Wool quality traits of purebred and crossbred Merino lambs orally drenched with *Spirulina* (Arthrospira platensis)

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**Abstract**

The objective of this study was to evaluate the effect of *Spirulina* supplementation, sire breed and sex on the wool characteristics of purebred and crossbred Merino weaned lambs under a single pasture-based management system. Lambs sired by Merino, White Suffolk, Dorset, Black Suffolk breeds were randomly allocated into 3 treatments – the control group grazing and no treatment, lambs had access to clean drinking water only without (0 mL), or low (100 mL) or high (200 mL) *Spirulina* groups. All lambs were kept as a single mob in paddocks, grazed for 9 weeks and wool samples analysed. Differences in wool quality between the control and supplemented groups were not significant (P>0.05). However, sire breed significantly (P<0.001) influenced fibre diameter, spinning fineness, comfort factor and fibre curvature with purebred Merinos having superior wool quality than crossbreds. Wethers grew higher quality wool than ewes. *Spirulina* has a potential as an alternative supplementary bioresource in dual-purpose sheep feeding because it does not compromise wool quality in supplemented weaner lambs.

**Materials and methods**

This study was conducted at the University of Tasmania Farm, Cambridge, Tasmania, Australia. All procedures had the University of Tasmania Animal Ethics approval and were conducted in accordance with the 1993 Tasmanian Animal Welfare Act and the 2004 Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

**Animal management and experimental design**

A completely randomised experimental design in which 24 weaner lambs with an average live weight of 37.6±5.2 kg and body condition score of 3.1±0.4 at 6 months of age was utilised. The experimental lambs had an in-built factorial of 4 sire breeds (Merino, White Suffolk, Dorset, Black Suffolk) and 2 genders (ewes, wethers). Lambs were randomly allocated into 3 treatments (8 lambs per treatment) – the control group grazing and ad libitum drinking water only without (0 mL), or low (100 mL of *Spirulina*) or high (200 mL) content of *Spirulina* dissolved in water. The *Spirulina* was commercially purchased (TAUW, Darwin, Australia) as a powder and dissolved in water utilising a weight:volume ratio of 1 g:10 mL (low) and 2 g:10 mL (high) and the solution delivered to the lambs by oral drenching. Both control and *Spirulina* supplemented groups of lambs were kept in a single mob and had ad libitum access to the basal diet of ryegrass pastures and crushed barley whose nutrient composition is depicted in Table 2. Lambs in the low and high *Spirulina* treatment groups were individually drenched daily with *Spirulina* solution prior to being released with the control group of lambs (also drenched with water only) into paddocks sown with ryegrass pastures. The lambs were allowed 3 weeks of adjustment to the *Spirulina* drench prior to the experimental phase lasting 6 weeks. At all times, lambs had ad libitum access to clean drinking water.

**Wool sampling and analysis**

Midside wool samples of approximately 10 cm² were shorn from each lamb by an experienced shearer using Oster-Sunbeam electric
shears (Boca Raton, FL, USA; Baxter and Cottle, 1998) at the start and completion of the feeding trial. Samples were accurately catalogued and commercially analysed at the Australian Wool Testing Authority (Melbourne, Australia) using LaserScan equipment (Heath et al., 2006). The wool quality traits assessed were: mean fibre diameter (FD) using LaserScan OFDA, standard deviation (SD), coefficient of variation (CV), comfort factor (CF), spinning fineness (SF), fibre curvature (CURV) and clean fleece yield (YIELD).

Chemical analysis of the basal diet

Dry matter content of the basal diet was determined by drying samples to a constant weight at 65°C in a fan forced oven. Ash content was determined by combusting samples in a furnace at 550°C for 5 h. Neutral and acid detergent fibre contents were measured using an Ankom fibre analyser (ANKOM 220; Ankom Technology, Macedon, NY, USA) (van Soest et al., 1991). Total nitrogen (N) content was measured using the Kjeldahl method (van Soest et al., 1991) and the crude protein estimated by multiplying N by 6.25. Ether extract was determined by the Soxhlet methodology, while in vitro digestibility and metabolisable energy were estimated using near infrared reflectance spectroscopy (Garnsworthy and Unal, 2004).

