Analysis of Poultry Production Data to Assess the Impact of a Poultry-Manure-to-Energy, Biomass Boiler in Broiler Rearing

by
Davina Hill and Nick Sparks
SRUC
West Mains Road
Edinburgh
Scotland
EH9 3JG

for
Mr Declan O'Connor
bhsl
Kantoher Business Park
Killeedy
Ballagh
Co. Limerick
Ireland

Summary

Production traits in live broilers and their eviscerated carcasses were compared between birds reared in sheds fitted with a specialist biomass, poultry-manure-to-energy boiler (referred to hereafter as bhsl) and those reared in sheds fitted with conventional whole-house gas heaters (control). The report consists of three parts: 1) analysis of the full set of farm data, which spans more than three years, 2) analysis of the twelve most recent months of farm data after managers have had time to optimise the bhsl system, and 3) analysis of the full set of processing data, which spans ten months (August 2014 to June 2015). In addition, we provide a glossary of technical terms and a guide to interpreting the statistical results.

Based on the full data set, we found that, on average, live birds from the bhsl system were heavier at a given age, younger at slaughter and showed a tendency towards lower on-farm mortality compared to control birds. The two systems did not differ stisticallyin the prevalence of foot pad or hock burn, mortality upon arrival at the plant or the proportion of birds rejected at the plant (condemnations).

Eviscerated carcasses from the bhsl system were heavier and yielded a greater proportion of meat than controls. There was no difference in the uniformity of carcasses from bhsl broilers compared to controls.

We expected that the effects of the bhsl boiler would vary seasonally, with the greatest benefits occurring in the cooler months of the year when staff managing conventional heating systems might restrict airflow through poultry sheds to conserve heat. Restricted airflow is associated with poorer performance generally and an increase in the incidence and severity of hock burns and pododermatitis. We therefore examined production traits by season of slaughter. We defined spring as the period from 16th March to 15th June, summer as the 16th June to 15th September, autumn as the 16th Sept to 15th December and winter as the 16th December to 15th March.

As expected, general on-farm performance was better during the cooler and wetter months of the year under the bhsl system than on control farms. This could occur if the bhsl system allows the producer to manage temperature and air quality better, bringing them closer to the optimal for the birds. Although not covered in this report, it may also indicate that it is easier to achieve optimal humidity levels in the bird area in the cooler months of the year. The faster growth rates of bhsl birds did not lead to increased pododermatitis or hock burn, and there was even a tendency for mortality to be lower in bhsl flocks. It had been postulated that the bhsl boiler would not only improve live bird performance but also reduce the variation in eviscerated carcass weight (ECW). However, we found no difference in the variation associated with the ECW of bhsl and control birds. This might be explained by the faster growth rates of bhsl birds, which took them closer to their genetic potential.

The farm data were analysed across more than three years, providing sufficient batches and flocks to allow robust statistical analyses. However we understand that producers are continuing to learn how to optimise the management of the additional heat provided by the bhsl boiler system. Therefore, it is feasible that producers were not maximising the benefits of the bhsl system early in the study, and that its benefits might increase in range and magnitude with time. Indeed, the difference in age at slaughter between the bhsl and control sheds was greater in the last twelve months (1.82 days old at slaughter) than across the 3.5 years of study as a whole (1.29 days), suggesting that growth is improving at a faster rate in bhsl birds than control birds. Similar improvements in live weight are apparent: the difference in live weight between bhsl and control birds was greater in the last twelve months (0.15kg) than across the study as a whole (0.08kg).

Glossary

Analysis of variance (ANOVA)	a statistical procedure used to test whether two or more treatments differ
Batch	A unit of birds (flock or part-flock) for which summary farm data (eg average weight, age at depopulation) were available.
Broiler	Meat chicken that typically takes between 35 and 48 days to reach slaughter weight
Carcass yield	Amount of saleable (human food chain) meat recovered from a carcass (often expressed as a percentage of total weight)
Coefficient of variance	A measure of spread that describes the amount of variability relative to the mean, often expressed as a percentage. For example, in a group with a low CoV for weight, individuals' body mass is usually close to the mean
Eviscerated carcass weight	Weight of carcass after the viscera (contents of the body cavity) have been removed.
Foot pad burn	Skin lesion found on the plantar surface (sole) of the foot. Typically associated with prolonged contact with moist litter (bedding material) and/or litter containing corrosive substances (often associated with incomplete breakdown of faecal material)
Hock burn	Skin lesion found on the hock (leg joint). Typically associated with prolonged contact with moist litter (bedding material) and/or litter containing corrosive substances (often associated with incomplete breakdown of faecal material)
Placement	The date that the day-olds for a flock were 'placed' or housed on the farm. When linked to density it refers to the number of birds placed per unit floor area (eg birds m^2).
Pododermatitis	See foot pad burn

Statistical methods and guide to interpreting the results

We analysed the data using statistical models called analysis of variance (ANOVA). The results of these models are provided in tables. We conclude that an effect is statistically significant when *P*-values estimated by the models are less than (‘<’) 0.05. All *P*-values <0.05 are presented in bold in the tables. For completeness, tables also provide chi-square estimate and degrees of freedom. These were used to calculate the *P*-values, and the results can be understood without referring to them.

Statistical results and means (including means presented in the figures) are adjusted for all significant variables in the model (i.e. for the variables in bold in the table). For example, a significant effect of the boiler on live weight in a model where age is significant means that there is a difference in live weight between the two boiler systems for birds of the same age. Non-significant effects were removed from the final models.

Statistical models require that observations are independent of each other or that non-independence is corrected for. Our models make sure that this assumption is met by correcting for the following variables:

- the date of sale (because observations made a few days apart may not be independent of each other)
- longitude and latitude (to correct for spatial non-independence – farms near each other may be more similar than those far apart)
- the identity of the shed (because all birds in the same shed experience similar conditions)
- the placement.

A good rule of thumb for determining whether two bars in a plot do not differ significantly is that the standard error bars overlap.

Running many tests increases the probability of finding spurious significant results, so it is considered good practice to use a more conservative *P*-value where multiple comparisons are carried out. Therefore, in situations where we make more than one statistical comparison within the same variable (e.g. the variable ‘season’ has four levels: spring, summer, autumn and winter, resulting in 6 potential comparisons if we compare each season with every other season), we adjust the *P*-value to account for this (known as False Discovery Rate), unless stated otherwise.

For each trait of interest (e.g. carcass weight), we test whether the effects of the boiler system on the trait differs between the seasons. This is known as testing for an interaction between boiler system and season, and is represented by boiler x season in the tables. A significant interaction means that the effects of the boiler on the trait differ between the seasons.

PART ONE: FARM RESULTS 2011-2015

Live weight

Overall, bhsl broilers were heavier (2.36±0.03kg) than broilers from control farms (2.28±0.01kg) after adjusting for age, season, latitude and placement density (Table 1a, Figure 1a). Of particular note, bhsl broilers sold in spring (*P*<0.001) or winter (*P*≤0.034) were heavier than control broilers sold in any season. There was no difference in body mass between bhsl and control broilers in summer and autumn (except that bhsl birds sold in autumn were heavier than control birds sold in summer, *P*=0.041). bhsl broilers sold in spring were heavier than bhsl broilers sold in the other seasons (*P*≤0.050), whereas on control farms broilers were only heavier in spring than summer (*P*=0.005). Live weight decreased with increasing latitude (i.e. broilers increased in body mass the further south they were reared) and placement density, and increased in live weight with age. Live weight was not influenced by longitude.

