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Review

Nutrition, rumination and heat stress as influential factors in dairy cows production: A review

Mária Kapusniaková, Miroslav Juráček, Ondrej Hanušovský, Michal Rolinec, Branislav Gálik, Andrej Duchoň, Stanislava Drotárová, Mária Kalúzová, Milan Šimko*

Slovak University of Agriculture in Nitra, Institute of Nutrition and Genomic, Slovak Republic

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The aim of this review is to consolidate the already much published knowledge concerning the gastrointestinal tract of the dairy cow in relation to nutrition. This review deals with the essential living conditions of dairy cows, with an attention to nutrition, and highlights the importance of correct ration design. Dairy cows in different production cycles have special requirements for the composition, structure and nutrient composition of their rations. This review document provides more detailed information on the physical structure of feedstuffs as well as the need for individual nutrients for the right functioning of the dairy cow. These factors determine total health, feed intake, rumination, the development of metabolic diseases and last but not least, milk yield and composition. Rumination is an important and valuable tool that indicates the correctness of these aspects. Many published studies point to the relationship between rumination and health status where early intervention can be made to prevent a reduction in milk yield and consequent negative selection from the breeding stock. Many studies describe rumination as indicator on which the very substantial and developing benefits of breeding as well as reproduction and health itself are built. The rumination-based relationships of heat stress and dairy cow health are also nowadays receiving a great deal of attention in studies. In nowadays also a great deal of attention in studies focus on relationship not only between rumination – heat stress but also dairy cow health status. Heat stress is characteristically labelled as an unwanted factor that has an adverse effect on dairy cow milk yield.

Keywords: dairy cows, nutrition, rumination, heat stress, milk yield

1 Introduction

One very important step in achieving the desired milk yield and excellent health of dairy cows is the correct provision of adequate complete nutrition. From a nutritional point of view, it is necessary to feed nutrient-balanced rations taking into account the individual requirements/needs of dairy cows in the appropriate production group. Nowadays, there are many studies dedicated specifically to investigating the nutrition-rumination-heat stress-health relationships. Most authors also point out the importance of the required forages content in the ration to ensure suitable conditions in terms of the rumen processes (Clark et al., 2001; Beauchemin, 2018; Brandstetter et al., 2019; Shen et al., 2020). Furthermore, the feed intake and rumination process can be affected by thy physical structure which is also in relationship with the quality of forage. So, the main goal of the review is consolidate the already much published knowledge concerning the gastrointestinal tract of the dairy cow in relation to nutrition.

2 Nutrition of high-producing dairy cows

Nutrition is the most influential factor that is monitored and leads to influences on fertility, body condition, calf production (herd renewal) animal health and finally milk yield (Erickson and Kalscheur, 2020). Nowadays, is very important feed efficiency (milk yield) in connection with dairy cows (Van Saun, 2022). However, it is important to note, as Erickson and Kalscheur (2020) and also Hanušovský et al. (2015), that a high producing dairy cow requires an enough nutrient balanced diet depending on the production group. In fact, it is very

***Corresponding Author:** Milan Šimko, Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources, Institute of Nutrition and Genomic, Trieda Andreja Hlinku 2, 949 76 Nitra, Slovakia
milan.simko@uniag.sk ORCID: https://orcid.org/0000-0003-3632-3779

important to mention that to provide high milk yield, it is not only enough to provide a correctly nutrient balanced feed but additionally to provide adequate length of feed particles (Beauchemin, 2018). The size of the individual particles determines the function and health of the total rumen processes. Nevertheless, feeding to ensure higher milk yields is nowadays done by feeding high levels of concentrate rations (Beauchemin and Yang, 2005). In this ration composition, the proportion of long particles is deficient, which has negative effects on the rumen total performance (Beauchemin et al., 2003). For this reason, dairy cows should be fed a ration based on a adequate quantity of physically effective fibre (peNDF) as it first promotes rumination, second promotes adequate salivation and lastly provides for the health of the total rumen processes (Brandstetter et al., 2019; Shen et al., 2020). The dry matter intake (DMI) of a dairy cow is affected by factors such as composition of the feed and additionally, by physiological factors, indicative individually for each individual (Van Saun, 2022). Factors related to feed composition include, for example, the physicochemical characteristics of the feed (neutral detergent fibre – NDF), the maturity of the feed (lignification), furthermore the particle size and fragility, the palatability of the feed, and finally the quality of the silage (Petrovski et al., 2022). In addition, factors related to feed management such as feed delivery, availability and also the order in which feeds are loaded into the feed batch mixer are also very important (Van Saun, 2022).

