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Simplification of the growth recording protocol for meat sheep applied in Morocco

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Abstract The study aimed to simplify the actual sheep weight recording protocol used in Morocco that is based on weighing lambs at four different intervals of 21 days. The study was simulated using the weights of 1554 Timahdite lambs, born between 2008 and 2012 in four state farms. Nine simplified protocols were applied, based on constant birth weight for all lambs or according to their type of birth and sex and number of weighings to be carried out. Comparison between the standard weights at 30, 70 and 90 days, calculated using the actual and simplified protocols, was based on the average bias, mean squared error and accuracy loss. Moreover, direct and maternal heritability estimates of the standard weights, calculated using the actual and simplified protocols, were compared. Similarly, the Spearman correlation coefficients between sheep rankings on the direct genetic indexes and correlation coefficients between sheep rankings on the maternal genetic indexes for weight at 30, 70 and 90 days, estimated using the actual protocol and each of the simplified protocols, were calculated. Based on these criteria, the closest standard weights' estimation to those of the actual protocol was performed using protocols based on constant birth weight for all lambs or according to their type of birth and sex, and two controls at 42 and 84 days or three controls at 42, 63 and 84 days, with only lambs more than 21 days old being weighed at each control. It was concluded that ignoring one or two controls out of the four currently practiced would not alter the shape of the lambs' growth curve and would allow standard weights to be estimated without much loss of accuracy.

Keywords: lamb, performance recording, birth weight, standard weight, simplified protocol

Introduction

To improve the productivity of sheep, a coherent genetic improvement program with the performance recording is imperative. For meat sheep, the growth recording protocol consists of weighing lambs regularly in order to calculate weights at standard ages and average daily gains during the growth period. Different protocols have been applied, from the simplest one that consisted of weighing lambs once around weaning to those based on several weighings. However, weight recording is in general a costly operation and increase the burden on the animals and farmers. To reduce the burden, many research studies have considered simplifying the growth protocols for sheep (Ben Gara et al., 1997; Tiphine et al., 2005; Ben Hamouda and Rekik, 2012) and goats (Naves et al., 2001; Atoui et al., 2020). However, any simplification could only be considered if the loss of accuracy due to the reduction in the number of weighings remains compatible with correct evaluation of selected animals.

In Morocco, the ANOC (Association Nationale Ovine et Caprine) has been using the French growth recording protocol named “F2” for the principal native breeds since the 1987-88 lambing season. It consists of weighing all the lambs present at each control at regular intervals of 21 days, starting from the 21st day after the first birth in the flock (Perret and Bibé, 1979). As a result, the technician carried out several controls in each farm during the lambing season, so that each lamb was weighed four times. However, with the extent of the lambing season, the high number of lambs to weigh at each control, the arduousness and the cost of weighing operation, the difficulties of access to some farms during the winter season..., the technician spent a lot of time in weighing lambs instead of devoting this time to the technical supervision of breeders (Boujenane et al., 1995). Therefore, the simplification of the actual weight recording is necessary in order to make it simple, easier and less restrictive for the breeders. In addition, any reduction in the growth recording system will allow the selection base to be broadened and thus will disseminate the genetic progress on a larger scale (Ben Gara et al., 1997).

The objective of the current study was to evaluate alternative protocols of simplifying the on-farm growth recording protocol applied by the ANOC in order to make it simpler, easier and more flexible, by comparing weights, heritability estimates and animals’ rankings on estimated genetic values from simplified and actual growth recording protocols.

Materials and methods

Simulated data

The study on the simplification of sheep growth recording was simulated using a data set from the database of ANOC. The initial data set included 1951 purebred Timahdite lambs born between 2008 and 2012 in four state farms located in the cradle of breed. The general management system of these flocks was semi-intensive. Ewes were grazing during the day on pastures and confined in the evening with or without supplementation, depending on the quality of pastures. The main mating period was from May to October. The season of lambing began in October and continued until March, with a concentration during December and January. At birth, lambs were ear tagged and weighed. They were then weighed at four different intervals of 21 days. The first weighing occurred 21 days after the birth of the first lamb in the flock. Lambs were weaned at about 90 days.