Table 1a. The effects of boiler system (bhsl or control) and season on live weight at sale in 16120 lots (lorry loads) of broilers from 39 farms on 998 days between November 2011 and June 2015

	Chi sq	Df	*P*
boiler	6.91	1	**0.009**
season	29.43	3	**<0.001**
latitude	19.51	1	**<0.001**
age at sale	68475.78	1	**<0.001**
placement density	6264.67	1	**<0.001**
boiler x season	17.80	3	**<0.001**
longitude	0.44	1	0.505

ANOVA correcting for date of sale, placement and shed; statistically significant effects are in bold

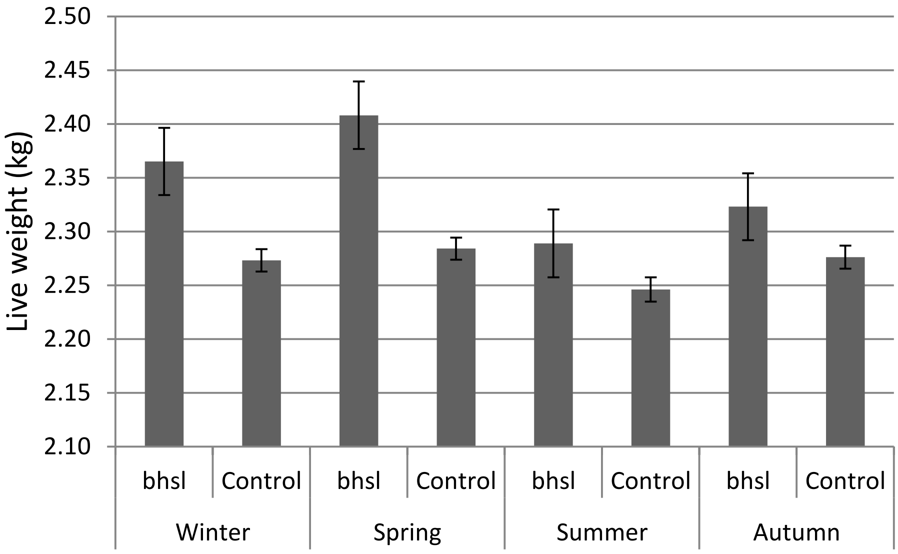

Figure 1a. Mean live weight at sale (±1SE) of broilers reared under the bhsl heating system compared to broilers from 38 control farms for each season of sale. Means are adjusted for the identity of the shed on the farm, placement identity on the farm, date of sale, age at sale, latitude and initial stocking density. Means are based on 16120 weighbridge lorry loads of broilers on 998 days between November 2011 and June 2015. Note that the y-axis is truncated at 2.10 kg.

Age at slaughter

Broilers grew more quickly under the bhsl system (35.62±0.26 days old at slaughter) than under other systems (36.91±0.09 days at slaughter), adjusting for live weight, season, latitude and placement density (Table 2a, Figure 2a). This was the case overall and within individual seasons (Figure 2a; *P*≤0.002 after correcting for multiple comparisons). bhsl broilers sold in spring grew more quickly than those sold in summer (*P*=0.005) and autumn (*P*=0.007). There was no difference in age at slaughter between bhsl broilers sold in spring and winter (*P*=0.199). Growth was less variable between the seasons in control than in bhsl birds, with no seasonal differences except between spring and summer (*P*=0.042). Age at slaughter increased with increasing latitude, live weight and placement density (Table 2a).

Table 2a. The effects of boiler and season on age at slaughter in 7688 batches of broilers from 39 farms on 998 days between November 2011 and June 2015

	Chi sq	Df	*P*
boiler	28.11	1	**<0.001**
season	15.73	3	**0.001**
latitude	31.75	1	**<0.001**
live weight	37197.30	1	**<0.001**
placement density	7915.28	1	**<0.001**
boiler x season	13.11	3	**0.004**
longitude	1.67	4 1	0.196

ANOVA correcting for date of slaughter, placement and shed; statistically significant effects are in bold

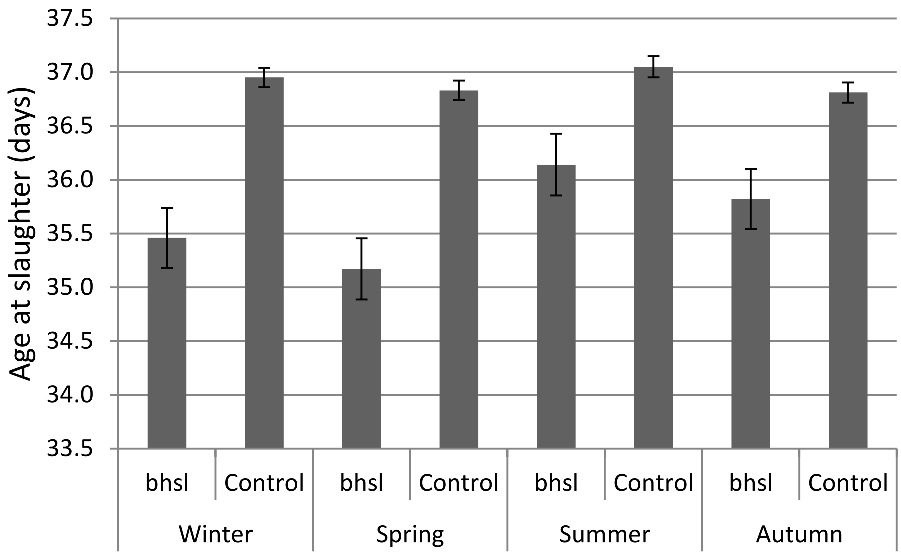

Figure 2a. Age at slaughter (±1SE) of broilers reared under the bhsl system versus those from 38 control farms in the four seasons of sale. Means are adjusted for shed identity within farm, placement identity on farm, date of sale, live weight, latitude and initial stocking density. Data are based on 7688 batches of broilers on 998 sale dates between November 2011 and June 2015. Note that the y-axis is truncated at 33.5 days.

Percentage on-farm mortality

There was a tendency towards a lower proportion of on-farm deaths in bhsl sheds (1.59±0.10%) than elsewhere (1.79±0.03%), although this was not statistically significant (Table 3a). There was also a tendency for mortality to be higher among birds sold in summer than in the other months (*P*=0.057 after adjustment for multiple testing; Figure 3a). Although mortality differed between the seasons, the effects of the boiler system on mortality did not differ seasonally (Table 3a, Figure 3a). Mortality decreased with increasing placement density and longitude and increased with weight.

Table 3a. The effects of boiler and season on mortality in 3925 batches of broilers on 864 days between December 2011 and February 2015 from 37 farms

	Chi sq	Df	*P*
boiler	3.42	1	0.064
season	8.11	3	**0.044**
longitude	4.91	1	**0.027**
live weight	45.59	1	**<0.001**
age at sale	19.37	1	**<0.001**
placement density	410.10	1	**<0.001**
latitude	0.47	1	0.491
boiler x season	0.86	3	0.836

