World Rabbit Science

JOURNAL OF THE WORLD RABBIT SCIENCE ASSOCIATION

July - September 2021

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HIERARCHICAL CLUSTERING AS A TOOL TO DEVELOP A CLASSIFICATION SCHEME FOR RABBIT MEAT QUALITY

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Abstract: This study aimed to characterise the quality of meat from commercially-raised rabbits. Animals came from five different producers and were slaughtered in three different plants under provincial or federal inspection jurisdiction. Animal behaviour evaluated by scan sampling prior to feed withdrawal (FW) and transport, as well as blood lactate concentration at exsanguination, did not raise concerns with respect to stress. Stomach pH was higher (P=0.047) when the FW time was short (≤13.5 h), at a mean value of 2.23. All pH values measured 1 h *post-mortem* from the *Biceps femoris* (BF) and almost all (97.6%) from the *Longissimus lumborum* (LL) were higher than 6. Values for ultimate pH measured 24 h *post-mortem* (pH_u) ranged from 5.80 to 6.83 and from 5.70 to 6.70 for BF and LL muscles, respectively. The maximum meat drip loss recorded was 2.6%, while cooking loss reached 30%. Meat lightness (L*) and colour intensity (C*) for the long FW times (≥23 h) were no different from those with short and intermediate (15.5 to 17.3 h) FW times. However, these colour parameters were higher for the short FW time class compared to the intermediate FW time class (P<0.02). A hierarchical cluster analysis based on pH_u, cooking loss and lightness (L*) from 200 rabbit loins was performed. Of the four clusters created, clusters 1 and 2 had the best and second-best meat quality, respectively. Clusters 3 and 4 had the lowest meat quality and presented DFD-like (dark, firm and dry) characteristics. Meat did not exhibit PSE-like (pale, soft, exudative) characteristics, even for the slaughter lot with the minimum mean pH_u. Of the eight slaughter lots evaluated, more than 50% of the meat from three of them fell into clusters 3 and 4; all three were in the intermediate FW time class. Overall, the quality of rabbit meat analysed was acceptable for commercial use, but rather variable. This suggests that there are factors within the value chain that are not yet fully controlled and require further investigation.

Key Words: cooking loss, DFD meat, feed withdrawal, hierarchical cluster analysis, pre-slaughter management, rabbit.

INTRODUCTION

According to the FAO (2017), global production of rabbit meat worldwide was about 1.4 million tonnes and came principally from Asia (75.3%), followed by Europe (21.3%), Africa (7.1%) and America (1.2%). Of the 1.2% produced in America, Canada and the US produced 1.03%. In 2016, the provinces of Ontario and Quebec were responsible for 55.32% and 35.49% of Canadian rabbit meat production, as 33.47% and 18.99% of the rabbit farms are located in these provinces, respectively (AAFC, 2019). Since 2011, rabbit production has been relatively stable in Quebec, partly because it is considered to be a specialty meat and is often associated with holiday celebrations. In 2014, consumption was relatively low at 0.0254 kg per capita in Canada (AAFC, 2019) and 0.040 kg in the Quebec province (MAPAQ, 2015). However, from 2010 to 2014, rabbit meat consumption increased to 3% per year in Quebec alone (MAPAQ, 2015). Although the agri-food activity of rabbit production is marginal in Quebec and in Canada in general, it

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contributes to the diversity of the food supply and its development can only be achieved if farmers produce adequate-quality meat.

Meat quality defects can cause economic losses for both producers and processors, and may cause a reduction in meat shelf life (Faucitano *et al.*, 2010; Adzitez and Nurul, 2011). Animals that are exposed to acute or chronic stress just before slaughter can yield either pale, soft and exudative (PSE) or dark, firm and dry (DFD) meat, respectively, which are two well-known meat quality defects (Adzitey and Nurul, 2011). The incidence of PSE meat reduces processing yield, and the high microbial spoilage associated with DFD meat decreases its shelf life (Faucitano *et al.*, 2010; Saucier, 2016; Ponnampalam *et al.*, 2017). Furthermore, because two of the most important variables driving consumer choice are the colour and consistency of raw meat (Dalle Zotte, 2002), PSE and DFD raw meats have lower value compared to normal meats due to their unattractive appearance (Viljoen *et al.*, 2002).

