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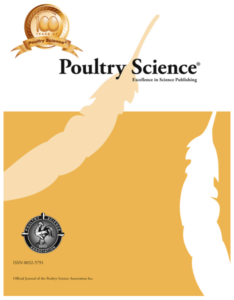

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ADAPTATION TO ALTERNATIVE DIETS IN BROILERS

The kinetics of growth, feed intake, and feed efficiency reveal a good capacity of adaptation of slow- and rapid-growing broilers to alternative diets

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ABSTRACT

Poultry production currently relies on the use of soybean as the main protein and energy source. Reducing its proportion in poultry diets and partly replacing it with local feedstuffs would improve sustainability by reducing dependence on importations and the environmental impact of production. In this study, we evaluated the impact of replacing soybean by sunflower meal, fava bean, canola meal, and dried distillers' grains with solubles on the performance of rapid- and slow-growing chickens. Animals were reared in groups and on the floor. Individual body weight and feed intake data were collected throughout each animal's life thanks to an electronic feed station. At 5 weeks (for broilers) and 12 weeks (for slow-growing chickens), the birds were slaughtered to obtain carcass composition and meat quality data.

Adaptation to the alternative diet was studied separately for each genotype. Firstly, we did ANOVA with diet effect on daily data of individual body weight, feed intake, and feed conversion ratio. Secondly, the variability of performances within the group was studied by ANOVA with effects of diet, period and their interaction. Finally, the correlations between daily performances and final performances at slaughter were calculated to understand the construction of final phenotypes and to identify early indicators of final performances.

The results first showed that the animals adapted well to the alternative diet, mean daily and final performances being mostly similar between the two diets for both genotypes (<3% on final BW). However, daily observations highlighted the critical importance of periods around dietary transitions by showing impacted performances for both genotypes. For example, FCR of LR-AD was 12 to 14% lower during the three days after transitions than during the three days before. It underlined the fact that adapting management of the batch to the alternative diet would be necessary. Correlations between daily and final performances showed that the slaughter performances of rapid-growing chickens were mostly determined by body weight whereas the main criterion was cumulative feed conversion for slow-growing chickens. These correlations also suggested that reserve making might be modified with the alternative diet, with rapid-growing chickens making more glycogen reserves and less fat reserves.

Key Words: alternative feedstuff, Radio frequency identification device, kinetics, feed efficiency, feed intake

INTRODUCTION

Nutrition represents 50 to 70% of the production costs in poultry production (van Horne, 2018). A large part of these costs comes from the reliance on soybean and cereals to feed animals, which often compete with human nutrition (Leinonen and Kyriazakis, 2016). In Europe, soybean is mostly imported from America (European Commission, 2019). Moreover, Lathuillière et al. (2017) reported that soybean is a major cause of deforestation in Brazil and that maize culture requires a large amount of water. There is thus a motivation to reduce the need of these two feedstuffs in poultry diets in order to ensure the sustainability of poultry production in a context of growing world demand. Sunflower and rapeseed meals, by-products of oil industry and Dried Distillers Grains with Solubles (DDGS), by-product of bioethanol production, can be used as alternative sources of proteins. Moreover, their protein content varies according to the method of production (Laudadio et al., 2013). In order to compensate a potential lack of protein, other sources can be added to the diet, such as fava bean, a legume rich in protein with a sustainable worldwide production (Jensen et al., 2010). However, their incorporation is limited due to these beans richness in protease inhibitors, lectins, phenolic compounds, saponins and non-starch polysaccharides that can affect the feed efficiency of the animals by impacting transit time, nutrient degradation or anatomy of the digestive tract for example (Diaz et al. 2006). It has been shown that replacing soybean by a unique feedstuff had negative consequences on performances. For example, replacing soybean by fava bean led to low digestibility in methionine and cysteine (Koivunen et al, 2016). Regarding performances, replacing soybean by fava bean led to a decrease of 3% to 9% in BW with an increase of 5.7 to 8.0% of FCR in standard and Label Rouge chickens (Diaz et al., 2006; Bosco et al., 2013). Replacing it by DDGS improved BW by 2.1% to 3% without modifying FCR (Foltyn et al., 2013). Finally, replacing by canola meal increased FCR by 1% due to a 7.1% decrease of BW and DFI (Toghyani et al., 2016).Taking into account these results, one nutritional strategy could be using a mixture of these alternative feedstuffs (sunflower and canola meals, DDGS, fava beans) instead of a unique feedstuff, assuming that the complementarity between feedstuffs and the limitation of the proportion of each anti-nutritional factor would favor bird adaptation.

We thus evaluated the ability to adapt of two genotypes with different levels of growth rates and nutritional requirements, i.e. rapid-growing standard chickens and slow-growing Label Rouge chickens. We compared the kinetics of mean body weight, feed intake, and feed efficiency, as well as the variability of these traits between the alternative and the control diet from hatch to slaughter. Finally, the analysis of the profiles of correlations between daily data and carcass and meat quality traits measured at slaughter was used to decipher how final phenotypes were constructed in both genotypes and diets and to find early predictors, other than morphological traits such as chicks or chickens' length and weight (Mendes et al., 2007; Moleenar et al., 2009). Measuring these traits in animals reared in individual cages induces a bias as it modifies animal feeding behavior and physical activity. Collective performances collected from birds reared in floor pens do not have this bias, but require a large number of animals for a rather poor statistical power (Alagawany et al., 2017; Gopinger et al., 2014). In order to be representative of production conditions (i.e. with animals reared on the floor and in groups), we thus collected individual feed intake and body weight data with an automaton developed in our lab.

MATERIALS AND METHODS

The present study was performed in agreement with the French National Regulation for human care and use of animals for research purposes and received the authorization number 2018062715076382.V2-15695. Animals were reared at the PEAT INRAE poultry experimental facility (2018, https://doi.org/10.15454/1.5572326250887292E12) registered by the French Ministry of Agriculture under license number C-37-175-1 for animal experimentation (INRAE, Centre Val de Loire, and Nouzilly, France).

Birds and Housing

Two batches of animals were reared successively for this experiment. In the first batch, 80 male SASSO naked neck chickens, a slow-growing genotype dedicated to Label Rouge production (LR) were reared from 1 to 82 days, between September and December 2018. In the second batch, 80 Cobb 500 male chickens (STD) were reared from 1 to 35 days, between January and February 2019. Lighting and temperature schedules for both genotypes are provided in Supp. Table 1. At 1 day of age, the animals were identified with a wing band and an electronic Radio frequency identification device (RFID) chip, then weighed and placed in one pen on a floor covered with wooden chips. The RFID chip was placed at the base of the neck and secured with a plastic string passing under the skin. The pen was divided into two parts by a mesh bulkhead and the animals were dispatched into one of the two groups, with an equal starting weight for both groups. In the first part, the animals were fed with a classic corn-soybean diet (CD) as used in usual commercial conditions. In the second part, the animals were fed with an alternative diet (AD) including less soybean meal and a higher proportion of alternative feedstuffs such as sunflower, rapeseed, and fava bean. The composition of the diets is shown in Table 1. Within a genotype, the diets were isoproteic and isoenergetic. The diets differed between the two genotypes in order to fulfill the needs of slow- or fast-growing broilers. A starter diet was given from hatch to 7 d for STD birds (2850 kcal.kg^{-1} DM; 21.5 % CP) and to 28 d for LR birds (2750 kcal.kg^{-1} DM; 20.0 % CP). A grower diet was given from 8 to 22 d for STD chickens (2900 kcal.kg^{-1} DM; 20.0 % CP) and from 29 to 63 d for LR chickens (2850 kcal.kg^{-1} DM; 18.0 % CP). A finisher diet was given from 23 to 35 d for STD chickens (2950 kcal.kg^{-1} DM; 18.5 % CP) and from 69 to 82 d for LR chickens (2900 kcal.kg^{-1} DM; 16.5 % CP).

