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Review

Ingestion behavior and forage intake by grazing cows in temperate climate. Review

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Abstract:

The objective was to review, based on predominantly recent publications, the knowledge on the components of the ingestion behavior (IB) of cows that graze in a temperate climate, and their relationship with the characteristics of the pastures that regulate the daily forage intake (FI). The components of IB that regulate FI are bite mass (BM, g DM bite^{-1}), bite rate (BR, bites min^{-1}), intake rate (IR, g DM min^{-1}) and grazing time (GT, min d^{-1}). The mass, height and density of pasture forage affect BM and consequently, FI. Pasture height is related to IB components and is useful for assessing FI. Based on studies in temperate pastures in a vegetative state, it is highlighted that the FI of cows increases with increases in pasture height, because they harvest bites of greater BM, which allows them to obtain high IRs. But there is evidence that IR may decrease in pastures that are too tall; to process larger bites, cows reduce their BR and execute more compound and chewing jaw movements. In contrast, in short pastures, cows increase their BR and GT, to remedy the reduction in IR due to harvesting lighter weight bites, although this does not fully compensate for the decrease in IR. Therefore, to maintain high IRs, cows should not be forced to consume forage at high grazing intensities.

Key words: Intake rate, Grazing time, Bite rate, Bite mass, Pasture height.

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Introduction

Dry matter (DM) intake and diet digestibility determine the supply of nutrients to housed or grazing cows, and consequently affect their production. Therefore, understanding the factors that affect the short-term forage intake by grazing cows is important for grazing management, even more so when the intake and, therefore, the production of grazing cows is lower than in housed cows.

Forage intake by grazing cattle can be evaluated from the ingestion behavior they exhibit during foraging, since they adapt this behavior according to characteristics of the pasture(1) and several factors such as the chemical composition of the forage (neutral detergent fiber, soluble carbohydrates and crude protein), the stimuli of the products of rumen fermentation ($N\text{-}NH_3$ and volatile fatty acids), the hormones of hunger (ghrelin), satiety (leptin and melatonin), rumen filling(2), post-ingestive consequences caused by the content of secondary metabolites in plants(3), supplementation, and physiological and nutritional status(4). However, in grazing, the bite mass along with pasture characteristics such as: mass, height and disappearance of forage are factors that regulate intake and, in one study, they explained 78 % of the variations in the weight gain of cattle(5). Corroborating this result, in a recently published meta-analysis(6), which included 103 publications with 278 experiments, it was confirmed that bite mass (BM) is a fundamental component of ingestion behavior (IB) in grazing; since it is sensitive to the main characteristics of the pasture canopy and is a determining factor for the intake rate (IR) and forage intake (FI).

