Effects of dry corn gluten feed on digestibility parameters and milk production in lactating dairy cows

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SUMMARY

The objectives of the study were to evaluate the effects of increasing amounts of dry corn gluten feed (DCGF) in replacement of corn silage in the ration of dairy cows on the lactation performance and the digestibility parameters. For that, 8 lactating Holstein primiparous cows were randomly assigned in a 4x4 Latin square design with 4 week periods and received control 50% forage (35% corn silage and 15% wheat straw) diets or diets containing 10%, 18% or 25% DCGF in replacement of corn silage (L-DCGF, M-DCGF and H-DCGF, respectively). The incorporation of DCGF has significantly modified the physical traits of the diets by increasing the proportion of small particles (< 8 mm) and decreasing the peNDF (physically effective neutral detergent fibre) and in the NDF intake according to the dietary DCGF content. In parallel, the apparent digestibility of NDF and crude protein was significantly depressed but the effective degradability of starch, crude protein and organic matter in rumen were significantly enhanced when DCGF was added to the diet. In addition, the milk production and quality remained similar whatever the diet regimen used. These results show that the dietary incorporation of DCGF up to 25% did not induce unfavourable effects on the milk production and composition in dairy primiparous cows.

Keywords: Dairy cows, dry corn gluten feed, diet, physical trait, digestibility, milk production.

Introduction

Corn gluten feed (CGF) exhibits remarkable nutritional characteristics, such as low starch content and highly digestible fibre content [6]. The CGF usually contains over 20% protein which a high proportion (65%) very efficiently degraded in the rumen [12]. For diets characteristically low in fibre but high in starch, such as those based on corn, wheat, and corn silage, the CGF as non forage fibre sources (NFFS) would appear to be very interesting among feedstuff.

The CGF is a by-product of corn processing which contains a large proportion of neutral detergent fibre (NDF), and which has been considered as a useful NFFS when forage stores are limiting [14]. The NFFS have different physical and chemical properties as compared to forages, eventually affecting the nature of the associated NDF. When compared to forage, NFFS have a smaller particle size and the higher specific gravity results in shortening the rumen retention time, the nutrient digestibility and the organic acid production [1]. Finally, because of the fine particle size and the fibre value, the inclusion of CGF in the ruminant diets has increased the dry matter intake (DMI), resulting in higher rumen pH, and in decreasing the nutrient dry matter (DM) digestibility [11]. However, studies examining the inclusion of CGF into corn silage-based diets and effects on milk production are limited. Because forages provide NDF in a form that is distinctively different from that of NFFS, experiments designed to define the effects of the various NDF sources have to be developed.

Data from studies conducted with steers suggest that the dry corn gluten feed (DCGF) induces similar average daily

RÉSUMÉ

Effets du gluten de maïs sec sur les paramètres de digestibilité et sur la production laitière chez la vache laitière en lactation

L’objectif de cette étude a été d’évaluer les effets de quantités croissantes de gluten de maïs sec (DCGF) en remplacement de l’ensilage de maïs dans la ration des vaches laitières sur les performances de lactation et les paramètres de digestibilité. A cette fin, en suivant une répartition des animaux sous forme d’un carré latin 4 x 4, 8 vaches laitières primipares de race Holstein ont aléatoirement reçu la ration contrôle constituée de 50 % de fourrages (35 % d’ensilage de maïs et 15 % de paille de blé) ou une ration contenant 10 %, 18 % ou 25 % de gluten de maïs sec en remplacement de l’ensilage de maïs (soit respectivement les rations L-DCGF, M-DCGF et H-DCGF) sur une période de 4 semaines. L’inclusion de DCGF a significativement modifié les paramètres physiques de la ration en augmentant la proportion de petites particules (8 mm) et en diminuant le pef (facteur d’efficacité physique des particules) ce qui a conduit à une diminution du peNDF (fibres physiques efficaces extraites par un détergent neutre) et de l’ingéré de NDF en fonction de la quantité de DCGF dans la ration. En parallèle, la digestibilité apparente du NDF et des protéines brutes a été significativement diminuée tandis que la dégradabilité réelle intra-ruminale de l’amidon, des protéines brutes et de la matière organique ont été significativement augmentée lorsque le DCGF a été ajouté à la ration. De surcroît, la production laitière et la qualité du lait sont restées similaires quelque soit le régime alimentaire utilisé. Ces résultats montrent que l’incorporation de DCGF dans la ration jusqu’à 25 % n’entraîne aucun effet défavorable sur la production laitière ou sur la composition du lait chez les vaches laitières primipares.