Feed Station

Body weight and feed intake were individually and continuously recorded throughout the experiment thanks to an electronic feed station (https://www.feed-a-gene.eu/media/bird-e-automate-de-consommation-alimentaire-pour-volailles). The feeder has a circular shape and consists of 8 independent accesses to feed, without corridors, so that the chickens can express their natural feeding behavior. Each access includes one feed tube, one feed trough, one antenna placed on the top of the feed trough to detect the animal's RFID chip, one scale for feed weight, and one scale to record animal weight placed under the tray on which the animal climbs to eat. The feed troughs and the trays can be changed according to the size of the animals. Raw data obtained from the station are 1) feed weight by access every second, 2) identity of animal, time and access number every time an antenna detects a chip, and 3) mean animal weight during each visit. A visit is defined by consecutive readings of the same chip at the same access with less than 10 seconds between consecutive detections of the chip. All scales and antennas are connected to a central system of data acquisition. Because of electronic problems, data were acquired from 12 days on for the LR chickens. Reliable data could be obtained from day 3 onward for the STD chickens.

Meal Definition and Calculation of Feed Intake per Meal

Consecutive visits were grouped into meals as follows. A meal started each time a new chip is detected and ended when another one was read or when the chip was no longer detected during an interval of two minutes. This limit was defined using preliminary experiments during which we compared the behavior of animals obtained by video recording and data coming from the station (unpublished data). Occasionally, the chip is not detected by the antenna immediately after an animal's arrival or that the signal is lost before an animal's departure. In order to correct for this bias, we calculated the variance of feed weight data by intervals of 10 seconds before the start and after the end of the meal. Video analyses showed that a large variance of feed weight in the station (>0.1 g) is associated with pecking movement in the feed trough, and thus, that an animal is eating. Meal length was extended to include these periods of large variance.

For meal n starting at second S_n and ending at second E_n, feed intake (FI_n) is calculated as the difference of mean feed weight recorded every second between meals n-1 and n and between meals n and n+1. Outlier values of feed weights in these intervals were removed using the Cook's distance with a threshold of 1/k, where k is the number of values in the interval. Feed intake of the meal was obtained as:

$$FI_n = \frac{1}{1+S_n-E_{n-1}} \sum_{i=1+E_{n-1}}^{S_n-1} FW_i - \frac{1}{1+S_{n+1}-E_n} \sum_{i=1+E_n}^{S_{n+1}-1} FW_i \, FI_n$$

$$= \frac{1}{1+S_n-E_{n-1}-NOV_1} \sum_{i=1+E_{n-1}}^{S_n-1} C_i \times FW_i$$

$$- \frac{1}{1+S_{n+1}-E_n-NOV_2} \sum_{i=1+E_n}^{S_{n+1}-1} C_i \times FW_i$$

where FI_n is the feed intake for meal n, FW_i the feed weight at second i, S_n and S_{n+1} the times at which meals n and n+1 start, E_{n-1} and E_n the times at which meals n-1 and n end, C_i a coefficient equal to 0 if the feed intake value at second i was an outlier and 1 if not, NOV_1 and NOV_2 the number of outlier values removed between meals n-1 and n and between means n and n+1, respectively.

When less than 10 seconds separated two successive meals M1 and M2 of respective durations D1 and D2, we did not obtain enough stable feed weight values to calculate a reliable mean feed weight between M1 and M2. A total feed intake (FI_{M1M2}) was calculated as the difference between mean feed weight before the start of M1 and after the end of M2. The feed intake of each meal (FI_{M1}, FI_{M2}) was then calculated according to the respective duration of each meal as:

$$FI_{M1} = \frac{D1}{D1 + D2} \times FI_{M1M2}$$

$$FI_{M2} = \frac{D2}{D1 + D2} \times FI_{M1M2}$$

In order to check the reliability of feed intake measured by the station, each time the feed tubes were refilled, the added quantity of feed was weighed and compared with the data obtained from the feed station after refilling.

The daily feed intake (DFI) was calculated as the sum of the feed intake of all meals eaten during a 24-hour period.

Body weight and daily gain calculation

Before calculating individual body weight (BW) on the different days, abnormal data were removed (weights below 25 g and above three times the mean BW of the previous day). Data outside the interval deviating from the mean by more than three standard deviations were then removed. Body weight (BW) was then calculated as the mean of all available weight data during a day for each animal.

In order to check the reliability of animal weight data from the station, animals were weighed manually, weekly for standard chickens and every two weeks for Label Rouge chickens.

Average Daily Gain and Feed Conversion Ratio Model

In order to smooth the daily variations of FCR, a moving average was used to calculate the daily feed conversion ratio, as already done in pigs (Huynh-Tran et al., 2017). Among the different possibilities tested, a moving average daily gain over 5 days (ADG) led to the lowest number of null or negative FCR values and the lowest daily coefficient of variation of FCR among individuals. Daily FCR was thus calculated as:

$$ADG_{ij} = \frac{BW_{i(j+2)} - BW_{i(j-2)}}{5}$$

$$DFCR_{ij} = \frac{DFI_{ij}}{ADG_{ij}}$$

with BW_{ij} being the mean weight of the animal i on day j and DFI_{ij} the daily feed intake of animal i for day j.

Cumulative feed conversion ratio

The daily cumulative feed conversion ratio for animal i on day j ($DCFCR_{ij}$) was calculated as the ratio of cumulated feed intake between the first day of data collection and day j to the weight gain over the same period:

$$DCFCRij = \frac{\sum_{k=1}^{k=j} DFI_{ik}}{BW_{ij} - BW_{i1}}$$

with DFI_{ik} being the daily feed intake of animal i for day k and BW_{ij} the body weight of animal i on day j.

Carcass Composition and Meat Quality

At 35 d for STD and 82 d for LR chickens, the animals were weighed after 8 hours of feed withdrawal and transferred to the slaughterhouse of the PEAT INRAE poultry experimental facility (2018, https://doi.org/10.15454/1.5572326250887292E12).

After 24 hours of chilling, body composition was characterized by measuring breast meat yield (BMY), *Pectoralis major* yield (PMY), *Pectoralis minor* yield (PmY), abdominal fat yield (AFY) and thigh yield (TY) in relation to body weight (BW). Except for the abdominal fat which was taken entirely, only the right part of the animals was taken and the weight of the different parts was doubled to obtain those yields. Meat quality was evaluated on the *Pectoralis major* muscle by measuring lightness (L*), yellowness (b*) and redness (a*) of the meat with a miniscan spectrocolorimeter (Hunterlab, Reston, VA, USA) and ultimate pH (pHu) with a portable pH meter (model 506, Crison Instruments SA, Alella, Barcelona, Spain).

Analysis of Variance

Analyses were done separately for each genotype, since the experiments had been conducted independently. The effect of the diet was first estimated separately for each day by applying the PROC ANOVA procedure of SAS 9.4 (2013) with diet as the single fixed effect to data calculated for each day: body weight (BW), average daily gain (ADG), feed intake (DFI), feed conversion ratio (DFCR), and cumulative feed conversion ratio (DCFCR). In a second step, three rearing phases were defined according to the feeding period: starter (S), grower (G), and finisher (F) phases when the animals were fed with the starter, grower, and finisher diets, respectively. The birds’ response to the diet depending on the feeding period was then analyzed with the following ANOVA model:

$$y_{ijk} = D_i + P_j + DP_{ij} + e_{ijk}$$

with y_{ijk} being the trait for animal k with diet i and period j, D_i the fixed effect of diet i, P_j the fixed effect of phase j (i.e. starter diet, grower diet, and finisher diet), DP_{ij} the interaction between diet i and phase j and e_{ijk} the residual for animal k. Both individual daily phenotypes and their coefficients of variation (calculated within-day) were analyzed, in order to consider the birds' response in term of mean and variability.

Diet effect on slaughter traits was estimated by one-way ANOVA within each genotype, diet being the only fixed effect of the model.

Correlations with Daily Data

Correlations between the daily data (BW, ADG, DFI, DFCR) and the data measured at slaughter (final BW and final cumulative feed conversion ratio ($CFCR_f$), BMY, PMY, PmY, AFY, TY, L, a*, b* and pHu) were calculated by using the Rcorr function of the package Hmisc of the R software (R Core team, 2017).

RESULTS

Validation of Growth and Feed Intake Data

On average, the absolute value of the difference between manual and automatically recorded data of body weight was low (2.2%). Similarly, the difference between feed weight displayed by the feed station and the real feed weight at each refilling was low (0.3 %).