Information available in the data set was lamb ID, sire ID, Dam ID, flock ID, age of dam, lamb’s birth date, birth type, sex, dates of 1st, 2nd, 3rd and 4th weighing, weights at these four weighings, and weights at birth (BW), 10 days (W10d), 30 days (W30d) and 70 days (W70d). These standard weights were calculated from the four measurements using the linear interpolation or extrapolation. Before analysis, the lambs born before October or after February, and all those with age at 1st weighing greater than 21 days, age at 2nd weighing less than 22 days or greater than 42 days, age at 3rd weighing less than 43 days or greater than 63 days or age at 4th weighing less than 64 days or greater than 84 days were removed from the data set. Similarly, W10d, W30d and W70d that were outside the range of mean ± 3×standard deviation were discarded. The data set after editing included 1554 lambs (46.9% males and 53.1 females), the progeny of 22 sires and 905 dams. Each sire had between 10 and 472 progenies, while each dam had from one to five offspring. The distribution of births over the five seasons (combination of year and month of birth) varied from 9.03% to 33.1%.

Approaches of simplifying growth recording protocol

The actual or the conventional on-farm growth recording protocol applied by the ANOC consisted of four weighings per lamb spaced 21 days apart, with the first weighing performed 21 days after the birth of the first lamb in the flock. Measurements obtained at these weighings were used to calculate W10d, W30d and W70d, which were then used to calculate the average daily gain from 10 to 30 days (ADG10-30) and from 30 to 70 days (ADG30-70). Birth weight of lambs was not recorded on-farm, except for lambs born on the day of control (Ait Bihi and Boujenane 1997). According to Ricordeau and Boccard (1961), ADG10-30 is an indicator of the mother's suckling ability, while ADG30-70 reflects the lamb’s growth potential. However, Tiphine et al. (2005) considered that the W30d is more important as a selection criterion than the ADG10-30, because it incorporates both the birth weight and the growth rate from birth to 30 days, thus giving a good idea on the mother’s suckling ability. To calculate the W30d, two weighings are necessary, one before and the other after 30 days. The weight before 30 days might be the one obtained at the first weighing, if the lamb was weighed. Otherwise, if the lamb was not weighed before 30 days, the birth weight might be considered as the first weighing. The majority of lambs born on-farm were not weighed at birth. Boggess et al. (1991) showed that for lambs with unknown birth weights, a constant birth weight should be used in adjusting standard weights to a constant age. The choice of birth weight constant might correspond to all lambs of the breed, type of birth, sex, or birth type × sex.

The analysis of current data set showed that birth weight of Timahdite lambs averaged 3.66±0.69 kg. Therefore, this mean was used as the constant birth weight for all lambs. In addition, using the statistical model that included the fixed effect of flock, age of dam, sex, type of birth, season of birth (combination of birth year and month), the variance analysis showed that type of birth, sex and type of birth × sex interaction had significant effects on the birth weight ($P<0.05$). Average birth weights estimated for type of birth and sex were 3.92±0.63 kg for single males, 3.72±0.60 kg for single females, 3.05±0.55 kg for twin males and 2.94±0.51 kg for twin females.

Simplified protocols

Simplified protocols based on one weighing

The simplest protocol that might be used to determine the weights of lambs at standard ages is the one based on one weighing. It consists of weighing lambs once around weaning age, that is used to determine the weight at any standard age. Thus, from the dates of birth and weighing, the age at weighing is determined, and then the ADG from birth to weighing date is calculated, which is subsequently used to calculate the weight at any standard age. Eventually, two cases might be considered:

- Birth weight was unknown (this is the case for the real conditions of on-farm growth recording).
  - ✓ Protocol 1: Weight at a standard age $WSA = (\frac{WW}{Age}) \times SA$

  where WSA= weight at a standard age (30, 70 or 90 days), WW= weight at weighing, Age= Age at weighing, SA= standard age.
- Birth weight (BW, either real or constant) was taken into account.

  Weight at a standard age $WSA = BW + (\frac{WW - BW}{Age}) \times SA$

Two protocols might be considered:

- ✓ Protocol 2: Constant birth weight for all lambs that did not have one: BW= 3.66±0.69 kg
- ✓ Protocol 3: Constant birth weight for lambs that did not have one according to their type of birth and sex: 3.92±0.63 kg for single males, 3.72±0.60 kg for single females, 3.05±0.55 kg for twin males and 2.94±0.51 kg for twin females.

