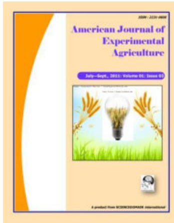

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Growth and Body Conformation Responses of Genetically Divergent Australian Sheep to Spirulina *(Arthrospira platensis)* Supplementation

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Research Article

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ABSTRACT

The hypothesis that supplementation with *Spirulina* will increase liveweight, growth and body conformation with significant interactions between sire breed and sex was tested using purebred Merino weaners and first-cross weaners from Merino dams sired by Dorset, Black Suffolk and White Suffolk rams under the same pasture-based management system. Our experimental objective was to evaluate the effects of varying levels of *Spirulina* supplementation, sire breed and gender on liveweight and body conformation traits. We utilized a complete randomized block experimental design balanced by 4 sire breeds, 3 supplementation levels and 2 sexes in which weaned prime lambs with an average liveweight of 37.6 ± 5.2 kg and body condition score of 3.1 ± 0.4 at 6 months of age were balanced by sire breed and gender and randomly allocated into 3 treatments (8 lambs per treatment) – the control group grazing without *Spirulina* (0%), low (10%wt/vol) and high (20%wt/vol) *Spirulina*. Lambs in the low and high *Spirulina* treatment groups were drenched daily with *Spirulina* prior to being released for grazing with the control group of lambs over a 6-week trial period, following a 3-week adjustment phase. Weekly measurements of chest girth, withers height, body length, body condition score and liveweight were taken. Mixed linear model procedures in SAS with sire breed, sex, *Spirulina* level and their second order interactions as fixed effects and sire as a random variable, were used for statistical analysis. *Spirulina level* significantly influenced lamb liveweight (P<0.018), body condition score (P<0.001) and body length (P<0.015). Lambs on *Spirulina* levels of 10% recorded the highest mean liveweight of 41.9 ± 0.7 kg. *Spirulina* levels of 20% did not significantly improve liveweight compared to the control group (0%).

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Highly significant sire breed interactions with *Spirulina* level (P<0.001) resulted in the heaviest (47.08 kg) and lightest (35.14 kg) average liveweights in Black Suffolk-sired crossbreds and purebred Merino lambs respectively, supplemented at the 20% *Spirulina* level. Body conformation (P<0.001) and liveweight (P<0.014) responses to *Spirulina* supplementation significantly varied between ewe and wether lambs. It was evident that a cost-effective supplementation strategy with *Spirulina* for optimal liveweight gains in weaner lambs was achieved at the 10% level. These findings will aid sheep farmers in making informed choices about appropriate sire breed and gender combinations in their enterprises when supplementing with *Spirulina* for growth improvement as a strategic pathway for the early attainment of market weights in prime lambs. We concluded that based on the empirical experimental evidence within the scope of this study, the tested hypothesis is acceptable.

Keywords: Spirulina; merino; growth; sirebreed, liveweight; crossbreds; body conformation.

1. INTRODUCTION

Spirulina (*Arthrospira platensis*) is a blue-green cyanobacterial alga with an extensive history of human consumption, whereas its adoption in animal feeds has only been within the last two decades (Belay *et al.,* 1993; Gupta *et al.,* 2008). *Spirulina* is 60-70% protein by weight (Belay *et al.,* 1993; Doreau *et al.,* 2010) and contains high levels of carotenoids, essential vitamins, minerals and fatty acids (Kistanova *et al.,* 2009; Panjaitan *et al.,* 2010; Toyomizu *et al.,* 2001). *Spirulina* can be cultivated in a liquid medium (Volkmann *et al.,* 2008) and has been found to out-yield traditional protein-rich feed sources like soybeans, and grains such as wheat, corn and barley in terms of production per land unit (Dismukes *et al.,* 2008; Kulpys *et al.,* 2009). Subsequently, supplementation with *Spirulina* has been trialed in sheep, cattle, swine and poultry (Bezerra *et al.,* 2010; Panjaitan *et al.,* 2010; Toyomizu *et al.,* 2001). Although, most of these studies are still in their infancy, ruminants have so far been identified as well suited to *Spirulina* supplementation due to their capacity to digest unprocessed algal material (Gouveia *et al.,* 2008). Furthermore, *Spirulina* supplementation has been associated with heightened rumen microbial crude protein production (Panjaitan *et al.,* 2010).