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

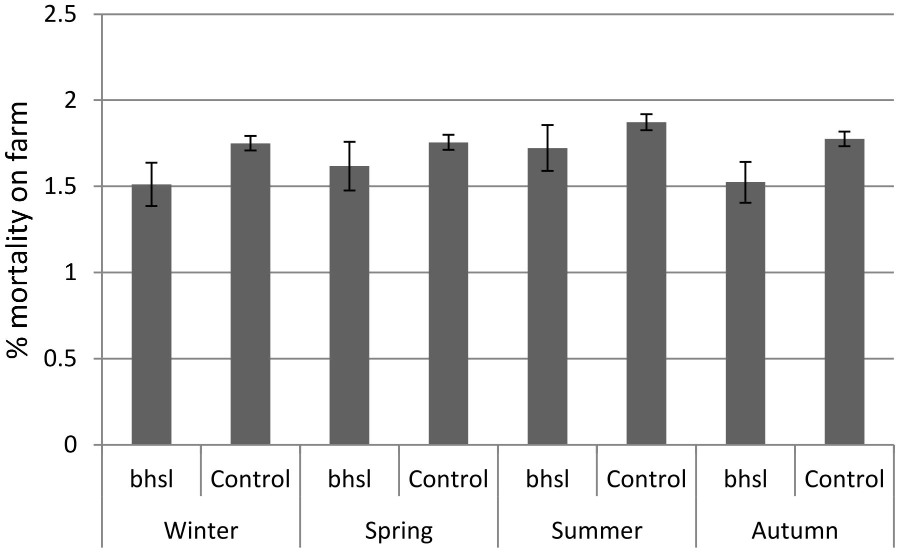

Figure 3a Percentage mortality (±1SE) of broilers reared under the bhsl system versus those from 36 other farms according to season of sale. Means are adjusted for shed identity within farm, placement identity within farm, date of sale, live weight, age at sale, longitude and initial stocking density. Data are based on 3925 batches of broilers on 864 sale dates between December 2011 and February 2015.

Proportion condemned

There was no effect of the boiler on the proportion of broilers rejected at the plant overall (bhsl: 0.028±0.010%; control: 0.040±0.003) or in individual seasons (*P*≥0.254 after adjustment for multiple comparison). There were however seasonal differences in the proportion condemned within a given system (Figure 4a). For example, more broilers from bhsl sheds were condemned in summer than in spring (*P*=0.021) or winter (*P*=0.025). Across the study, the proportion condemned decreased with increasing placement density and live weight, but was not influenced by latitude or longitude.

Table 4a. The effects of boiler and season on the proportion of condemnations in 12317 lots of broilers on 996 days between November 2011 and June 2015 from 39 farms

	Chi sq	Df	*P*
boiler	0.79	1	0.373
season	39.67	3	**<0.001**
live weight	548.15	1	**<0.001**
placement density	292.80	1	**<0.001**
boiler x season	16.97	3	**0.001**
longitude	0.15	1	0.701
latitude	3.23	1	0.072

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

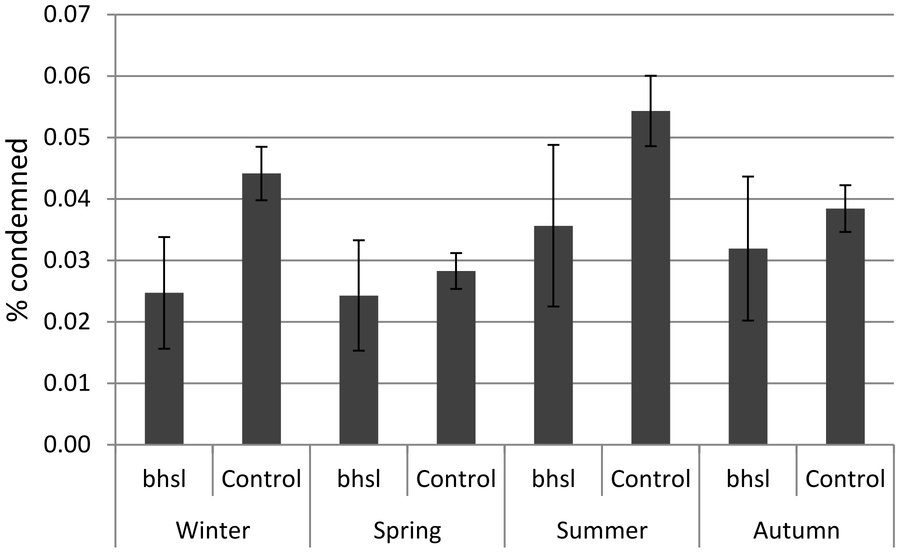

Figure 4a. Mean percentage of broilers per lot that were rejected at the processing plant (±1SE). This compares those reared under the bhsl system with those reared by 38 control producers based on season of sale. Means are adjusted for shed identity within farm, placement identity on farm, date of sale, live weight and initial stocking density. Data comprise 12317 batches of broilers on 996 sale days between November 2011 and June 2015.

Prevalence of foot pad burn

There was no overall effect of the boiler on the prevalence of foot pad burn (bhsl: 0.35±0.05%; control: 0.39±0.01%), nor were there any differential effects of the boiler over the four seasons (Table 5a). Foot pad burn increased with live weight and decreased with placement density. There was no effect of latitude, longitude or season on foot pad burn (Table 5a, Figure 5a).

Table 5a. Testing for the effects of boiler and season on the prevalence of foot pad burn in 12032 lots of broilers from 603 placements on 991 days between November 2011 and June 2015 from 38 farms

	Chi sq	Df	*P*
live weight	28.01	1	**<0.001**
placement density	196.52	1	**<0.001**
longitude	1.28	1	0.258
boiler	1.03	1	0.311
latitude	0.06	1	0.811
season	0.94	3	0.815
boiler x season	2.21	3	0.529

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

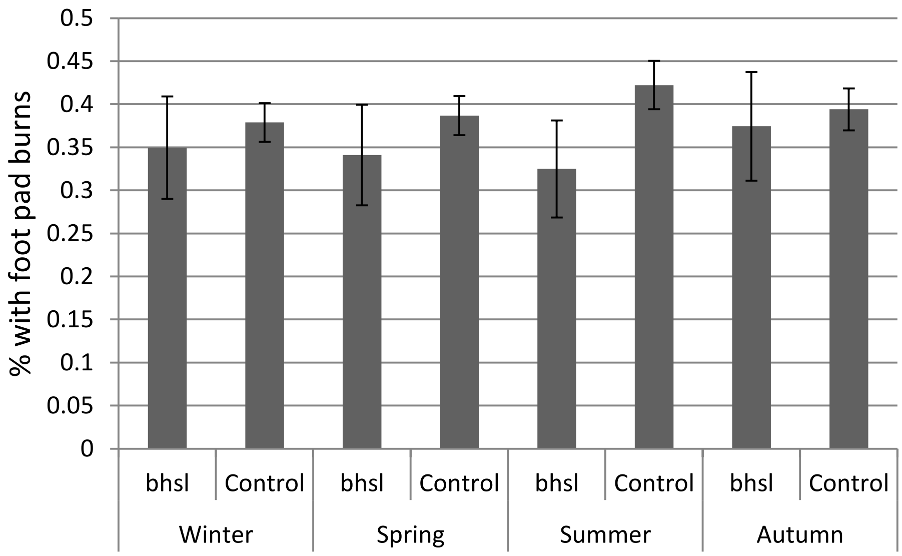

Figure 5a Mean prevalence of foot pad burn (±1SE) in bhsl broilers versus those reared by 37 other producers by season of sale. Means are adjusted for shed identity within farm, placement identity on farm, date of sale, live weight and placement density. Data are based on 12032 batches of broilers on 991 days between November 2011 and June 2015.

Prevalence of hock burn

As with the prevalence of foot pad burn, bhsl sheds (0.39±0.08%) did not differ from control sheds (0.42±0.02%) in the prevalence of hock burn. The season did not influence hock burn, and there were no differential effects of the boiler over the four seasons (Table 6a, Figure 6a). The prevalence of hock burn decreased with increasing placement density and latitude and increased with live weight. Longitude had no effect on hock burn.