Simplified protocols based on two or three weighings

The explored simplification method consisted of the elimination of one or two of the four weighings carried out in the conventional protocol. Thus, the first weighing might occur 42 days (2 times the regular interval) after the first birth in the flock, instead of 21 days, because the number of early lambs in the flock is often reduced. Moreover, the interval between two successive weighings might be either 21 or 42 days. At each control, only lambs more than 21 days old were weighed. In this way, the number of controls would be reduced to:

- Two controls at 42 and 63 days after the first birth in the flock, i.e. 2nd and 3rd controls in the actual protocol;
- Two controls at 42 and 84 days after the first birth in the flock, i.e. 2nd and 4th controls in the actual protocol;
- Three controls at 42, 63 and 84 days after the first birth in the flock, i.e. 2nd, 3rd and 4th controls in the actual protocol.

Therefore, by combining the approach for determining birth weight of lambs that did not have one (constant birth weight, i.e. the same for all lambs, or constant birth weight according to their type of birth and sex) and the number of weighings to be carried out per lamb (2 or 3), six more growth recording protocols might be considered:

- ✓ Protocol 4: Constant BW for all lambs that did not have one and two weighings at 42 and 63 days after the first birth in the flock.
- ✓ Protocol 5: Constant BW for all lambs that did not have one and two weighings at 42 and 84 days after the first birth in the flock.
- ✓ Protocol 6: Constant BW for all lambs that did not have one and three weighings at 42, 63 and 84 days after the first birth in the flock.
- ✓ Protocol 7: Constant BW for lambs that did not have one according to their type of birth and sex, and two weighings at 42 and 63 days after the first birth in the flock.
- ✓ Protocol 8: Constant BW for lambs that did not have one according to their type of birth and sex, and two weighings at 42 and 84 days after the first birth in the flock.
- ✓ Protocol 9: Constant BW for lambs that did not have one according to their type of birth and sex, and three weighings at 42, 63 and 84 days after the first birth in the flock.

Noteworthy, for these simplified protocols, W30d, W70d and W90d were calculated by using the age and measurement at a specific weighing. In addition, although lambs' birth weights were available in the present data set, we assumed that they were unknown in order to simulate the conditions of the on-farm growth recording applied by the ANOC with a view to exploring the different simplified protocols.

Assessment of simplified protocols

In the present study, W30d, W70d and W90d, calculated from the actual protocol that was based on four weights spaced 21 days apart, with the first weight being measured 21 days after the birth of the first lamb in the flock, were taken as the actual or reference weights. Comparison between the actual weights and weights calculated from each simplified protocol (1 to 9) was based on average bias or mean absolute difference, mean squared error (MSE) and loss of accuracy (Gonzalo et al., 2003) given by the following formulas:

$$\text{Average bias} = \frac{1}{n} \sum_{i=1}^{n} |P_a - P_s|$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(P_a - P_s)^2$$

$$\text{Loss of accuracy} = (1 - R^2)x100$$

where P_a is the actual weight at a standard age (30, 70 or 90 days), P_s is the weight at the same standard age calculated using a simplified protocol and n is the number of observations. In addition, R^2 is the coefficient of determination of simple regression of actual weight at a standard age on the weight at the same standard age calculated using a simplified protocol (Gonzalo et al., 2003). The simplified protocol with lowest average bias, MSE and loss of accuracy was considered as the closest to the actual protocol.