There is currently an increasing demand for sheep meat, particularly prime lamb. This follows heightened domestic and export market demands from Australia's traditional export markets in the US and EU, and emerging Asian markets (Hopkins *et al.,* 2007a; McLeod *et al.,* 2010; Rowe, 2010). This trend is expected to continue into the foreseeable future (Martin and Phillips, 2011). About 80% of Australia's national flock remains predominantly Merino-based, a wool specialist breed, regardless of the current relatively lower economic value of wool (Greeff *et al.,* 2008; Hatcher *et al.,* 2010; Swan, 2010; Warner *et al.,* 2007). Hence, to capitalise on the present high demand for prime lamb, farmers are using selective crossbreeding strategies wherein meat-type terminal sires are joined with purebred Merino ewes (Ingham *et al.,* 2007; Kopke *et al.,* 2008). This permits the exploitation of individual and maternal heterosis, and blends desirable meat and wool traits into a single 'dual-purpose' lamb (Fogarty *et al.,* 2006; Rowe, 2010; Safari *et al.,* 2005; Thornton, 2010).

Lamb productivity is a derivative of feed nutrition (Black, 1983; Geesink and Zerby, 2010; Hopkins *et al.,* 2007b; McLeod *et al.,* 2010) as growth rates and liveweights are foremost indicators of operational profitability (Afolayan *et al.,* 2006; Cam *et al.,* 2010). Profitability in dual-purpose meatsheep production is driven primarily by protein-rich feed supplementation. However, viability in the production of traditional protein-rich feeds like canola and lupins is dependent on unpredictable variations in climate and land availability (Poppi and McLennan 2010; Smith *et al.,* 2010). Therefore, feed-lotting (Gaunt *et al.,* 2010) and grain finishing (Martin and Phillips, 2011) in prime lamb production are gaining increasing popularity, particularly in drought-prone regions. Consequently, the identification of alternative protein-rich feed sources is imperative in dealing with volatile production costs and variable climatic conditions (Poppi and McLennan, 2010).

Our experimental objective was to evaluate liveweight, growth and body conformation responses of genetically divergent weaner prime lambs to *Spirulina* supplementation and to estimate phenotypic correlations between growth and body conformation traits under the same management system.

2. MATERIALS AND METHODS

2.1 Animal Welfare and Ethics Clearance

This experiment was approved by the University of Tasmania Animal Ethics Committee, and was conducted from April to June 2011 at the University of Tasmania Farm, Cambridge, Hobart, 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.

2.2 Experimental Design and Animal Management

Twenty-four weaned lambs from purebred Merino dams sired by Dorset, White Suffolk, Black Suffolk and Merino rams lambs with an average liveweight of 37.6 ± 5.2 kg and body condition score of 3.1 ± 0.4 at 6 weeks of age were balanced by sire breed and gender and randomly allocated into 3 treatments (8 lambs per treatment) – the control group grazing without *Spirulina* (0%), low (10%wt/vol) and high (20%wt/vol) *Spirulina levels*. A balanced 4 x 3 x 2 complete randomized block experimental design representing 4 sire breeds (Dorset, White Suffolk, Black Suffolk, Merino), 3 *Spirulina* treatment levels (0%, 10%, 20%wt/vol), and sex (ewes, wethers) was utilized. After an initial 3-week adjustment phase, the supplementation and grazing trial continued for 6-weeks. Lambs were daily supplemented according to their assigned *Spirulina* treatment before being released into paddocks for grazing with the control group of lambs. The *Spirulina* was obtained from a commercial retailer in powdered form (TAAU, Australia) and its chemical composition was: moisture (5.0 g/100g), fat (4.1 g/100g), protein (62.0 g/100g), ash (11.4g/100g) and carbohydrate (17.5 g/100g) (Lopez, 2004). Hence, the treatment was delivered as a 1g: 10ml solution in water using a sheep drenching gun. After receiving their daily *Spirulina* drench, all lambs were released into sown mixed pasture paddocks for grazing as per normal commercial sheep production and had *ad libitum* access to drinking water.