Meat quality is influenced by many factors including pre-slaughter management, such as feed withdrawal (FW), transport and lairage time. Pre-slaughter FW is important for reducing transport-related sickness, incidence of downers and death, as well as microbial contamination during transport (Martín-Peláez *et al.*, 2008). Furthermore, FW reduces the volume of the gastrointestinal tract, in particular the stomach, which also reduces puncture risk during evisceration (Dalle Zotte, 2002). However, previous studies have established that extended FW could result in a reduction in live body weight (Bianchi *et al.*,2008; Frobose *et al.*, 2014). Within the first hours of FW, stomach weight reduction is observed, while a prolonged FW can cause degradation of body tissues, loss of nutrients and humidity, leading in turn to quality and yield losses (Bianchi *et al.*, 2008). An extended FW period is ascribed to poor animal welfare conditions as expressed by an increase in aggressivity, with longer and more intense fighting (Faucitano *et al.*, 2006), and can reduce the levels of muscular glycogen reserves, which can lead to undesirable meat with a high pH (Faucitano *et al.*, 2006; Verga *et al.*, 2009). Furthermore, it has been reported that longer transport journeys increase bruising and mortality (Petracci *et al.*, 2008).

Pork is classified into five quality categories based on the ultimate pH (pH_u), colour and meat drip loss: PSE, PFN (pale, firm, non-exudative), RSE (reddish-pink, firm, exudative), RFN (reddish-pink, firm, non-exudative; normal pork) and DFD (Faucitano *et al.*, 2010). For beef, the classification method considers carcass yield and texture, but also colour in order to identify DFD meat (Polkinghorne and Thompson, 2010; Ponnampalam *et al.*, 2017). Traditionally, PSE meat was associated with pigs and DFD meat with all species (Adzitey and Nurul, 2011). However, PSE-like meat has now been identified in turkey, chicken and cattle (Adzitey and Nurul, 2011). DFD-like meats have been reported in the literature for rabbits (Jolley, 1990; Koné *et al.*, 2016; Składanowska-Baryza *et al.*, 2018), whereas PSE-like meat has not (Cavani *et al.*, 2009; Blasco *et al.*, 2018).

To our knowledge, no formal and specific meat quality classification has ever been defined for rabbit meat. Despite the implementation of a code of good practices (RMAAQ, 2019), meat quality may vary. Thus, the aim of this study was to characterise meat quality from rabbits commercially raised in Quebec and slaughtered in facilities under federal or provincial jurisdiction. Using a hierarchical cluster analysis based on pH_u, cooking loss and lightness (L*), a classification of rabbit meat quality is proposed.

MATERIALS AND METHODS

All experimental procedures involving live rabbits were approved by Université Laval's Animal Use and Care Committee, which strictly adheres to the Guidelines of the Canadian Council on Animal Care (CCAC, 2009). Rabbits were commercially raised and analyses were performed from January 2018 to August 2019.

Producer selection

Five rabbit producers were selected in collaboration with the *Syndicat des producteurs de lapins du Québec* to represent the vast majority of procedures in operation within the province of Quebec. Rabbits were slaughtered in three different abattoirs located in either Ontario or Quebec. They operated under provincial or federal inspection. The pre-slaughter management practices are presented in Table 1 for each slaughter lot.

Table 1: Pre-slaughter management according to the producer and the season[1].

Slaughter lot designation	Producers	Inspection juridiction[2]	Season	Rabbits per lot	Feed withdrawal time at the farm (h)	Transport time (h)	Lairage time (h)	Total feed withdrawal time (h) [3]
A-P1-W	A	Provincial 1	Winter	270	6.66	0.17	1.67	8.5
B-F1-W	B	Federal 1	Winter	450	2.5	5	19	26.5
C-F1-W	C	Federal 1	Winter	900	10	5	14	29.0
D-P1-W	D	Provincial 1	Winter	747	9.67	2.25	3.58	15.5
D-P1-S	D	Provincial 1	Summer	800	9.75	2	1.75	13.5
D-P2-S	D	Provincial 2	Summer	805	12.75	2.25	1	16.0
D-F2-S	D	Federal 2	Summer	760	12.75	2.25	2.33	17.3
E-F1-S	E	Federal 1	Summer	320	0	7	16	23.0

[1]Pre-slaughter management varies according to which abattoir the rabbits were delivered.
[2]Indicates the slaughterhouse inspection jurisdiction under which rabbits were slaughtered. Provincial 1 and 2 were located in Quebec; Federal 1 was located in Ontario; Federal 2 is the same slaughterhouse as Provincial 2, but after it received federal accreditation.
[3]Total feed withdrawal time includes all time segments: feed withdrawal time while at the farm, during transport and in lairage at the abattoir.