Mots clés : Vaches laitières, gluten de maïs sec, ration, caractéristique physique, digestibilité, production laitière.
gains and food efficiency values than corn [18]. However, BERNARD et al. [7] reported decreases in the milk fat, milk yield, milk protein and lactose without DMI modification when DCGF was given to lactating dairy cows at 27% of diet DM. By contrast, using diets containing DCGF from 0 to 20% of DM, FIRKINS et al. [13] reported increases in milk yield and milk protein according to the DCGF amount. Alfalfa silage constituted 15% of the DM across diets and DCGF often replaced corn silage and soybean meal. Until recently, no data has proposed an upper limit for the DCGF incorporation in the diet of dairy cows. OHAJURUKA and PALMQUIST [27] evaluated diets with high proportions of dietary DCGF and concluded that the upper limit of DCGF was 15 to 20% of diet DM. However, as the CGF is relatively inexpensive, the use of large quantities (i.e. 50 to 60% of dietary DM) would be economically important. Wet corn gluten feed (WCGF) has some nutritional advantages over dry corn gluten feed but the dry product is easier to handle. Wet corn gluten feed has a bunk life of a few days in summer and one to two weeks in winter. Because of bunk life and transportation costs, wet corn gluten feed is only an option to producers that are in relative close proximity of the milling plant. The objectives of this research were to evaluate the effects of increasing amounts of DCGF into the diets in order to replace corn silage on lactation performance and digestibility parameters in lactating Holstein primiparous cows.

Materials and Methods

COWS AND EXPERIMENTAL DIETS

Eight dairy Holstein primiparous cows, weighing 515 ± 20 kg, lactating for 98 ± 20 days, were randomly assigned in a 4x4 Latin square design with 4 week periods. Each period lasted 30 days and the last period was used for sample and data collection. One of the two cows in each group was ruminally cannulated with soft plastic canulas of 10 cm internal diameter (Ankom, pliable rumen canula # 29, 4 inches, NY, USA). Cows were housed and fed individually in a tie stall barn and had free access to water. Cows were milked twice daily at 06:00 and 18:00 hours. The compared fibre sources were corn silage and DCFG. All DCFG used in this experiment were received from the same source (Cargill, Bursa, Turkey) and presented the same composition. The DCFG contained 24.7% crude protein (CP), 42.7% NDF, 13.0% acid detergent fibre (ADF) and 2.4% lignin on the DM basis.

Dietary treatments (Table I) were 1) a control diet (C) containing 50% forage (35% of corn silage and 15% DM wheat straw), 2) a low DCFG diet (L-DCGF) in which 10% of the corn silage was replaced by DCFG, 3) a medium DCFG diet (M-DCGF) in which 18% of the corn silage was replaced by DCFG, and 4) a high DCFG diet (H-DCGF) in which 25% of the corn silage was replaced by DCFG. Corn was also added to the diets with DCFG in order to make the diets isocaloric and isonitrogenic. In addition, soybean meal and soybean seed amounts were reduced according to the DCFG supply in the diets. All diets were distributed as total mixed rations (TMR) and were formulated to meet or exceed the requirements of a 515 kg cow producing 25 kg milk/d containing 3.4% milk fat, 3.0% protein and 4.8% lactose, according to the NRC (National Research Council) 2001 [26]. The TMR were mixed once daily and given to cows for ad libitum intake twice daily at 0900 and 1800 hours. The amount of food offered was daily adjusted to obtain approximately 10% orts. The Penn State Particle Separator (PSPS) was used to measure particle size for TMR as described by KONONOFF et al. [20].