Diet effect on growth parameters

Effect on the mean The ADG of LR chicken showed the same trends of kinetics in both diets, with a first phase of increasing, followed by a plateau and a last phase of decreasing (Fig. 1c). As the length of the plateau lasted 10 days with the AD diet and 20 days with the CD diet, ADG decreased earlier with AD (after 55 d) than with CD (after 70 d). The ADG of animals fed with the AD diet was 8 to 28% higher between 15 and 33 d (starter phase and start of grower phase), and 8 to 45% higher between 48 and 57 d (grower phase). In contrast, from 60 to 68d (finisher phase), animals fed with AD showed a 10 to 40% lower ADG than with the CD diet (Supp. Table 3). This kinetics was consistent with a slight advantage of BW for birds fed AD from 14 to 40 days and from 49 to 61 days (4.3 to 8.5%) and the absence of difference after this age (Fig. 1a, Supp. Table 2). Unlike the LR chickens, ADG increased until the end of the experiment for both diets in STD chickens (Figure 1d), which are slaughtered at a much younger age than LR chickens. Diet had a much smaller impact in STD than in LR chickens, as shown by the global analysis by feeding period in which diet effect on ADG and BW was significant in STD chickens, but not in LR chickens (Table 2). Only during a 5-days period between 27 and 31 d was ADG 5 to 15% higher with AD than with CD (Supp. Table 3). Consistent with the absence of difference in ADG between diets, the growth curves of STD birds were similar between the two diets (Fig. 1b).

Effect on the variability. The CV for ADG in STD chickens and for BW in both genotypes was stable and low at all ages, usually lower than 20% (Fig. 1a, 1b, 1d). In contrast, CV for ADG in LR chickens varied with age for both diets, being stable until 35 days and increasing from 35 to 82 d up to values as high as 50% (Fig. 1c). Despite similar trends, the kinetics of the CV of ADG during the three periods differs between the two diets. For the AD diet, CV increased from the starter to the grower diets while the increase occurred between the grower and finisher phases for the CD diet (Table 3). A significant interaction between diet and phase was also observed on BW variability in LR chickens. Indeed, LR animals fed with AD were 14.3% less variable than those fed with CD, only during the grower phase, whereas STD chickens fed with AD showed a 27.1% higher variability than those fed with CD over the whole period (Table 3).

Diet effect on feed intake and efficiency traits.

Effect on the mean. For both diets and genotypes, as expected, DFI increased with age (Fig. 2). No difference was observed between diets in LR chickens, except at 20, 26, 28 and 42 days, with no clear advantage for CD or AD (Fig. 2a, Supp. Table 4). In contrast, in STD chickens, DFI was continuously higher with AD than with CD, but the difference was significant only during the 4th week, before the last diet change (Fig. 2b, Supp. Table 4). During this period, DFI was 7.4 to 12.4% higher with AD than with CD. Summarizing information by feeding period, we observed a diet effect in STD chickens, DFI being 3.8% higher for chickens fed with AD than with CD (Table 2).

DFCR was highly variable between consecutive days, especially in LR chickens (Fig. 2c, 2d, Supp. Table 5), while curves for DCFCR were smoothened (Fig. 3a, 3b). Thus, in LR chickens DFCR was significantly better with AD for several days around the first diet change (17-32 d), but better for CD for several days around the second diet change (60-68 d), whereas a continuous difference was observed for DCFCR between 17 to 40 days, AD birds being 6.8 to 13% more efficient than CD birds during this period (Supp. Table 6). Consistent with the other findings, when summarized by nutrition periods, diet effect was seen only during the starter phase for DFCR, while it was seen for both the starter and grower phases for DCFCR.

Like the LR chickens, differences of DFCR between diets in STD chickens were sporadic and limited to 5 days between 9 and 25 d (Fig. 2d, Supp. Table 5). During these 5 days, DFCR was 10.7 to 14.7 % lower for CD birds. This was confirmed by the analysis of DFCR by period (Table 2), for which a diet by period interaction was significant, due to a positive effect of the AD diet, but only during the starter phase. When considering DCFCR, diet effect was no longer significant (Fig. 3b, Table 2).

Effect on the variability. Change with age of DFI, DFCR, and DCFCR coefficients of variation differed between traits and genotypes, although similar trends were found between diets. The general trend was an increase in the CV of the 3 traits with age in LR chickens (Fig. 2a, 2c, 3a) and a decrease in STD chickens (Fig. 2b, 2d, 3b). Within each genotype, the CV of DFI and DFCR of LR increased with time, with a steeper slope in the starter phase than in the grower and finisher phases. The CV of DCFCR of LR-CD animals increased continuously whereas it remained stable after the first change of diet for LR-AD. In STD chickens, after a peak with high CV values during the starter phase, the CV decreased and stabilized during the grower and finisher phases for DFI and DFCR. A similar profile was observed for DCFCR, although the decrease in CV was more pronounced with AD than with CD.

Differences of variability between diets for DFI, DFCR, and DCFCR were strong in STD (Fig. 2, Fig. 3; Table 3). Alternative diet led to a decrease in the variability of those performances during the grower (DFI: -49%, DFCR: -30.4%, DCFCR: -44%) and finisher phases (DFI: -20%, DFCR: -30.4%, DCFCR: -58.4%) in STD chickens. In the case of LR chickens, the CV differed between diets during these phases for DFI and DCFCR traits. When significant, performances were less variable with the AD than with the CD diet.

Diet effect on carcass composition and meat quality

Body composition and meat quality traits were not affected by diet in LR chickens, except for thigh yield, which was slightly higher with the AD than with the CD diet (Table 4). In STD chickens, the abdominal fat percentage was significantly lower with AD compared to CD (-14%, $P<0.001$). When fed with the CD diet, STD chickens had a more acidic (lower pHu) and yellower (higher b* value) meat than those fed with AD. No diet effect was observed on the variability of the studied traits regardless of the genotype (data not shown).

Correlations between Daily Traits and Cumulative Feed Conversion Ratio or Slaughter Traits (Supp. Table 7).

Feed Intake. On the whole, DFI was positively correlated with the $CFCR_f$ (Figure 4). In LR chickens, the correlation was lower during the starter phase (0.32 with AD, 0.22 with CD), increased during the grower phase (0.44 with AD, 0.47 with CD), and remained stable during the finisher phase (0.50 with AD, 0.61 with CD). In STD chickens, DFI and $CFCR_f$ were poorly correlated during the starter phase (on average 0.23 with AD and 0.40 with CD). During the grower phase, the correlation became stable and reached a higher level with CD (0.62 on average) than with AD (0.21 on average). During the finisher phase, a high correlation between DFI and $CFCR_f$ was maintained for STD chickens fed with CD diet (0.61), whereas it increased for those fed with the AD diet (0.53).

On the other hand, a moderate correlation with slaughter weight was observed for LR chickens starting at the first change of diet, stronger for those fed with AD (0.36) than with CD (0.24). We also observed a moderate positive correlation between DFI and breast final pH for these animals, particularly during the finisher phase (0.23 with CD, 0.32 with AD), whereas this correlation was low and negative in STD chickens (-0.04 with CD, -0.13 with AD). In STD chickens fed AD, the correlation between DFI and pHu was strongest at the beginning of the grower phase (-0.30 between 25.7 and 40 % of the age at slaughter). During the same period, DFI was positively correlated with slaughter weight, as well as breast and abdominal fat yields (0.50, 0.40, and 0.30, respectively), whereas these correlations became weak during the finisher phase.

Body Weight. As expected, the correlation between daily BW and slaughter weight increased with time to reach 1 on the last day (Figure 5). Even at the youngest ages, this correlation was found to be higher than 0.50, independently of the treatment. Correlations between body weight and other slaughter traits were weak and rather stable with age in LR chickens. We only observed moderate positive correlations in LR-AD birds with fatness during the starter phase (0.32) and breast yield during the finisher phase (0.31). During this period, a moderate, positive correlation was also found with thigh yield in LR-CD chickens (0.23). In contrast, corresponding correlations varied with age or diet in STD chickens. Thus, correlations with meat ultimate pH or $CFCR_f$ were stable across ages, but more pronounced with the AD than with the CD diet (-0.39 and 0.01 for pHu and -0.43 and -0.27 for CFCRf, respectively). While weak correlations were found between daily BW and thigh yield for both diets, different profiles were found for fat yield, the correlation being stable and moderate (0.32) for STD-CD chickens, but low for STD-AD chickens. Finally, correlations between daily BW and breast yield increased with age and reached quite significant values during the finisher phase in STD chickens (0.58 with AD, 0.56 with CD).