Behavioural observations

For each slaughter lot (n = 8), animal behaviour was evaluated by visual scan sampling at one minute intervals for a total of 10 min using an observation grid on 10% of the total cages prior to FW. The number of rabbits sitting, lying down or moving was recorded. Observations also included occurrence and types of activities and interactions. Aggressive behaviours relate to chasing and triggering escape, leaping, biting another rabbit, bouncing and paw scraping. All behavioural assessments were performed by the same observer.

Physiological measures

For each lot slaughtered in the abattoirs located in Quebec, 25 rabbits were randomly selected from the dressing line. Blood samples were collected at exsanguination to measure blood lactate level, in duplicate, using a hand-held lactate analyser (Lactate scout +, EKF Diagnostics, Cardiff, Wales, UK) according to the manufacturer's specifications.

Full gastrointestinal tracts (GIT) were promptly removed and weighed after slaughter. Stomachs and caeca were tied at both ends, removed and weighed when full and then again when empty. The pH of the caecum and stomach contents was measured using a portable pH meter (ROSS, Orion Star A221, Thermo Scientific, Beverly, CA, USA) combined with an Orion Kniphe electrode (ThermoFisher, Nepean, ON, Canada) and a temperature compensation probe (928,007 MD, micro probes ATC, Maryland, USA). Stomach and caecum contents were weighed and kept at –20°C until the percentage of dry matter (DM) was evaluated. DM was calculated after lyophilisation (model 50L Virtual EL-85, VirTis, Los Angeles, CA, USA) at 20°C for 3 d. The water content was determined by calculating the weight difference between the wet and dry contents (Saucier *et al.*, 2007).

Meat quality measurement

To determine the meat quality, the rabbit carcasses were analysed according to Koné *et al.* (2019). Muscular pH of the *Longissimus lumborum* (LL) and the *Biceps femoris* (BF) muscles were measured 1 h (pH1h) *post-mortem* for animals slaughtered in the abattoirs located in Quebec (since we had access to the processing line), and after 24 h (ultimate pH (pH_u)) with a portable pH meter (ROSS, Orion 4 Star, Thermo Scientific) combined with an Orion Kniphe electrode (ThermoFisher) and an Orion™ Stainless-Steel Automatic Temperature Compensation (ATC) Probes (#927007MD, Thermo Scientific; Blasco and Ouhayoun, 1996). Meat colour was measured 24 h after slaughter on LL muscle cross sections between the 6th and 7th lumbar vertebrae (Dalle Zotte *et al.*, 2015) and on the exposed surface overlying the BF (Dalle Zotte *et al.*, 2009). After exposing the cut muscle surface to ambient air for 20 min ("blooming time"; Koné *et al.*, 2019), meat colour was evaluated using a Chroma meter (CR 400, Minolta Ltd., Osaka, Japan) equipped with a conical open port and an 8 mm aperture, a diffuse illumination/0° viewing angle geometry and a D65 light source according to the reflectance coordinates (L*, a*, b*; CIE, 1976). Parameters used to compare meat colour were lightness (L*), redness (a*), yellowness (b*), colour intensity (chroma, C*) and the hue angle (h). Equation (1) was used to calculate the chroma, while Equation (2) was used to determine the hue angle (Pathare *et al.*, 2013):

$$C^* = \sqrt{(a^{*2} + b^{*2})} \quad (1)$$

$$h = Tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (2)$$

For samples with a negative a* value, 180° was added to the calculated h value (McLellan *et al.*, 1995). Drip loss was measured by the weight difference of a piece of LL (2 cm thick×2.5 cm in diameter) after storage at 4°C for 48 h using an EZ-Driploss cup (Meat Extract Collector, Sarstedt AG & Co. KG, Nümbrecht, Germany; Rasmussen and Anderson, 1996). The cooking loss was evaluated using a similar piece of LL muscle (Pla, 1999) and is expressed as a percentage of the initial weight loss. Samples were placed individually into a Whirl-Pak bag (S-19793, Nasco Whirl-Pak®, USA), the air was removed from the bag, and it was then submerged in a water bath at 70°C for 15 min. Samples were then cooled in an ice-water bath, removed from the bag and weighed after removing the excess moisture with filter paper (Vergara *et al.*, 2005).

