


Growth performance and carcass classification of pure Pelibuey and crossbred lambs raised under an intensive production system in a warm-humid climate



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Abstract:

The effect of breed on growth, characteristics, and carcass classification was investigated using 11 Charollais x Pelibuey (ChP) lambs, 10 Dorper x Pelibuey (DP) lambs, and 18 Pelibuey (P) lambs in an intensive production system in a warm-humid climate. A significant effect of genotype ($P < 0.05$) was observed on birth weight (BW), weaning weight (WW), and

daily weight gain (DWG), all of which were higher in the ChP genotype. ChP and DP lambs reached commercial weight 35 and 23 d earlier, respectively than P lambs. Genotype has a marked influence on the carcass characteristics, affect conformation and classification of carcass. The probability of obtaining a carcass with good conformation and MEX 1 classification (good: MEX 1) is 72 % higher for the ChP genotype than for the P genotype. The loin and leg yields of the ChP genotype were higher than those of the other genotypes. The pH, temperature, and instrumental color of the carcass, meat, and subcutaneous fat were affected by genotype. ChP lambs showed better growth, characteristics, and carcass classification than lambs of the DP and P genotypes.

Key words: Lamb, Hair sheep, Carcass, Commercial cuts, Meat.

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Introduction

In Mexico, sheep production is important due to the high demand for and insufficient domestic production of meat⁽¹⁾. In warm-humid regions, local forage production is favorable, and sheep meat production could be improved year-round to meet domestic demand. In local sheep production systems, including those in warm-humid regions, meat production can be improved by the use of specific technologies and management strategies⁽²⁾. One of these strategies is the crossing of local breeds such as the Pelibuey breed of sheep with large wool breeds to produce crossbred lambs, since the animals resulting from these crosses present greater daily weight gain⁽³⁾.

The Pelibuey is a medium-sized hair breed and is distributed throughout a large portion of the Mexican territory⁽⁴⁾. It is a breed that is used for meat production because it possesses hardiness characteristics that allow it to adapt to different climates^(5,6). It has low reproductive seasonality, high prolificacy, and resistance to parasites, although fattening animals have lower growth rates than the traditional wool breeds⁽⁷⁾. Due to their specific characteristics and under the conditions of the production systems in use in Mexico, Pelibuey sheep can be used as a maternal breed for crossing with other breeds specialized for meat production⁽⁶⁾ to obtain lambs that develop carcasses with better meat conformation. However, the productive performance and carcass characteristics of the Pelibuey breed have been less satisfactory than those of other breeds with better meat conformation⁽⁴⁾, and sometimes these carcass

characteristics are not improved by crossing with certain specialized wool breeds⁽⁵⁾. Due to the recent introduction into Mexico of new breeds of sheep with greater specialization for meat production (for example, the Charollais and Dorper breeds) and the possibility that these breeds may be of potential use in crossing with the Pelibuey breed, it is necessary to evaluate the productive performance (birth weight, weaning weight, daily weight gain, and fattening days) and the carcass meat characteristics of lambs that result from crossing with the Pelibuey breed.

Standards for the evaluation of the quality of sheep carcass meat vary worldwide. To guide and strengthen the chain of production, processing, marketing, and consumption of sheep meat and to define the quality characteristics of sheep carcasses for national commercialization in Mexico, the Mexican standard for the classification of sheep carcass meat, NMX-FF-106-SCFI-2006, was used. However, there are few reports of its application in the evaluation of sheep carcass meat. Likewise, there is little information on the growth and characteristics of either purebred Pelibuey lambs or lambs obtained by crossing this breed with breeds such as Dorper and Charollais. To meet the current and future demand of the domestic market, it is important to determine the effect of breed on the growth of lambs, their age at slaughter, and the quality of the carcass meat for breeds currently in use in Mexico and thereby to generate information that contributes to the commercialization of quality carcass meat. The objective of the present study was to evaluate the effect of breed on the growth, characteristics, and carcass classification of purebred Pelibuey lambs and lambs obtained by crossing the Pelibuey breed with the Dorper and Charollais breeds.

Material and methods

The research was conducted from 2015 to 2017 at the facilities of the Ovine Experimental Area of the Córdoba Campus Colegio de Postgraduados, located on the Córdoba-Veracruz federal highway at km 348, Amatlán de los Reyes, Veracruz, Mexico. The geographic location is 18° 51' 20" N and 96° 51' 37" W, at an altitude of 650 m asl. The climate is warm-humid with abundant rains in summer, the average annual temperature is 22 °C, and the annual rainfall is 2,000 mm⁽⁸⁾. The experiment was conducted according to the criteria set forth in the Official Mexican Standard on technical specifications for the production and sanitary meat processing (NOM-009-ZOO-1994), technical specifications for the production and humane treatment in the mobilization of animals (NOM-051-ZOO-1995), use of laboratory animals (NOM-062-ZOO-1999), and methods for killing domestic and wild animals (NOM-033-SAG/ZOO-2014), in accordance with the Regulations for the Use and Care of Animals Intended for Research of the Colegio de Postgraduados.