Cumulative Feed Efficiency. As expected, the correlation between DCFCR and $CFCR_f$ increased with age to reach 1 at slaughter (Figure 6). For LR chickens, better efficiency was associated with a higher breast yield and weight at slaughter, especially with CD (-0.29 and -0.47, respectively). Similar trends were observed for STD chickens during the finisher phase (-0.27 and -0.36 with AD, -0.33 and -0.34 with CD). Abdominal fat percentage and thigh yield were poorly correlated with DCFCR. Finally, a lower breast meat pH and thus more acidic meat was associated with a lower DCFCR, at least for LR-CD chickens during the grower and finisher phases (0.40). This trend was not found in STD chickens.

DISCUSSION

The aim of our study was to determine the capacity of adaptation of slow and fast-growing chickens to a diet containing a mixture of alternative feedstuffs, in real conditions of production, i.e. on floor and in group. Previous studies showed that FI recorded in cages differed from FI recorded on the floor. However, since many factors such as sex, diet composition, and cage or litter material influenced FI, BW, and FCR, the results of these studies were inconsistent (Akpobome and Fanguy, 1992; Plavnik et al., 2002; Santos et al., 2008; Simsek et al., 2014; Zhao et al., 2015). Automatons have already been developed to record FI on the floor. However, none are capable of simultaneously measuring FI and body weight throughout the whole life of animals and without limiting the expression of natural behaviours due to the presence of systems of isolation of animals (Bley and Bessei, 2008; Howie et al., 2009; Tu et al., 2011; Basso et al., 2014; Yan et al., 2019). Thus, only synthetic FCR could be obtained with those automatons while ours is able to measure the kinetics of these types of traits.

The current study showed that differences between the two diets are moderate in terms of final performances in both genotypes, indicating that chickens are able to adapt to a diet composed of a mixture of alternative feedstuffs, with a higher proportion of wheat than corn and a partial replacement of soybean by DDGS, rapeseed, fava bean, and sunflower meals. The literature on the adaptation of chickens to a partial substitution of soybean by these feedstuffs showed contrasted results both in slow- and fast-growing chickens. Depending on the study, alternative diets led to better, similar, or worse FCR (Alagawany et al., 2017; Bosco et al., 2013; Diaz et al., 2006; Foltyn et al., 2013; Koivunen et al, 2016; Méda et al., 2015; Toghyani et al., 2017). An absence of effect on FCR does not necessarily mean that there is no effect on performances that contribute to FCR. For example, for the LR chickens in this study as well as for the STD chickens in Diaz et al. (2006), the absence of effect of the alternative diet on FCR was due to a joint increase in FI and BW rate with AD. This discrepancy between studies could be due to many factors such as the animals (genotype, age, sex) and the feedstuffs (quality, fiber percentage, and transformation process). The most striking difference in the adaptability of chickens to the alternative diet was found in the variability of performances. Animals fed with the alternative diet had more homogeneous performances for FI and daily and cumulative FCR, especially in STD chickens.

Another interest of the daily data is that it highlighted the importance of transition periods around diet changes. Modifications of performances around the time of the diet change could indicate a difficulty in adapting to the new diet if it appears after the transition or a necessity to change the diet earlier if it appears before the transition. These modifications are genotype and diet dependent and could be linked to several factors. For example, some diets has been shown to modify the development of digestive tract and thus its capacity of absorption (Nassiri Moghaddam et al., 2012). A difference of palatability between successive diets can be a cause of variations occurring after transitions. The drop we observed in weight gain despite the continuous increase in FI before the second diet change for the LR-AD chickens can suggest that the animals' needs are not fulfilled anymore and that the diet change should have been done 3 to 4 days earlier, whereas this is not the case with the classic diet or with the STD chickens. Similarly, the strong increase in the coefficient of variation of FI in STD chickens before the first diet change may indicate that this diet change occurs too late for some of the birds. This daily information could also help us to identify animals that are resilient to disturbances in their environment, especially around times of dietary transitions.

Finally, the correlation profiles between daily measurements and phenotypes measured at slaughter are useful to understand early indicators of final phenotypes. These indicators differ between genotypes and diets, which also highlights the fact that final phenotype construction differs between genotypes and diets. For example, DFI is a good indicator of final FCR in STD chickens fed with CD, as the correlation between both traits is high as early as the first diet change. In contrast, when fed with AD, the correlation between both traits increased later, after the second diet change. The correlations between BW, AFY, BMY, and breast meat pHu in STD chickens also show that animals do not respond to CD and AD in the same way. For instance, although increased BW at early ages appears to be an indicator of increased breast meat yield at slaughter for both diets, it also seems to be associated with higher muscle glycogen reserves which are the cause of lower ultimate pH (Le Bihan-Duval et al., 2008) for birds fed the AD, and of higher abdominal fatness for birds fed the CD. This is maybe why the correlation between BW at an early age and $CFCR_f$ seems a little bit lower with CD than with AD, the energy cost of glycogen deposition in breast muscle being lower than the energy cost of abdominal fat deposition. In the current study, we also found indications showing that better FCR at early ages could be a predictor of higher breast development at slaughter in LR chickens, and could be of interest to limit the production costs of this alternative production and to satisfy the needs of the growing market of cuts and further processed products.

To conclude, both genotypes showed a good ability to adapt to alternative diets. Taking into account the costs of feedstuffs and mean feed intake, using these alternative diets would increase feed cost by 1.5% for LR chicken and 3.4% for the STD chicken, close to the 0.5-4% of increasing already found in literature (Nguyen et al., 2011). This represents an increase of respectively 0.9% and 2% of the total production costs (Chenut, 2016). However, it has been shown that replacing soybean by local feedstuffs can decrease greenhouse gas emission up to 41% depending of the percentage of replacement and the genotype (Méda et al., 2015). This element is important to evaluate the environmental impact of both diets which has to be taken into account in the perspective of making poultry meat production more sustainable.

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Table 1. Composition and age of distribution of classical (CD) and alternative (AD) diets for standard (STD) and Label Rouge (LR) genotypes.

Table 2. Diet and period effects on body weight (BW), average daily gain (ADG), feed intake (DFI), feed efficiency (DFCR) and cumulated feed efficiency

