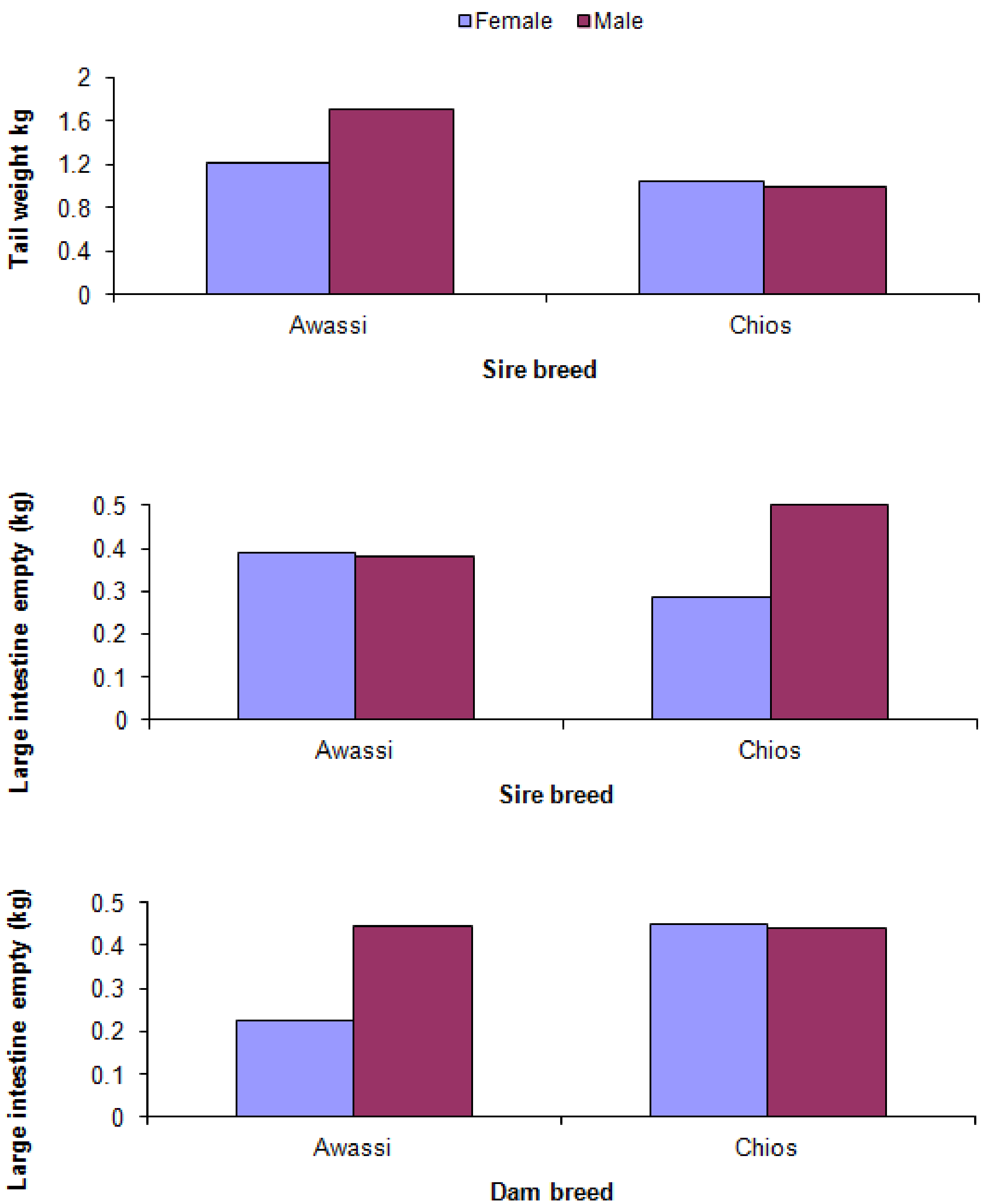

Figure 3. Interaction effect of sire breed and sex on tail weight and large intestine empty (P<0.05). Interaction effect of dam breed and sex on large intestine empty (P<0.05).