TOTAL TRACT DIGESTIBILITY

Acid in soluble ash (AIA) was used as a marker to measure total tract digestibility [33]. Samples of faeces were collected on day 18 (at 08:00, 14:00, 20:00 and 02:00 hour), day 19 (at 10:00, 16:00, 22:00 and 04:00 hour) and on day 20 (at 12:00, 18:00, 24:00, and 06:00 hour). Faeces were collected by grab sampling (failing voluntary defecation); 250 g of faeces was collected from each cow in each time and period. Faecal samples were dried in a forced-air oven at 60°C for 48 hours, then ground to pass through a 1 mm screen. Total tract nutrient digestibility of starch, crude protein (CP), NDF, and organic matter (OM) was calculated from faecal lignin concentration and nutrient concentrations in diets and faeces and the results were expressed as percentage (%) according to the following formula:

\[
\text{Digestible nutrient (%) = 100 – 100 \times \left(\frac{\text{AIA in food (%)} \times \text{OM}}{\text{AIA in faeces (%)} \times \text{OM}}\right)}
\]

IN SITU MEASUREMENTS

Ruminal degradation of TMR diets were measured using in situ bags made from nitrogen-free polyester, with a 50 μm pore size (Ankom, R1020-10 × 20 cm, forage bags, 14502, NY, USA). The TMR diets were dried at 60°C for 48 hours and ground through a 2 mm screen, then the samples were weighed (5 g sample) into nylon bags. Starting on day 15 of each experimental period, four duplicate nylon bags containing four TMR diets were incubated in the rumen of each cow for 2, 4, 8, 12, 24, 48, 72, and 96 hours during the four experimental periods. After each incubation time, bags of each TMR were withdrawn from the rumen and plunged into cold water for 10 minutes to stop fermentation. Bags were then washed for approximately 120 minutes in cold water and allowed to dry for 60 minutes before being placed in a forced-air oven at 60°C for 48 hours, and then analyzed as described later for OM, CP, and starch. To determine the DM losses during bag washing, 4 nylon bags (5 g sample) of each not ruminally incubated TMR diet were washed in lukewarm water for 1 hour at 39°C, washed in cold water and then oven dried for 60°C for 48 hours. Percentages of disappearance of OM, CP, and starch at each incubation time were calculated from the proportion remaining in the bag after the ruminal incubation. The disappearance rate was fitted to the following equation [29]. Disappearance of OM, CP and starch were calculated as: a + b (1-e^-ct), where a is the soluble fraction (%), b, the degradable fraction (%), and c the rate of
The parameters, a, b and c were obtained by fitting the data using a non-linear model of ØRSKOV and Mc DONALD [29]. The effective degradability of starch (EDS), CP (EDCP), and OM (EDOM) were calculated by the equation of ØRSKOV and Mc DONALD [29] as 

$$EDS, EDCP, \text{ and } EDOM = a + \frac{bc}{(k + c)}$$

where k is the estimated rate of outflow from the rumen. The EDS, EDCP, and EDOM were estimated using a ruminal outflow rate of 5%/hour.

**SAMPLE COLLECTION AND ANALYSIS**

Food offered and orts were measured and daily recorded during the last 10 day period to calculate food intake. The TMR were collected once weekly for the particle distribution analysis and the DM determination. The samples were dried in 55°C oven for 48 hours, and then ground through a 1-mm diameter screen for analysis of NDF, ADF (acid detergent fibre), starch, ash and CP. Analytical DM content of the samples was determined by drying at 105°C for 12 hours [2]. The ash was determined by combustion at 550°C for 6 hours. The NDF and ADF contents were determined using the methods described by VAN SOEST et al. [34] using amylase (Sigma Chemical Co., St. Louis, MO, USA) and sodium sulphite for the NDF procedure. Starch was determined using a colorimetric assay including a refined corn starch sample as described by BAL et al. [4] and CP was determined by the KJELDAHL method [2]. Weekly DM and NDF analyses were performed on TMR samples, which were dried in a forced-air oven at 55°C for 48 hours.

Experimental cows were milked twice daily at 06:00 and 18:00 h, and milk weights were recorded (Milko Scope MK II, De Laval, Sweden). Milk samples were collected every 10 days at a.m. and p.m. milking and analyzed for fat, protein, lactose, and SNF by infrared spectrophotometry (Foss 605B Milko-Scan, Foss Electric, Hillerød, Denmark) according to the corresponding volume measured at each milking time, and 4% FCM was calculated.