	STD						LR					
	CD			AD			CD			AD		
Ingredient (%)	1-7 d	8-22 d	23-35 d	1-7 d	8-22 d	23-35 d	1-28 d	29-63 d	64-82 d	1-28 d	29-63 d	64-82 d
Corn	30.650	35.970	39.800	20.420	18.890	23.500	29.620	42.920	46.620	18.250		16.950
Wheat	30.100	30.100	30.100	30.100	30.100	30.100	38.550	30.100	30.100	40.100	57.950	45.100
Fava bean					12.000	13.000				10.000	13.000	12.000
Soybean meal	32.860	28.520	25.150	24.220	11.610	7.130	28.080	23.160	19.840	18.540	6.730	5.200
Rapeseed meal				5.000	5.000	8.000				5.000	5.000	5.000
Wheat DDGS				3.000	5.000	5.000				3.000	5.000	
High fiber sunflower meal				8.120	7.730	5.190					5.020	8.000
Soybean oil	2.210	1.900	1.990	5.000	5.000	5.000		0.360	0.570	1.420	3.820	3.800
Corn gluten												1.100
Calcium carbonate	0.710	0.169	0.002	0.655	0.142		0.600	0.274	0.300	0.590	0.390	0.350
Bicalcic phosphate	2.160	1.850	1.540	2.050	1.730	1.400	1.970	1.870	1.560	1.880	1.540	1.350
Salt	0.236	0.207	0.211	0.192	0.150	0.158	0.270	0.246	0.280	0.254	0.180	0.230
Vitamins and minerals	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400	0.400
Sodium carbonate	0.135	0.173	0.175	0.196	0.262	0.250	0.100	0.129	0.081	0.114	0.227	0.160
DL-Methionine	0.269	0.275	0.231	0.234	0.285	0.234	0.204	0.211	0.114	0.207	0.230	0.114
HCL Lysine	0.176	0.264	0.250	0.287	0.414	0.392	0.154	0.243	0.125	0.183	0.373	0.214
Threonine	0.076	0.111	0.094	0.088	0.157	0.135	0.052	0.087	0.010	0.062	0.140	0.032
Valine	0.021	0.061	0.041	0.038	0.130	0.106						
Tryptophane						0.005						
Calculated composition												
AMEn, kcal/kg	2850	2900	2950	2850	2900	2950	2750	2850	2900	2750	2850	2890
CP, g/kg	215.0	200.4	187.1	215.0	194.3	181.3	200.0	179.8	165.0	200.0	179.0	164.9
Lys, g/kg	11.200	10.900	10.000	11.200	10.900	10.000	10.000	9.500	7.800	10.000	9.500	7.810
Met + Cys, g/kg	8.400	8.170	7.500	8.400	8.170	7.500	7.500	7.200	6.000	7.500	7.200	6.000
Trp, g/kg	2.280	2.060	1.890	2.280	1.840	1.700	2.100	1.790	1.620	1.990	1.730	1.490

(DCFCR).

			Label Rouge chickens					Standard chickens				
			BW (g)	ADG (g.d^{-1})	DFI (g.d^{-1})	DFCR	DCFCR	BW (g)	ADG (g.d^{-1})	DFI (g.d^{-1})	DFCR	DCFCR
LS Means^{3}	Diet^{1}	AD	1472^{a}	31.7^{a}	98.3	3.09^{b}	1.95^{b}	724	47.8	93.6b	1.79^{b}	1.44
		CD	1431^{b}	31^{b}	98.1	3.20^{a}	2.05^{a}	727	46.8	90.2a	1.86^{a}	1.46
	Period^{2}	S	370^{c}	21.3^{c}	46.5^{c}	2.32^{c}	1.70^{c}	121^{c}	17.3^{c}	27.9^{c}	1.67^{c}	1.25^{b}
		G	1366^{b}	37.9^{b}	104.2^{b}	2.82^{b}	1.94^{b}	498^{b}	42.8^{b}	77.7^{b}	1.85^{b}	1.53^{a}
		F	2620^{a}	35.0^{a}	143.8^{a}	4.28^{a}	2.36^{a}	1558^{a}	81.9^{a}	170.1^{a}	1.96^{a}	1.57^{a}
	Diet×Period	AD×S	381	22.1^{d}	45.9	2.20	1.64^{e}	117	17.5	28.1	1.54^{d}	1.26
		AD×G	1398	38.6^{a}	105.8	2.80	1.86^{c}	493	43.1	76.6	1.86^{bc}	1.51
		AD×F	2639	34.5^{c}	143.1	4.26	2.35^{a}	1562	82.9	174.2	1.97^{a}	1.55
		CD×S	359	20.5^{d}	47.1	2.44	1.77^{d}	125	17.1	27.7	1.79^{c}	1.24
		CD×G	1334	37.1^{b}	102.6	2.84	2.02^{b}	503	42.4	76.8	1.85^{c}	1.56
		CD×F	2601	35.5^{c}	144.5	4.30	2.38^{a}	1554	80.9	166.0	1.95^{ab}	1.57
P-value	Diet		0.003	0.020	0.870	0.010	0.001	0.811	0.090	0.050	0.030	0.506
	Period		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Diet×Period		0.277	0.001	0.107	0.100	0.001	0.842	0.432	0.070	0.001	0.523

[1] AD: alternative diet; CD: control diet

[2] S: starter diet (d1 to d7 for STD, d1 to d28 for LR); G: grower diet (d8 to d22 for STD, d29 to d63 for LR); F: finisher diet (d23 to d35 for STD, d69 to d82 for LR)

[3] within effect, trait and genotype, LS means values with different superscripts are significantly different (*P*<0.05)

Table 3. Diet and period effects on the coefficient of variation of body weight (BW), average daily gain (ADG), feed intake (DFI), feed efficiency (DFCR) and cumulated feed efficiency (DCFCR) for each chicken genotype.

			Label Rouge chickens					Standard chickens				
			BW (%)	ADG (%)	DFI (%)	DFCR (%)	DCFCR (%)	BW (%)	ADG (%)	DFI (%)	DFCR (%)	DCFCR (%)
LS Means[3]	Diet[1]	AD	8.7^{b}	20.3	21.6^{a}	28.0^{a}	18.0^{b}	10.8^{a}	13.0	20.5^{b}	23.9^{b}	33.1^{b}
		CD	9.5^{a}	22.6	27.4^{b}	31.0^{b}	24.0^{a}	8.5^{b}	12.9	25.0^{a}	34.3^{a}	43.0^{a}
	Period[2]	S	8.8^{b}	14.1^{c}	15.9^{a}	19.3^{a}	16.1^{c}	8.5^{b}	13.4	26.9^{a}	42.3^{a}	52.4^{a}
		G	9.1^{ab}	20.5^{b}	25.8^{b}	32.0^{b}	22.4^{b}	10.0^{a}	13.0	22.0^{b}	23.4^{b}	36.1^{b}
		F	9.3^{a}	29.8^{a}	31.8^{c}	37.0^{c}	34.5^{a}	10.4^{a}	12.5	19.4^{c}	21.5^{c}	25.6^{c}
	Diet×Period	AD×S	8.7^{c}	11.1^{d}	16.1^{d}	16.2^{c}	15.2^{e}	9.8	13.6	26.6^{a}	37.6	58.4^{a}
		AD×G	8.4^{c}	21.7^{bc}	23.9^{c}	32.4^{b}	19.9^{c}	11.5	13.5	17.7^{c}	16.7	26.1^{c}
		AD×F	9.0^{bc}	28.1^{ab}	24.9^{bc}	35.2^{ab}	18.8^{cd}	11.2	11.9	17.2^{bc}	17.2	14.7^{d}
		CD×S	8.9^{c}	17.1^{cd}	15.7^{d}	22.5^{c}	17.0^{de}	7.3	13.2	27.2^{a}	47.0	46.3^{ab}
		CD×G	9.8^{a}	19.3^{c}	27.7^{b}	31.4^{b}	24.8^{b}	8.6	12.3	26.4^{a}	30.0	46.1^{a}
		CD×F	9.7^{ab}	31.6^{a}	38.7^{a}	38.8^{a}	30.1^{a}	9.6	13.3	21.5^{ab}	25.8	36.4^{b}
P-value	Diet		0.001	0.130	0.001	0.020	0.001	0.001	0.940	0.001	0.001	0.001
	Period		0.010	0.001	0.001	0.001	0.001	0.001	0.615	0.001	0.001	0.001
	Diet×Period		0.002	0.046	0.001	0.036	0.001	0.192	0.105	0.020	0.276	0.001

[1] AD: alternative diet; CD: control diet

[2] S: starter diet (d1 to d7 for STD, d1 to d28 for LR); G: grower diet (d8 to d22 for STD, d29 to d63 for LR); F: finisher diet (d23 to d35 for STD, d69 to d82 for LR)

[3] within effect, trait and genotype, LS means values with different superscripts are significantly different ($P<0.05$)

Table 4. Body composition and meat characteristics of label rouge (LR) and Cobb500 (STD) genotypes fed with either the alternative diet or the classical diet.