2.1 Carbohydrates as the main source of energy

Carbohydrates are a very important component and also a source of energy for the dairy cow as stated by Šimko et al. (2010). Adewuyi et al. (2005) add that they affect not only the correct and desired reproductive indices but also the health of the individuals and constitute as reported by Clark et al. (2001) mostly 60–70% of the total feed ration. Dairy cows have different energy requirements per kg of milk produced, particularly in terms of the percentage of fat in the milk. The recommended net energy requirements are summarised in Table 1 (Van Saun, 2022). Carbohydrates are divided into structural carbohydrates and non-structural carbohydrates. Under structural are classified crude fibre, acid detergent and neutral detergent fibre found in plant cell walls. Non-structural carbohydrates are contained inside plants and include sugars, starch and also organic acids (Clark et al., 2001; Van Saun 2022). Starch in diets for dairy cow are in percentuage from 20% (dry cows) and 35% for cow in lactating season (Ravelo et al., 2022). Sugars and starch as described by Van Saun (2022) are referred to as non-structural carbohydrates (NFC) and their maximum recommended percentages in feed are around the values of 38–44%. Their fermentation provides the energy component that keeps the dairy cow's organism running the right way.

Table 1 Net energy requirement for milk yield (1 kg) by fat content

Concentration of milk fat (%)	Energy requirement per kg of milk produced (MJ NEL)
3.5	2.92
4	3.13
4.5	3.34
5	3.51

Source: Van Saun, 2022
MJ NEL – megajoules of net energy for lactation

2.2 Fibre in the diet of dairy cows

Fibre is classified as one of the most important fed carbohydrates for ruminants, providing a rumination effect to maintain rumen health, although compared to NFC, NDF has a lower energy content (Salfer et al., 2018). Fibre feeding should be in sufficient amounts for the group to maintain essential attributes as an example buffering pH by salivation (around values 6.0–6.5), besides health and also rumen processes function (Clark et al., 2001). The recommended fibre content is depended on milk yield as a percentage of dry matter per kilogram is shown in Table 2. Dietary fibre and its ingestion at higher ration, as also reported by Salfer et al. (2018) and Allen (1996), has a negative effect on DMI due to increasing rumen filling capacity. Measurement of dietary fibre is carried out through chemical analyses which determine acid detergent fibre (ADF) and also neutral detergent fibre (NDF), but chemical measurement alone is not sufficient to assess the quality of the dietary fibre fed, and it is therefore necessary to determine physically effective fibre (peNDF) (Clark et al., 2001; Beauchemin et al., 2003; White et al., 2017). Neutral detergent fibre is characterised by its positive effect on the ruminal processes of ruminants but on the other side by a lower energy distribution (Weiss, 2022; Van Saun, 2022). For

Table 2 Recommended neutral detergent fibre content in rations for dairy cows

Milk yield ($kg.day^{-1}$)	NDF ($\%.kg^{-1}$ DM TMR)
15–20	45
20–30	40
30–40	35
>40	30

Source: Chamberlain, 1996
$\%.kg^{-1}$ DM TMR – percentage per kilograms dry matter total mix ration

fibre to have a positive effect on the rumen environment, it is necessary that its physical characteristics are not clear (Van Saun, 2022).

2.3 Physically effective fibre (peNDF)

A neutral detergent fiber fraction is an effective fiber that takes into account the physical properties of the neutral detergent fiber affecting rumination time (Beauchemin and Yang, 2005; Brandstetter et al., 2019). The influence of rumination is realized by the reduction of particle size, which also acts to remove indigestible particles from the rumen (Welch, 1982). Kmicikewycz et al. (2015) describe, forage length as important for maintaining rumen function and an addition milk fat percentage. A reduction in feed particle size results in a reduction in rumination time leading to a reduction in salivary secretion (Beauchemin et al., 2003). Due to reduced salivation, there is an inadequate supply of buffers within the rumen environment and a decrease in pH by the same token (Beauchemin et al., 2003; Beauchemin and Yang, 2005; Beauchemin, 2018). This is due to the fact that ruminant saliva is alkaline, containing urea, sodium bicarbonate ($NaHCO_3$) equally important too sodium hydrogen phosphate (Na_2HPO_4) and its pH value ranges 8.2–8.4 (Beauchemin et al., 2003; Beauchemin and Yang, 2005). In addition, among other things, short particles also contribute to a reduction in fibre digestion, a decrease in milk fat or to the development of laminitis (Beauchemin et al., 2003). A decrease in pH value over a longer period of time is a characteristic element promoting the development of the metabolic disease acidosis (Beauchemin et al., 2003; Beauchemin, 2018).