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**Table I: Ingredients and chemical composition of the total mixed diets (according to BIRICI K et al. [8]) given to the dairy Holstein primiparous cows randomly assigned in a 4x4 Latin square design with 4 week periods.**

<table>
<thead>
<tr>
<th>Ingredients (% of DM)</th>
<th>C</th>
<th>L-DCGF</th>
<th>M-DCGF</th>
<th>H-DCGF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn silage</td>
<td>35.00</td>
<td>25.00</td>
<td>17.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>15.00</td>
<td>15.00</td>
<td>15.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Dry corn gluten feed</td>
<td>0.00</td>
<td>10.00</td>
<td>18.00</td>
<td>25.00</td>
</tr>
<tr>
<td>Corn grain ground</td>
<td>26.41</td>
<td>32.18</td>
<td>36.27</td>
<td>37.30</td>
</tr>
<tr>
<td>Soybean meal (44% CP)</td>
<td>14.17</td>
<td>12.51</td>
<td>10.22</td>
<td>8.19</td>
</tr>
<tr>
<td>Soybean seed, extruded</td>
<td>7.39</td>
<td>3.28</td>
<td>1.41</td>
<td>2.41</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>0.31</td>
<td>0.31</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>1.36</td>
<td>1.36</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>VMP</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Salt (NaCl)</td>
<td>0.31</td>
<td>0.31</td>
<td>0.32</td>
<td>0.32</td>
</tr>
</tbody>
</table>

**C**: Control diet (without dry corn gluten feed) with 35% corn silage, 15% wheat straw and 50% concentrate; **L-DCGF**: Low dry corn gluten feed with 25% corn silage, 15% wheat straw, 10% dry corn gluten feed and 50% concentrate; **M-DCGF**: Medium dry corn gluten feed with 15% corn silage, 15% wheat straw, 18% dry corn gluten feed and 50% concentrate; **H-DCGF**: High dry corn gluten feed with 10% corn silage, 15% wheat straw, 25% dry corn gluten feed and 50% concentrate.  

**DM**: Dry matter; **CP**: Crude protein; **VMP**: Vitamin mineral premix (Kavimix VM, Kartal Kimya A.S., Gebze, Turkey) supplying (/ kg): Vitamin A: 12 000 000 IU, Vitamin D3: 3 000 000 IU, Vitamin E: 30 g, Mn: 50 g, Fe: 50 g, Zn: 50 g, Cu: 10 g, I: 0.8 g, Se: 0.15 g, Antioxidant: 10 g; **EE**: Ether extract; **NDF**: Neutral detergent fibre; **FNDF**: neutral detergent fibre from forage, calculated from ingredient analysis; **ADF**: Acid detergent fibre; **NFC**: Non fibre carbohydrate (%) calculated as: 100 – [NDF (%) + CP (%) + EE (%) + ash (%)]; **NEL**: Net energy lactation calculated from [26].
STATISTICAL ANALYSIS

Data were analyzed as a replicated 4x4 Latin square design with model effects for square, cow within square, period, treatment, and square x treatment using the general linear models of SPSS, followed by the Tukey test procedure (version 10.0, SPSS Inc, Chicago, USA). If treatment effects were significant, means were compared using Least Squares Differences and differences were considered as significant when the P value was less than 0.05.

Results

Ingredients and chemical compositions of the total mixed diets were shown in Table I. The DM content was low in the C diet compared to the DCGF-enriched diets in which the corn silage was substituted with DCGF (with a 90% DM). The CP contents between the 4 diet regimens were similar whereas the NDF and FNDF (forage NDF) contents were moderately lowered in the DCGF-enriched diets and the NFC (Non Fibre Carbohydrate) and starch contents have slightly increased. Nevertheless, the dietary net energy lactation (NEL) calculated according to the NRC recommendations [26] were closely related between the 4 diet regimens, varying from 1.61 for the control diet to 1.64 Mcal/kg for the high DCGF diet (H-DCGF).