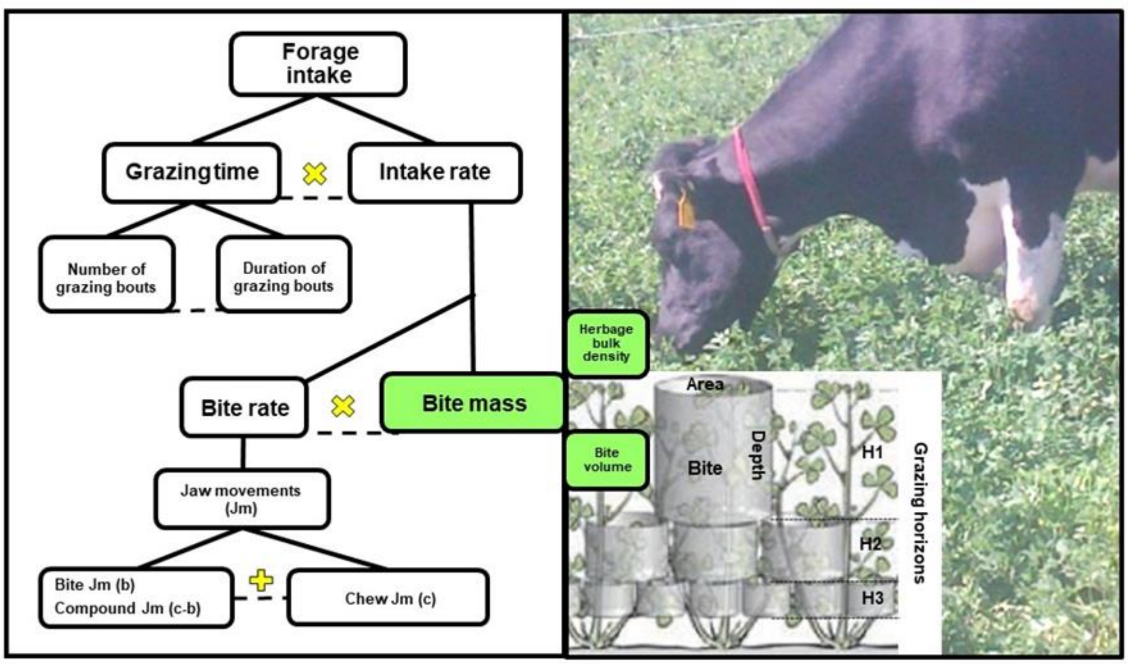
Due to the importance of forage intake in grazing animal production and due to the effects of the characteristics of the induced grassland (pasture) on ingestion behavior, the purpose of this review is to characterize the components of the ingestion behavior of grazing cows in temperate climate, based on mainly recent research results, made mostly in homogeneous temperate climate pastures (monophyte, with little spatial variation in the vertical and horizontal axes). These studies have made it possible to advance in the understanding of the functional relationships between pasture characteristics and the dimensions of the bite and IR(7). The predominance of the study of the ingestive behavior of cattle in homogeneous pastures is due to the greater difficulty in the methodology to evaluate this behavior in more heterogeneous vegetation, with plants that differ in their morphology and structure(8).

At the beginning of this document, the components of ingestion behavior and the space-time scales of the grazing environment are defined and described; then, concepts about bite dimensions are presented, to analyze their relationship with forage density and impact on forage intake. Later, the importance of pasture height and its reduction, as measures of forage abundance, on ingestion behavior and intake is addressed. At the end, the pattern of cow grazing activity and results of ingestion behavior and intake are described.