The Penn State Particle Separator (PSPS) method is typically used to determine the physically effective NDF (Beauchemin et al., 2003; Beauchemin, 2018). For the calculation as described by many sources (Beauchemin and Yang, 2005; White et al., 2017), it is necessary to know the proportion of the individual parts on the sieves with a hole diameter of 19 mm and 8 mm, which are summed and then divided by one hundred. Then as reported by Beauchemin and Yang (2005) the physical effective factor (pef) is obtained and at last after multiplying the physical effective factor with the neutral detergent fibre content, the physically effective neutral detergent fibre (peNDF) content is obtained (White et al., 2017). Recommendations for the percentages of each TMR particle on the evaluation screens are listed in Table 3.

3 Rumination

Rumination is one of the main indicators of the rumen processes functioning of a dairy herd, which is affected by many factors. Reece and Rowe (2017); Antanaitis et al. (2018) and Cocco et al. (2021) describe the concept of rumination as a natural physiological process in which food is fed back from the rumen into the oral caity for another rumination. The process of rumination to be specific of four phases such as regurgitation or penetration of food or backward transport. The second phase is remastication or rumination, the third is resalivation or salivation and the fourth phase is redeglutation ingestion of feed. Beauchemin (1991) describe rumination as a process, that is necessary to maintain correct digestion and passage of feed through the gastrointestinal tract of the dairy cow. Rumination is closely related to total rumen process from digestion, health to pH (Gregorini et al., 2013; Cocco et al., 2021). Many authors attribute the importance of rumination to increased salivary secretion, which reduces the potential incidence of metabolic diseases (mainly acidosis) (Beauchemin, 1991; Paudyal, 2021; Ning et al., 2022). They also characterise the concept of rumination as an important activity through which the particles of a given feed are reduced Paudyal (2021) also report that a given physical distribution of the feed provides for easier digestion or passage from the rumen to the small intestine. Russell and Rychlik (2001) points out, this is very important for the bacterias located in the rumen. It also has an important role in providing them with better access to the different feed particles. Brandstetter (2019) and Paudyal (2021) add that rumination should be long and intensive to maintain correct passage respectively rumen health and motorics of the dairy cow. Rumination is practiced by dairy cows at the same time as other activities as described by Beauchemin (1991) and Cocco et al. (2021), as like walking, defecating or breastfeeding,

Table 3 Particle size recommendations for dairy cows (total mix ration)

Screen	Pore size (mm)	Particle size (mm)	TMR (%)
Upper sieve	19	>19	2–8
Middle sieve	8	8.1–19	30–50
Lower sieve	4	4.1–19	10–20
Bottom pan		≤4	30–40

Source: Heinrichs, 2013
TMR – total mix ration (%)

however, Schirmann et al. (2012) and Tucker et al. (2021) agreed that rumination when cows are resting is the best practice. Lindgren (2009) states that if dairy cows are disturbed for example by the milking process, rumination is reduced to paused.

3.1 Rumination time

As a percentage, a dairy cow should spend ±40% of the day ruminating (Bar and Solomon, 2010). Ning et al. (2022) report that cattle spend about 522 minutes per day ruminating, however, in primiparous cattle this time is usually ±60 minutes shorter, resulting in around 463 minutes spent with rumination. These percentages are reached if factors related to the management of the farm are respected (Bar and Solomon, 2010; Cocco et al., 2021; Paudyal, 2021). Nutrition is a very important factor influencing the rumination process (Paudyal, 2021; Ning et al., 2022). Term nutrition is specific with the includes aspects such the quantity fed for the animals, the composition of the ration, equally important is the structure of the ration and another very important factor is the frequency of feeding (Beauchemin, 2018; Cook et al., 2021; Ning et al., 2022), while Cocco (2021) adds that it also depends on the health status of the dairy cows and also on the climatic factors. Šimko et al. (2013) report that mixing time in the feed batch mixer is also an important factor affecting ration structure, which should not be in the positive or negative values. A shorter mixing time results in incorrect (insufficient) homogeneity of the feed ration and on the other side, a time longer than the specified time will cause shortening of the individual feed particles.