The particle size analysis, the physically effective fibre NDF (peNDF), the NDF intake (NDFI) and the DM intake (DMI) are presented in Table II. The proportions of particles retained on the 19.0 mm and 8.00 mm screens from the DCGF-enriched total mixed diets were significant lower than that obtained from the control diet (P < 0.05) while the percentages of smaller particles (between 1.2 and 8.0 mm and below 1.2 mm) significantly increased (P < 0.05). In parallel, the physical effectiveness factor (pef) gradually declined according to the DCGF content in the diets (P < 0.05). These modifications in the particle size distribution were the most marked in the H-DCGF diet. In the same way, the peNDF was progressively and significantly depressed as the DCGF ratio increased in the diets (P < 0.05), the H-DCGF diet exhibiting the lowest peNDF value. In cows feeding with M and H-DCGF diets, it was observed that the NDF intake (NDFI) was significantly decreased compared to cows receiving the control diet or the L-DCGF diet (P < 0.05). However, the dry matter intake (DMI) expressed by kg/day or as % of body weight has not significantly differed according to the diets.

The milk production and composition are presented in Table III. The global milk yield, 4% fat corrected milk (4% FCM) and the solids not fat (SNF) were not statistically different in cows fed with increasing DCGF contents. The milk fat, protein and lactose yields ranged from 0.70 to 0.79 kg/day, 0.64 to 0.67 kg/day and 0.99 to 1.06 kg/day, respectively.

<table>
<thead>
<tr>
<th>Retained DM (%) according to the particle size (in mm)</th>
<th>C</th>
<th>L-DCGF</th>
<th>M-DCGF</th>
<th>H-DCGF</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0 to 8.00 mm</td>
<td>6.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.90&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.70&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.40&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.23</td>
</tr>
<tr>
<td>8.0 to 1.2 mm</td>
<td>30.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.40&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.80&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.15</td>
</tr>
<tr>
<td>&lt; 1.2 mm</td>
<td>46.50&lt;sup&gt;d&lt;/sup&gt;</td>
<td>58.25&lt;sup&gt;c&lt;/sup&gt;</td>
<td>62.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>62.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.68</td>
</tr>
<tr>
<td>pef</td>
<td>0.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.79&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.76&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.01</td>
</tr>
<tr>
<td>peNDF (% of DM)</td>
<td>31.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>27.12&lt;sup&gt;c&lt;/sup&gt;</td>
<td>25.69&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.54</td>
</tr>
<tr>
<td>NDFI (kg of DM/day)</td>
<td>6.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.31&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.12</td>
</tr>
<tr>
<td>NDFI (% of body weight)</td>
<td>1.24&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.19&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.02</td>
</tr>
<tr>
<td>DMI (kg/day)</td>
<td>17.86</td>
<td>17.47</td>
<td>16.95</td>
<td>17.34</td>
<td>0.32</td>
</tr>
<tr>
<td>DMI (% of body weight)</td>
<td>3.35</td>
<td>3.31</td>
<td>3.18</td>
<td>3.25</td>
<td>0.05</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>534.50</td>
<td>528.00</td>
<td>532.75</td>
<td>532.75</td>
<td>5.19</td>
</tr>
</tbody>
</table>

C: Control diet (without dry corn gluten feed) with 35% corn silage, 15% wheat straw and 50% concentrate; L-DCGF: Low dry corn gluten feed with 25% corn silage, 15% wheat straw, 10% dry corn gluten feed and 50% concentrate; M-DCGF: Medium dry corn gluten feed with 15% corn silage, 15% wheat straw, 18% dry corn gluten feed and 50% concentrate; H-DCGF: High dry corn gluten feed with 10% corn silage, 15% wheat straw, 25% dry corn gluten feed and 50% concentrate; SE: Standard error.

pef: Physical effectiveness factor determined by the fraction retained on a 1.2 mm sieve using horizontal shaking with PSPS (Penn State Particle Separator); peNDF: physically effective neutral detergent fibre measured as the NDF content of the TMR multiplied by pef according to MERTENS [25]; NDF: Neutral detergent fibre intake; DMI: Dry matter intake.

Different superscripts a,b,c,d in the same row indicate significant differences between the diet-regimens (P < 0.05).
They have gradually declined but not significantly according to the DCGF content in the diet. When the milk composition was considered, no significant difference was noticed in the fat, protein and lactose percentages although the fat percentage has tended to decrease in the cows fed with the H-DCGF diet.