Statistical analysis

To determine the differences in the behavioural parameters between slaughter lots, data were assessed using the SAS (Statistical Analysis System, SAS Institute Inc. 2002) GLIMMIX procedure. The LSMEANS statement adjusted by a Tukey's test was used to compare the differences between slaughter lots. In a second analysis, season was used as a fixed effect in order to evaluate its impact; producer was used as a random variable.

For the physiological and meat quality parameters, data were analysed using the SAS GLIMMIX procedure. To measure the effect of FW time, three classes were established according to what was applied by the selected producers (class 1, short≤13.5 h; class 2, 13.5 h<intermediate<23 h; and class 3, long≥23 h; Table 1). FW time, class and season were used as fixed variables, whereas slaughter lot and slaughterhouse were random variables.

Pearson's correlation coefficients were calculated on the residuals of lot analysis to measure the associations between the parameters under study using JMP 15 (SAS Institute Inc. 2002). For the principal component analysis (PCA), only the lots that were slaughtered in the abattoirs located in Quebec were considered. This was because access to the processing line was denied for lots slaughtered in the Ontario abattoir, therefore preventing the collection of physiological data. SAS software was used for this analysis.

A hierarchical cluster analysis was performed using Minitab software (Release 19) to identify groups of rabbit meat with different quality characteristics. Between each pair of observations, the Euclidian distance was used to measure the resemblance between groups and a complete linkage clustering method was used to associate similar samples. Four clusters were formed based on three meat quality variables (pH_u, cooking loss and L*). An analysis of variance (ANOVA) using the SAS software MIXED procedure was performed to evaluate differences between quality characteristics of the groups formed by the cluster analysis, and the LSMEANS statement adjusted by a Tukey's test was used to compare the differences between clusters.

RESULTS

Behavioural parameters

According to Figure 1, only a small percentage of rabbits were observed to be moving (≤3.1%), whereas most were sitting or lying down. Rabbits from A-P1-W were documented as moving more frequently than those from E-F1-S. Rabbits from D-P2-S, A-P1-W and D-P1-W were found to be sitting more often (60.6, 53.5 and 51.9%, respectively) than rabbits from D-P1-S and E-F1-S (35.7 and 32.7%, respectively). Values obtained for the other slaughter lots ranged from 39.8 to 51.5%. Results for rabbits lying down were essentially the opposite of those sitting.

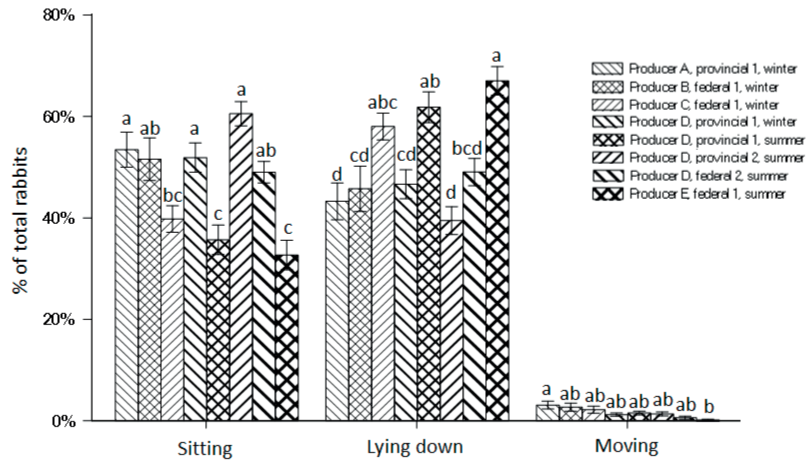

Figure 1: Percentage of rabbits sitting, lying down or moving during observations, prior to feed withdrawal, at each farm visit (mean±standard error). Bars with different letters differ significantly at $P<0.05$.

For all slaughter lots, limited interaction between rabbits prior to FW was observed (Table 2). However, the proportion of rabbits exhibiting nonaggressive interactions was higher (P=0.046) for C-F1-W (4.0%) compared to D-P1-S (1.0%; Table 2). A-P1-W was the only slaughter lot where rabbits expressed aggressive behaviour (biting another rabbit; 0.4%).