Simplification of the growth recording protocol was also assessed by changes in heritability estimates of the weights determined using the actual and simplified protocols. Thus, six different models were fitted for each of these weights, by ignoring or including the maternal additive genetic effect, covariance between direct-maternal additive genetic effect and maternal permanent environmental effect. Based on the Akaike's information criterion (AIC), the most appropriate animal model for estimating (co)variance components of the majority of standard weights at 30, 70 and 90 days, calculated using the actual and simplified protocols, included fixed effects (flock, age of dam, sex, type of birth, season of birth (combination of birth year and month)) and direct and maternal genetic random effects, assuming that the covariance between direct and maternal genetic effects was equal to zero.

$$y = Xb + Z_a a + Z_m m + e$$

where y is a vector of observations, b is a vector of fixed effects with incidence matrix X, a ~N(0, A σ_a^2) and m ~N(0, A σ_m^2) are vectors of direct and maternal additive genetic effects with incidence matrices Z_a and Z_m, respectively, and e ~N(0, I_n σ_e^2) is a vector of random residual effects. Also, σ_a^2 is the direct additive genetic variance, σ_m^2 is the maternal additive genetic variance, σ_e^2 is the residual variance, A is the additive genetic relationship matrix, and I_n is the identity matrix of order equal to the number of records.

Similarly, Spearman correlation coefficients between sheep rankings on direct genetic indexes and Spearman correlation coefficients between sheep rankings on maternal genetic indexes for W30d, W70d and W90d, estimated using the actual protocol and each of the simplified protocols, were calculated.

The statistical analyses were performed by the SAS procedures (MEANS, FREQ, GLM, REG, RANK and CORR) (SAS, 2002). Direct and maternal heritabilities of weights, as well as genetic values (direct and maternal effects) of animals were estimated using the MTDFREML software (Boldman et al., 1995).

Comparison of arithmetic means of the same weight, calculated using the actual and each simplified protocol, was tested using the z score (Kaps and Lamberson, 2004):

$$z \approx \frac{\bar{x}_i - \bar{x}_j}{\sqrt{\frac{S_i^2}{n_i} + \frac{S_j^2}{nj}}}$$

The significance of differences between heritability estimates for a weight, calculated using the actual protocol and estimates for the same weight calculated using each simplified protocol, was assessed by the z score: $z \approx \frac{x_i - x_j}{\sqrt{\sigma_i^2 + \sigma_j^2}}$

where $\bar{x}_i$ and $\bar{x}_j$ are the arithmetic means of the same weight calculated using the actual and simplified protocols, respectively, S_i and S_j are the respective standard deviations, n_i and n_j are the respective numbers of observations, x_i and x_j are the heritability estimates using the actual protocol and a simplified protocol, respectively, σ_i and σ_j are the respective standard errors. The absence of difference was performed at the significance level of 5%.

Results and discussion

Descriptive statistics of age and weight at weighing

Age and weight of lambs at different weighings using the actual weight recording protocol are shown in Table 1. The first, second, third and fourth weighing occurred 12.3, 33.2, 54.0 and 75.1 days after the first birth in the flock, respectively. The respective lambs' weights averaged 6.57 ± 1.46 kg, 11.1 ± 1.87 kg, 15.2 ± 2.21 kg and 19.1 ± 2.50 kg.

Descriptive statistics of weights at standard ages

Lamb weights at 10, 30, 70 and 90 days calculated from the actual growth recording protocol averaged 6.08 ± 1.08 kg, 10.4 ± 1.49 kg, 18.2 ± 2.28 kg and 21.9 ± 2.87 kg, respectively (Table 2). In addition, the average daily gains from 10 to 30, 30 to 70 and 30 to 90 days were 215 ± 50.6 g/day, 196 ± 36.4 g/day and 192 ± 36.9 g/day, respectively. These results showed that the growth rate before 30 days was higher than that after 30 days, indicating the presence of favorable maternal effect during the first month of suckling. Boujenane (2006) has reviewed information on growth performance of Moroccan local breeds and stated that average daily gain from birth to 30 days and from 30 to 90 days of

Timahdite lambs was 158 and 155 g/day, respectively. In addition, Boujenane (2022) reported that the absolute growth rate, based on the first derivative of von Bertalanffy function with respect to time which is the mean growth rate of all Timahdite lambs from birth to weaning, was 166 ± 51 g/day.