As shown in Table IV, the total tract digestibility of the organic matter (OM) and of starch was not affected by the dietary treatments. However, the NDF and crude protein digestibilities have remained markedly higher in cows fed with the control diets than in animals fed with the DCGF-enriched diets ($P < 0.05$). The predicted parameters of rumen degradation of starch, crude protein and organic matter in the four TMR diets and their effective degradability are shown in Table V. As the soluble fraction (a) of starch progressively increased and the degradable fraction (b) declined ($P < 0.05$), the effective degradability (ED) markedly increased as the DCGF ratio increased in the diet ($P < 0.05$). In the same way, the a fractions ($P < 0.05$) and the rates of degradation (c) for the crude proteins ($P < 0.01$) and for the organic matter ($P < 0.05$) significantly increased when the DCGF-enriched diets were ruminally incubated whereas the b fractions decreased ($P < 0.05$ for the crude protein). In addition, it was observed that the crude protein ED was significantly higher with the M- and L-DCGF diets than with the H-DCGF and control diets ($P < 0.05$) and that the organic matter ED was significantly higher with the H- and M-DCGF diets than with the L-DCGF and control diets ($P < 0.05$).

**Discussion**

The inclusion of DCGF into the diet in partial replacement of the corn silage has significantly modified the chemical composition and the physical characteristics of the total mixed rations. Firstly, the total and forage NDF were increased and the non fibre carbohydrates (NFC) were decreased in DCGF-enriched diets compared to the control diet. However, the crude proteins ($P < 0.01$) and for the organic matter ($P < 0.05$) significantly increased when the DCGF-enriched diets were ruminally incubated whereas the b fractions decreased ($P < 0.05$ for the crude protein). In addition, it was observed that the crude protein ED was significantly higher with the M- and L-DCGF diets than with the H-DCGF and control diets ($P < 0.05$) and that the organic matter ED was significantly higher with the H- and M-DCGF diets than with the L-DCGF and control diets ($P < 0.05$).
as reflected throughout the same values of the dietary net energy lactation calculated according to the NRC [26] whatever the DCGF proportion in the diet, the energy supply was similar for the 4 diet regimens. Secondly, the DCGF-enriched total mixed diets significantly contained less big particles (above 8.0 mm) and more mild and small particles (below 8 mm and 1.2 mm) than the control diet as previously described by BIRICIK et al. [8], leading to significant gradual declines of the physical effectiveness factor (pef) and of the peNDF contents in the ration. GENCOGLU and TURKMEN [15] have reported that the increase in the dietary peNDF and the intake of particles above 19.0 mm may be among the factors that affect the total chewing activity of dairy cattle. In parallel, the NDF intake was significantly diminished when cows were fed with the M- and H-DCGF diets whereas the total dry matter intake (DMI) was unchanged. However, VAN BAALÉ et al. [32] reported that when both a portion of the forage and corn in the diet is replaced by wet corn gluten feed (WCGF), the DMI will increase in dairy cows. By contrast, DROPPPO et al. [10] observed decreased DMI when WCGF partly replaced grain and soybean meal. Nevertheless, as the present study was conducted from April to July in Bursa (Northwest of Turkey) where peak summer temperatures often culminate above 40°C, the lack of the DMI variations may be due to heat stress in the dairy cows.

Contrary to the total tract digestibility of starch and organic matter which were remained roughly constant whatever the dietary DCGF proportion in the present study, the total tract NDF and crude protein digestibilities from DCGF-enriched diets were significantly lowered. MERTENS and LOFTEN [23] suggested that a decreased cellulolytic microbial activity induced by the decrease in the ruminal pH was the mechanism responsible for the reduction of the fibre digestion by cows fed with mixed forage-concentrate diets. On the other hand, YANG and BEAUCHÉMIN [36] reported that increasing the peNDF content of a corn silage based diet improves digestibility, especially fibre digestibility in the total tract because of the improvement of the rumen pH. In coherence with these previous data, the highest daily mean rumen pHs and the peNDF contents observed with the not DCGF supplemented (control) diet [8] were equalled to the highest NDF and crude protein digestibilities in the present study. When predicted parameters of rumen degradation of starch, crude protein and organic matter in the 4 diet regimens were analyzed, it was observed that the corresponding effective degradabilities were significantly enhanced in DCGF-enriched diets, the highest values being observed with the H-DCGF for the starch and organic matter degradabilities and with the M-DCGF for the crude protein degradability. The enhancement of the respective effective degradabilities was associated with in one hand, the significant increases in the soluble fraction (a) in each case and in the degradation rates (c) for crude protein and organic matter and with, on the other hand, the significant decrease in the degradable fraction (b) for starch and crude protein. However, the high effective degradability of starch may be related to the increased corn grain contents in the DCGF-enriched diets instead of the DCGF content directly [35]. Consequently, the high rumen starch digestibility would have lead to the over-estimation of the organic matter digestibility which was expected to be slower in the DCGF-enriched diets than in the control diet.