2.3 Liveweight and Body Conformation Measurements

At weekly intervals, each lamb was individually assessed for chest girth (CG), withers height (WH), body length (BL), body condition score (BCS) and liveweight (BWT) measurements. CG was the body circumference measured at just behind the forelegs (Afolayan *et al.,* 2006). WH was the distance between the highest peak over the scapulae and the ground (Sowande and Sobola, 2008). BL refers to the span between the base of the neck, the vertebrae between the scapulae, to the far point of the pubic bone (Sowande and Sobola, 2008). BCS was subjectively measured (Phythian *et al.,* 2011), always by the same researcher, gauging fat depth on a 0-5 point scale as described by McLeod *et al.* (2010). BWT was monitored using an electronic walk-over weighing scale equipped with an automatic sheep ID scanning digitally downloadable data capability. Body conformation measurements in centimetres were taken using the same measuring tape. During assessment it was ensured that lambs were gently restrained in a relaxed state on all four legs with their heads comfortably erect.

2.4 Statistical Analyses

Using BWT values, the average daily gain (ADG) of individual lambs was computed in kg/day by dividing the weight change by the interval between weighings. All data were analysed using 'Statistical Analysis System' software (SAS Institute, 2009). Initially, summary statistics by sex, sire breed and *Spirulina* level were computed. The means, standard deviations, minima, maxima and range of values were examined for data entry errors or outliers. Factorial ANOVA (PROC GLM) and Mixed Model (PROC MIXED) (SAS Institute, 2009) procedures were used to fit the fixed effects of *Spirulina* level, sire breed, sex and their second-order interactions on BWT, ADG, CG, WH, BL, BCS. Sire was fitted as a random effect in the mixed model. Separation of mean differences using Duncan's multiple range tests and Bonferroni pairwise comparison tests was conducted at $P<0.05$ level of significance. Pearson's correlation coefficients (PROC CORR) between dependent variables were also estimated and significance established using Bonferroni tests (SAS, 2009).

3. RESULTS

3.1 Effect of *Spirulina* Level, Sire Breed and Sex on Growth and Body Conformation Traits

Spirulina supplementation caused lambs to grow longer bodies (BL) than the control group ($P<0.015$), although no significant differences were detected between 10% and 20% *Spirulina* levels (Table 1). Lambs in the 20% *Spirulina* treatment group had greater BCS (3.4 ± 0.1) than their counterparts in the 10% and 0% (control) treatment groups ($P<0.001$). It was also evident that lambs receiving 10% *Spirulina* levels recorded the heaviest BWT of 41.9 ± 0.7 kg ($P<0.018$), but there were no BWT differences between the 20% and control treatment groups. Moreover, *Spirulina* supplementation level did not affect CG ($P>0.376$), WH ($P>0.669$) or ADG ($P>0.759$).

All body measurements were influenced by sire breed ($P<0.0001$; Table 1). Black Suffolk-sired lambs had the largest CG (99.0 ± 0.7 cm) while Merino-sired lambs had the smallest average WH (61.6 ± 0.4 cm). Black Suffolk-sired lambs had the longest BL (67.0 ± 0.3 cm), while White Suffolk- and Dorset-sired lambs did not significantly differ, although had longer BL than Merino-sired lambs (62.6 ± 0.5 cm). Lamb BCS and BWT followed similar trends among sire breeds in which Black Suffolk-sired lambs had the highest BCS (3.7 ± 0.1) and BWT (46.3 ± 0.6 kg). White Suffolk- and Dorset-sired lambs BCS and BWT proved similar, but significantly higher than Merino-sired lambs, whose average BCS (3.1 ± 0.03) and BWT (33.5 ± 0.4 kg) were the lowest. ADG did not differ regardless of sire breed ($P>0.502$).

Table 1. Least square means and standard errors (LSM ± SE) of liveweight, body conformation, condition score and average daily gains in *Spirulina* supplemented prime lambs.