D-P1-W had more rabbits resting than A-P1-W (89.0 *vs*. 79.8%; P=0.06; Table 2). Slaughter lot D-P2-S (3.8%) had more rabbits that were drinking than B-F1-W (0.8%), C-F1-W (1.2%) and E-F2-S (0.9%; all P-values<0.005; Table 2). A-P1-W, E-F2-S, D-P1-S, D-P2-S and D-F2-S had more rabbits that were grooming than D-P1-W (all P-values<0.049; Table 2).

B-F1-W (7.0%) had more rabbits that were eating than E-F1-S (1.8%; P=0.01). Slaughter lots A-P1-W *and* C-F1-W had a higher proportion of rabbits that were moving than E-F1-S (both P-values<0.08; Table 2). No major difference was observed between slaughter lots for the proportion of rabbits biting or scratching their cage, mating, stretching, shaking, stamping their feet and sneezing. However, E-F1-S was the only one with rabbits that stood up (0.3%).

Of the four rabbit lots from producer D, D-P1-W (51.9%), D-P2-S (60.6%) and D-F2-S (49.0%) had more rabbits that were sitting than D-P1-S (35.7%; all P-values<0.04; Figure 1). D-P1-S (62.8%) had more rabbits lying down than D-P1-W (46.9%) and D-P2-S (38.1%; both P-values<0.02; Figure 1). With respect to interactions presented in Table 2, D-P1-W (1.9%) had fewer rabbits grooming than D-P1-S (8.0%), D-P2-S (9.5%) and D-F2-S (8.9%; all P-values<0.049). No other interactions were different between slaughter lots from producer D.

With respect to season, rabbits were more active in winter than in summer (P=0.045). Animals exhibited fewer interactions in summer (P=0.009). When the animals interacted in winter, none of these interactions were aggressive (P=0.001). Interestingly though, sneezing was more common during the summer (P=0.009).

Physiological parameters

For rabbits slaughtered in Quebec, we had access to the processing line, which enabled us to measure various physiological parameters. The mean, standard deviation, minimum and maximum of different physiological parameters that were measured are presented in Figure 2. Means for blood lactate ranged from 0.88±0.19 mmol/L for D-F2-S to 8.74±4.29 mmol/L for D-P1-S (Figure 2A).

GIT mean weight ranged from 344.69±32.82 g (D-P2-S) to 463.85±58.53 g (A-P1-W; Figure 2B). Stomach mean weight ranged from 65.66±18.25 g (D-P1-W) to 111.97±22.83 g (AP1-W; Figure 2C). Average caecum weight was

Table 2: Percentage (%) of rabbits presenting different types of interactions and activities during observations made prior to feed withdrawal at the farm[1].