Table 6a. Testing for the effects of boiler and season on the proportion of broilers with hock burn in 12030 lots from 603 placements on 991 days from 38 farms

	Chi sq	Df	*P*
latitude	5.92	1	**0.015**
live weight	52.39	1	**<0.001**
placement density	181.96	1	**<0.001**
longitude	0.31	1	0.575
boiler	0.30	1	0.585
season	0.20	3	0.977
boiler x season	3.13	3	0.372

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

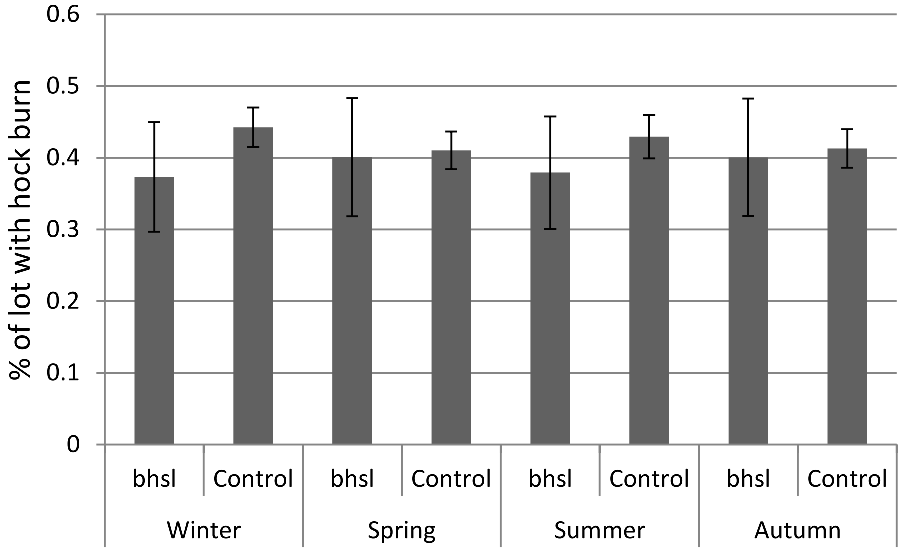

Figure 6a Mean prevalence of hock burn (±1SE) in broilers reared under the bhsl system versus those reared on 37 other farms by season of sale. Means are adjusted for shed identity within farm, placement identity within the farm, date of sale, live weight, latitude and initial stocking density. Data are based on 12030 lots on 991 days between November 2011 and June 2015.

Prevalence of broilers found dead on arrival

The proportion of broilers found dead upon arrival at the processing plant did not differ between the bhsl (0.028±0.009%) and control (0.034±0.003%) systems. The biomass boiler did not have seasonal effects on birds found dead on arrival. Mortality upon arrival was higher in summer and lower in spring than in other seasons ($P \leq 0.020$ after adjusting for multiple comparisons), but there was no difference between autumn and winter ($P=0.698$). The proportion of broilers found dead increased with live weight and decreased with placement density. Latitude and longitude had no effect on mortality on arrival.

Table 7a. Testing for the effects of boiler and season on the proportion of birds found dead on arrival in 12115 lots of broilers from 605 placements on 996 days from 38 farms

	Chi sq	Df	*P*
season	22.95	3	**<0.001**
live weight	199.78	1	**<0.001**
placement density	6.28	1	**0.012**
latitude	3.01	1	0.083
boiler	0.04	1	0.834
longitude	0.07	1	0.792
boiler x season	7.46	3	0.059

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

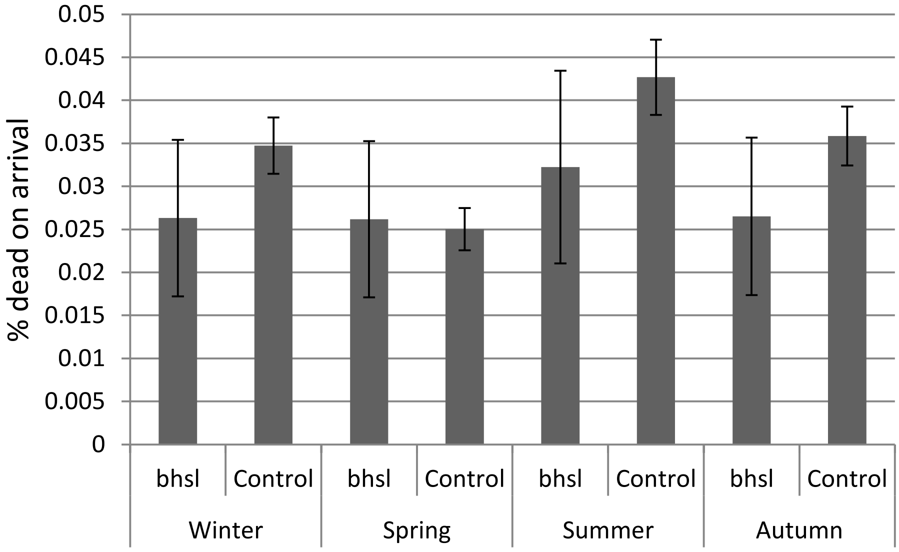

Figure 7a Mean percentage of broilers found dead on arrival (±1SE) among those reared under the bhsl system versus those from 37 other farms by season of sale. Means are adjusted for shed identity within farm, placement identity on farm, date of sale, live weight and initial stocking density. Data are based on 12115 lots of broilers on 996 days between November 2011 and June 2015

PART TWO: FARM RESULTS 2014-2015 (12 MONTHS)

Live weight

Broilers were heavier under the bhsl system (2.39±0.05kg) than other systems (2.24±0.02kg) after adjusting for age, season, location and placement density (Table 1b, Figure 1b). Broilers sold in the summer were lighter than those sold in other seasons (P≤0.009, after correcting for multiple testing). Live weight decreased with increasing latitude (i.e. broilers increased in body mass the further south they were raised), longitude (broilers increased in body mass the further east they were raised) and placement density. Live weight increased with increasing age.

Table 1b. The effects of boiler and season on live weight at sale in 5027 lots (lorry loads) of broilers on 311 days between June 2014 and June 2015 from 34 farms

	Chi sq	Df	*P*
boiler	9.62	1	**0.002**
season	16.71	3	**0.001**
latitude	33.80	1	**<0.001**
longitude	4.28	1	**0.039**
age at sale	17140.42	1	**<0.001**
placement density	2737.32	1	**<0.001**
boiler x season	6.36	3	0.095

ANOVA correcting for date of sale, placement and shed; statistically significant effects are in bold

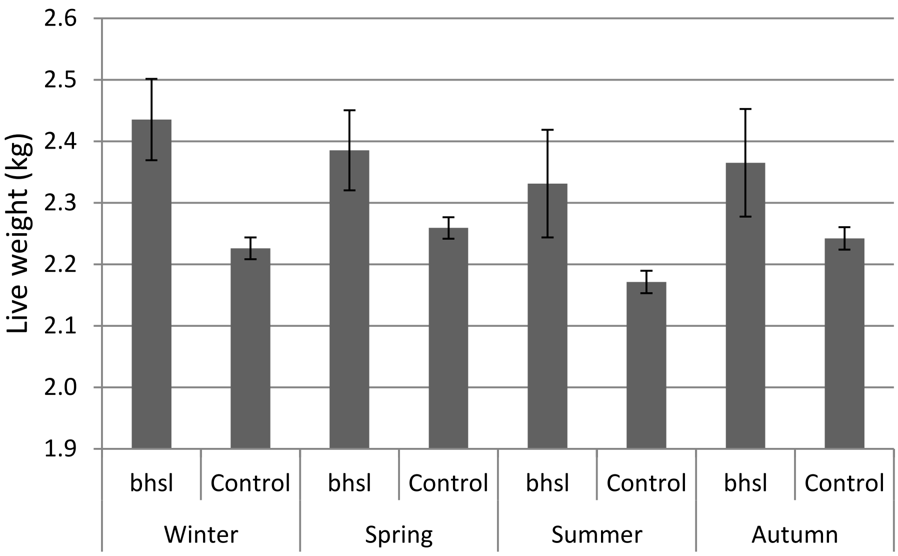

Figure 1b. Mean live weight at sale (±1SE) of broilers reared under the bhsl heating system compared to those from 33 other producers for each season of sale. Means are adjusted for shed identity on the farm, placement identity on the farm, date of sale, age at sale, latitude, longitude and initial stocking density. Data are based on 5027 weighbridge lorry loads of broilers on 331 days between June 2014 and June 2015. Note that the y-axis is truncated