In the present study, no effect of the dietary DCGF incorporation was evidenced on the milk yield or on the milk composition. By contrast, DROPPPO et al. [10] reported decreases

<table>
<thead>
<tr>
<th>Starch</th>
<th>C</th>
<th>L-DCGF</th>
<th>M-DCGF</th>
<th>H-DCGF</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>a (% of total DM)</td>
<td>35.86&lt;sup&gt;c&lt;/sup&gt;</td>
<td>42.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td>44.05&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.68</td>
</tr>
<tr>
<td>b (% of total DM)</td>
<td>69.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>61.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>59.92&lt;sup&gt;b&lt;/sup&gt;</td>
<td>51.30&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.86</td>
</tr>
<tr>
<td>c (% / hour)</td>
<td>0.040</td>
<td>0.043</td>
<td>0.046</td>
<td>0.099</td>
<td>0.008</td>
</tr>
<tr>
<td>ED at 5%/hour</td>
<td>66.46&lt;sup&gt;c&lt;/sup&gt;</td>
<td>70.96&lt;sup&gt;b&lt;/sup&gt;</td>
<td>71.85&lt;sup&gt;b&lt;/sup&gt;</td>
<td>79.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.65</td>
</tr>
</tbody>
</table>

| Crude protein | a (% of total DM) | 27.23<sup>d</sup> | 30.61<sup>c</sup> | 40.01<sup>b</sup> | 42.69<sup>a</sup> | 0.88 |
| b (% of total DM) | 78.23<sup>a</sup> | 64.89<sup>b</sup> | 56.02<sup>c</sup> | 52.95<sup>c</sup> | 1.42 |
| c (% / hour) | 0.025<sup>b</sup> | 0.033<sup>b</sup> | 0.042<sup>a</sup> | 0.038<sup>a</sup> | 0.0014 |
| ED at 5%/hour | 51.65<sup>c</sup> | 55.67<sup>b</sup> | 60.21<sup>a</sup> | 53.78<sup>bc</sup> | 0.54 |

| Organic matter | a (% of total DM) | 29.96<sup>c</sup> | 32.52<sup>b</sup> | 35.09<sup>a</sup> | 33.92<sup>ab</sup> | 0.38 |
| b (% of total DM) | 56.55 | 51.66 | 54.60 | 51.23 | 0.95 |
| c (% / hour) | 0.026<sup>b</sup> | 0.030<sup>ab</sup> | 0.027<sup>ab</sup> | 0.034<sup>a</sup> | 0.0011 |
| ED at 5%/hour | 48.61<sup>b</sup> | 49.76<sup>b</sup> | 52.13<sup>a</sup> | 53.41<sup>a</sup> | 0.38 |

C: Control diet (without dry corn gluten feed) with 35% corn silage, 15% wheat straw and 50% concentrate; L-DCGF: Low dry corn gluten feed with 25% corn silage, 15% wheat straw, 10% dry corn gluten feed and 50% concentrate; M-DCGF: Medium dry corn gluten feed with 15% corn silage, 15% wheat straw, 18% dry corn gluten feed and 50% concentrate; H-DCGF: High dry corn gluten feed with 10% corn silage, 15% wheat straw, 25% dry corn gluten feed and 50% concentrate; SE: Standard error; DM: dry matter; a: soluble fraction (% of total DM); b: degradable fraction (% of total DM); c: rate of degradation; ED: Effective degradability.