	Producer[2]									
Variables	A Provincial 1 Winter	B Federal 1 Winter	C Federal 1 Winter	D Provincial 1 Winter	D Provincial 1 Summer	D Provincial 2 Summer	D Federal 2 Summer	E Federal 1 Summer	SEM[3]	*P*-value
Interaction,%										
Nonaggressive[4]	3.3±0.6^{ab} (1.60-4.9)[5]	3.0±1.0^{ab} (1.2-4.8)	4.0±0.9^{a} (2.8-5.2)	2.7±0.9^{ab} (1.1-4.2)	1.0±0.3^{b} (0.0-2.5)	2.2±0.6^{ab} (0.0-3.7)	1.3±0.3^{ab} (0.0-2.8)	2.1±0.8^{ab} (0.0-3.8)	0.007	0.05
Aggressive	0.4±0.4 (0.1-0.6)	NO (0.0-0.2)	NO (0.0-0.2)	NO (0.0-0.2)	NO (0.0-0.2)	NO (0.0-0.2)	NO (0.0-0.2)	NO (0.0-0.2)	0.001	ND
No interaction	96.4±0.7 (94.1-98.6)	97.0±1.0 (94.6-99.4)	96.0±0.9 (94.4-97.6)	97.4±0.9 (95.2-99.4)	99.0±0.3 (96.9-100.0)	99.2±1.7 (97.1-100.0)	97.6±1.2 (95.5-99.6)	98.1±0.8 (95.8-100.0)	0.01	ND
Type of activity,%										
Resting	79.8±2.6^{y} (75.3-84.2)	84.9±1.7^{xy} (80.2-89.6)	84.5±1.5^{xy} (81.4-87.6)	89.0±1.6^{x} (84.9-93.1)	83.1±1.6^{xy} (79.0-87.2)	81.9±2.2^{xy} (77.8-86.0)	82.6±3.0^{xy} (78.5-86.6)	87.3±1.9^{xy} (82.9-91.8)	0.03	0.07
Drinking	1.6±0.6^{ab} (0.6-2.7)	0.8±0.3^{b} (0.0-1.9)	1.2±0.3^{b} (0.5-1.9)	1.9±0.6^{ab} (0.9-2.9)	1.6±0.3^{ab} (0.6-2.6)	3.8±0.5^{a} (2.8-4.7)	2.7±0.8^{ab} (1.7-3.7)	0.9±0.3^{b} (0.0-2.0)	0.008	0.001
Grooming	10.7±2.2^{a} (7.7-13.7)	4.8±0.9^{ab} (1.6-7.9)	7.0±1.3^{ab} (5.0-9.1)	1.9±0.5^{b} (0.0-4.6)	8.0±1.2^{a} (5.3-10.7)	9.5±1.3^{a} (6.8-12.3)	8.9±1.2^{a} (6.2-11.7)	8.2±1.7^{a} (5.3-11.2)	0.01	0.001
Biting their cage	NO	NO	0.4±0.3 (0.1-0.7)	NO	NO	0.2±0.2 (0.0-0.6)	0.2±0.2 (0.0-0.6)	0.6±0.3 (0.2-1.0)	0.002	ND
Eating	5.3±1.1^{ab} (3.3-7.3)	7.0±1.1^{a} (4.9-9.1)	4.0±0.9^{ab} (2.6-5.3)	6.7±1.0^{ab} (4.8-8.5)	5.2±0.5^{ab} (3.4-7.1)	4.2±0.9^{ab} (2.3-6.0)	3.4±0.9^{ab} (1.6-5.2)	1.8±0.6^{b} (0.0-3.8)	0.01	0.006
Mating	NO	0.2±0.2 (0.0-0.6)	0.6±0.3 (0.3-0.9)	0.1±0.1 (0.0-0.5)	NO	0.3±0.2 (0.0-0.7)	0.1±0.1 (0.0-0.5)	NO	0.002	ND
Moving	2.4±0.7^{x} (1.2-3.4)	2.1±0.7^{xy} (0.9-3.2)	2.0±0.6^{x} (1.2-2.7)	0.4±0.3^{xy} (0.0-1.4)	1.4±0.4^{xy} (0.4-2.4)	0.8±0.3^{xy} (0.0-1.8)	0.7±0.3^{xy} (0.0-1.7)	NO^{y}	0.006	0.01
Stretching	0.4±0.2 (0.0-0.7)	0.2±0.2 (0.0-0.5)	0.3±0.2 (0.0-0.5)	NO	NO	NO	NO	0.2±0.2 (0.0-0.5)	0.002	ND
Shaking	NO	0.2±0.2 (0.0-0.4)	NO	NO	0.2±0.15 (0.0-0.4)	0.1±0.1 (0.0-0.3)	NO	NO	0.001	ND
Stamping their feet	NO	NO	NO	NO	NO	0.1±0.1 (0.0-0.2)	NO	0.2±0.15 (0.0-0.3)	0.001	ND
Sneezing	NO	NO	NO	NO	0.1±0.1 (0.0-0.3)	0.3±0.2 (0.1-0.6)	0.2±0.2 (0.0-0.4)	0.2±0.2 (0.0-0.4)	0.001	ND
Standing up	NO	NO	NO	NO	NO	NO	NO	0.1±0.2 (0.0-0.3)	0.001	ND
Scratching the cage	NO	NO	NO	NO	0.1±0.1 (0.0-0.2)	NO	NO	0.3±0.2 (0.1-0.5)	0.001	ND

[1]Mean±standard error. Observations made by scan sampling on a subsample of 10% of total cages within each slaughter lot.
[2]Indicates the slaughterhouse inspection jurisdiction at which rabbits were slaughtered. Provincial 1 and 2 were located in Quebec; Federal 1 was located in Ontario; Federal 2 is the same slaughterhouse as Provincial 2, but after it received federal accreditation.
[3]SEM: Standard error of the mean.
[4]Different letters (a–d) within rows indicate difference at $P<0.05$ and (x-y) at $P<0.10$. ND: not different; NO: not observed. Tukey's test was carried out to compare the differences between producers.
[5] Confidence interval (lower limit-upper limit).