Table 1. Descriptive statistics of lamb age (days) and weight (kg) at different weighings from the actual growth recording protocol

Variable	Number	Mean	Standard deviation	Minimum	Maximum
Age at 1st weighing	1554	12.3	5.36	1	21
Age at 2nd weighing	1554	33.2	5.32	22	42
Age at 3rd weighing	1554	54.0	5.36	43	63
Age at 4th weighing	1554	75.1	5.44	64	84
Weight at 1st weighing	1554	6.57	1.46	2.40	11.5
Weight at 2nd weighing	1554	11.1	1.87	5.00	16.0
weight at 3rd weighing	1554	15.2	2.21	7.50	21.2
Weight at 4th weighing	1554	19.1	2.50	11.0	26.0

Table 2. Descriptive statistics of lamb growth traits from the actual growth recording protocol

Trait[1]	Number	Mean	Standard deviation	Minimum	Maximum
Birth weight (kg)	1554	3.66	0.69	1.90	6.50
W10d (kg)	1554	6.08	1.08	2.10	10.3
W30d (kg)	1554	10.4	1.49	5.20	13.0
W70d (kg)	1554	18.2	2.28	9.60	23.0
W90d (kg)	1554	21.9	2.87	11.6	28.0
ADG10-30 (g/d)	1554	215	50.6	15	435
ADG30-70 (g/d)	1554	196	36.4	82	302
ADG30-90 (g/d)	1554	192	36.9	79	299

[1]W30d: weight at 30 days, W70d: weight at 70 days, W90d: weight at 90 days and ADG: average daily gain.

Comparison of actual and simplified growth recording protocols

Arithmetic means of W30d, W70d and W90d, as well as the average bias, mean squared error and loss of accuracy of simplified protocols compared to actual protocol are presented in Table 3. The means, calculated using the nine simplified protocols, varied from 7.66 kg to 10.4 kg for W30d, 17.9 kg to 18.5 kg for W70d and 21.9 kg to 23.0 kg for W90d. Moreover, except the means of weights calculated using protocols 5, 8 and 9 that were not significantly different from those calculated using the actual protocol (P>0.05), the means of at least one standard weight obtained from the other simplified protocols were significantly different from those of weights obtained from the actual protocol (P<0.05).

For W30d, the highest average bias was generated using protocol 1 (2.72±0.98 kg) and the lowest was engendered using protocols 4 to 9 (0.18 and 0.19 kg). Likewise, the MSE and loss of accuracy were highest when the W30d was calculated using protocol 1 (8.34±5.26 kg^2) and protocol 3 (46.1%), respectively; and were lowest when protocols 7, 8 and 9 were applied (0.11±0.44 kg^2 and 5.04%, respectively). For the estimation of W70d, protocols 5, 8 and 9 generated the lowest average bias (0.02 kg and 0.16 kg), MSE (0.01 kg^2 and 0.06 kg^2) and loss of accuracy (0.01% and 1.07%), whereas protocols 4, 6 and 7 produced the highest statistics (average bias=0.82±0.79 kg, MSE=1.31±3.14 kg^2 and loss of accuracy=17.3%). Applying protocols 4 and 7, which were based on two weighings at 42 and 63 days, to calculate the W90d generated the highest average bias (1.83±1.62), MSE (5.98±12.5) and loss of accuracy (45.4%), whereas protocols 5, 6, 8 and 9 produced the lowest statistics (average bias ≤ 0.38 kg, MSE ≤ 0.28 kg^2 and loss of accuracy ≤ 3.28%).

By comparing the simplest protocols 1, 2 and 3, protocol 2 that included the constant birth weight for all lambs was better than protocols 1 and 3. Moreover, using these three protocols, W70d and W90d were estimated more accurately than W30d. This is because the unique weighing took place around weaning age that was closer to 70 and 90 days than to 30 days. Furthermore, protocol 1 that did not include birth weight at all was inappropriate for calculating W30d. Thus, the lack of birth weight led to incorrect estimation of W30d, indicating that the presence of birth weight is very important for an accurate estimation of this weight. This result is in agreement with the findings of Boggess et al. (1991) for sheep and Atoui et al. (2020) for goats.

Therefore, based on these three statistics, the closest estimation of W30d, W70d and W90d to the actual growth recording protocol was given by protocols 5, 8 and 9. These protocols were based on a constant birth weight for all lambs that do not have one or according to their type of birth and sex, and two controls at 42 and 84 days or three controls at 42, 63 and 84 days, with only lambs more than 21 days old were weighed at each control. The present conclusion is in agreement with the result of Ben Hamouda and Rekik (2012) in Tunisia who suggested simplifying the actual protocol based on four measurements to two or three measurements and a birth weight, with the first measurement occurring 46 days after birth and the interval between successive controls, might vary between 30 and 40 days.