Age at slaughter

Broilers grew more quickly under the bhsl system (34.53±0.41 days old at slaughter) than under other systems (36.35±0.14 days), adjusting for live weight, latitude, longitude and placement density (Table 2b, Figure 2b). This was also the case within individual seasons

(Figure 2b; *P*≤0.030 after correcting for multiple comparisons). In bhsl sheds, there were no seasonal effects of the boiler (*P*≥0.456). Control broilers sold in spring grew more quickly than those sold in summer (*P*=0.007) and there was a trend towards faster growth in those sold in autumn than summer (*P*=0.051). There were no other seasonal effects in control sheds (*P*≥0.119). Age at slaughter increased with increasing longitude and latitude, live weight and placement density (Table 2b).

Table 2b. The effects of boiler and season on age at slaughter in 2253 batches of broilers on 311 days between June 2014 and June 2015 from 34 farms

	Chi sq	Df	*P*
boiler	18.88	1	**<0.001**
season	10.06	3	**0.018**
latitude	51.40	1	**<0.001**
longitude	3728.50	1	**<0.001**
live weight	6.04	1	**0.014**
placement density	10032.53	1	**<0.001**
boiler x season	2.94	3	0.401

ANOVA correcting for date of slaughter, placement and shed; significant effects are in bold

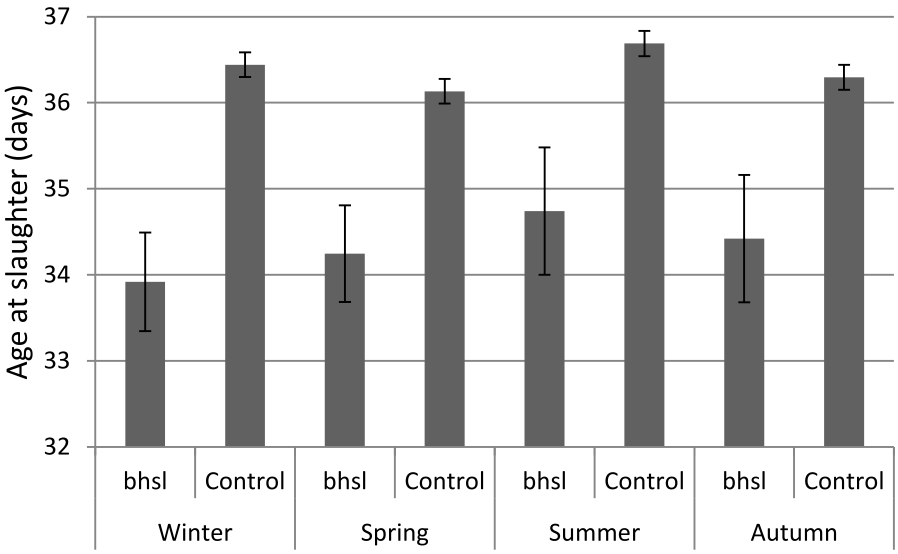

Figure 2b. Age at slaughter (±1SE) of broilers reared under the bhsl heating system compared to those from 33 other farms across the seasons when broilers were sold. Means are adjusted for shed identity within farm, placement identity on farm, date of sale, live weight, latitude, longitude and initial stocking density. Data are based on 2253 batches of broilers on 311 days between June 2014 and June 2015. Note that the y-axis is truncated at 32 days.

Farm mortality

Percentage mortality did not differ between sheds with (1.86±0.15%) and without (1.84±0.03%) the bhsl biomass boiler, and was not influenced by season, longitude or latitude (Table 3b, Figure 3b). Mortality increased with live weight and age, and decreased with increasing placement density (Table 3b).

Table 3b. Testing for the effects of boiler and season on percentage mortality in 1368 batches of broilers on 304 days between February 2014 and February 2015 from 32 farms

	Chi sq	Df	*P*
boiler	0.042	1	0.838
season	6.008	3	0.111
longitude	0.079	1	0.779
live weight	15.240	1	**<0.001**
age at sale	8.175	1	**0.004**
placement density	115.781	1	**<0.001**
latitude	0.005	1	0.947
boiler x season	0.474	3	0.925

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

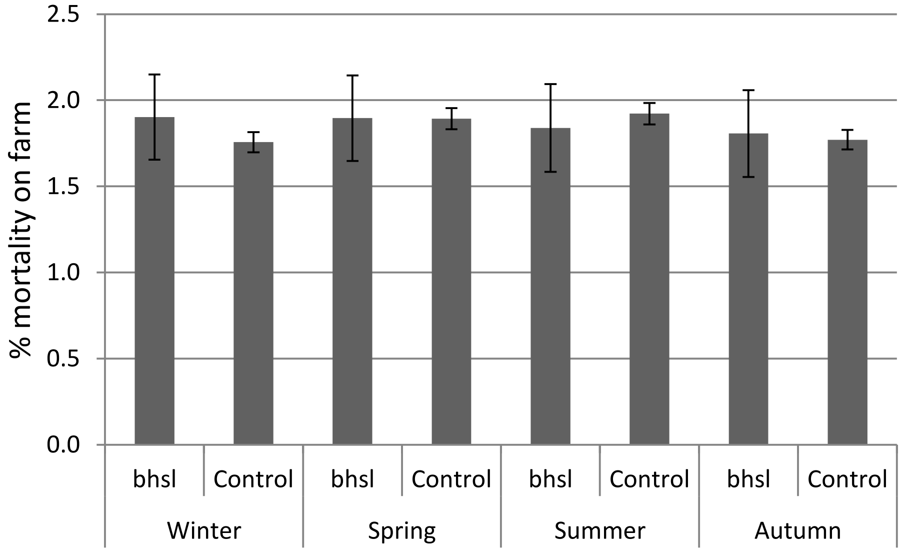

Figure 3b Percentage mortality (±1SE) of bhsl broilers compared to those from 31 control farms according to season of sale. Means are adjusted for shed identity within farm, placement identity within farm, date of sale, live weight, age at sale and initial stocking density. Data are based on 1364 batches of broilers on 304 sale dates between February 2014 and February 2015.

Proportion condemned

There was no overall effect of the boiler (bhsl: 0.079±0.008%; other: 0.077±0.002) or the season on the proportion of broilers rejected at the plant (Table 4b, Figure 4b). Neither were there any seasonal effects of the boiler system on the proportion condemned. The proportion of broilers condemned decreased with increasing placement density, latitude and live weight, but was not influenced by longitude.