Trait[1]	Genotype	LS Means Diet[2] AD	LS Means Diet[2] CD	*P*-value of diet effect
Slaughter weight (g)	LR	3010	2951	0.371
	STD	2334	2355	0.720
AFY (%)	LR	3.53	3.95	0.080
	STD	1.57	1.83	0.001
BMY (%)	LR	14.56	14.40	0.550
	STD	20.44	20.40	0.970
TY (%)	LR	25.64	25.16	0.030
	STD	22.58	22.94	0.100
L*	LR	48.76	49.14	0.520
	STD	47.99	47.38	0.250
a*	LR	-1.06	-1.09	0.860
	STD	-0.51	-0.72	0.100
b*	LR	9.82	9.48	0.230
	STD	8.02	8.89	0.001
pHu	LR	5.74	5.72	0.350
	STD	5.89	5.79	0.001

[1] AFY: abdominal fat yield, BMY: breast muscle yield, TY: thigh yield, L*: breast meat luminance, a*: breast meat redness, b*: breast meat yellowness, pHu: breast meat pH 24 h after slaughter

[2] AD: alternative diet; CD: control diet

Figure 1. Kinetics of the mean (solid line) and of the coefficient of variation (dotted line) for BW (1a for LR; 1b for STD) and ADG (1c for LR; 1d for STD) for chickens fed with classical diet (in red) or alternative diet (in blue). Black vertical lines are indicating diet changes. Green horizontal lines are indicating the periods of significance of the diet effect.

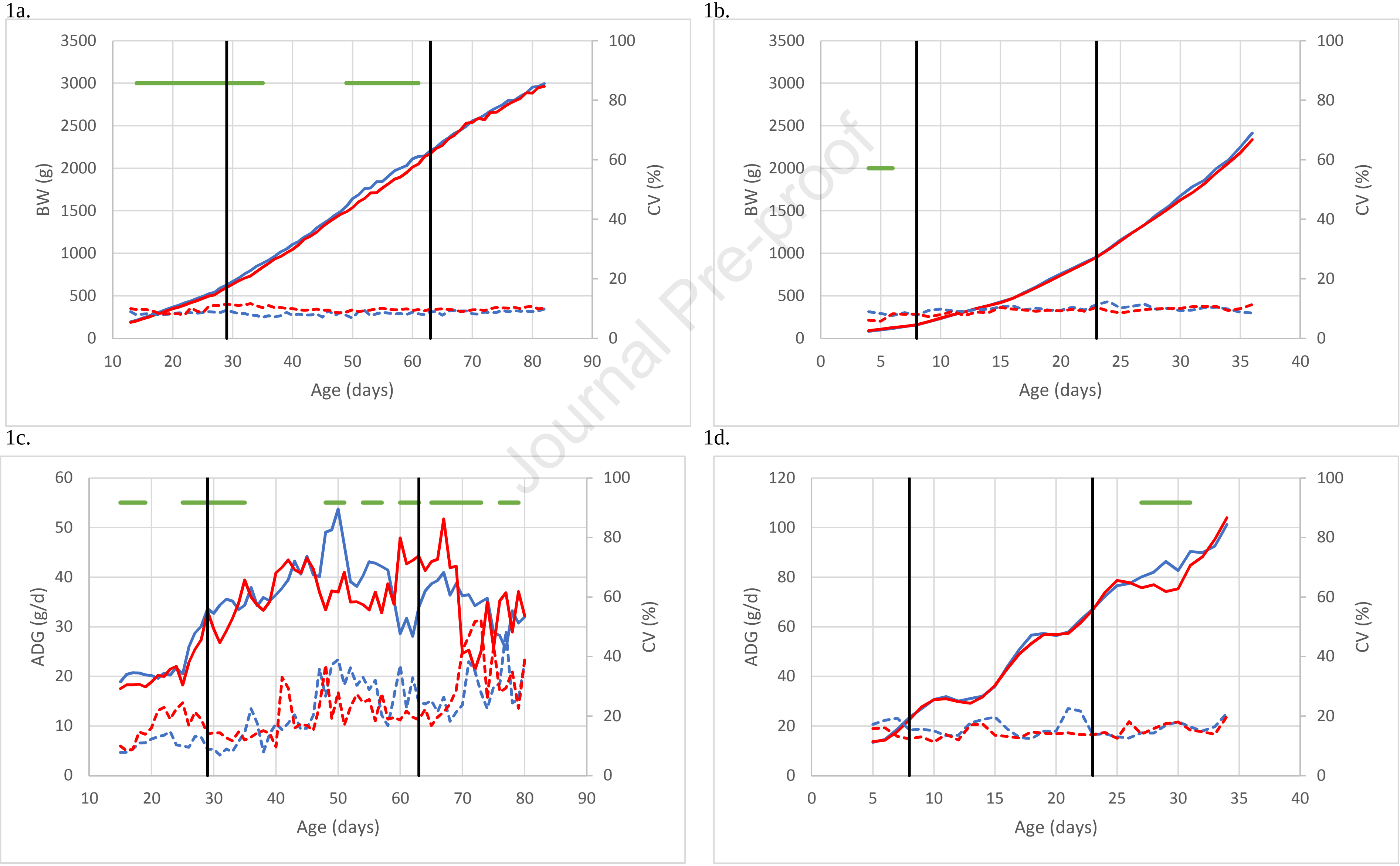


Figure 2. Kinetics of the mean (solid line) and of the coefficient of variation (dotted line) for DFI (2a for LR; 2b for STD) and DFCR (2c for LR; 2d for STD) for chickens fed with classical diet (in red) or alternative diet (in blue). Black vertical lines are indicating diet changes. Green horizontal lines are indicating the periods of significance of the diet effect.