Table 3. Arithmetic means ± standard deviation ($\bar{X}$ ±SD, kg) of weight at 30, 70 and 90 days (W30d, W70d and W90d, respectively), average bias (Bias) ± SE (kg), mean squared error (MSE) ± SE (kg^2) and loss of accuracy (Loss, %) from simplified protocols compared to actual protocol[1]

Trait	Actual protocol	Protocol 1				Protocol 2				Protocol 3			
	$\bar{X}$ ±SD	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss
W30d	10.4±1.49	7.66±0.99	2.72±0.98*	8.34±5.26	43.7	9.85±0.97*	0.92±0.63	1.25±1.54	42.7	9.85±0.93*	0.95±0.65	1.33±1.63	46.1
W70d	18.2±2.28	17.9±2.31	0.44±0.38*	0.34±0.54	4.22	18.1±2.25	0.24±0.24	0.12±0.24	1.99	18.1±2.16	0.37±0.29	0.22±0.34	3.92
W90d	21.9±2.87	23.0±2.97	1.09±0.75*	1.75±2.42	7.16	22.2±2.90*	0.57±0.49	0.56±1.02	5.51	22.2±2.78*	0.62±0.54	0.68±1.18	7.04

Trait	Actual protocol	Protocol 4				Protocol 5				Protocol 6			
	$\bar{X}$ ±SD	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss
W30d	10.4±1.49	10.4±1.45	0.19±0.28	0.12±0.46	5.31	10.4±1.45	0.19±0.28	0.12±0.46	5.31	10.4±1.45	0.19±0.28	0.12±0.46	5.31
W70d	18.2±2.28	18.5±2.66*	0.82±0.79	1.31±3.14	17.3	18.2±2.27	0.16±0.18	0.06±0.13	1.07	18.5±2.66*	0.82±0.79	1.31±3.14	17.3
W90d	21.9±2.87	22.5±3.51*	1.83±1.62	5.98±12.5	45.4	22.0±2.86	0.38±0.37	0.28±0.70	3.28	21.9±2.87	0.00±0.00	0.00±0.00	0

Trait	Actual protocol	Protocol 7				Protocol 8				Protocol 9			
	$\bar{X}$ ±SD	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss	$\bar{X}$ ±SD	Bias±SE	MSE±SE	Loss
W30d	10.4±1.49	10.4±1.46	0.18±0.27	0.11±0.44	5.04	10.4±1.46	0.18±0.27	0.11±0.44	5.04	10.4±1.46	0.18±0.27	0.11±0.44	5.04
W70d	18.2±2.28	18.5±2.66*	0.82±0.79	1.31±3.14	17.3	18.2±2.27	0.16±0.18	0.06±0.13	1.07	18.2±2.28	0.02±0.02	0.01±0.01	0.01
W90d	21.9±2.87	22.5±3.51*	1.83±1.62	5.98±12.5	45.4	22.0±2.86	0.38±0.37	0.28±0.70	3.28	21.9±2.87	0.00±0.00	0.00±0.00	0

*P<0.05

[1]Protocol 1: $WSA = (\frac{WW}{Age}) \times SA$

Protocol 2: $WSA = FBW + (\frac{WW - BW}{Age}) \times SA$, with constant birth weight for all lambs that did not have one

Protocol 3: $WSA = CBW + (\frac{WW - BW}{Age}) \times SA$, with constant birth weight for all lambs that did not have one, according to their type of birth and sex

Protocol 4: Constant BW for lambs that did not have one, two controls at 42 and 63 days, only lambs more than 21 days old were weighed at each control
Protocol 5: Constant BW for lambs that did not have one, two controls at 42 and 84 days, only lambs more than 21 days old were weighed at each control
Protocol 6: Constant BW for lambs that did not have one, three controls at 42, 63 and 84 days, only lambs more than 21 days old were weighed at each control
Protocol 7: Constant BW for lambs that did not have one according to their type of birth and sex, two controls at 42 and 63 days, only lambs more than 21 days old were weighed at each control
Protocol 8: Constant BW for lambs that did not have one according to their type of birth and sex, two controls at 42 and 84 days, only lambs more than 21 days old were weighed at each control
Protocol 9: Constant BW for lambs that did not have one according to their type of birth and sex, three controls at 42, 63 and 84 days, only lambs more than 21 days old were weighed at each control