Ingestion behavior and grazing scales

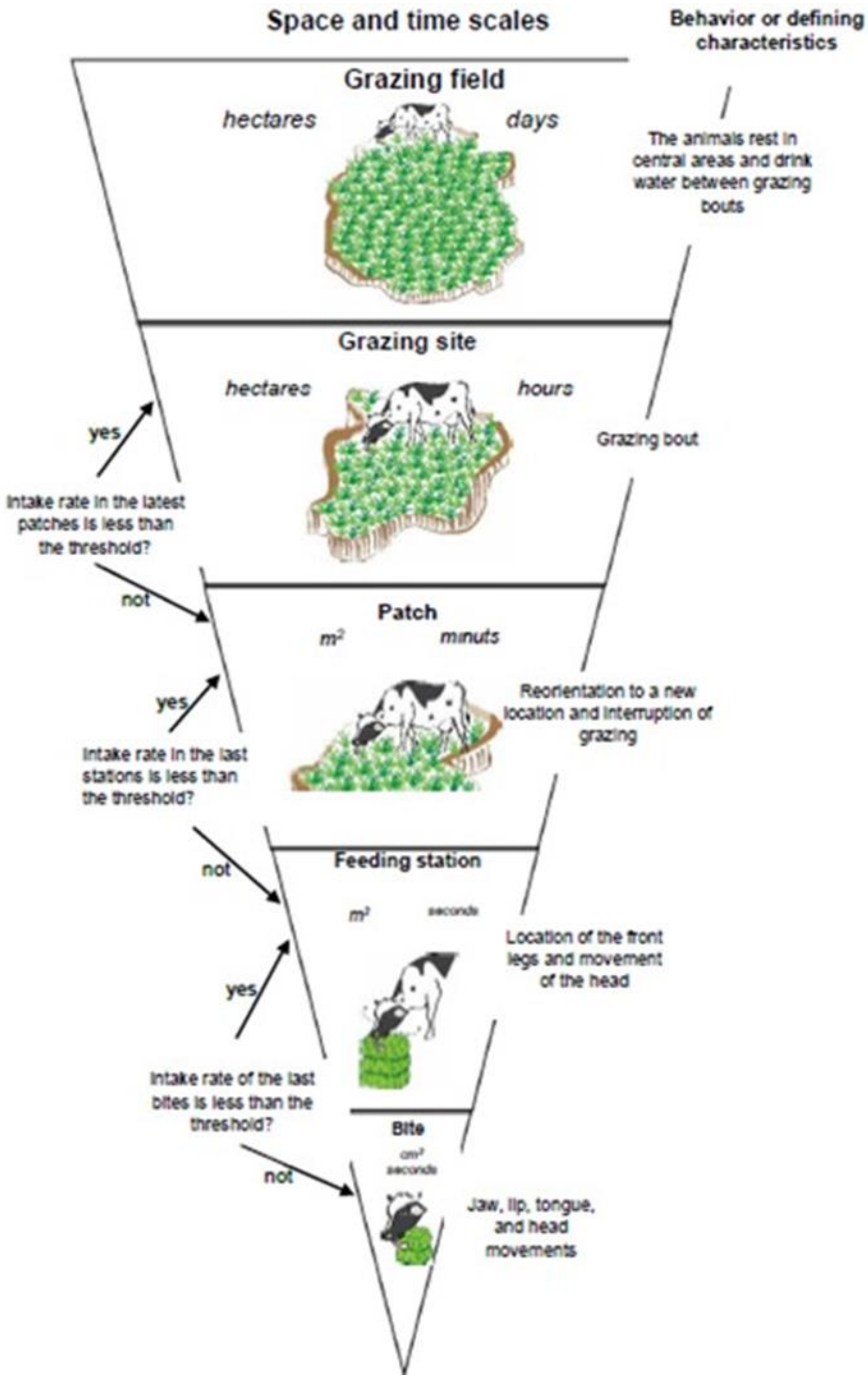
Knowledge of the IB of cows is essential to understand and manage their FI. In the analysis of the IB of cows to evaluate FI (g DM d^{-1}), components of the behavior of the animals and attributes of the pasture are included (Figure 1). The components are BM (g DM $bite^{-1}$), bite rate (BR, bites min^{-1}), IR (g DM min^{-1}) and grazing time (GT, min d^{-1}). Cows collect forage at different hierarchical scales of space and time of the grazing environment, making decisions, which together are known as ingestion behavior, equivalent to foraging dynamics (Figure 2)[9].

Figure 1: Components of the ingestion behavior of grazing cows[1,10,11].



The smallest scale of foraging dynamics is the bite, and its obtaining is defined as the placement of forage in the mouth and its detachment from the rest of the plant by movements of the mouth and head[8,12]. With movements of the lips, tongue and jaws, the bite is apprehended and accommodated inside the mouth and with movements of the head, the tension to achieve the rupture of the forage is obtained. During this operation, cattle use their tongue to introduce forage into their mouths and to expand the bite area[13].

Figure 2: Spatial and temporal scales of grazing behavior of large herbivores[9,11,12]



The next spatial scale is the feeding station, an area in which the animal selects and takes bites with neck movements without moving its front legs[14]. The level immediately above is the patch, which consists of a set of feeding stations[13].

Foraging at these scales can last from 1 sec to 30 min, on areas that range from a few cm^2 to 1 ha[9]. The next scale is the grazing site, which is made up of different patches where the cow consumes forage during a grazing session[13]. The time of permanence at this scale varies between 1 and 4 h, on areas that range from 1 to 4 ha[9]. Finally, the upper scale of grazing behavior is the grazing field, which involves more time (weeks) and space (km^2). This scale can be reached by herds of cattle that, during grazing, move within large grasslands[15]. The time of permanence of large herbivores (including cattle) at the different scales is generally a function of the quantity and quality of the forage found there[9]; in addition to other factors that include the topography of the area[16], the location of the water[17], the season of the year[18], as well as components of the social behavior of cattle[19]. The genotype of the animal is a factor in which contradictory results have been found; in a study, the grazing of Beefmaster × Simford cows was compared with that of smaller Baladi cows, the Baladi cows exhibited greater grazing time and distance walked[18]. In another study, early-maturing (Angus and Hereford) and late-maturing (Limousin, Charolais) young bulls were compared, and no differences were found in ingestive behavior and intake between genotypes[20]. Nevertheless, forage intake in F1 Hereford × Angus cows during gestation was lower than in Hereford and Angus cows[21].