Table 4b. Testing for the effects of boiler and season on the number of condemnations in 3826 lots of broilers on 311 days between June 2014 and June 2015 from 34 farms

	Chi sq	Df	*P*
latitude	4.38	1	**0.036**
live weight	155.52	1	**<0.001**
placement density	147.60	1	**<0.001**
season	4.40	3	0.222
longitude	0.26	1	0.610
boiler	0.26	1	0.610
boiler x season	2.23	3	0.527

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

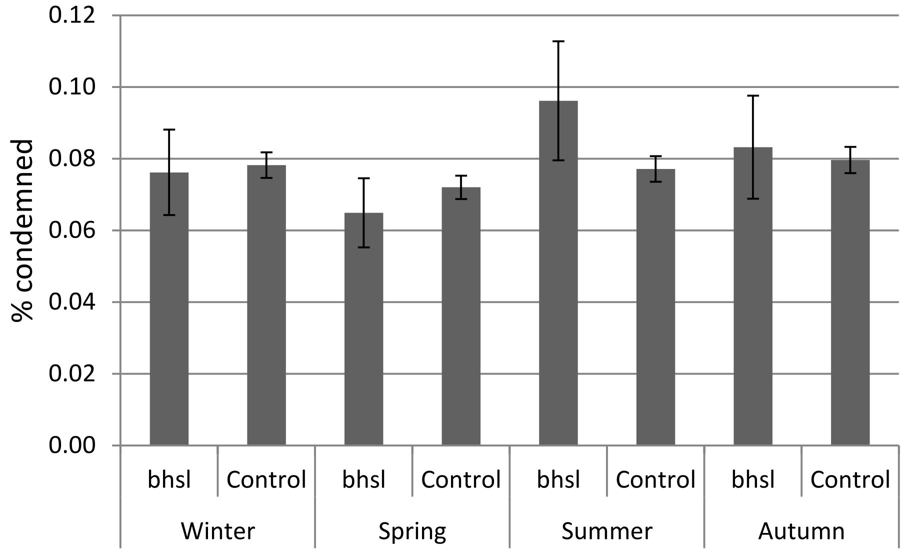

Figure 4b. Mean percentage of broilers per lot that were rejected at the plant (±1SE) summarised by producer (bhsl versus 33 control farms) and season of sale. Means are adjusted for shed identity within farm, placement identity on farm, date of sale, latitude, live weight and placement density. Data comprise 3826 batches of broilers on 311 sale days between June 2014 and June 2015.

Prevalence of foot pad burn

There was no overall effect of the boiler on the prevalence of foot pad burn (bhsl: 0.55±0.10%; control: 0.49±0.02%), nor did the effects of the boiler differ seasonally (Table 5b). Foot pad burn increased with live weight and decreased with placement density. There was no effect of latitude, longitude or season on foot pad burn (Table 5b, Figure 5b).

Table 5b. Testing for the effects of boiler system and season on the prevalence of foot pad burn in 3678 lots of broilers from 204 placements on 311 days between June 2014 and June 2015 from 33 farms

	Chi sq	Df	*P*
live weight	18.23	1	**<0.001**
placement density	130.80	1	**<0.001**
season	7.18	3	0.066
longitude	1.81	1	0.178
boiler	0.20	1	0.653
latitude	0.07	1	0.785
boiler x season	0.59	3	0.900

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

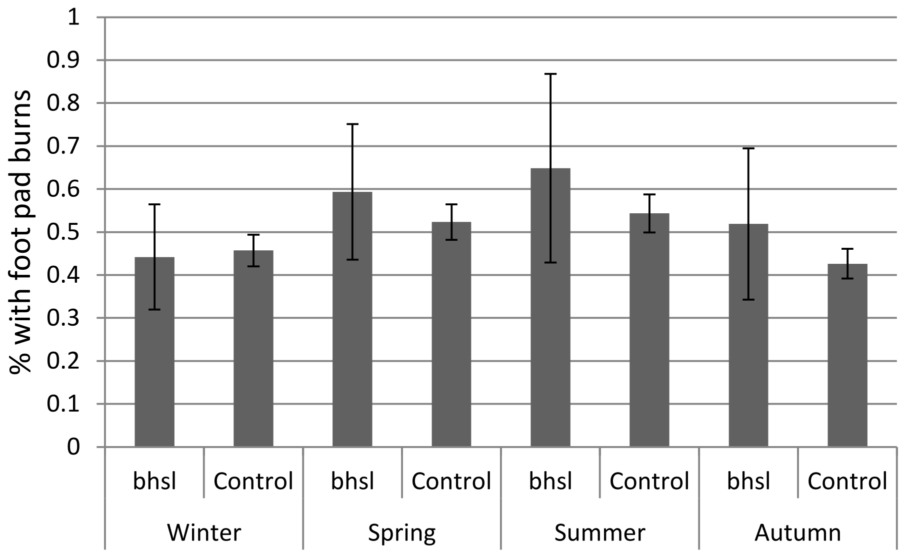

Figure 5b Mean prevalence per lot of foot pad burn (±1SE) among broilers reared under the bhsl system compared to those reared on 32 control farms by season of sale. Means are adjusted for shed identity within farm, placement identity on farm, date of sale, live weight and initial stocking density. Data are based on 3678 batches of broilers on 311 days between June 2014 and June 2015.

Prevalence of hock burn

bhsl farms (0.64±0.05%) did not differ from other farms (0.70±0.01%) in the prevalence of hock burn. There were no differential effects of the boiler system over the four seasons (Table 6b, Figure 6b), but the overall prevalence of hock burn varied seasonally. Hock burn was more prevalent in birds sold in spring than winter (P=0.040), and in summer compared to autumn and winter (P<0.001). The proportion of birds with hock burn decreased with increasing placement density and increased with live weight. Longitude and latitude had no effect on hock burn.

Table 6b. Testing for the effects of boiler system and season on the proportion of birds with hock burn in 3678 lots from 204 placements on 311 days from 33 farms

	Chi sq	Df	*P*
season	20.94	3	**<0.001**
live weight	34.44	1	**<0.001**
placement density	122.10	1	**<0.001**
boiler	1.22	1	0.270
longitude	1.47	1	0.225
latitude	0.14	1	0.707
boiler x season	1.15	3	0.764

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

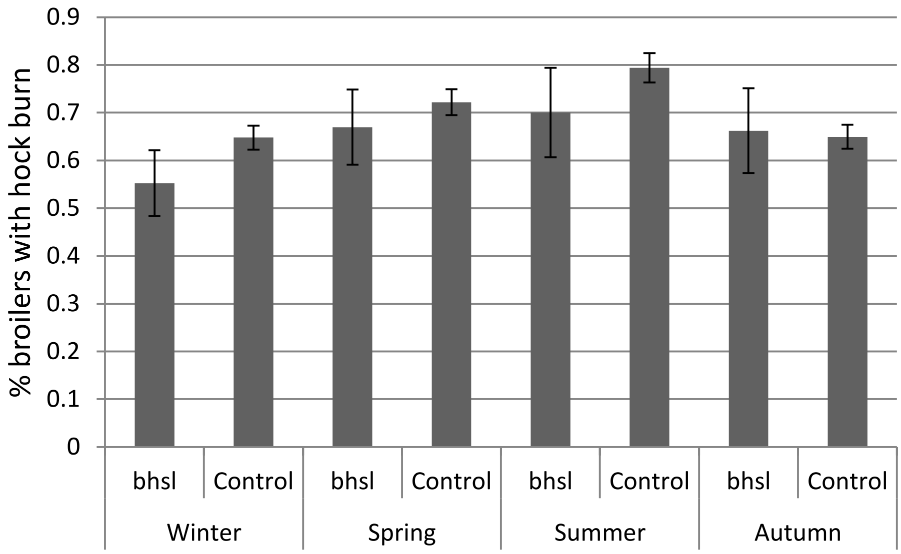

Figure 6b Mean prevalence of hock burn (±1SE) in broilers reared under the bhsl system versus those from 33 control farms by season of sale. Means are adjusted for shed identity within farm, placement identity within the farm, date of sale, live weight and initial stocking density. Data are based on 3678 lots on 311 days between June 2014 and June 2015.