Comparison of direct and maternal heritability estimates

Direct and maternal heritability estimates for standard weights, calculated using the actual and simplified protocols, are presented in Table 4. Direct heritability estimates for W30d, W70d and W90d, calculated using the actual protocol, were 0.35 ± 0.13, 0.06 ± 0.06 and 0.05 ± 0.05, respectively. Maternal heritability estimates of the same weights were 0.01 ± 0.05, 0.04 ± 0.04 and 0.04 ± 0.04, respectively. Except direct heritability estimate of W30d, the other direct and maternal heritability estimates are in line with those reported by Boujenane and Kansari (2002) for W30d (0.02 and 0.07, respectively), W70d (0.07 and 0.08, respectively) and W90d (0.06 and 0.01, respectively) of the same breed. More importantly, direct heritability estimates for W30d, W70d and W90d, calculated using each simplified protocol on one hand and the actual protocol on the other hand, were not significantly different (P>0.05), except those of W30d that were calculated using protocols 1, 2 and 3 (P<0.05). In addition, the maternal heritability estimates for W30d, W70d and W90d, using the actual protocol, were comparable to those of the same weights obtained using simplified protocols (P>0.05). Ben Gara et al. (1997) reported that there was no differences between heritability estimates of weights estimated from the conventional and their proposed simplified protocols. Therefore, except protocols 1, 2 and 3, the other simplified protocols generated weights that have similar direct and maternal heritability estimates as those of weights calculated using the actual protocol. Thus, the genetic progress made on W30d, W70d and W90d calculated using protocols 4, 5,…, or 9 will be similar to the one achieved when these weights were calculated using the actual protocol.

Correlation coefficients between genetic values

The Spearman correlation coefficients between animals' rankings on direct genetic values as well as between the rankings on maternal genetic values for W30d, W70d and W90d were calculated using the actual and each simplified protocol (Table 5). All correlation coefficients were significantly different from zero (P<0.001) and higher than 0.48. Correlation coefficients between animals' rankings on direct genetic values for W30d, calculated from the actual and each simplified protocol, varied from 0.598 (protocol 1) to 0.962 (protocols 4, 5 and 6). Correlation coefficients between animals' rankings on maternal genetic values for W30d, calculated from the actual and each simplified protocol, varied from 0.440 (protocol 9) to 0.951 (protocol 5). Likewise, correlation coefficients between animals' rankings on direct genetic values for W70d, calculated from the actual and each simplified protocol, varied from 0.804 (protocols 4, 7 and 9) to 0.999 (protocol 6). The corresponding correlation coefficients between animals' rankings on maternal genetic values varied from 0.872 (protocols 4, 7 and 9) to 0.999 (protocol 6). For W90d, the correlation coefficients between animals' rankings on direct genetic values, calculated using actual and each simplified protocol, varied from 0.483 (protocol 7) to 1.000 (protocols 6 and 9). The correlation coefficients between animals' rankings on maternal genetic values varied from 0.653 (protocols 4 and 7) to 1.000 (protocols 6 and 9). Ben Gara et al. (1997) reported that the Pearson correlation coefficients between direct genetic values of sheep for W30d, W70d and W90d, estimated using the conventional and simplified protocols, were high and varied between 0.74 and 0.99. The generally higher Spearman correlation coefficients found in the present study indicated that the ranking of sheep on their direct and maternal genetic indexes for W30d, W70d and W90d, calculated from the actual protocol on the one hand, and from simplified protocols 5, 8 and 9 on the other hand, will remain almost unchanged.