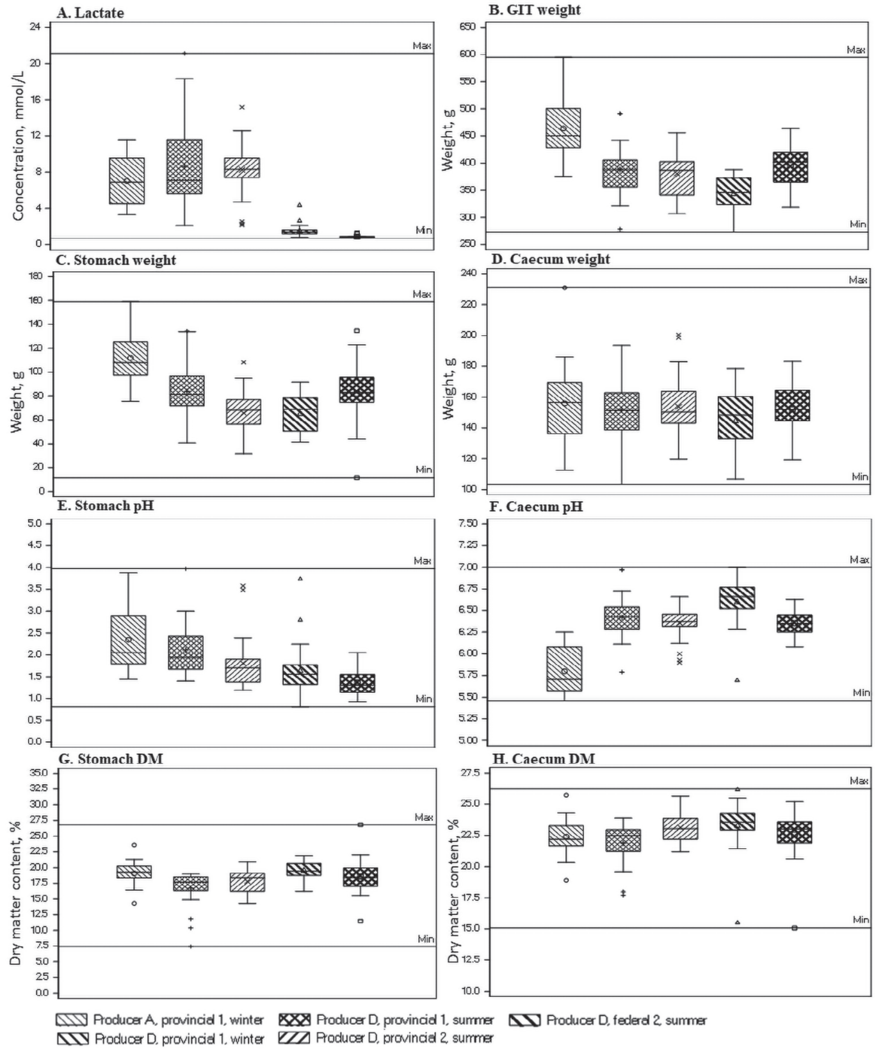

Figure 2: Physiological parameters (means±standard deviations) measured from rabbits (n=120) slaughtered in the province of Quebec; blood lactate concentration (A), gastrointestinal tract (GIT) weight (B), stomach weight (C), caecum weight (D), stomach pH (E), caecum pH (F), stomach DM (G) and caecum DM (H). Max=maximum and Min=minimum. Stomach DM and caecum DM=Stomach and caecum dry matter.

relatively stable for all slaughter lots, with means ranging from 144.92±19.70 g for D-P2-S to 155.90±26.04 g for A-P1-W (Figure 2D).

For stomach pH, averages ranged from 1.37±0.29 for D-F2-S to 2.35±0.73 for A-P1-W (Figure 2E). Except for A-P1-W, caecum pH was relatively similar for all slaughter lots, with means ranging from 6.35±0.14 (D-F2-S) to 6.61±0.25 (D-P2-S; Figure 2F). Slaughter lot A-P1-W was the only one with a mean caecum pH that was below 6 (5.80±0.26), and the minimum value observed (5.46) was also from this lot. The stomach pH and caecum pH levels from A-P1-W were above and below all of the others, respectively.