	Body weight, body condition score, conformation and average daily gain					
Fixed effects	**CG (cm)**	**WH (cm)**	**BL (cm)**	**BCS (0-5)**	**BWT (kg)**	**ADG (kg/d)**
Sire breed						
White Suffolk	94.4 ± 0.7[b]	62.8 ± 0.4[a]	67.0 ± 0.4[b]	3.3 ± 0.1[b]	42.9 ± 0.5[b]	0.2 ± 0.0
Black Suffolk	99.0 ± 0.7[a]	63.6 ± 0.4[a]	68.8 ± 0.3[a]	3.7 ± 0.1[a]	46.3 ± 0.6[a]	0.1 ± 0.0
Dorset	93.8 ± 0.5[b]	63.5 ± 0.4[a]	66.9 ± 0.3[b]	3.2 ± 0.0[b]	41.8 ± 0.4[b]	0.2 ± 0.0
Merino	95.0 ± 0.9[b]	61.6 ± 0.4[b]	62.6 ± 0.5[c]	3.1 ± 0.0[c]	33.5 ± 0.4[c]	0.1 ± 0.0
p-values	*<0.0001****	*<0.001****	*<0.001****	*<0.001****	*<0.001****	*0.502*[ns]
Sex						
Ewes	94.9 ± 0.6[b]	62.4 ± 0.3[b]	66.2 ± 0.4	3.3 ± 0.0	40.1 ± 0.6[b]	0.1 ± 0.0
Wethers	96.2 ± 0.5[a]	63.4 ± 0.3[a]	66.5 ± 0.3	3.3 ± 0.0	42.1 ± 0.5[a]	0.1 ± 0.0
p- values	*0.034**	*0.009***	*0.269*[ns]	*0.346*[ns]	*<0.001****	*0.605*[ns]
Spirulina level						
0% (Control)	95.0 ± 0.6	62.9 ± 0.4	65.7 ± 0.4[b]	3.2 ± 0.1[b]	40.6 ± 0.7[b]	0.1 ±0.0
10%	95.6 ± 0.6	62.7 ± 0.4	66.6 ± 0.4[a]	3.3 ± 0.0[b]	41.9 ± 0.7[a]	0.2 ± 0.0
20%	76.1 ± 0.7	63.1 ± 0.3	66.8 ± 0.4[a]	3.4 ± 0.1[a]	40.8 ± 0.6[b]	0.1 ± 0.0
p- values	*0.376*[ns]	*0.669*[ns]	*0.015**	*<0.001****	*0.018***	*0.759*[ns]

*Column means within a fixed effect bearing different superscripts significantly differ (P<0.05). Chest girth (CG), withers height (WH), body length (BL), body condition score (BCS), body weight (BWT), and average daily weight gain (ADG). Level of significance: [ns] not significant (P>0.05), * significant (P<0.05), ** highly significant (P<0.01), and *** very highly significant (P<0.001).*

CG, WH and BWT were all significantly affected by sex (Table 1). Wethers had larger CG (96.2 ± 0.5 cm) and WH (63.4 ± 0.3 cm) than ewes (94.9 ± 0.6 cm and 62.4 ± 0.3 cm respectively). Correspondingly, mean BWT was heavier in wethers (42.1 ± 0.5 kg) than ewes (40.1 ± 0.6 kg; P<0.001). BL (P>0.346), BCS (P>0.346) and ADG (P>0.605) did not differ between sexes (Table 1).