Experimental animals and diet

Thirty-nine (39) male lambs from an experimental herd: Charollais x Pelibuey (n= 11), Dorper x Pelibuey (n= 10), and Pelibuey (n= 18), were reared by their mothers. In the first week of lactation, the lambs stayed with their mothers; after this period, the ewes went out to pasture from 1000 to 1400 h, returning to nurse their young and to stay all night. The lambs were provided with a commercial diet (Agribands Purina Mexico® creep feeding) from birth to weaning in feeders with restricted access for mothers. After weaning, the lambs were fed a diet of mechanically minced sugarcane forage with an approximate particle size of 3.0 cm and a commercial feed concentrate (Agribands Purina Mexico®) containing 15% crude protein (CP) and consisting mainly of ground cereals, a combination of oilseed pastes, cereal by-products, molasses, coconut paste, and vegetable oil. This food was offered freely to the lambs only once daily (0700 to 0800 h). Water was available *ad libitum* in cup drinkers. In the central region of Veracruz, Mexico, where the present study was developed, sheep producers manage the diet tested in this research during the fattening period. In this sense, the management conditions that sheep producers currently apply are being evaluated, so the diet of the sheep studied was not modified, in order to adopt and transfer the results of this research to the producer's local sheep.

Lamb growth performance

The weight of the lambs was measured at birth (within the first 24 h of life, BW) and every 15 d thereafter until they reached slaughter weight (approximately 45 kg). The lambs' weaning weights (WW) were also recorded (approximately 75 d). The fattening days (FD) were determined as the number of days between weaning and slaughter. The daily weight gain (DWG) was determined from the difference in the slaughter weight and the WW divided by the FD. The lambs were slaughtered at similar average live weights.

Lamb carcass yield

The slaughter of the animals was conducted in the municipal slaughterhouse of Orizaba, Veracruz, Mexico, at 18 km from the facilities of the Colegio de Postgraduados under the specifications established in standard NOM-033-SAG/ZOO-2014. Each lamb was individually carried, and the animals were transported at a population density of 0.2 m²/lamb to minimize the likelihood of injury. Prior to slaughter (1200 h), food availability to the lambs

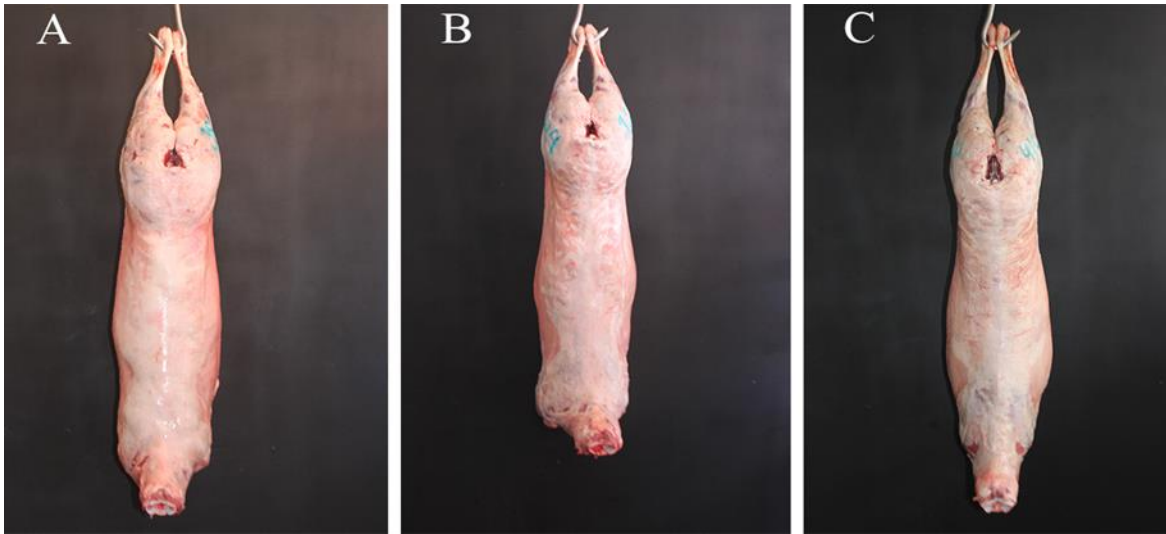
was reduced, and they were fasted for 4 h and transported to the slaughterhouse on the day of the slaughter. The live weight (LW) of the lambs was recorded at the slaughterhouse. They were then stunned using a captive bolt pistol, and exsanguination was performed through a cut in the carotid artery and the jugular vein. The animals were then skinned and eviscerated. Non-carcass components such as the head and hooves were removed and weighed separately. The weights of the blood, skin, full and empty green viscera, red viscera, and bile were also recorded. The hot carcass weight (HCW) was recorded immediately to determine the hot carcass yield ($HCW/LW \times 100$).

When the carcasses reached room temperature, they were stored in a cold room at 4 °C for 24 h, where they were hung by both Achilles tendons. Subsequently, the following measurements were made: cold carcass weight (CCW) for determining the cold carcass yield (CCW/LW), weight loss ($HCW - CCW$), dorsal fat thickness, and rib eye perimeter. To determine the fat thickness and the area of the rib eye of the *longissimus dorsi*, a cut was made between the 12th and 13th ribs, the thickness of the dorsal fat was measured with a digital caliper, and the perimeter of the rib eye was drawn on acetate paper. The rib eye area was estimated from the perimeter using an LI 3100 leaf area meter (LICOR®, Lincoln, NE, USA).