Stomach DM ranged from 16.68±2.81% for D-P1-S to 19.67±1.72% for D-P2-S (Figure 2G). Caecum DM also was relatively stable for all slaughter lots, with means ranging from 21.88±1.64% (D-P1-S) to 23.79±6.35% (A-P1-W; Figure 2H).

FW times observed were categorised into three classes to assess their effect on the parameters measured. Long FW times (≥23 h) were observed for rabbits that were slaughtered outside of Quebec in Flinton Ontario where, unfortunately, we did not have access to the processing line. However, statistical analysis revealed a significant interaction between FW time classes and season for blood lactate concentrations (P=0.005). The concentrations were lowest for rabbits slaughtered in summer after intermediate FW times. Overall, blood lactate concentrations were higher in winter than in summer (P=0.005) and when the FW time was short (≤13.5 h; P=0.002). Stomach pH was also higher when the FW time was short (P=0.047), at 2.23±0.66.

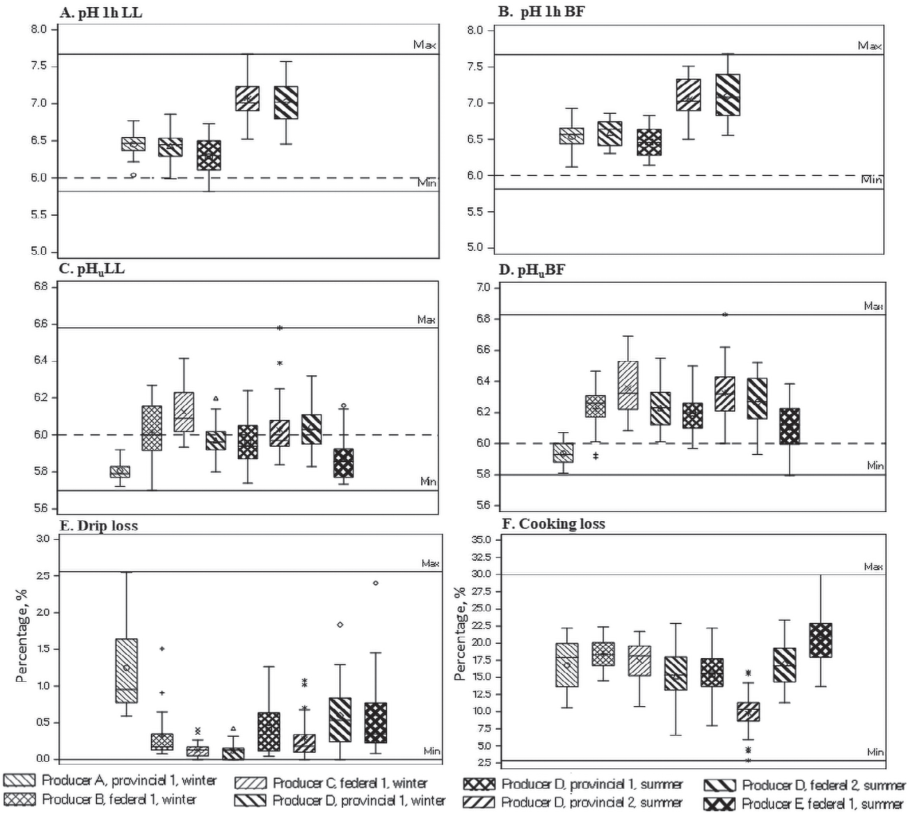

Figure 3: Meat quality characteristics (means±standard deviations) measured from rabbits (n=200) slaughtered in different abattoirs and raised at different farms; pH1hLL (A), pH1hBF (B), pH_uLL (C), pH_uBF (D), drip loss (E) and cooking loss (F). Data for pH1h LL and BF were available only for rabbits slaughtered in Quebec (n=120). Max = maximum and Min=minimum. The pH1hBF and pH_uBF=pH after 1 h and 24 h *post-mortem* of the *Biceps femoris* (BF) muscle, respectively; pH1hLL and pH_uLL=pH after 1 h and 24 h *post-mortem* of the *Longissimus lumborum* (LL) muscle, respectively. Drip loss and cooking loss were from the LL muscle. Dotted lines indicate pH=6.

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