Statistical analysis

All data were analysed using the ‘Statistical Analysis System’ software package (SAS, 2009). Initially, summary statistics by Spirulina supplementation level, sire breed and sex, were computed with means, standard deviations, and minimum and maximum values scrutinised for any data entry errors or outliers. Subsequently, multivariate analysis of variance in generalised linear model (PROC GLM) and mixed model (PROC MIXED) analyses (SAS, 2009) were used to fit the fixed effects of Spirulina supplementation level, sire breed, sex and their second-order interactions on wool FD, CV, SD, SF, CF, CURV, and YIELD. Sire was fitted as a random effect in the Mixed Model. Significant differences and mean separations were carried out using Duncan’s multiple range and Bonferroni’s probability pairwise comparison tests (SAS, 2009) Pearson correlation coefficients between dependent variables were estimated using PROC CORR (SAS, 2009) with significance determined using Bonferroni’s probability pairwise comparison test (SAS, 2009).

Results

Effect of Spirulina supplementation level, sire breed and sex on wool traits

Spirulina supplementation level had no significant effect on any wool quality trait, compared to the control group (P>0.05; Table 3). However, wethers produced wool with lower FD (P<0.046), SD (P<0.046) and SF (P<0.019) than ewes. Comfort factor was lower in ewes than wethers (79.9±3.31 and 88.1±2.2%, respectively; Table 4).

Merino-sired lambs had lower FD (18.0±0.1 µm), SF (17.1±1.0 µm), CURV (63.5±1.5°/mm) and higher CF (96.2±3.5%) compared to all other sire breeds studied (P<0.001). Among the crossbreds, Black Suffolk-sired lambs had the highest SF (26.1±0.6 µm) and Dorset-sired lambs the least (23.8±0.9 µm; Table 4).

Table 1. Nutrient composition of Spirulina (Arthrospira platensis).

| Components            | Value  |
|-----------------------|--------|
| Vitamins and minerals |        |
| beta-carotene, µg/100 g | 140,000 |
| Total carotenoids, mg/kg | 1700   |
| Provitamin A, U kg⁻¹   | 2,330,000 |
| B1, mg/kg              | 130-150 |
| B2, mg/kg              | 1.5-2.0 |
| Calcium, mg/kg         | 1200   |
| Magnesium, mg/kg       | 3300   |
| Sodium, mg/kg          | 22000  |
| Potassium, mg/kg       | 26000  |
| Fatty acids, % total   |        |
| Gamma-linolenic acid   | 17.1-40.1 |
| Amino acids, % total protein |        |
| Methionine             | 2.05-2.50 |
| Cysteine               | 0.5-0.9  |

Table 2. Chemical composition of feed components.

| Chemical composition | Spirulina | Barley grain | Ryegrass pasture |
|----------------------|-----------|--------------|------------------|
| DM, g/100 g          | 96.0      | 93.2         | 44.7             |
| NDF, g/100 g DM      | 32.6      | 18.5         | 22.4             |
| NDF, g/100 g DM      | 30.3      | 17.2         | 20.8             |
| ADF, g/100 g DM      | 18.3      | 6.0          | 23.0             |
| NFC, g/100 g DM      | 7.9       | 68.7         | 43.5             |
| Ash, g/100 g DM      | 9.5       | 3.2          | 11.9             |
| EE, g/100 g DM       | 5.9       | 2.0          | 3.0              |
| CF, g/100 g DM       | 62.2      | 8.9          | 20.8             |
| ME, kJ/100 g DM      | 1707.5    | 1723.7       | 1701.1           |

DM, dry matter; NDF, neutral detergent fibre; NDFa, nitrogen free NDF; ADF, acid detergent fibre; NFC, non fibrous carbohydrate; EE, ether extract; CF, crude protein; ME, metabolisable energy.