Lamb carcass conformation-classification and commercial meat cuts

The carcasses were evaluated by five trained evaluators. The training of the evaluators consisted of several training sessions in ovine carcass quality. The photographic standards used for the evaluation of the carcasses obtained in this experiment are shown in Figure 1. The evaluation of the carcasses was based on the criteria of the Mexican standard for the classification of lamb carcasses (NMX-FF-106-SCFI-2006)⁽⁹⁾. This standard describes three carcass conformation categories (excellent, good, and deficient) and four quality grade categories for the complete carcass; in order of decreasing quality, the better are Mexico Extra (MEX EXT), Mexico 1 (MEX 1), Mexico 2 (MEX 2), and Out of Classification (O/C). The criteria for classification include age of the animal, slaughter weight, carcass conformation, and dorsal fat thickness in the *longissimus dorsi* muscle at the height of the 12th rib (fat/conformation ratio).

Figure 1. Lamb carcasses classified according to the Mexican standard NMX-FF-106-SCFI-2006



(A) Charollais x Pelibuey (Good conformation, MEX 1 quality grade); (B) Dorper x Pelibuey (Good conformation, MEX 1 quality grade); and (C) Pelibuey (Deficient conformation, MEX 2 quality grade).

The carcasses were divided longitudinally along the dorsal spine. The right half was divided into six commercial sections in a modification of the procedure described: *cuello* (neck, 1st to 5th cervical vertebrae); *hombro* (shoulder, bone base: scapula and humerus including the first 5 ribs in a perpendicular section located under this); *brazuelo* (foreshank and breast, including the radius, from the 2nd to the 11th rib in a perpendicular section with the flank); *costillar* (ribs, 5th to 12th thoracic vertebrae); *lomo* (loin, *longissimus lumborum* from the 13th thoracic vertebra to the 7th lumbar vertebra); and *pierna* (leg, the section between the last lumbar vertebra and the first sacral vertebra)⁽¹⁰⁾. The sections were weighed individually, and the yield (%) was determined with respect to the weight of the right half of the carcass⁽¹¹⁾.

Measurements of carcass color, temperature, and pH

Instrumental color, temperature, and pH of the carcasses were measured at 30 min and 24 h after slaughter. The instrumental color was measured according to the CIE L*a*b* scale. For the color_{30min} of the carcass, the reading was made of the *rectus abdominis* muscle⁽¹¹⁾; for the color_{24h}, the reading was made of the *longissimus dorsi*, and for the fat color, the reading was made of the fat coverage of the leg. A portable colorimeter was used to measure this variable (Mod CR-300/410, Minolta, Tokyo, Japan). Illuminant D65 was used as an observation standard at a visual angle of 10° and an 8 mm of aperture. The temperature of the hot carcass (HC) and that of the cold carcass (CC) were measured by inserting a food-grade punch

thermometer into the muscle mass (leg). The $\text{pH}_{30\text{min}}$ was measured using a potentiometer equipped with a puncture electrode (pH meter Mod HI 99163, Hanna, TX, USA) after calibration of the equipment using buffer solutions at pH 4.0 and 7.0, choosing the same point for all the carcasses. The $\text{pH}_{24\text{h}}$ of the meat (*longissimus dorsi*) was measured according using a potentiometer (Mod pH 1100, Oaklon, Eutech Instruments, Singapore) previously calibrated with pH 4.0, 7.0, and 10.0 buffer solutions. All measurements were performed in triplicate.

Statistical analysis

The data were analyzed using the GLIMMIX procedure in SAS 9.3 (SAS Institute Inc., Cary, NC, USA). The type of breed was considered as the main effect in the model. For the DWG and FD variables, the following covariance model was used:

$$y_{ij} = \mu + \text{breed}_i + (\beta + \delta_i)X_{ij} + \text{animal}_j + \epsilon_{ij};$$

where

$i = 1,2,3;$

$j = 1, \dots, 39,$

y_{ij} are the FD of breed i in animal j ,

μ is the general mean,

breed_i is the fixed effect due to genotype i ,

$(\beta + \delta_i)X_{ij}$, β is the intercept of the covariate X_{ij} weaning weight,

δ_i is the slope of the genotype,

animal_j is the random effect due to the animal, assuming $\text{animal}_j \sim \text{IIDN}(0, \sigma_{\text{animal}}^2)$,

ϵ_{ij} is the experimental error with $\epsilon_{ijk} \sim \text{IIDN}(0, \sigma^2)$.

To analyze the variables of productive development, carcass characteristics, commercial cuts, and carcass and meat quality, the following mixed model was used:

$$y_{ij} = \mu + \text{breed}_i + \text{animal}_j + \epsilon_{ij};$$

where

$i = 1,2,3; j = 1, \dots, 39,$

y_{ij} is the variable of the response of the type of cross i , in animal j ,

μ is the general mean,

breed_i is the fixed effect due to breed, animal_j is the random effect due to the animal, assuming $\text{animal}_j \sim \text{IIDN}(0, \sigma_{\text{animal}}^2)$,

ϵ_{ij} is the experimental error, assuming, $\epsilon_{ijk} \sim \text{IIDN}(0, \sigma^2)$.