Different superscripts a, b, c in the same row indicate significant differences between the diet-regimens (P < 0.05).
in the DMI and the milk yield when WCGF is increased from 18.6 to 37.1% of the DM diet in partial replacement of grain and soybean meal. In disagreement with that, VAN BAALÉ et al. [32] have observed that primiparous and multiparous cows exhibited increased FCM yield and DMI when forage and grain (corn) were partially substituted with WCGF. However, Schroeder [30] observed a quadratic response on the DMI and the fat corrected milk (FCM) yield when WCGF was used to replace forage and barley grain at 15, 30 and 45% of the DM diet; indeed, when the dietary WCGF content was between 15 and 30%, he has also observed improvement of the FCM yield and of the DMI. In the current study, as the milk production was low, it was suggested that the lack of differences in the milk yield according to the dietary DCGF content would be due to the occurrence of heat stress in dairy cows. In the same way, Orman and Ogan [28] observed that the seasons affect milk production in the Northwest of Turkey.

The milk fat yield and the milk fat proportions have decreased, but not significantly, when cows were fed with the DCGF-enriched diets. On the contrary, STAPLES et al. [31] found that cows fed with 20% WCGF-enriched diets produced more milk with a higher fat content than that cows fed with a diet without WCGF. Mc LEOD et al. [22] found that the milk fat production increased only during late lactation while the milk protein production decreased in parallel when cows were fed with high WCGF contents (37.1% of the DM). BODDUGARI et al. [9] observed reductions in DMI and in milk protein percentage, but not differences in the total milk and FCM yields when WCGF replaced 50, 75, or 100% of the grain in diets mixed with 54.3% forage. GUNDERSON et al. [17] found no difference in milk yield or milk composition in cows fed with 0, 10, 20 and 30% WCGF (DM basis). Similarly, ARMENTANO and DENTINE [3] reported no difference in the milk yield or composition between WCGF-enriched and control diets for lactating cows. MERTENS [25] have suggested that the peNDF requirement would be around 22% of DM for maintaining the ruminal pH constant and the milk fat percentage at 3.4% during the early and mid lactation. Based on measurements using the Penn State Particle Separator (PSPS), several studies reported that the increased peNDF intake was coupled to the increased milk fat content [19, 35] and to the decreased milk protein content [19], whereas other studies failed to demonstrate such peNDF effects on the milk composition [15, 21]. Results obtained from the current study showed that the peNDF did not significantly affect the milk fat and protein percentages. This can be probably explained by the fact that all diets provided adequate peNDF amounts. Likewise, ZEBELI et al. [37] observed that milk parameters are less sensitive to the dietary peNDF effects than other variables, such as ruminal pH, chewing activity and fibre digestibility. Indeed, a low milk fat content was consistent with a low mean rumen pH (5.50) and a low acetate / propionate ratio (between 1.7 and 2.0) [5]. In the present model of DCGF-enriched diets, the mean daily ruminal pHs were ranged from 5.91 to 6.02 and the acetate / propionate ratios were comprised between 2.16 and 2.71[8]. These results are consistent with those of MERTENS [24] who reported that FCM yield in dairy cows was the greatest when diets based on alfalfa hay (AH), corn silage, or Bermuda grass hay contained 35% dietary NDF. Consequently, the same author [25] concluded that the effects of particle size on the milk fat content were likely to be observed when NDF contents were inferior to the minimum recommended requirement.

The milk protein yields and percentages in the present study were remained similar among diets whatever the dietary DCGF content. According to GRIEVE et al. [16], similar milk protein contents across treatments probably resulted from similar energy dietary contents and organic matter digestibility in the total tract since the milk protein excretion appears to be positively correlated with the dietary energy. As the supplied dietary net energy lactation (NEL) in the present study was similar between the 4 diet regimens, the milk protein production might be remained unchanged.

As a conclusion, although the enrichment of diets with DCGF (between 10 to 25% of the DM in replacement of the corn silage) has significantly modified some chemical and physical traits of the total mixed rations and affected the total tract digestibilities of NDF and crude proteins as well as the starch, crude protein and organic matter effective degradabilities, no negative effect on the milk production and composition was evidenced, probably because of a sufficient provide in NDF and peNDF.

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References