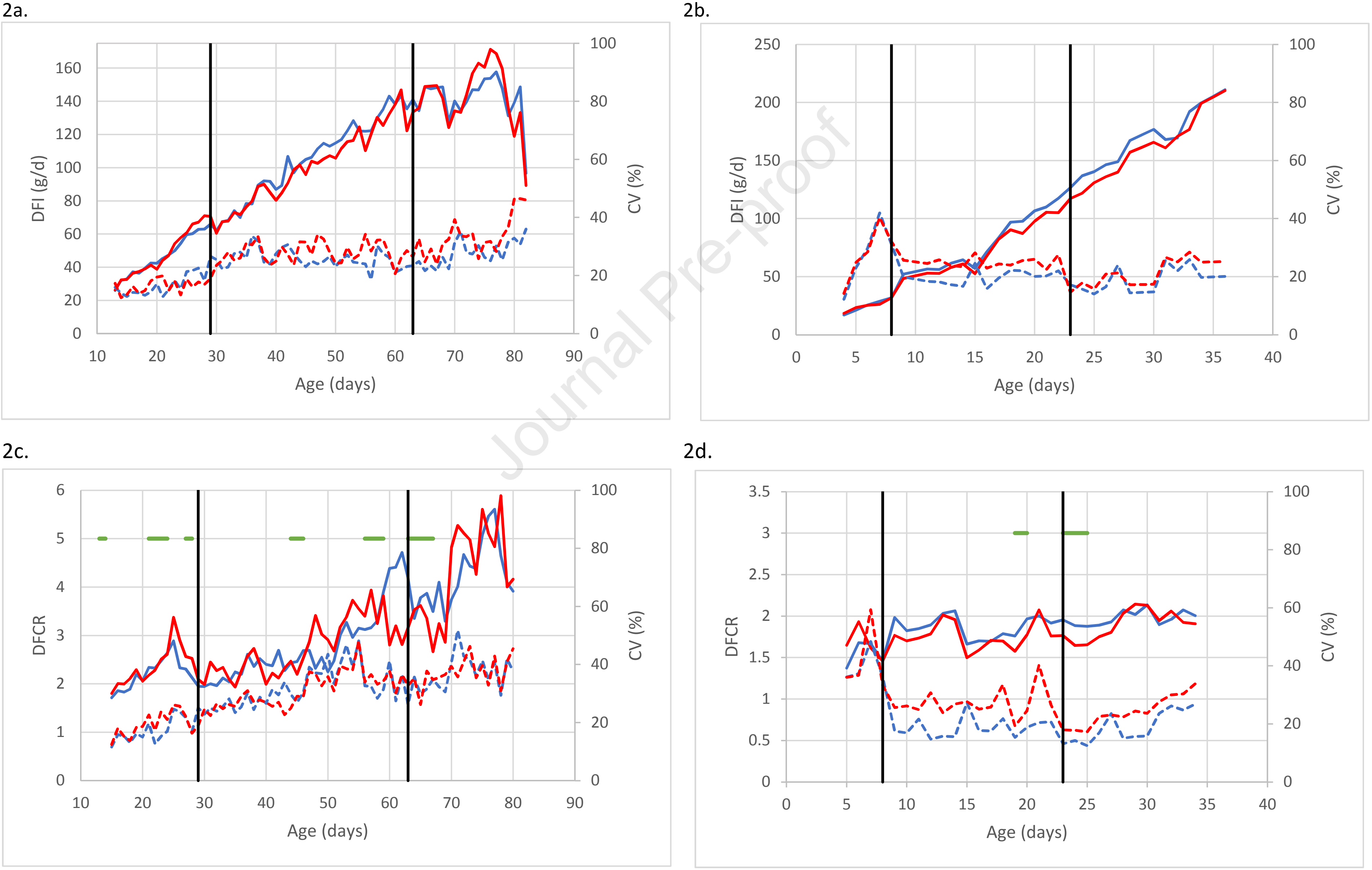
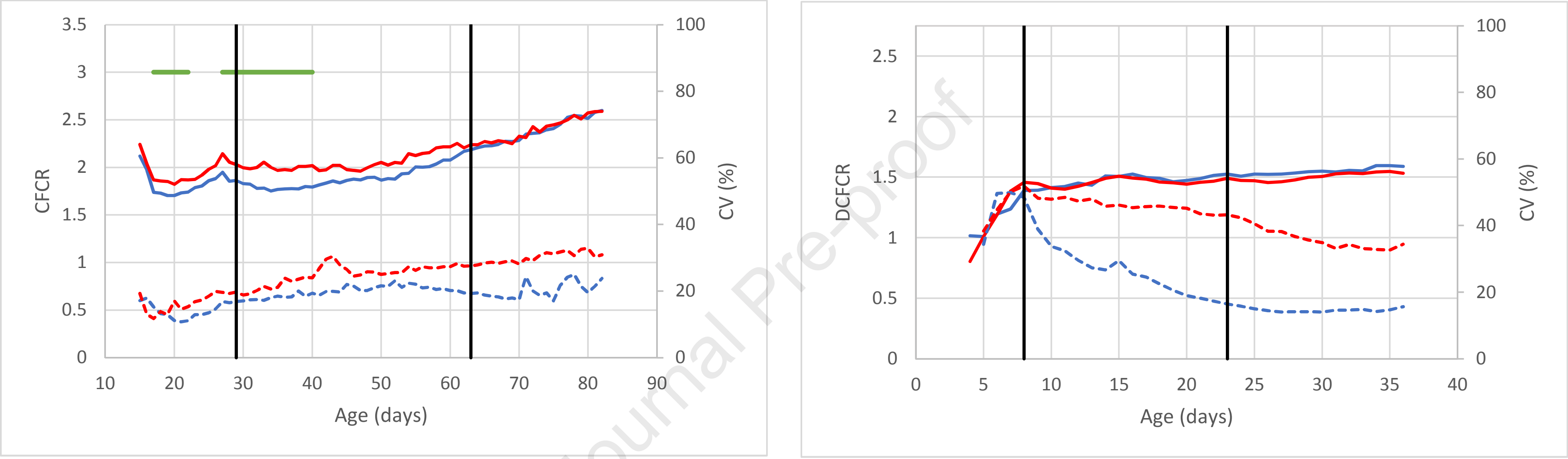


Figure 3. Kinetics of the mean (solid line) and of the coefficient of variation (dotted line) for DCFCR (1a for LR; 1b for STD) for chickens fed with classical diet (in red) or alternative diet (in blue). Black vertical lines are indicating diet changes. Green horizontal lines are indicating the periods of significance of the diet effect.

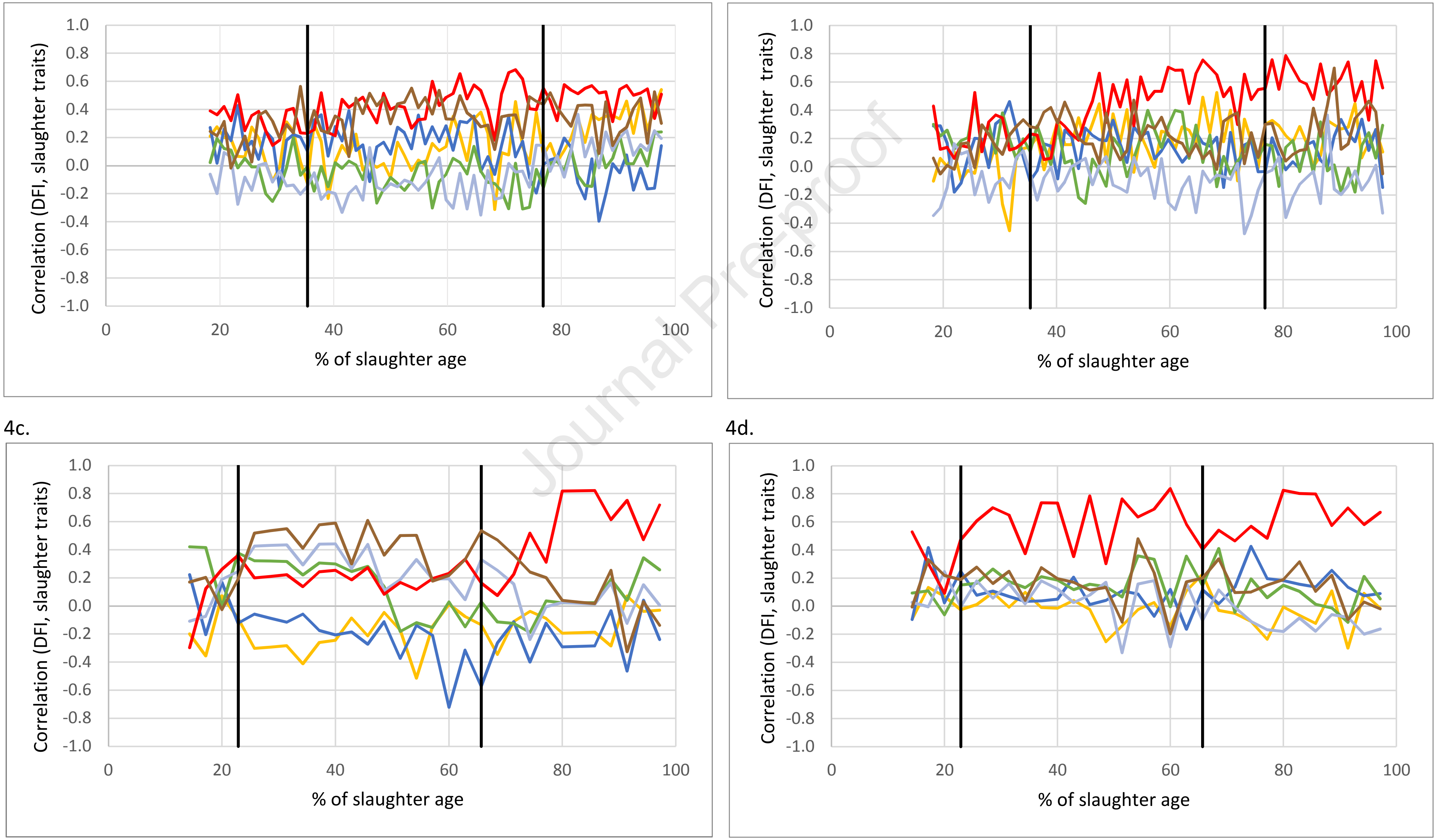

3a.

3b.

Figure 4. Profiles of correlations for LR (a: AD, b: CD) and STD (c: AD, d: CD) chickens between DFI and traits measured at slaughter (pHu in yellow, thigh yield in dark blue, AFP in green, BMY in light blue, CFCRf in red, BW at slaughter in brown). Black lines indicate diet changes.

4a.