Fisher's LSD method and Satterthwaite's degrees of freedom correction method were used to compare means. The cumulative logit model was used to compare the carcass conformation and the quality grade of the genotypes. The linear predictor is $\eta_{ci} = \eta_c + \tau_i$, where η_{ci} is the linear predictor in category c th ($c = 0, 1$) for the i th genotype ($i = 1, 2, 3$), η_c is the intercept for the c th category, and τ_i is the i th fixed effect of the genotype. The Mexican standard for the classification of lamb carcasses establishes three categories for the conformation of the carcass (excellent, good, and deficient) and four categories for the quality grade of the whole carcass (in decreasing order of quality, these categories are MEX EXT, MEX 1, MEX 2, and O/C). In this study, only two categories for conformation (good and deficient) and two categories for quality grade (MEX 1 and MEX 2) were obtained and considered in the model for the analysis.

Results and discussion

Lamb growth performance

The productive performance of the lambs according to genotype is shown in Table 1. The analysis of variance showed that there is a highly significant effect ($P= 0.0001$) of genotype on the variables BW, WW, and DWG. The average BW and WW were significantly greater in the Charollais x Pelibuey (ChP) genotype than in the Dorper x Pelibuey (DP) genotype (by 0.47 kg and 2.94 kg, respectively) and in the Pelibuey (P) genotype (by 0.69 kg and 4.05 kg, respectively). There was a significant effect of genotype ($P=0.0020$) and covariate weaning weight ($P=0.0073$) on the number of FD. The number of FD required for the lambs to reach commercial weight was not significantly different in ChP and DP lambs, but FD in those groups differed significantly from that in P lambs. ChP and DP lambs reached commercial weight 35 and 23 d earlier than P lambs, respectively. The average daily weight gain (DWG) from weaning to slaughter differed significantly in the three groups; ChP and DP lambs showed higher DWG than P lambs (Figure 2). DWG was greater in the ChP genotype than in the DP genotype.

Table 1. Productive behavior of Charollais x Pelibuey (ChP), Dorper x Pelibuey (DP), and Pelibuey (P) lambs

Variable	ChP (n= 11)	DP (n= 10)	P (n= 18)
Birth weight, kg	3.93 ± 0.24 ^a	3.46 ± 0.24 ^{ab}	3.24 ± 0.16 ^b
Weaning weight, kg	19.39 ± 0.91 ^a	16.45 ± 0.92 ^b	15.34 ± 0.60 ^b
FD (weaning to slaughter)	106.87 ± 7.07 ^b	118.01 ± 6.76 ^b	141.35 ± 5.36 ^a
DWG, kg/d (weaning to slaughter)	0.278 ± 0.01 ^a	0.235 ± 0.01 ^b	0.207 ± 0.01 ^c

FD= fattening days; DWG= daily weight gain; The data are reported as the mean ± the standard error.

^{abc} Means within the same row marked with different letters are significantly different ($P < 0.05$).

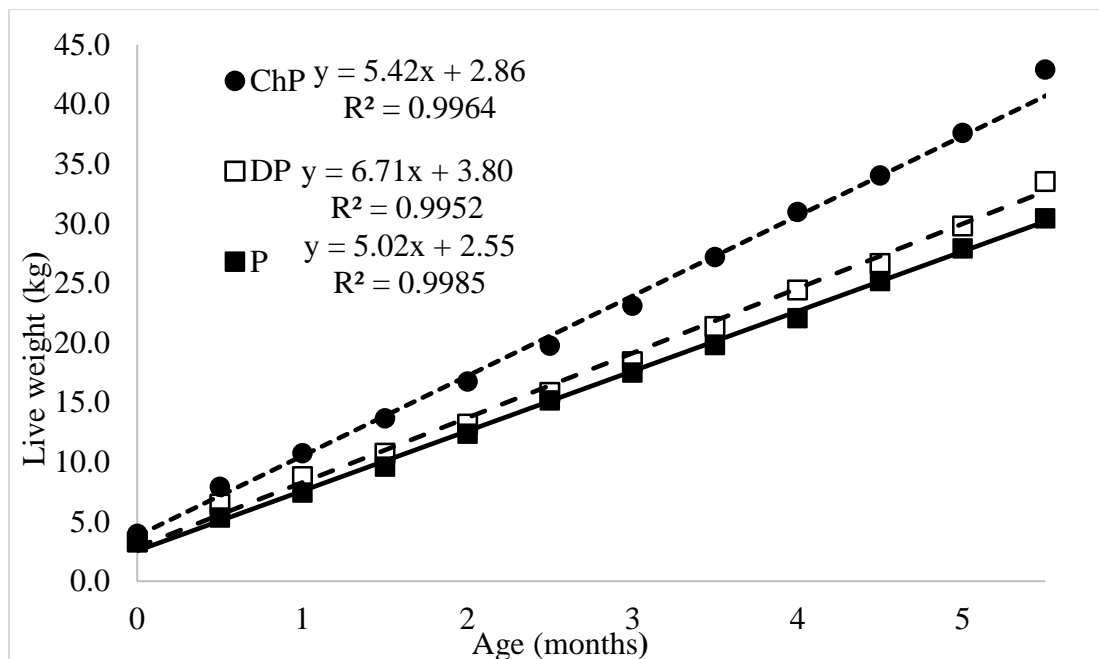
The present study showed that crossing of Pelibuey ewes with Charollais rams results in better productive development (BW, WW, FD and DWG) of lambs raised in conditions of high temperature and humidity, that is, in the study area where the present investigation was developed, the temperature varies from 12 to 32 °C (minimum of 9 °C and maximum of 37 °C) and it rains 25.1 d on a month with at least 1 mm of precipitation. The lambs from ewes with meat suitability (Katahdin) and rams of four breeds (Charollais, Dorper, Suffolk, and Textel) under better environmental conditions for the production of sheep (dry temperate climate at 1,962 m asl), were that the best productive behavior was found in lambs from the Katahdin x Charollais crossing⁽¹²⁾. The production values cited in that study are similar to the values found in the present study. The BW values found in this study are superior to those reported in other studies⁽¹³⁾ in lambs from Black Belly x Pelibuey ewes and rams of three different breeds (Dorset, Hampshire, and Suffolk) and lambs from Pelibuey ewes and hair breed rams (Pelibuey, Katahdin, and Dorper), with average reported values of 3.18 ± 0.34 and 2.9 ± 0.09 kg, respectively.