In the research on FI by dairy cows in pastures, short-term studies on bite scales[22,23], feeding station[24,25], patch[26,27] and grazing site[16] have predominated. One reason that research has focused more on the short term is because few researchers have access to automatic recording of IB and personnel trained to make long-term observations[7]. However, precision livestock farming, which includes the use of technological tools to assess cattle behavior[28], can contribute to making management decisions in real-time and better understanding the plant-animal relationship in grazing systems. In this regard, there are several sensors and devices that have been used for the monitoring of jaw movements and the ingestion behavior of grazing cattle[12].

The FI of grazing animals can be described arithmetically as the product of two components, IR and GT[1] and, in turn, IR as the product of BR and BM[29]. For its part, BR is determined by jaw movements (Figure 1) that can be differentiated with equipment that registers either mechanical signals[30] or acoustic signals[31]. Jaw movements are for chewing, bite and compound (chewing-bite)[23], the latter have been identified exclusively with acoustic analysis[32]. A recently published meta-analysis[6] that involved 103 publications with 278 experiments confirmed that BM is a fundamental component of IB in grazing, as it is sensitive to the main characteristics of the pasture canopy and is a determining factor for IR and FI.

To understand the foraging strategy of grazing animals and to be able to optimize the FI between the scales, more than two decades ago, it was postulated in a model that the movement between the smaller scales is governed by the IR of the hierarchical scales immediately below (Figure 2)[33]. For instance, when a cow harvests bites within a feeding station, grazing may continue until the IR of the last bites falls below a threshold. If that situation occurs, the cow will move to the next upper hierarchical scale, in which the harvest of bites will be carried out at the patch level, and there in turn it will remain until the IR reaches the lower threshold.

In this regard, it has been highlighted that the time of permanence of animals harvesting bites at each feeding station reflects the condition of the forage canopy; when the structural quality of the forage is better in leaf/stem ratio, mass, height and density of forage, the time of permanence will be greater[13]. In a study, it was documented that cattle and sheep remained less between feeding stations and moved more quickly between them in native pastures of southern Brazil of low height (4 and 8 cm) than of greater height (12 and 16 cm)[14]. Likewise, in another study, it was obtained that the time of permanence of steers in the feeding station of ryegrass (*Lolium multiflorum* Lam.) with black oats (*Avena strigosa* Schreb) increased with increases in pasture height (10, 20, 30 and 40 cm)[34].

In relation to the FI at the feeding station level, in a study, it was obtained that steers grazing wheat (*Triticum aestivum* L.) of greater height (23.6 cm) had 1.9 times higher IR of forage and harvested more bites in the area grazed per feeding station than in pastures of lower height (20.4 and 19.5 cm)[35]. This is evidence that the foraging strategy used by cattle to achieve a high forage intake during grazing is to increase their IR in patches with high amounts of forage (greater height) and move more quickly between feeding stations when they find patches of lower forage supply (lower height).

The distance between potential patches for forage intake is also important in IR components. In this regard, it was obtained that the number of bites, the times of permanence, the speed of movement and the proportion of total forage consumed by cows in patches of alfalfa (*Medicago sativa* L.) and fescue (*Festuca arundinacea* L.) increased and the IR decreased with the increase in the distance between patches (1, 4 and 8 m)[27]; the cows made a more uniform use of the species as the distance between patches increased.

Bite dimensions

The FI of a grazing animal is related to the capacity of its harvesting apparatus[11] and to the dynamics of the functional response, which is the relationship between IR and some variables that describe the abundance of forage in the grazing area, for example, biomass, height and density of the forage[36]. Therefore, the FI per bite can be evaluated by bite dimensions and forage bulk density (FBD). BM can be quantified with the use of arithmetic, as the product of bite volume (BV) and FBD[1]. BV is not the volume of the oral cavity, but the volume occupied by the forage in the pasture that is harvested with the bite, which has been considered a cylinder of determined depth and area (Figure 1). As a result of a meta-analysis, it was published that there is a curvilinear relationship between BV (y) and pasture height (x), y=9.63*(1-exp (0.00125x)), n=90, RMSE=0.30, due to the responses between the depth and the area of the bite due to the effect of the increase in pasture height[10].