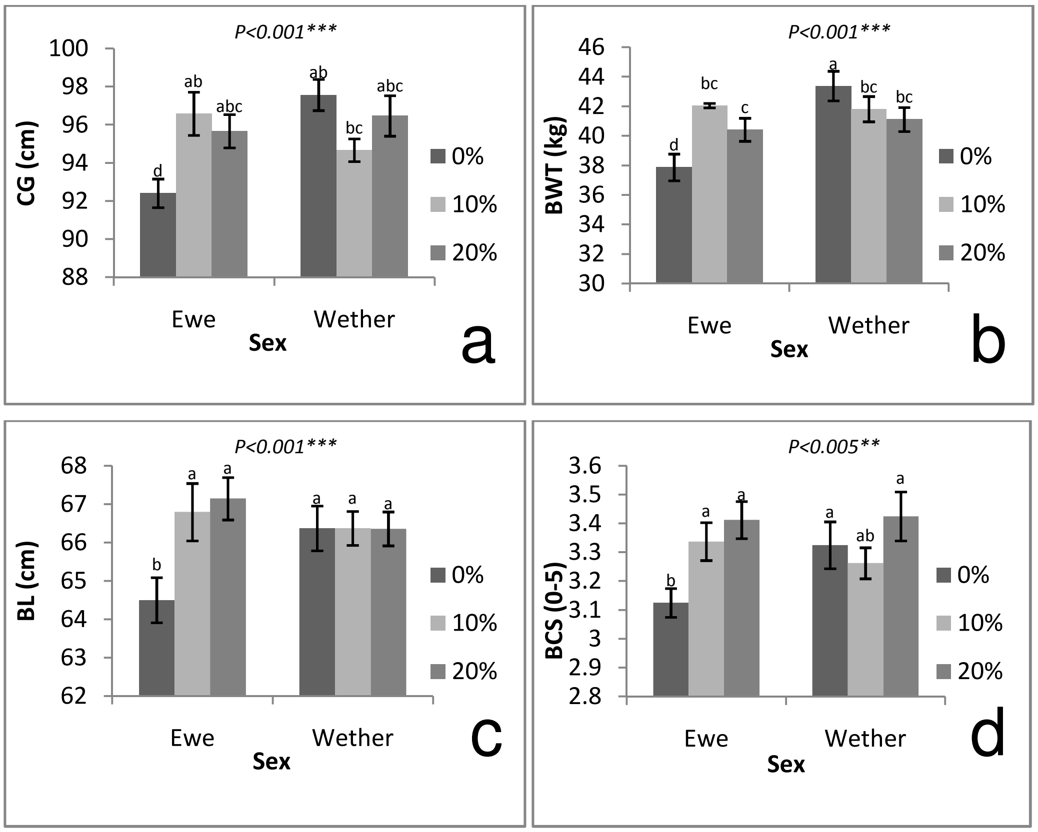

Figure 1. Interactions between sex and *Spirulina* supplementation levels on body conformation traits.

*CG (a), BWT (b), BL (c), and BCS (d), and level of significance (P values), of prime lambs. Level of significance: ** highly significant (P<0.01), *** very highly significant (P<0.001). Chest girth (CG), body length (BL), body condition score (BCS), and liveweight (BWT). Different superscripts signify differences (P<0.05) within fixed effects.*

3.2 Effect of *Spirulina* Level and Sex Interactions

Spirulina level and sex interactions were found to impact lamb CG (P<0.001), BL (P<0.001), BWT (P<0.001), and BCS (P<0.005; Fig. 1), but not WH (P>0.159) or ADG (P>0.780). Ewes in the control group had the lowest CG (92.4 cm), with highest CG of 97.6 cm observed in control group wethers. Mean BL of control group ewes (64.5 cm) was lower than all the other lambs, regardless of treatment or sex, which did not differ. Similarly, control group ewes had lower BCS (3.1) compared to all other treatment groups, except wethers on 10% *Spirulina* levels (3.3). Control group wethers had the greatest BWT (43.4 kg) and paradoxically control group ewes had the least BWT (37.9 kg). Between 10% and 20% *Spirulina* level groups there were no significant differences in BWT. However, ewes given 20% *Spirulina* levels had lower mean BWT than ewes receiving 10% (40.4 kg and 42.1 kg respectively).