Table 4. Direct (h^2_d) and maternal (h^2_m) heritability estimates ± standard error (SE) for weight at 30, 70 and 90 days (W30d, W70d and W90d, respectively) calculated from actual and simplified protocols

Trait	Actual protocol		Protocol 1		Protocol 2		Protocol 3		Protocol 4	
	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE
W30d	0.35±0.13	0.01±0.05	0.02±0.04*	0.06±0.04	0.03±0.05*	0.04±0.04	0.03±0.05*	0.04±0.04	0.33±0.13	0.01±0.05
W70d	0.06±0.06	0.04±0.04	0.02±0.04	0.06±0.04	0.04±0.05	0.04±0.04	0.04±0.05	0.04±0.04	0.13±0.08	0.02±0.04
W90d	0.05±0.05	0.04±0.04	0.02±0.04	0.06±0.04	0.04±0.05	0.04±0.04	0.04±0.05	0.04±0.04	0.06±0.05	0.02±0.04

Trait	Protocol 5		Protocol 6		Protocol 7		Protocol 8		Protocol 9	
	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE	h^2_d ± SE	h^2_m ± SE
W30d	0.33±0.13	0.01±0.05	0.33±0.13	0.01±0.05	0.33±0.13	0.01±0.05	0.33 ±0.13	0.01 ±0.05	0.33±0.13	0.01±0.05
W70d	0.05±0.05	0.05±0.04	0.13±0.08	0.02±0.04	0.13±0.08	0.02±0.04	0.05±0.05	0.05±0.04	0.06±0.06	0.04±0.04
W90d	0.03±0.04	0.03±0.03	0.05±0.05	0.04±0.04	0.06±0.05	0.02±0.04	0.03±0.04	0.03±0.03	0.05±0.05	0.04±0.04

*Estimates that were different (P<0.05) from those using the actual protocol

Table 5. Spearman correlation coefficients between rankings on direct genetic indexes ($r_{da,ds}$) and Spearman correlation coefficients between rankings on maternal genetic indexes ($r_{ma,ms}$) of sheep for weight at 30, 70 and 90 days (W30d, W70d and W90d, respectively) calculated using the actual protocol and each of the simplified protocol[1]

Trait	Protocol 1		Protocol 2		Protocol 3	
	$r_{da,ds}$	$r_{ma,ms}$	$r_{da,ds}$	$r_{ma,ms}$	$r_{da,ds}$	$r_{ma,ms}$
W30d	0.598	0.775	0.601	0.779	0.604	0.779
W70d	0.942	0.961	0.962	0.983	0.968	0.984
W90d	0.882	0.942	0.925	0.961	0.931	0.962

Trait	Protocol 4		Protocol 5		Protocol 6	
	$r_{da,ds}$	$r_{ma,ms}$	$r_{da,ds}$	$r_{ma,ms}$	$r_{da,ds}$	$r_{ma,ms}$
W30d	0.962	0.947	0.962	0.951	0.962	0.950
W70d	0.804	0.872	0.985	0.991	0.999	0.999
W90d	0.484	0.653	0.962	0.974	1.000	1.000

Trait	Protocol 7		Protocol 8		Protocol 9	
	$r_{da,ds}$	$r_{ma,ms}$	$r_{da,ds}$	$r_{ma,ms}$	$r_{da,ds}$	$r_{ma,ms}$
W30d	0.961	0.946	0.961	0.942	0.961	0.440
W70d	0.804	0.872	0.985	0.991	0.804	0.872
W90d	0.483	0.653	0.962	0.973	1.000	1.000

[1]d: direct genetic effects; m: maternal genetic effects; a actual protocol; s: simplified protocol

Conclusions

From this study, it was concluded that based on the average bias, MSE, loss of accuracy, heritability estimates and Spearman correlation coefficients between animals' rankings on the estimated genetic values, protocols 5, 8 and 9 allowed W30d, W70d and W90d to be estimated with a correct accuracy comparable to the actual protocol. These three protocols were based on a constant birth weight for all lambs that did not have one or a constant birth weight according to their type of birth and sex, and two controls at 42 and 84 days or three controls at 42, 63 and 84 days, with only lambs more than 21 days old weighed at each recording. Thus, ignoring one or two recordings out of the four currently applied would not alter the shape of the lambs' growth curve and would allow weights at standard ages to be estimated without much loss in accuracy. This simplification of growth recording is an alternative to improve the economic aspect of the recording system and to reduce the burden on the animals and breeders.

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Conflicts of interest

The author declares that he has no conflict of interest.

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