The DWG (kg/d) in the present study for the three genotypes was higher than the values in P (0.181 ± 0.02), Pelibuey x Suffolk (0.206 ± 0.03), DP (0.222 ± 0.03), F1 x Dorset (0.217 ± 0.05), F1 x Hampshire (0.219 ± 0.05), and F1 x Suffolk (0.222 ± 0.04) lambs^(4,13). These differences may be due to the breeds used in the crossbreeding and to the management of the lambs during fattening. It is important to mention that no BW, WW, FD, or DWG values have previously been reported for the Charollais x Pelibuey (ChP) crossing. For the first time, this study showed that the performance of ChP lambs with respect to the variables is better than that of other crosses, even under stressful climatic conditions of high temperature and humidity of study area. Thus, this crossing is a good alternative to produce sheep in the tropics.

Figure 2 shows the change in live weight from birth to 5.5 mo according to genotype. The graph shows that at the age of 5.5 mo, lambs of the ChP and DP genotypes showed a higher

growth rate, with average monthly weight gains of 6.71 and 5.42 kg, respectively, than lambs of the P genotype (5.02 kg), despite the fact that the initial weights of the lambs of the three genotypes were very similar. ChP lambs reached the commercial weight for slaughter 35 and 12 d before lambs of the P and DP genotypes, respectively. The Dorper breed has been recommended for the production of lambs with meat suitability in crossbreeding⁽¹⁴⁾. However, the results obtained in this investigation show that crossing of Charollais rams with Pelibuey ewes results in lambs that are more suitable to produce meat due to their better growth rate.

Figure 2. Change in live weight from birth to 5.5 months of age of Charollais x Pelibuey (ChP, closed circles), Dorper x Pelibuey (DP, open boxes), and Pelibuey (P, closed boxes) lambs. The regression lines are presented for each breed from birth to 5.5 mo of age



Lamb carcass yield

The analysis of variance showed a highly significant effect of genotype on carcass weight loss ($P=0.0072$) and on the weight of empty green viscera ($P=0.0001$). This means that the Charollais x Pelibuey breed presented less loss of empty green viscera, followed by the Dorper x Pelibuey breed, while the pure Pelibuey breed had a lower loss of this characteristic. There was no significant effect of genotype on the remaining variables (Table 2), such as weight loss, dorsal fat thickness, area of the rib, and red viscera, so the behavior of the characteristics of the carcasses was similar between races and crosses of sheep evaluated.

Weight loss between hot and cold carcasses was lower in the ChP genotype; the weight of empty green viscera was significantly different among the three breeds and was higher in the hair breeds (P and DP). Lambs of the three genotypes showed similar average cold carcass yield (CCY) values because the weight of the animals at slaughter was standardized.

Table 2. Characteristics of the carcasses of Charollais x Pelibuey (ChP), Dorper x Pelibuey (DP), and Pelibuey (P) lambs

Variable	ChP (n = 11)	DP (n = 10)	P (n = 18)
Empty live weight, kg	44.85 ± 0.85	42.96 ± 0.89	43.17 ± 0.66
Hot carcass weight, kg	22.21 ± 0.47	21.45 ± 0.49	21.40 ± 0.36
Cold carcass weight, kg	21.86 ± 0.46	21.03 ± 0.49	20.91 ± 0.36
Hot carcass yield, %	49.53 ± 0.44	49.89 ± 0.46	49.53 ± 0.34
Cold carcass yield, %	48.74 ± 0.43	48.90 ± 0.45	48.46 ± 0.33
Loss of weight, kg	0.35 ± 0.03 ^b	0.42 ± 0.03 ^{ab}	0.50 ± 0.02 ^a
Dorsal fat thickness, mm	1.51 ± 0.17	1.63 ± 0.18	1.56 ± 0.13
Area of the rib, cm ²	14.66 ± 0.69	15.43 ± 0.81	15.83 ± 1.33
Red viscera, kg	1.98 ± 0.39	1.98 ± 0.41	2.39 ± 0.30
Empty green viscera, kg	3.84 ± 0.13 ^c	4.31 ± 0.13 ^b	4.87 ± 0.10 ^a

The data are reported as the mean ± the standard error (SE).

^{abc} Means within a row marked with different letters are significantly different ($P < 0.05$).