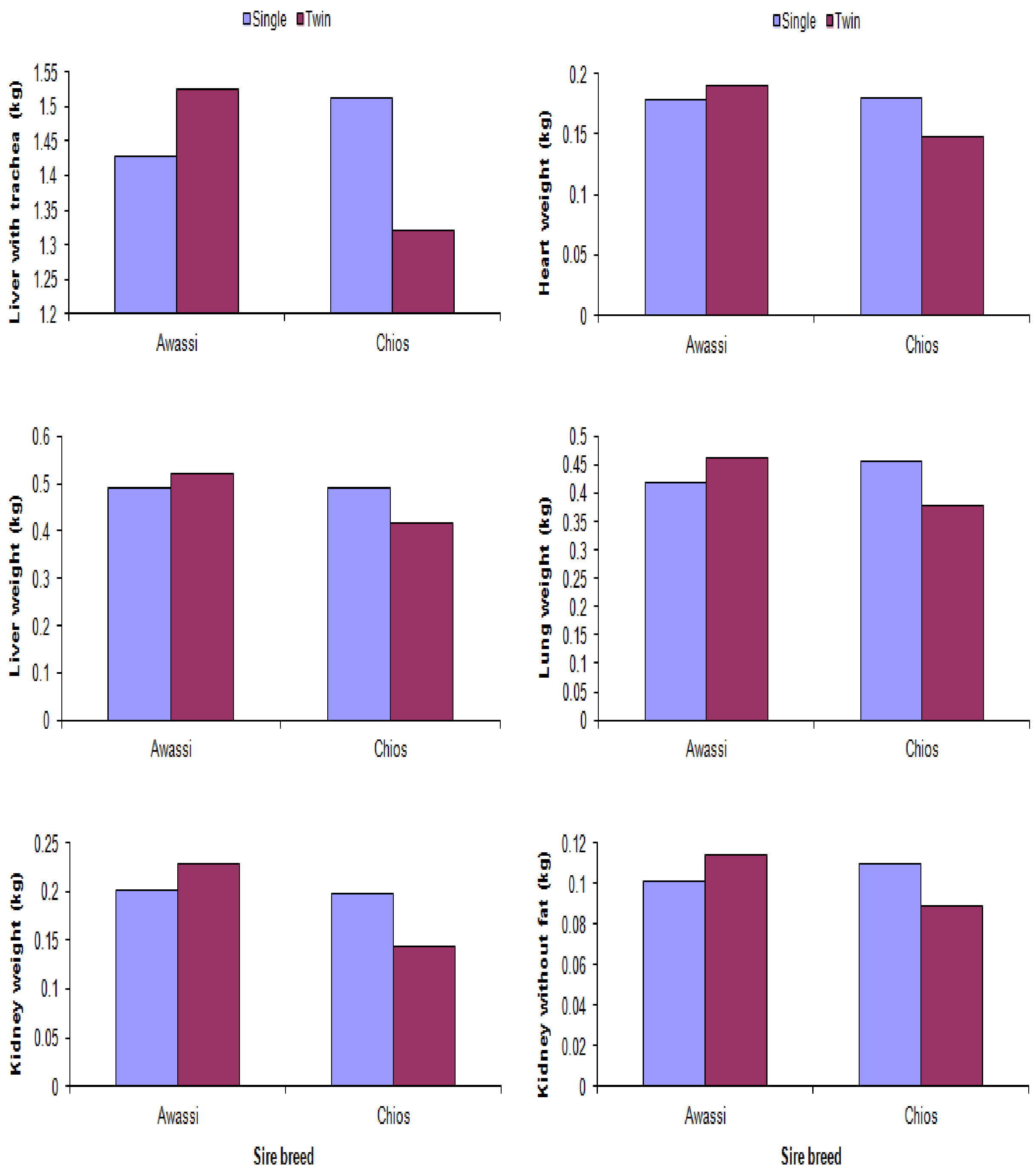

Figure 4. Interaction effect of sire breed and birth type on liver with trachea, liver, heart, lung (P<0.05), kidney and kidney without fat weights (P<0.01).