3.3 Effect of Sire Breed and Sex Interactions

Merino-sired wether lambs had larger CG of 98.2 cm than ewe lambs (91.9 cm; P<0.001; Table 2). BL of Black Suffolk-sired ewes was longer (69.4 cm) than that of wethers (68.2 cm; P<0.001). A similar trend was also observed in the BL of Merino-sired lambs (61.3 cm in ewes and 64.0 cm in wethers). Mean WH was higher in wethers than ewes in Black Suffolk- (64.6 cm and 62.7 cm, respectively) and White Suffolk-sired lambs (66.7 cm and 67.4 cm, respectively; P<0.001). White Suffolk-sired wether lambs also had greater BCS (3.4) than ewe lambs (P<0.001). BWT in Merino-sired wethers (35.2 kg) was heavier than in their ewe counterparts (31.7 kg). A similar scenario was also observed in Black Suffolk-sired lambs (47.1 kg and 45.5 kg in wether and ewe lambs, respectively; P<0.014).

Table 2. Interactions between sire breed and sex on growth and body conformation traits

Sire breed	Sex	CG (cm)	WH (cm)	BL (cm)	BCS (0-5)	BWT (kg)	ADG (kg/day)
Black Suffolk	Ewe	98.6^{a}	62.7^{bcd}	69.4^{a}	3.7^{a}	45.5^{b}	0.12
	Wether	99.5^{a}	64.6^{ab}	68.2^{bc}	3.8^{a}	47.1^{a}	0.14
Dorset	Ewe	94.3^{bc}	63.5^{abc}	66.5^{cd}	3.3^{bcd}	41.1^{de}	0.14
	Wether	93.4^{bcd}	63.5^{abc}	67.2^{bcd}	3.1^{cde}	42.5^{cde}	0.15
Merino	Ewe	91.9^{cd}	61.3^{cd}	61.3^{f}	3.0^{de}	31.7^{g}	0.11
	Wether	98.2^{a}	61.9^{cd}	64.0^{e}	3.1^{cde}	35.2^{f}	0.11
White Suffolk	Ewe	94.8^{bc}	62.1^{cd}	67.4^{bcd}	3.2^{cde}	42.2^{cde}	0.15
	Wether	94.00^{bcd}	63.5^{abc}	66.7^{cd}	3.4^{bc}	43.7^{cd}	0.17
p-values		*<0.001****	*<0.001****	*<0.001****	*<0.001****	*<0.014**	*<0.977*^{ns}

*Level of significance: ^{ns} not significant (P>0.05), * significant (P<0.05), ** highly significant (P<0.01), and *** very highly significant (P<0.001). Chest girth (CG), body length (BL), body condition score (BCS), liveweight (BWT), and average daily gain (ADG). Different superscripts signify differences (P<0.05) within second-order interactions.*

3.4 Effect of Sire Breed and *Spirulina* Level Interactions

Black Suffolk-sired lambs in the 20% *Spirulina* supplementation group had the largest CG (101.9 cm), WH (65.1 cm), BL (68.7 cm) and BWT (47.1 kg) (P<0.001; Table 3). ADG was not influenced by sire breed and *Spirulina* level interactions as there were no distinct and consistent patterns (P>0.937; Table 3).

3.5 Phenotypic Relationships between Growth and Body Conformation Traits

Positive and significant correlations between CG, WH, BL, BCS and BWT were observed (P<0.001; Table 4). The strongest correlation of 0.83 was between BL and BWT. Only ADG had negligible correlations with all the other body conformation traits except BWT (P>0.05).

Table 3. Sire breed and *Spirulina* level interactions on growth and body conformation traits

Sire breed	*Spirulina* level (%)	CG (cm)	WH (cm)	BL (cm)	BCS (0-5)	BWT (kg)	ADG (kg/day)
Black Suffolk	0	97.0^{a}	62.9^{a}	68.2^{a}	3.5^{a}	44.7^{a}	0.15
	10	98.3^{a}	62.9^{a}	69.6^{a}	3.6^{a}	47.0^{b}	0.16
	20	101.9^{b}	65.1^{b}	68.7^{a}	4.1^{b}	47.1^{b}	0.10
Dorset	0	93.2^{a}	63.5^{ab}	66.0^{a}	3.1^{a}	41.5^{ab}	0.14
	10	95.1^{a}	64.5^{b}	67.2^{a}	3.2^{a}	43.2^{a}	0.17
	20	93.2^{a}	62.6^{a}	67.4^{a}	3.3^{a}	40.8^{b}	0.13
Merino	0	94.6^{ab}	61.6^{ab}	60.6^{a}	3.0^{a}	32.1^{a}	0.10
	10	93.4^{b}	60.5^{a}	62.5^{b}	3.1^{a}	33.1^{a}	0.12
	20	97.1^{a}	62.7^{b}	64.8^{c}	3.1^{a}	35.1^{b}	0.12
White Suffolk	0	95.2^{ab}	63.5^{a}	67.9^{a}	3.3^{a}	44.2^{a}	0.15
	10	95.8^{b}	63.00^{a}	67.1^{a}	3.3^{a}	44.4^{a}	0.16
	20	92.1^{a}	62.1^{a}	66.1^{b}	3.2^{a}	40.2^{b}	0.17
p-values		*<0.001****	*<0.001****	*<0.001****	*<0.001****	*<0.001****	*<0.936*^{ns}