Table 3. Least square means and standard error of Spirulina supplemented crossbred and purebred Merino lambs’ wool quality traits.

| Wool quality trait | Control | Low | High | P     |
|--------------------|---------|-----|------|-------|
| FD, µm             | 23.7±1.1| 24.6±1.3 | 24.3±1.2 | 0.687 |
| SD                 | 4.6±0.3 | 4.4±0.2 | 16.8±1.2 | 0.542 |
| CV, %              | 19.5±0.8| 17.8±0.5 | 5.1±0.8  | 0.123 |
| CF, %              | 85.5±3.0| 81.8±4.3 | 84.7±3.5 | 0.620 |
| SF, µm             | 22.9±1.0| 23.4±1.2 | 23.0±1.1 | 0.865 |
| CURV, °/mm         | 71.4±2.8| 71.4±2.3 | 73.8±2.3 | 0.657 |
| YIELD, %           | 75.0±1.4| 72.7±1.0 | 74.6±1.0 | 0.173 |

FD, mean fibre diameter; SD, standard deviation; CV, coefficient of variation; CF, comfort factor; SF, spinning fineness; CURV, fibre curvature; YIELD, clean fleece yield.
Correlations among wool traits

Table 5 shows that there were highly significant relationships (P<0.001) between FD and SF (0.99), CF with both FD (-0.87) and SF (-0.88), FD and CURV (0.39), SF and CURV (0.37), and SD with YIELD (0.29). All other correlations were not significant (P>0.05).

Table 5. Pearson’s correlation among wool quality traits.

| Wool quality trait | FD | CV | SD | CF | SF | CURV | YIELD |
|--------------------|----|----|----|----|----|-------|-------|
| FD                 | 0.12 (ns) | 0.17 (ns) | -0.87*** | 0.99*** | 0.39** | 0.13 (ns) |
| CV                 | -0.21 (ns) | -0.18 (ns) | 0.12 (ns) | 0.37 (ns) | 0.06 (ns) |
| SF                 | -0.25 (ns) | -0.88*** | -0.87 (ns) | 0.04 (ns) |
| CURV               | 0.35* | 0.11 (ns) | 0.21 (ns) |

CV, coefficient of variation; SD, standard deviation; CF, comfort factor; SF, spinning fineness; CURV, fibre curvature; YIELD, clean fleece yield. **Column means within a fixed effect with different superscripts are significantly different (P<0.05).

Discussion

Wool growth and quality depend on the type of protein supplement, its nutritional value, and level of supplementation (Malau-Aduli et al., 2009b; Masters et al., 1998; Rowe et al., 1989). Protein-rich supplements vary in amino acid availability thus affecting follicular uptake and wool fibre proliferation (Li et al., 2008). Therefore, increasing amino acid availability within the body-pool by increasing protein-rich supplementation generally results in heighted follicular uptake that favours nutrient partitioning towards faster growth, but also coarser wool fibre synthesis in crossbred lambs (Malau-Aduli and Holman, 2010; Malau-Aduli et al., 2009a). This coarser fibre is characteristic of lesser quality wool (Holman and Malau-Aduli, 2012). However, in this study, there were no observable detrimental effects of Spirulina supplementation on wool quality traits. Spirulina has a lower content of sulphur-containing amino acids compared to other protein-rich lamb supplements (Ciferri and Tiboni, 1985; Volkmann et al., 2008). Methionine and cysteine are sulphur amino acids which are essential for wool proliferation (Liu and Masters, 2003). Cysteine plays a vital role in the wool fibre synthesis process.