In this study, genotype was not found to affect the CCY and lambs with standardized weights at slaughter and from hair sheep ewes and rams of the Dorset, Hampshire, Suffolk, Pelibuey, and Rambouillet breeds^(5,13). Those authors showed that there were no significant differences in CCY among the genotypes studied, but the values reported for CCY were lower than those obtained in this investigation. Carcass yield can be affected by factors such as the age of the lamb, wool growth, nutrition, and breed⁽¹⁵⁾. Results in this research showed no effect of breed on the CCY. In this sense, state that with the standardization of the weight at slaughter, the carcass yield is not affected⁽⁵⁾. In this study, ChP lamb carcasses lost less weight at 24 h after slaughter (0.15 kg) than P and DP carcasses. In contrast, in the crossing of Pelibuey with Rambouillet and Suffolk breeds, no differences were found in this variable⁽⁵⁾.

Another important characteristic of the carcass is dorsal fat thickness. Low values of this parameter are an indicator of lean meat, which is preferred in the Mexican market⁽⁵⁾. The average dorsal fat thickness values in this study were very low (ChP= 1.51 ± 0.17 mm, DP= 1.63 ± 0.18 mm, P= 1.56 ± 0.13 mm) despite the high slaughter weight of the animals. Similar values have been reported for Pelibuey (1.2), Pelibuey x Kathadin (1.8 mm), DP (1.8 mm),

Pelibuey x Rambouillet (1.7 mm), and Pelibuey x Suffolk (1.4 mm) lambs^(16,17). On the other hand, higher values of dorsal fat thickness (6.33 ± 1.22 mm) have been reported in lambs obtained by crossing Kathadin ewes with Charollais rams⁽¹⁶⁾. This may be because the Katahdin and Charollais breeds undergo rapid growth and accumulate dorsal fat at a young age compared to the Pelibuey breed, which is slower-growing and tends to accumulate more visceral fat than dorsal fat⁽²⁾.

The rib eye area is an indicator of the muscle conformation of the carcass⁽¹⁸⁾; the greater the rib eye area, the better is the muscle conformation. In this study, genotype did not influence the rib eye area or the area of the *longissimus dorsi* muscle (ChP= 14.66 ± 0.69 cm², DP= 15.43 ± 0.81 cm², and P= 15.83 ± 1.33 cm²). Lower values have been reported in DP (11.01 cm²), Pelibuey, Pelibuey x Rambouillet and Pelibuey x Suffolk (5.16 ± 0.13 cm²) and Black Belly (10.89 cm²) lambs^(5,16,17,19). The highest rib eye area values (19.8 ± 0.5 cm²) were found in Kathadhin x Charollais and Katahdin x Dorper lambs treated with β -adrenergic agonists during fattening⁽²⁰⁾. Breed, diet, and hormonal treatment affect muscle development⁽²¹⁾.

Classification, conformation of the carcass, and commercial cuts

The estimated probabilities of carcass conformation and quality grade according to genotype are shown in Figure 3. The *f* analysis showed a statistically significant effect among genotypes ($P < 0.0382$) on the carcass conformation and quality grade. Of the carcasses evaluated according to the NMX-FF-106-SCFI-2006 standard, the ChP genotype showed better carcass conformation and quality grade than the DP and P genotypes. The lambs obtained from the crossing of Pelibuey ewes with the Charollais breed showed better carcass conformation and quality grade than the other animals, as shown by the fact that the probability of obtaining good conformation and MEX 1 quality grade in the ChP genotype is 0.10 and 0.72 units higher, respectively, than that for the DP and P genotypes. The P genotype showed the highest percentage (72 %) of carcasses with deficient conformation and MEX 2 quality grade, whereas 10 % of the carcasses of the DP genotype and none of the carcasses of the ChP genotype displayed deficient quality and conformation. In general, crossbreeding DP and ChP resulted in better classification, better carcass conformation, and better-quality grade than was obtained with genotype P.

Figure 3. Estimated probabilities of achieving specific carcass conformation categories and quality grades for Charollais x Pelibuey (ChP), Dorper x Pelibuey (DP), and Pelibuey (P) lambs using a *cumulative logit* model