*Level of significance: ^{ns} not significant (P>0.05), and *** very highly significant (P<0.001). Chest girth (CG), body length (BL), body condition score (BCS), liveweight (BWT), and average daily gain (ADG). Different superscripts signify differences (P<0.05) within sire breed.*

Table 4: Pearson's correlation coefficients between body weight and body measurements in genetically divergent F_1 lambs

Trait	CG	WH	BL	BCS	BWT	ADG
CG		0.68***	0.59***	0.60***	0.59***	-0.02^{ns}
WH			0.64***	0.55***	0.63***	0.13^{ns}
BL				0.55***	0.83***	0.06^{ns}
BCS					0.67***	0.01^{ns}
BWT						0.15*
ADG						

*Level of significance: ^{ns} not significant (P>0.05), * significant (P<0.05), and *** very highly significant (P<0.001). Chest girth (CG), wither height (WH), body length (BL), body condition score (BCS), body weight (BWT), and average daily weight gain (ADG).*

4. DISCUSSION

Our results demonstrated that through *Spirulina* supplementation, liveweight and body conformation measurements can be better improved and managed under a typical pasture-based system. Moreover, *Spirulina* supplementation level interacted significantly with lamb sire breed and sex. This permits targeted management practises to be refined to suit different operational systems. To optimize growth and liveweight, lambs must have access to high quality feeds, particularly protein-rich feed supplements (Karlsson and Martinsson 2011; Liu *et al.,* 2003; Mitchell, 2007). *Spirulina*'s 60-70% protein content (Belay *et al.,* 1993; Doreau *et al.,* 2010; Mata *et al.,* 2010) suggests that its increased use as a supplement in ruminants is expected to result in proportional improvements in lamb BWT, body conformations and ADG due to its association with increased rumen microbial crude protein production (Panjaitan *et al.,* 2010; Quigley and Poppi, 2009). Our results demonstrate that the increase in liveweight and body condition score was only observed when the level of *Spirulina* supplementation was 10%. This is consistent with recently conducted trials with *Spirulina* (Bezerra *et al.,* 2010) and other protein-rich supplement sources such as canola and lupins (Malau-Aduli and Akuoch 2012; Malau-Aduli and Holman 2010; Malau-Aduli *et al.* 2009a; Malau-Aduli *et al.,* 2009b; Malau-Aduli *et al.,* 2009c).

A possible explanation for this observation is that excessively high dietary protein intake is known to suppress optimal sheep growth. This effect stems from the negative correlation between protein accretion and fat deposition rates, the later being exacerbated by high feed protein levels (Mitchell, 2007). Excess protein gets deaminated and lost in the urine or gets broken down in the liver and could lead to conditions of fatty liver and ketosis. *Spirulina* contains many essential fatty acids including γ-linolenic acid (Belay *et al.,* 1993) that get deposited subcutaneously (underneath the skin) as triacylglycerols in the adipose tissue, thus explaining the observed proportional increase of BCS with increased *Spirulina* supplementation levels. However, the insignificant influence of *Spirulina* level on ADG, CG and WH in the current study suggests that the physiological mechanisms involved are not fully understood at the moment. Thus, clarification of nutrient partitioning into different tissues including muscle, adipose and wool would allow greater insight into the underlying mechanisms in this species since lamb productivity is a function of genetic and environmental interactions (Black, 1983; Oddy and Sainz, 2002). Thus, prime lamb productivity depends on not only environmental factors such as feed ration quality and quantity, but also on genetic factors in terms of lamb sire breed and sex (Malau-Aduli *et al.,* 2009c; Sobrinho *et al.,* 2003).