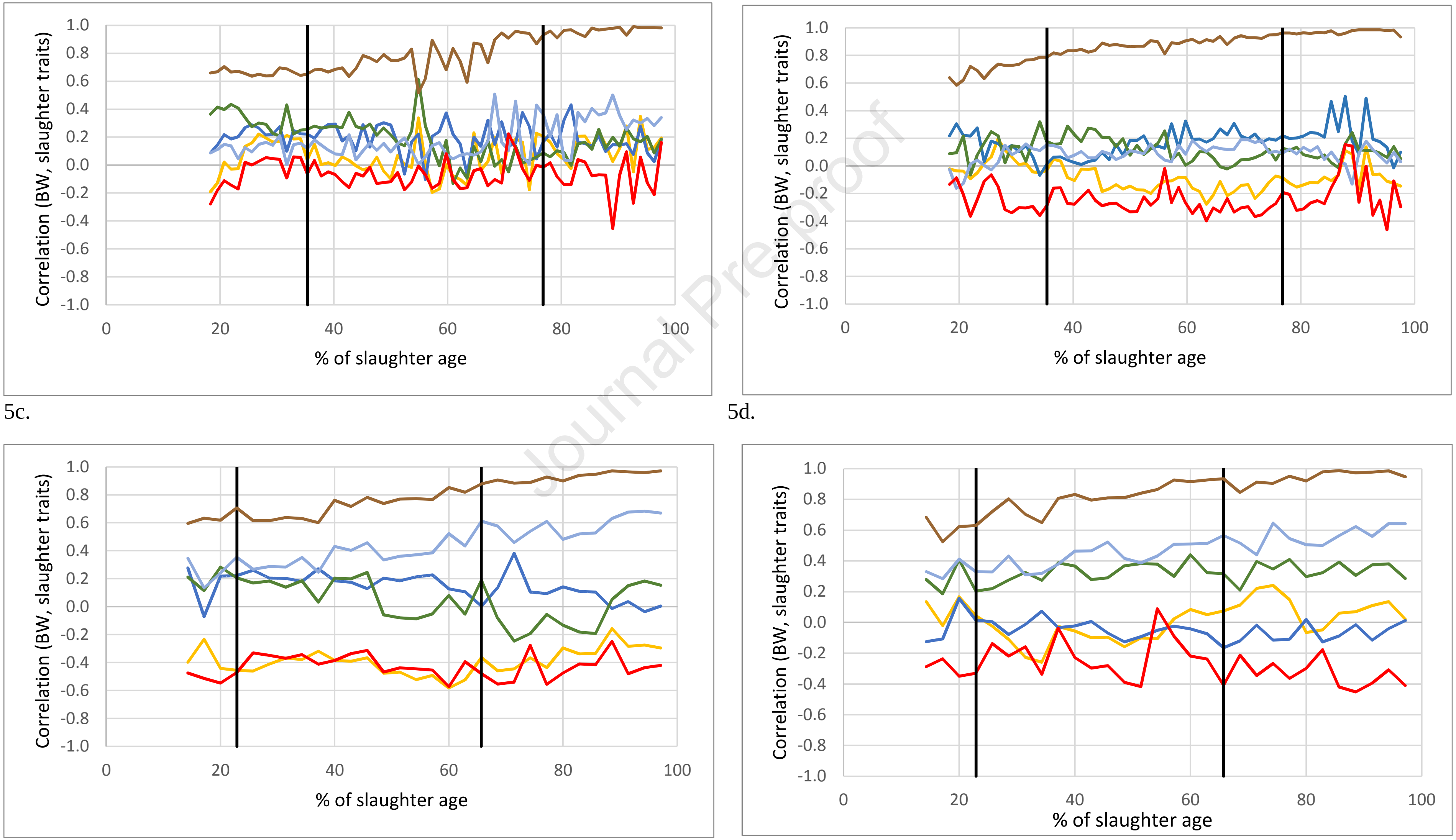
4b.



4c.

4d.

Figure 5. Profiles of correlations for LR (a: AD, b: CD) and STD (c: AD, d: CD) chickens between BW and traits measured at slaughter (pHu in yellow, thigh yield in dark blue, AFP in green, BMY in light blue, CFCRf in red, BW at slaughter in brown). Black lines indicate diet changes.



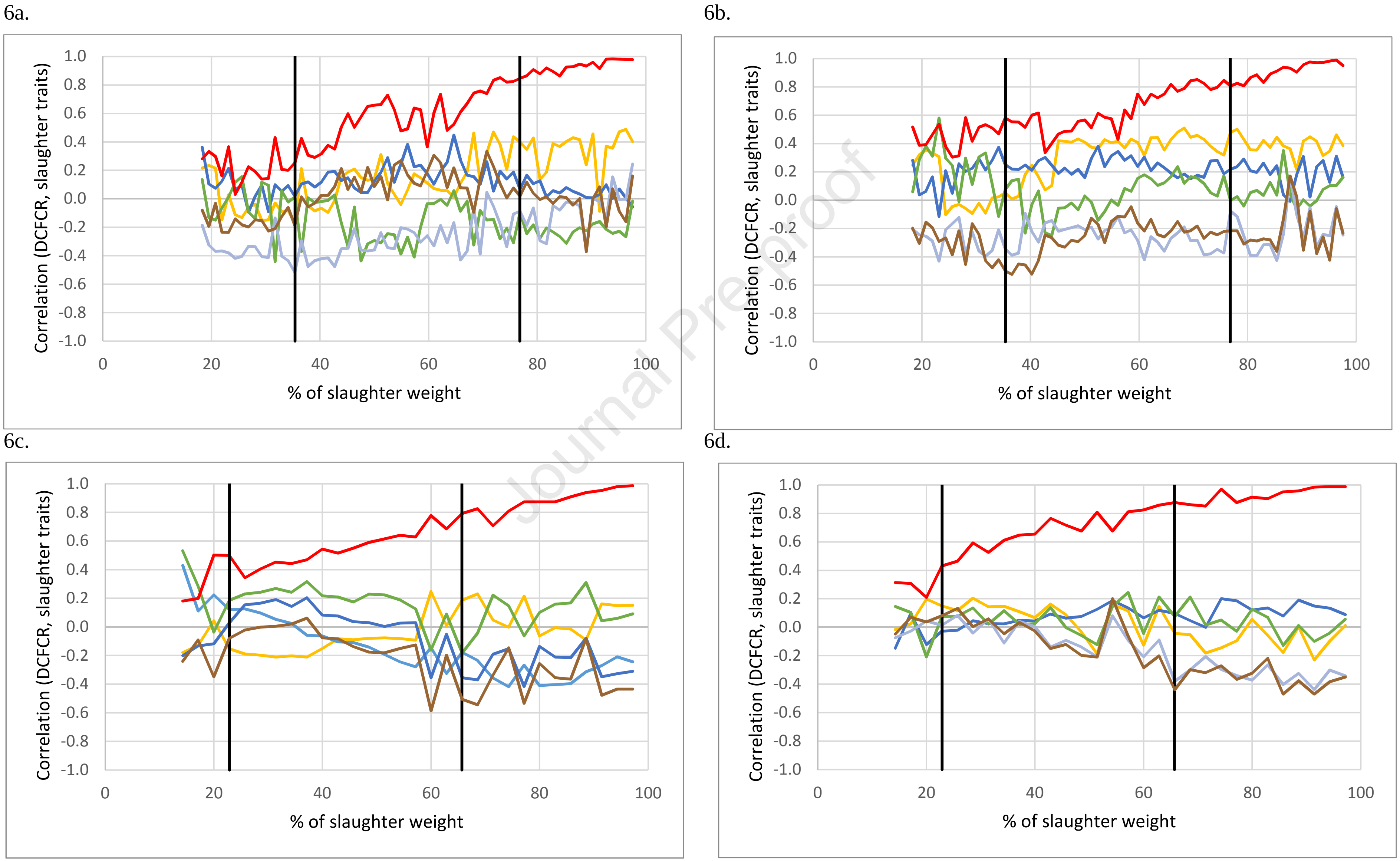
5a.

5b.

5c.

5d.

Figure 6. Profiles of correlations for LR (a: AD, b: CD) and STD (c: AD, d: CD) chickens between DCFCR and traits measured at slaughter (pHu in yellow, thigh yield in dark blue, AFP in green, BMY in light blue, CFCRf in red, BW at slaughter in brown). Black lines indicate diet changes.



6a.

6b.

6c.

6d.

The authors declare they have no conflict of interest.