Table 4. Sire breed and sex least square means and standard error of Spirulina supplemented crossbred and purebred Merino lambs’ wool quality traits.

| Sire breed | FD, μm | CV, % | SD | CF, % | SF, μm | CURV, °/mm | YIELD, % |
|------------|--------|-------|----|-------|--------|------------|----------|
| Black Suffolk | 27.2±0.7a | 19.4±0.9 | 5.3±0.2 | 74.5±4.3 | 26.1±0.6 | 74.3±3.0 | 74.2±1.3 |
| Dorset | 25.0±0.9b | 18.1±0.7 | 4.6±0.3 | 85.4±3.8 | 23.8±0.9 | 75.2±2.7 | 74.1±1.2 |
| Merino | 18.0±1.1c | 17.0±1.4 | 4.4±1.1 | 96.2±3.5 | 17.1±1.0 | 63.5±1.5 | 75.2±1.7 |
| White Suffolk | 26.7±0.4a | 17.2±1.1 | 4.7±0.2 | 79.9±2.1 | 25.2±0.3 | 75.9±2.5 | 72.7±1.0 |
| P | 0.001 | 0.474 | 0.073 | 0.001 | 0.00 | 0.004 | 0.399 |
| Sex | | | | | | |
| Ewes | 25.1±0.9a | 18.3±1.0 | 5.3±0.5 | 79.9±3.3 | 24.0±0.9 | 71.8±1.8 | 74.8±0.8 |
| Wethers | 23.4±0.9b | 17.8±0.4 | 4.1±0.2 | 88.1±2.2 | 22.2±0.9 | 72.7±2.2 | 74.3±1.0 |
| P | 0.046 | 0.620 | 0.046 | 0.016 | 0.19 | 0.721 | 0.186 |

FD, mean fibre diameter; CV, coefficient of variation; SD, standard deviation; CF, comfort factor; SF, spinning fineness; CURV, fibre curvature; YIELD, clean fleece yield. **Column means within a fixed effect with different superscripts are significantly different (P<0.05).

Figure 1. Interaction between Spirulina supplementation level and sex on clean fleece yield (YIELD) of grazing purebred and crossbred Merino lambs. Means (±standard error) within sire breeds with different superscripts are significantly different (P<0.05).

Figure 2. Interaction between sire breed and sex on fibre curvature (CURV). Means (±standard error) within sire breeds with different superscripts are significantly different (P<0.05).
role during the differentiation of intermediate filament- and keratin associated proteins during wool synthesis (Plowman, 2007). Furthermore, methionine acts as a source of cysteine in the trans sulphuration pathway (Liu and Masters, 2003). *Spirulina*’s relatively minor content of these sulphur amino acids could likely explain insignificant differences in wool traits between the un-supplemented control and *Spirulina* supplemented group of lambs.

Ewes generally have smaller live weights than wethers (Cam et al., 2010; Holman et al., 2012). This difference could result in considerable variation with other prioritised sinks requiring more of the available amino acids (Rogers and Schlink, 2010). Our sex and sire breed findings were similar to published literature that have demonstrated hormonal differences between sexes (Egan and Russell, 1981; Wallace, 1979) and wool follicle trait variations between sire breeds (Lee and Williams, 1993; Scales et al., 2000) as having major impacts on wool traits. Similarly, the correlations between wool traits is in line with published literature (Notter et al., 2007). The strongly positive correlation between JD and FD is expected as JD is calculated from FD and CV values (Butler and Dolling, 1992; Holman and Malau-Aduli, 2012). Likewise, CF represents the proportion of fibres over 30 µm (Holman and Malau-Aduli, 2012; Wood, 2003) and is a function of FD, thus the strong correlation between JD and FD. However, SF and CF had an antagonistic relationship, hence the negative correlation. The insignificant correlation between JD and YIELD with other wool traits has already been previously reported (Hatcher et al., 2010).

### Conclusions

The hypothesis that *Spirulina* supplementation via oral drenching will not be detrimental to wool quality in grazing purebred and cross-bred Merino lambs holds true and should be accepted. The responses of lambs of different sire breeds and sex to *Spirulina* supplementation in terms of interaction effects on wool traits add to our current knowledge of supplementing crossbred sheep. Finally, there is the need for further investigation into the underlying mechanisms behind our findings, particularly with regard to circulating plasma metabolites and proteomic profiles of supplemented lambs. This would provide a comprehensive understanding of *Spirulina*’s future applications as a protein-rich lamb feed supplement.

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