Prevalence of broilers found dead on arrival (DOA)

The prevalence of broilers found DOA at the processing plant did not differ between those raised in bhsl sheds (0.072±0.005%) and elsewhere (0.067±0.002%), and the biomass boiler did not have seasonal effects on birds found DOA. The proportion of broilers found DOA increased with broilers' live weight, but was not influenced by season, placement density, latitude or longitude.

Table 7b. Testing for the effects of boiler and season on the proportion of broilers found dead on arrival at the processing plant (3679 lots of broilers from 204 placements on 311 days from 33 farms)

	Chi sq	Df	*P*
live weight	8.7086	1	**0.003**
season	5.5266	3	0.137
boiler	0.8651	1	0.352
latitude	0.9120	1	0.340
longitude	0.7798	1	0.377
placement density	0.0003	1	0.987
boiler x season	3.2981	3	0.348

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

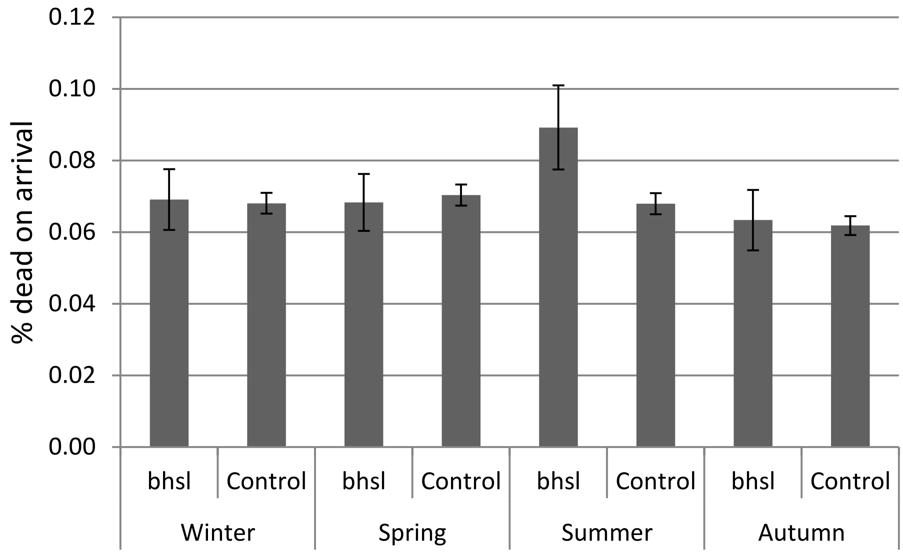

Figure 7b Mean prevalence of broilers found dead on arrival (±1SE) among those reared under the bhsl system versus those from 32 control farms by season of sale. Means are adjusted for shed identity within farm, placement identity on farm, date of sale and live weight. Data are based on 3679 lots of broilers on 311 days between June 2014 and June 2015

PART THREE: PROCESSING RESULTS

Mean eviscerated carcass weight

As with live weight, the mean weight of eviscerated carcasses was greater in broilers raised on bhsl farms (1.72±0.02 kg) than at control farms (1.60±0.01 kg) after adjusting for age, latitude and placement density (Table 8, Figure 8). The effect of the biomass boiler also depended on the season: bhsl broilers sold in winter were heavier than those sold in other seasons (*P*<0.001), but there were no seasonal differences on control farms (*P*≥0.309). Eviscerated carcass weight decreased with increasing latitude and placement density, and increased with age. Carcass weight was not associated with longitude.

Table 8. The effects of boiler system and season on mean carcass weight in 2132 flocks of broilers from 358 placements on 217 days between August 2014 and June 2015 from 27 farms

	Chi sq	Df	*P*
boiler	27.85	1	**<0.001**
season	4.25	3	0.236
latitude	29.94	1	**<0.001**
age at slaughter	75.31	1	**<0.001**
placement density	3.18	1	**<0.001**
boiler x season	38.23	3	**<0.001**
longitude	0.34	1	0.563

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

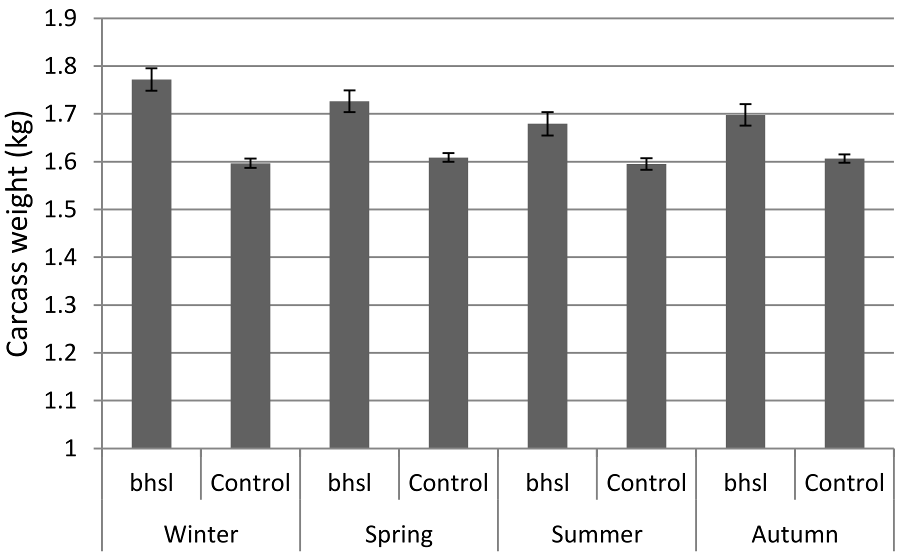

Figure 8. Mean eviscerated carcass weights (±1SE) in broilers reared under the bhsl system compared to those from 26 control farms by season of sale. Means are adjusted for shed identity within the farm, placement identity within the farm, date of sale, age at slaughter, latitude and initial stocking density. Data are based on 2132 flocks from 358 placements on 217 days between August 2014 and June 2015.

Standard deviation in eviscerated carcass weight

There was no difference in uniformity, expressed as the standard deviation of the mean, in eviscerated carcass weight between broilers reared under the bhsl (0.223±0.008 kg) and control (0.213±0.002 kg) systems. The season did not influence uniformity, and there were no differential effects of season between boiler systems (Table 9). Uniformity increased with age at slaughter and decreased with latitude (Table 9). Longitude and placement density did not influence uniformity.