Bite depth can be defined as the difference between the initial mean height of the tillers and the mean height of the tillers measured after grazing[8] and, in grass pastures, it can be known from the measurement of the length of the extended tillers before and after grazing[14]. In addition, results obtained in different species of forages and ruminants show that there is a linear relationship between the depth of the bite (y) and the length of the extended tillers (x), y= 1.1 + 0.52x, R^2 =0.84, n =203, which highlights that the depth of the bite corresponds to 52 % of the length of the tillers[1]. The slope value of the previous model approximates the slope obtained with another model based on data from experiments conducted with cattle, which indicated that the depth of the bite (y) increases linearly with the height of the pasture (x), y=1.41+0.44x, RMSE= 1.4, n= 149[10].

Based on the above, there is evidence[1,10] to support that the depth of the bite in cattle is close to 50 % of the height of the pasture. However, in a previous experiment on bite depth[26], it was concluded that caution should be exercised with this concept of proportionality, despite the fact that, in the same experiment, bite depth values of 40 to 55 % of the height of an English ryegrass (*Lolium perenne* L.) pasture were documented in cows. It was also reported that the depth of the bite increased progressively during the first 10 to 20 bites, which indicates that cattle can be cautious when evaluating the patches during grazing[26].

The area of the bite in studies with manually built plots is calculated as the quotient of the total grazed area between the number of bites made[37]. The area of the bite in cattle increases with the height of the pasture, with a curvilinear relationship and a theoretical maximum of 153.6 cm^2[10]. FBD refers to the relationship between the mass of the forage and the volume occupied by that mass in the pasture. In studies on bite dimensions, FBD is estimated by the quotient of the forage mass and the volume of the canopy stratum[38]. The decrease in FBD has a positive effect on the bite area of cattle; at lower FBD values, the bite area was close to 130 cm^2, while for high FBD values, the bite area had a minimum value of 33 cm^2[10].

The height and density of temperate pastures do not vary independently but are usually inversely related. In very short pastures (generally denser), larger areas of bite are not possible, since the short components (essentially leaves) that are at the edges of the area of the bite that the animal tries to take escape capture by the tongue and grasp by the teeth and the dental arcade[12]. On the contrary, in the temperate climate pastures of greater height in a vegetative state, the depth and the area of the bite are greater because the apprehension of the components of the canopy is facilitated[13]. In these cases, the cattle execute compound jaws movements; the animal takes a new bite when it is still chewing the bite it previously took[23].

The height of the pasture in the intake

So far, the effects of pasture height and FBD on bite dimensions have been highlighted. But it is important to discuss the impact that the height of the pasture has on the FI in grazing and to explain how the latter is regulated by IB components and by BM[6,10]. Nevertheless, in temperate and tropical pastures, in a vegetative state, FI will be positively affected by the height of the pasture, as long as canopies with high density of green leaves are maintained[29,39,40].

The increase in FI by grazing dairy cows is a classic response to the increase in pasture height, which is explained by the changes that occur in the components of IB during grazing, also by the effect of changes in pasture height (Figure 3). This was evidenced from a classic work conducted with ewes in temperate pastures[40] and in recent years, results obtained with beef cattle in tropical pastures[29] confirmed the same. The classic response of IR and BM due to the effect of pasture height is that these variables increase with the increase in height[29,40,41,42]. However, recent studies in which different pasture heights were evaluated in *Cynodon* sp. (10, 15, 20, 25, 30 and 35 cm) and *Avena strigosa* Schreb (15, 20, 25, 30, 35, 40, 45 and 50 cm) highlighted that, although the same pattern was found, IR and BM decreased in the tallest pastures that were evaluated[24]; the results showed a functional response in the form of a dome, where the IR of forage was higher at intermediate pasture heights in both species (39.2 g DM min^{-1} with 19 cm in *Cynodon* and 54 g DM min^{-1} with 29.3 cm in oats)[43]. The authors of the work highlighted that this response was the result of changes in BM in tall pastures (30 and 35 cm in *Cynodon*, 45 and 50 cm in oats) and attributed the decrease in BM to a reduction in its volume, due to a smaller bite area driven by the selective behavior of the animals, since it was not related to pasture restrictions that limited the formation of the bite[43].