The observed discrepancy in CG, BL and BCS between ewe and wether lambs in the current study seems to be due to variation in mature sizes and/or involvement of the endocrine system (Lewis *et al.,* 2006). It has been demonstrated recently that the high estrogen level of ewe which is associated with the closure of bone growth plate, also causes the rapid stoppage of growth of female lambs than wethers (Sowande and Sobola, 2008; Warner *et al.,* 2007). Based on these reports, it is evident that that nutrient demands, absorption and partitioning in ewes is different from those of wethers and results in the utilization of *Spirulina* for increasing liveweight and body conformation. Previous studies demonstrated that genetic variation between lambs influences nutrient partitioning and absorption despite the feeding of the same or identical rations (Hegarty *et al.,* 2006; Lewis *et al.,* 2006; Oddy and Sainz, 2002; Cake *et al.,* 2007; Wynn and Thwaites, 1981).

In the current study, liveweight and body conformation responses to *Spirulina* supplementation in Merino-and Black Suffolk-sired lambs were in accordance with our experimental hypothesis, although *Spirulina* supplementation did not elicit the expected response in Dorset- and White Suffolk-sired lambs as was hypothesised. This discrepancy might be due to variation in genetic predisposition for muscle growth as opposed to body fat deposition (Allingham *et al.,* 2006). Also, feed use efficiency is enhanced by sire genetics as previously demonstrated (Mitchell, 2007; Ponnampalam *et al.,* 2007). For instance, Lewis (2006) found that lambs whose parents were selected for high growth estimated breeding values grew larger than lambs whose lineage was selected for low growth, despite identical basal nutritional levels. Furthermore, the positive response of Merino-sired lambs to *Spirulina* supplementation levels is particularly worth mentioning as they were the only purebred and wool specialist group investigated in current study.

Therefore, we can infer from our result that *Spirulina*'s growth promoting qualities in non-meat type sheep breeds and in combination with heterosis due to crossbreeding (Leymaster, 2001; Petrovic *et al.,* 2011) does not impact the nutrient use efficiency or partitioning in the first crosses. Furthermore, the result of current study confirmed the widely accepted interaction between sire breed and sex on liveweight and body conformation measurements, the basis of which has been extensively studied in the last decade (Afolayan *et al.,* 2006; Cam *et al.,* 2010; Fogarty *et al.,* 2005a; Fogarty *et al.,* 2005b; Hopkins *et al.,* 2007b; Ponnampalam *et al.,* 2007). Thus, a demonstration of the strong positive correlations between body measurements and liveweight in our present study reaffirms current consensus (Abbasi and Ghafouri-Kesbi, 2011; López-Carlos *et al.,* 2010; Otoikhian *et al.,* 2008; Sowande and Sobola, 2008). Based on previous reports and our current findings, it is therefore imperative to include body conformation measurements in selective breeding programs aimed towards increasing lamb liveweight (Abbasi and Ghafouri-Kesbi, 2011; Afolayan *et al.,* 2006). Additionally, body conformation measurements would allow selection to prioritize growth of particular anatomical areas in lamb which would certainly improve the lamb productivity.

5. CONCLUSION

We have demonstrated herein, that both purebred Merino and Black Suffolk-sired crossbred lambs achieved higher liveweights and body conformation measurements with *Spirulina* supplementation than control lambs. Furthermore, 10% *Spirulina* supplementation levels resulted in increased liveweights over and above that observed in the control and 20% *Spirulina* treatment groups. The linear increase in liveweight and body conformation measurements response to *Spirulina* supplementation observed in ewes was not reflected in wethers. These outcomes strongly recommend the establishment of *Spirulina* usage as an alternative sheep supplementary feed source for growth improvement as a strategic pathway for the early attainment of market weights in prime lambs.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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