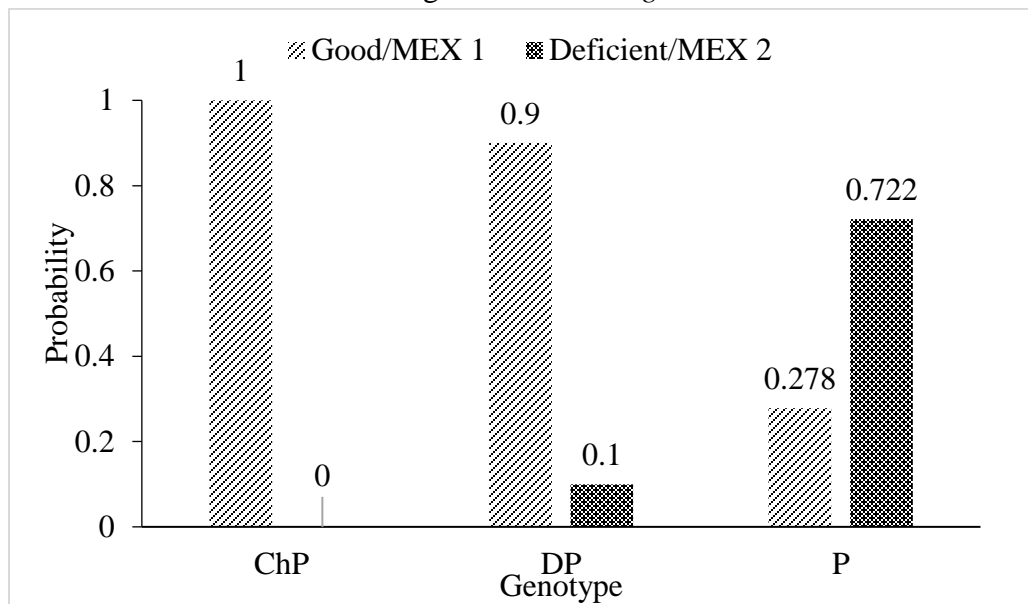


Figure 1 shows the photographic standards used to evaluate the carcasses obtained in this experiment. The crossing of Pelibuey ewes with rams from the Charollais and Dorper breeds conferred better carcass conformation and quality grade because the latter two breeds present better meat conformation⁽¹⁾ than the pure Pelibuey breed. In this study, the crossing of Katahdin x Charollais was shown to yield carcasses with excellent conformation and MEX EXT quality grade; in that case, both of the breeds used in the cross are suitable for meat production⁽¹⁶⁾.

The average weight of the half carcass and the weight and yield of commercial cuts according to genotype are shown in Table 3. The analysis of variance showed a highly significant effect of genotype on the average weight of the neck ($P=0.0036$), loin ($P=0.0339$), and leg ($P=0.0001$), but no significant effect of genotype was observed for the other commercial cuts or for the average weight of the half carcass. In the yield of the commercial cuts, there was a significant effect of genotype on the neck ($P=0.0060$), the foreshank+breast ($P=0.0289$), the loin ($P=0.0484$), and the leg ($P=0.0088$). The P genotype presented higher neck weight and yield than the ChP and DP genotypes, whereas only the P genotype presented greater loin weight than the DP genotype. It was observed that of the three genotypes ChP presented greater leg weight and yield and greater foreshank+breast yield than the other two genotypes.

Table 3. The average weight of the half carcass and the weight and yield of the commercial cuts of Charollais x Pelibuey (ChP), Dorper x Pelibuey (DP), and Pelibuey (P) lambs

Variable	ChP (n = 11)	DP (n = 10)	P (n = 18)
Half-carcass weight	10.45 ± 0.26	10.17 ± 0.27	10.36 ± 0.20
Commercial cuts (kg)			
Neck	0.58 ± 0.03 ^b	0.56 ± 0.03 ^b	0.71 ± 0.02 ^a
Shoulder	1.57 ± 0.05	1.57 ± 0.05	1.54 ± 0.04
Foreshank+breast	2.43 ± 0.12	2.23 ± 0.13	2.13 ± 0.09
Ribs	1.18 ± 0.07	1.14 ± 0.07	1.14 ± 0.06
Loin	1.58 ± 0.08 ^{ab}	1.46 ± 0.08 ^b	1.72 ± 0.06 ^a
Leg	3.44 ± 0.09 ^a	3.13 ± 0.09 ^b	3.15 ± 0.08 ^b
Yield of commercial cuts (%)			
Neck	5.68 ± 0.37 ^b	5.64 ± 0.35 ^b	6.96 ± 0.28 ^a
Shoulder	15.52 ± 0.44	15.51 ± 0.42	14.83 ± 0.33
Foreshank+breast	24.28 ± 1.05 ^a	21.91 ± 0.99 ^{ab}	20.59 ± 0.79 ^b
Ribs	10.51 ± 0.35	11.22 ± 0.33	10.47 ± 0.26
Loin	15.31 ± 0.71 ^{ab}	14.39 ± 0.68 ^b	16.57 ± 0.53 ^a
Leg	32.81 ± 0.58 ^a	31.35 ± 0.55 ^{ab}	30.41 ± 0.43 ^b

The data are reported as the mean ± the standard error (SE).

^{ab} Means within the same row marked with different letters are significantly different ($P < 0.05$).

The leg and loin are cuts of great commercial value and represent 43.3 % of the yield of the carcass⁽¹⁰⁾. In this study, the yield obtained for both cuts was greater than the reported value in all three genotypes: ChP (48.12 %), DP (45.74 %), and P (46.98 %). In this study, the crossing of Pelibuey with Charollais resulted in greater weight of the leg, which is a cut of high commercial value⁽⁵⁾. However, 1 to 4 % differences among the genotypes were observed in the weights of the neck, loin, leg, and foreshank+breast cuts minimal differences in the weights of the majority of commercial cuts in the evaluation of 15 wool breeds specialized for the production of wool or meat⁽²²⁾. In crossbred lambs of hair breeds (DP) and hair x wool breeds and reported differences in cut yield of approximately 1%, similar to the differences found in this study⁽²³⁾.

pH, temperature, and instrumental color of the carcass and meat

Table 4 presents the average values of pH, temperature, and instrumental color of the *rectus abdominis* muscle, meat, and subcutaneous fat according to genotype. Of the variables measured in the carcass, $T_{30\text{min}}$ ($P=0.0658$), L^* ($P=0.0001$), and a^* ($P=0.0107$) were affected by genotype. The analysis of variance also showed significant differences in the variables

pH_{24h} ($P=0.0607$), L* ($P=0.0001$), a* ($P=0.0001$), and b* ($P=0.0006$), measured in the meat (*longissimus dorsi*) and in L* ($P=0.0001$) of the subcutaneous fat; no differences were observed in the remaining variables. The ChP genotype presented a higher carcass temperature than the P genotype; however, the 24-h *post mortem* temperature was similar among the three genotypes (T_{24h} , $P=0.2643$) because the carcasses were maintained under the same storage conditions (24 h at 4°C). The average value of pH_{24h} was greater in the ChP genotype than in the P genotype.