Table 9. Testing for the effects of boiler system and season on uniformity in eviscerated carcass weight (standard deviation of the mean) in 2130 flocks of broilers from 358 placements and 27 farms on 217 days between August 2014 and June 2015

	Chi sq	Df	*P*
age at slaughter	5409.90	1	**<0.001**
latitude	5.28	1	**0.022**
season	6.29	3	0.098
boiler	1.54	1	0.215
placement density	0.38	1	0.536
longitude	0.05	1	0.823
boiler x season	6.36	3	0.095

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

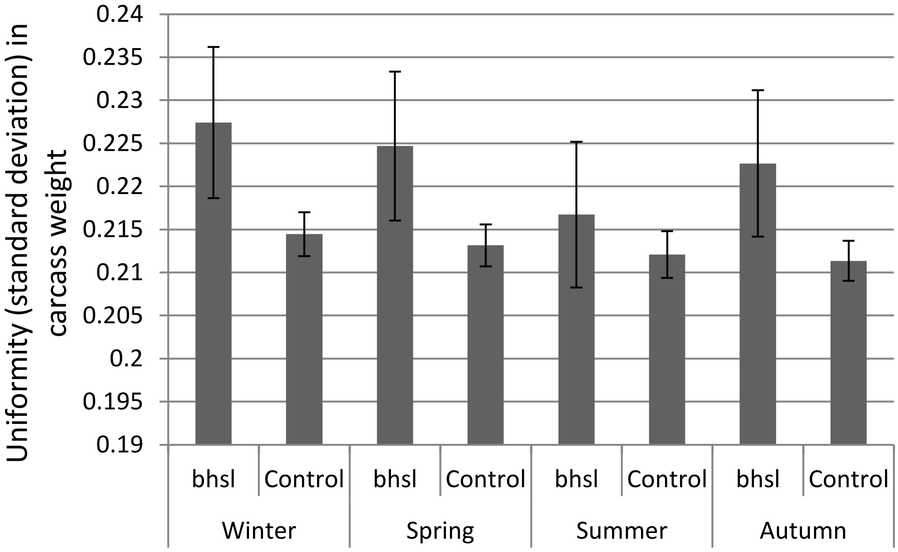

Figure 9 Uniformity (±1SE) based on the standard deviation of the mean carcass weight of broilers reared under the bhsl system versus those from 26 control producers summarised by season of sale. Means are adjusted for shed identity within farm, placement identity within farm, date of sale, age at slaughter and latitude. Data are based on 2130 flocks from 358 placements on 217 days between August 2014 and June 2015.

Coefficient of variance in eviscerated carcass weight

Uniformity, expressed as the coefficient of variance (CoV), in eviscerated carcass weight, did not differ between broilers reared under the bhsl (0.130±0.003 kg) and control (0.134±0.001 kg) system overall. The effects of the boiler differed between the seasons (Table 10, Figure 10), but individual contrasts were not statistically significant after correcting for multiple testing (*P*≥0.343; comparison between bhsl and control systems in winter without correction: *P*=0.014). As with standard deviation, uniformity expressed as CoV increased with age at slaughter and with placement density (Table 10). Longitude and latitude did not influence uniformity.

Table 10. Testing for the effects of boiler and season on uniformity in eviscerated carcass weight (coefficient of variance) in 2127 flocks of broilers from 358 placements and 27 farms on 217 days between August 2014 and June 2015

	Chi sq	Df	*P*
boiler	2.06	1	0.152
season	2.10	3	0.552
age at slaughter	20.24	1	**<0.001**
placement density	229.89	1	**<0.001**
boiler x season	9.59	3	**0.022**
latitude	2.80	1	0.094
longitude	0.06	1	0.799

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

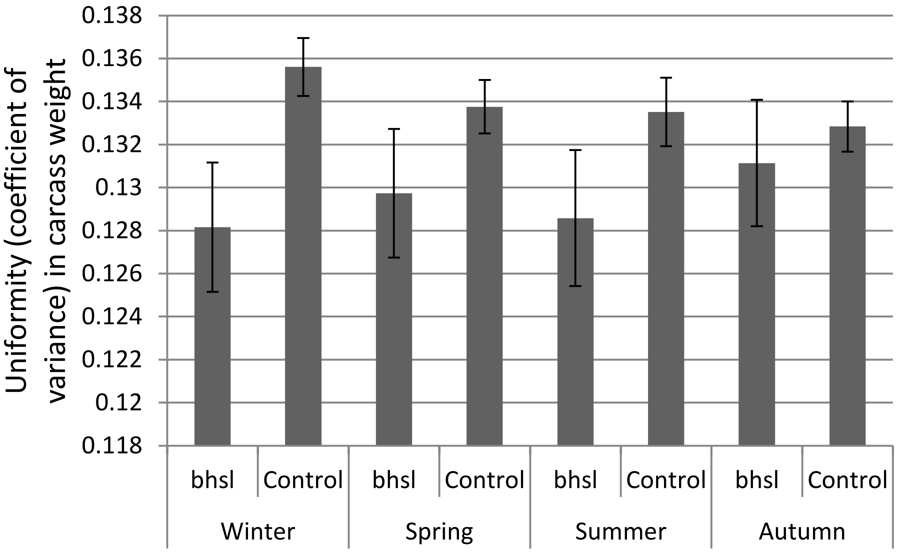

Figure 10 Uniformity (±1SE) based on the coefficient of variance in carcass weight of broilers reared under the bhsl system compared to those reared on 26 other farms, and summarised by season of sale. Means are adjusted for shed identity within farm, placement identity within farm, date of sale, age at slaughter and initial stocking density. Data are based on 2127 flocks from 358 placements on 217 days between August 2014 and June 2015

Percentage carcass yield after evisceration

Meat yield tended to be greater from broilers raised under the bhsl system (73.33±0.15%) than on control farms (73.03±0.06%) after adjusting for age, season and placement density, although this was not statistically significant (Table 11, Figure 11). The effect of the boiler depended on the season: in winter, broilers from bhsl sheds yielded a greater proportion of meat than those from other sheds (*P*=0.046 after adjusting for multiple testing). Yield increased with broiler age and placement density. Latitude and longitude had no effect on yield.

Table 11. The effects of boiler and season on percentage meat yield in 2132 flocks of broilers from 358 placements and 27 farms on 217 days between August 2014 and June 2015

	Chi sq	Df	*P*
boiler	3.73	1	0.053
season	4.59	3	0.205
age at slaughter	84.10	1	**<0.001**
placement density	99.26	1	**<0.001**
boiler x season	8.88	3	**0.031**
longitude	1.05	1	0.306
latitude	0.39	1	0.530

ANOVA correcting for date of sale, placement and shed; significant effects are in bold

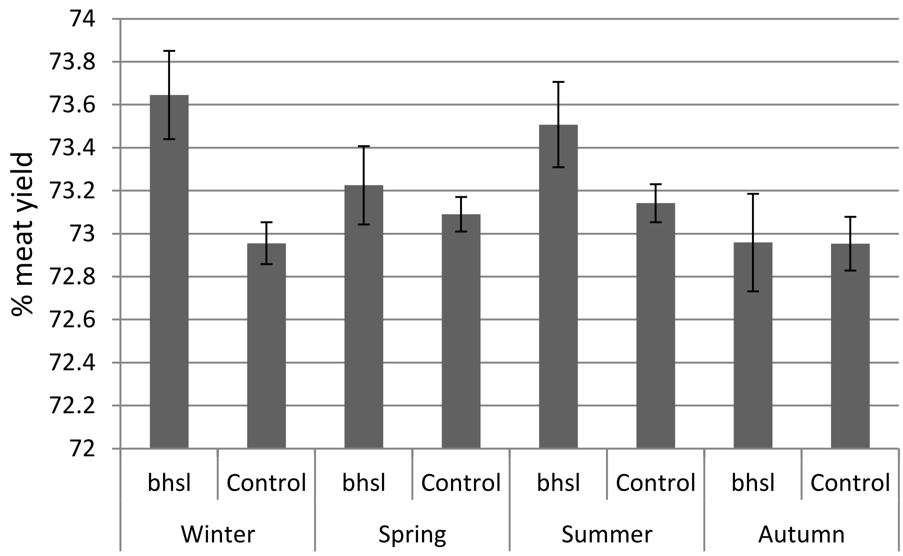

Figure 11. Mean eviscerated carcass weights (±1SE) in broilers reared under the bhsl system compared to those raised on 26 other farms, summarised by season of sale. Means are adjusted for shed identity within the farm, placement identity within the farm, date of sale, age at slaughter and initial stocking density. Data are based on 2132 flocks from 358 placements on 217 days between August 2014 and June 2015.