With the increase in pasture height, cattle also increase the total jaw movements per gram of DM consumed[38], because animals must execute a greater number of jaw movements per each bite because these are of greater mass and, therefore, they require a greater number of chews so that the forage can be swallowed[6,41]. In summary, BM and FI in temperate pastures, in a vegetative state, can be higher in pastures with intermediate[43] and tall heights[29], and to process larger bites, cattle increase the number of compound jaw movements[23].

Another important change in the IB of grazing cows in response to the increase in pasture height is the reduction in BR and GT (Figure 3); the first is a consequence of the greater amount of forage apprehended per bite, which implies an increase in the time per bite[24] due to the increase in the number of chewing jaw movements[34]. In other words, as cattle apprehend more forage per bite, they spend more time chewing, which postpones taking the next bite[6,34].

The reduction of the height of the pasture in consumption

So far, it has been mentioned how FI is explained by the IB of the animals and by structural characteristics of the pasture canopy (amount of forage, FBD and pasture height) that regulate BM, based on studies where these variables were evaluated in plants of different heights in a vegetative state. However, it is important to discuss the effect of the reduction in pasture height on FI, which occurs with the rapid depletion of the forage resource that occurs during grazing throughout the day. The harvest of bites during grazing is carried out through horizons of the forage canopy, at a more or less constant depth of 50 % of the height of the pasture[11].

Cattle begin grazing at horizon 1 (H1), consume 50 % of the height of the forage and then continue to horizon 2 (H2), where they will harvest approximately the same proportion of height corresponding to the horizon, until they reach horizon 3 (H3) and end at a grazing limit height (Figure 1). In a study conducted with cattle, it was obtained that the depth, area and BM in wheat, sorghum (*Sorghum sacharatum* L.) and alfalfa (*Medicago sativa* L.) varied across grazing horizons[22]. From H1 to H3, bite depths decreased by 76, 78 and 70 %, bite areas decreased by 44, 56 and 56 % and consequently BMs were lower by 61, 71 and 87 % for wheat, sorghum and alfalfa, respectively.

In the vertical structure of the pasture is part of the cause of the variation in the dimensions of the bite because the increase of the pseudostem, stem and dead material from the surface of the pasture to its base become barriers to the formation of the bite[11,38], and consequently they modify the BM and in turn the FI. It has also been documented that the pseudostem and the heights of regrowth and dead material within the forage canopy are partial regulators of the bite depth[26]. Therefore, the decrease in the bite area from H1 to H3 is due to the decrease in leaves at the base of the forage canopy and due to the difficulty of apprehension of the forage that escapes the sweep of the tongue[22]. In addition, the increase in FBD in the lower strata of the pastures[38,39] negatively affects the bite area[10].

Based on the above, there is evidence to highlight that the decrease in FI that occurs with the reduction of the height of the pasture, when animals are forced to harvest to the lowest horizon of the pasture, is due to the harvest of small bites. Strip grazing is associated with situations of rapid depletion of the forage resource and when the levels of reduction of pasture height in this situation are not controlled, FI can be negatively affected[44]. Nevertheless, in situations of different management, in which the pastures do not exhibit changes in their condition during the day, IR is constant, and the intake behavior is similar throughout the day[29]. Rotatinuous grazing (low intensity and high grazing frequencies) is a management strategy to maintain high forage IRs since animals harvest most bites at H1[1,45].

Therefore, it is important to note that the control of grazing intensity during pasture management is a useful management measure to have an idea of the level of FI. For example, in order to maximize the FI in dairy cows grazing *Lolium arundinaceum*, it has been highlighted that grazing management should be carried out at low grazing intensities; residual forage heights of 12 and 15 cm in autumn-winter and spring, respectively[25]. While in cattle under grazing of black oats cv. Iapar 61, *Cynodon* sp. cv. Tifton 85[24] and sorghum (*Sorghum bicolor* L.)[46], it was found that high IRs remained up to a reduction level of 40 % of the height of the pasture. Shorter residual forage not only translates into lower intake, but also into lower selectivity, which contributes to a lower intake of digestible organic matter, and therefore lower milk production[25].