Many authors describe that the length of rumination time depends mainly on the fibre content of the total mix ration (Hulsen, 2011; Kaufman et al., 2016; Tucker et al., 2021). DeRensis et al. (2015) describe that dairy cows fed adequate quantity of NDF (±35%) rumination averages 470–520 minutes per 24 hours, which is 7–8 hours as presented by Cocco et al. (2021). Calamari et al. (2014) and Paudyal (2021) show that rumination is associated with dairy cattle health, moreover with detection and so helps in preventing or reducing costs and also in maintaining milk yield. Tucker et al. (2021) describes rumination time as an excellent indicator of dairy cow health and besides describe that most of the rumination process takes place mainly when cows are lying still without disturbance (at night), and also attribute a significant proportion to afternoon rest. Cocco (2021) describe that monitoring daily rumination time helps with the early detection of metabolic diseases in dairy cows such as ketosis, further acidosis and hypocalcemia. Increased or prolonged rumination time has a positive effect on salivation which buffers to neutralize the rumen environment and leading to the rumen health (Beauchemin 1991; Schirmann et al., 2009; Cocco et al., 2021). On the other side, dairy cows with health disorders are expected to have a significant decrease in rumination time, which is however large enough to be detected by specific tools called algorithms or by visual inspection (Stangaferro et al., 2016). According to DeVries et al. (2009), limited rumination time is mostly associated with the occurrence of diseases, mainly ruminal acidosis and also with stress in dairy cows (Schirmann et al., 2009). Paudyal (2021) in addition add the existence of various digestive diseases, mastitis and also the existence of metritis (Schirmann et al., 2016).

4 Heat stress

Rumination can also be a good indicator of heat stress in dairy cows (Paudyal, 2021). Heat stress is considered as one of the causes of metabolic diseases (Min et al., 2019) and also a sharp decline in the curve related to milk yield (Pejman and Habib, 2012; Tao, 2020). Min et al. (2019) describe that the effect of heat stress is reflected in reproductive performance and also in the total quality or composition of individual components in milk (Nasrollahi et al., 2019; Min et al., 2019). Dairy cows are very susceptible to increasing values related to the thermoneutral zone. The thermoneutral zone of dairy cows is between 5 and 25 °C (Pejman and Habib, 2012; Becker et al., 2020) and when increased, undesirable processes such as a decrease in feed intake occur (Das et al., 2016; Conte et al., 2018) which is reflected as reported by Müschner-Siemens et al. (2020) in reduced milk yield. Becker et al. (2020) describe that the thermoneutral zone is the range of temperatures where a given dairy cow does not fight to maintain her body temperature. Studies by Acatincăi et al. (2010), Soriani et al. (2013) and Moretti et al. (2017) concluded that exceeding the upper limit of the comfort temperature zone is negatively correlated with rumination time. Most authors describe the fact that increasing temperature above the comfort zone has a higher impact on high producing dairy cows, which are characterised by a higher metabolic rate compared to lower producing cows (Calamari et al., 2013; Pejman and Habib, 2012; Müschner-Siemens et al., 2020).

Heat stress is understood or assessed into individual grades using the temperature and humidity index (THI) (Calamari et al., 2013). The Temperature-Humidity Index, as reported by Bernabucci et al. (2014), is a climate index incorporating temperature information and also relative humidity information (Polsky and Keyserlingk 2017; Tao et al., 2020) in a single value (Bernabucci et al., 2014). The equation currently used to calculate the temperature and humidity index according to Salama et al. (2014) and Tao et al. (2020) is:

$$THI = [1.8 \times Tdb + 32] - [0.55 - 0.0055 \times RH] \times \times [1.8 \times Tdb - 26]$$

where: *Tdb* – dry air temperature (°C); *RH* – relative humidity (%)

When evaluating the temperature and humidity index, three levels are classified. The first one is characterised by the dairy cow being out of danger or out of the danger zone and represents a value of <68. The second level is mildly stressful and values are from 68 to 74. Finally, the third level is ≥75, which affecting the total milk yield. DeRensis et al. (2015) and Ravagnolo et al. (2000) describe that reductions in milk yield and associated financial losses are expected at THI values as low as 72–75.

During the high index level, there is a slower passage of feed through the gastrointestinal tract of the dairy cows (Pejman and Habib, 2012). Conte et al. (2018) also describe that fibre intake in combination with heat stress has a large effect on digestion. West et al. (2003) reported that in dairy cows fed diets with lower contents of neutral detergent fibre (30% NDF DM) has been positive effects such as higher production per day, reduced respiration rate and last but not least, lower body temperature were observed. On the other side, in dairy cows fed neutral detergent fibre in higher contents (42% DM), has increased heat stress-induced impairment.

5 Conclusions

In this review is discussed a relationship between the nutrition – rumination – heat stress – health status of dairy cow. We pointed out how these aspects are interrelated and also how one factor is dependent on the other factors. It is also brought to the attention that the health status of the dairy cow, on which milk yield is based, is determined by dry matter intake, which correlates with various factors. On the basis of the literature reviewed, is suggested to feed the ration in terms of NDF in the quantities required in relation to the lactation period and in relation to digestion and physiological processes. And, of course, it is also very necessary to implement feeding with adequate peNDF, which plays a major role in maintaining the functionality of the rumen apparatus of the dairy cow.

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