Table 4. The pH, temperature, and instrumental color of the *rectus abdominis* muscle and meat of Charollais x Pelibuey (ChP), Dorper x Pelibuey (DP), and Pelibuey (P) lambs

Variable	ChP (n = 11)	DP (n = 10)	P (n = 18)
pH _{30min}	6.64 ± 0.06	6.72 ± 0.06	6.75 ± 0.04
pH _{24h}	5.66 ± 0.02 ^a	5.61 ± 0.02 ^{ab}	5.59 ± 0.02 ^b
T _{30min} (°C)	39.88 ± 0.23 ^a	39.37 ± 0.24 ^{ab}	39.19 ± 0.18 ^b
T _{24h} (°C)	4.64 ± 0.19	4.20 ± 0.20	4.33 ± 0.15
<i>Rectus abdominis</i>	L*	41.35 ± 0.78 ^b	38.20 ± 0.82 ^c
	a*	12.78 ± 1.40 ^b	13.30 ± 1.46 ^b
	b*	-0.81 ± 0.33	-0.94 ± 0.35
<i>Longissimus dorsi</i> _{24h}	L*	33.69 ± 0.66 ^b	32.61 ± 0.69 ^b
	a*	14.73 ± 0.42 ^b	13.84 ± 0.45 ^b
	b*	4.29 ± 0.23 ^a	3.33 ± 0.24 ^b
Subcutaneous fat	L*	68.41 ± 1.38 ^b	67.98 ± 1.45 ^b
	a*	3.32 ± 0.45	3.6 ± 0.48
	b*	4.29 ± 0.46	4.31 ± 0.49

The data are reported as the mean ± the standard error (SE).

^{ab} Means within the same row marked with different letters are significantly different ($P<0.05$).

The pH and color of meat are important indicators of quality and influence the visual appearance of the meat⁽²⁴⁾. The difference in pH at 24 h *post mortem* among the genotypes in this study was probably because the T_{30min} of the carcass tends to be lower in hair breeds than in wool breeds⁽²⁵⁾, and it has been shown that the meat of fast-growing lambs tends to have a higher pH⁽²⁶⁾. However, the pH_{24h} values for the three genotypes in this study fell within the preferred range for this parameter⁽²⁷⁾.

The color of the *rectus abdominis* muscle (30 min *post mortem*) was significantly affected by genotype in this study. The values of a* were similar to those reported in Rasa Aragonesa lamb carcasses for different thicknesses of dorsal fat with a slaughter weight of 50-60 kg⁽²⁸⁾. Values higher reported in the present study for L* (51.12) and a* (11.64) in Rasa Aragonesa lambs, with a slaughter weight of 24 kg⁽²⁹⁾.

In the color of meat (*longissimus dorsi*), the ChP and DP genotypes presented indices of L* (luminosity) and a* (red) lower than those presented by the P genotype. During storage, the ferric metmyoglobin (MetMb) accumulation rate on the surface of the meat is governed by intrinsic factors (age of the animal, breed, sex, diet, pH, and metabolic type of the muscle) and extrinsic factors (temperature, oxygen availability, lighting, growth of surface microbes, and type of packaging) or a combination of these factors^(30,31). In this study, it was observed that genotype affected the color of the meat; meat color was probably also affected by the exposure time of the carcasses prior to cold-room storage⁽²⁶⁾. Found an effect of genotype on the a* and b* indices of meat color in hair breed lambs and lambs obtained by crossing hair and wool breeds⁽³²⁾.

With respect to subcutaneous fat, there were no significant differences in the indices a* ($P=0.7484$) or b* ($P=0.4617$) among the three genotypes. The b* (yellow) index of subcutaneous fat was similar in the three genotypes because the lambs underwent the same management during fattening and remained stabled; grazing lambs tend to have higher b* index values⁽²⁶⁾ due to the presence of high levels of carotenoids in the fat⁽³²⁾, resulting in a yellow color that is unattractive to consumers.

Conclusions and implications

Breed had a significant effect on the growth, characteristics, and classification of lamb carcasses. The crossing of Pelibuey sheep with the Charollais breed (ChP) resulted in higher DWG. ChP and DP lambs reached commercial weight one month earlier than P lambs. With the ChP crossing, there is a high probability (0.72) of obtaining carcasses that show good conformation and good quality grade (MEX 1). Therefore, the ChP crossing can be an option for the commercial breeding and fattening of lambs to produce quality meat in hot, humid climates. In this study it was found that the genotype of the evaluated sheep presented different conditions in the composition of the meat, such as an increase in pH, temperature variations, changes in the instrumental color of the carcass, amount of meat and subcutaneous fat, however, these parameters are within the acceptable ranges of meat quality for each breed. In this sense, it is feasible for sheep producers in the Center of Veracruz, México that they can use the crosses of the breeds evaluated in this study to maintain or increase the productivity of their herds.

Acknowledgments and declaration of conflict of interest

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