Grazing cattle and sheep are able to increase their BR and GT in situations of low BM (Figure 3) as a behavioral strategy to partially compensate for the reduction in IR[6,7]. However, the decrease in the amount of forage ingested per bite is not fully compensated and, as a result, FI is lower[7]. Due to differences in animal behavior, the response occurs in continuous and rotational grazing but not in strip grazing; in these cases, height becomes a very limiting factor, causing the animals to choose not to graze for a longer time due to the low compensation associated with very small bite masses[20,47].

Grazing time and forage intake

During the day, the cows carry out grazing, rumination and other activities. Some results of the time that cows spend on each activity in temperate climate in grazing of English ryegrass are shown in Table 1. Cows in temperate pastures exhibit different grazing sessions during the day, between three and four sessions, two of greater intensity, at noon and before dusk[2].

In a study on grazing of English ryegrass with morning forage allocation, cows spent between 70 and 80 % of their time on grazing after morning and evening milkings[48]. In this regard, in another study[49], it was found that, as the first 4 h after morning milking (after 0800 h) and evening milking (after 1500 h) elapsed, the percentage of cows in grazing decreased from 94 to 35 % (morning milking) and from 87 to 9 % (afternoon milking).

In relation to rumination and inactivity times for dairy cows, they spend more than 70 % of their time on these activities at night[48,49]. Although the greatest rumination time occurs during the night, there are also periods of rumination in the day. Rumination at night is associated with the natural behavior exhibited by ruminants; at dusk they consume forage as quickly as possible and reserve the rumination for the night when they hide with relative safety and the risks of being preyed on decrease[2].

Because the total daily grazing time is the cumulative result of all grazing sessions or events, for FI estimation purposes, the GT must be active grazing, which is determined by the number and length of grazing sessions (GSs) during the day[13]. GS by definition refers to a long sequence of grazing, which is characterized by a minimum of 20 min of active grazing, whose interruption occurs by the performance of any other activity, also for a minimum period of 20 min[50].

From studies conducted on rotational grazing of pastures dominated by English ryegrass, it has been found that dairy cows can perform around 5.6 to 10.0 GSs throughout the day (Table 1) and the length of the GS is approximately 90 min. The number of GSs and their duration have been associated with the quality and quantity of forage; if the mass of available forage is high, the number of GSs is higher and their duration is shorter[25]. In these situations, cattle become more selective and can therefore harvest higher quality forage in less time[50].

FI in dairy cows grazing pastures dominated by English ryegrass is approximately 3 % of their live weight (LW), based on the integration of results on reported IB components[48,51] (Table 1). Nevertheless, the variation around this mean can be high due to pasture, grazing management and animal factors. In a review of temperate pasture grazing, FI values of 1.6 to 3 % of LW were reported in dairy cows.

Intake rate of different categories

Based on the results in Table 1, the BR is similar between heifers and adult cows (59 bites min^{-1} on average), while the average BM is higher in adult animals (0.41 g) than in young animals (0.22 g). This is due to the greater length in the arcade of the incisors of the cows because it determines the area and volume of the bite and consequently the BM[10]. Therefore, the average IR reported in heifers is lower (12.8 g DM min^{-1}) than in cows (24 g DM min^{-1}).

Conclusions

Although cows on low-height (short) pastures have the ability to increase BR and GT, as a behavioral strategy to remedy the reduction in IR due to harvesting lower weight bites, the animals do not compensate for the decrease in the amount of forage ingested per bite and, as a result, FI may be low. Therefore, when cows are kept in very short pastures or in situations of overgrazing, it is certain that IRs will be low and consequently the daily forage intake will be lower. Due to the relationship of pasture height and IB components and FI, in practice the monitoring of pasture height can be a useful tool for assessing FI and maintaining high IRs in cattle. However, in Mexico it is necessary to develop studies focused on evaluating the IR of grazing cattle at different pasture heights, which allow generating practical implications for grazing management.

Acknowledgements and conflict of interest

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Figure 3: Forage intake and components of ingestion behavior in response to pasture height[29,40]

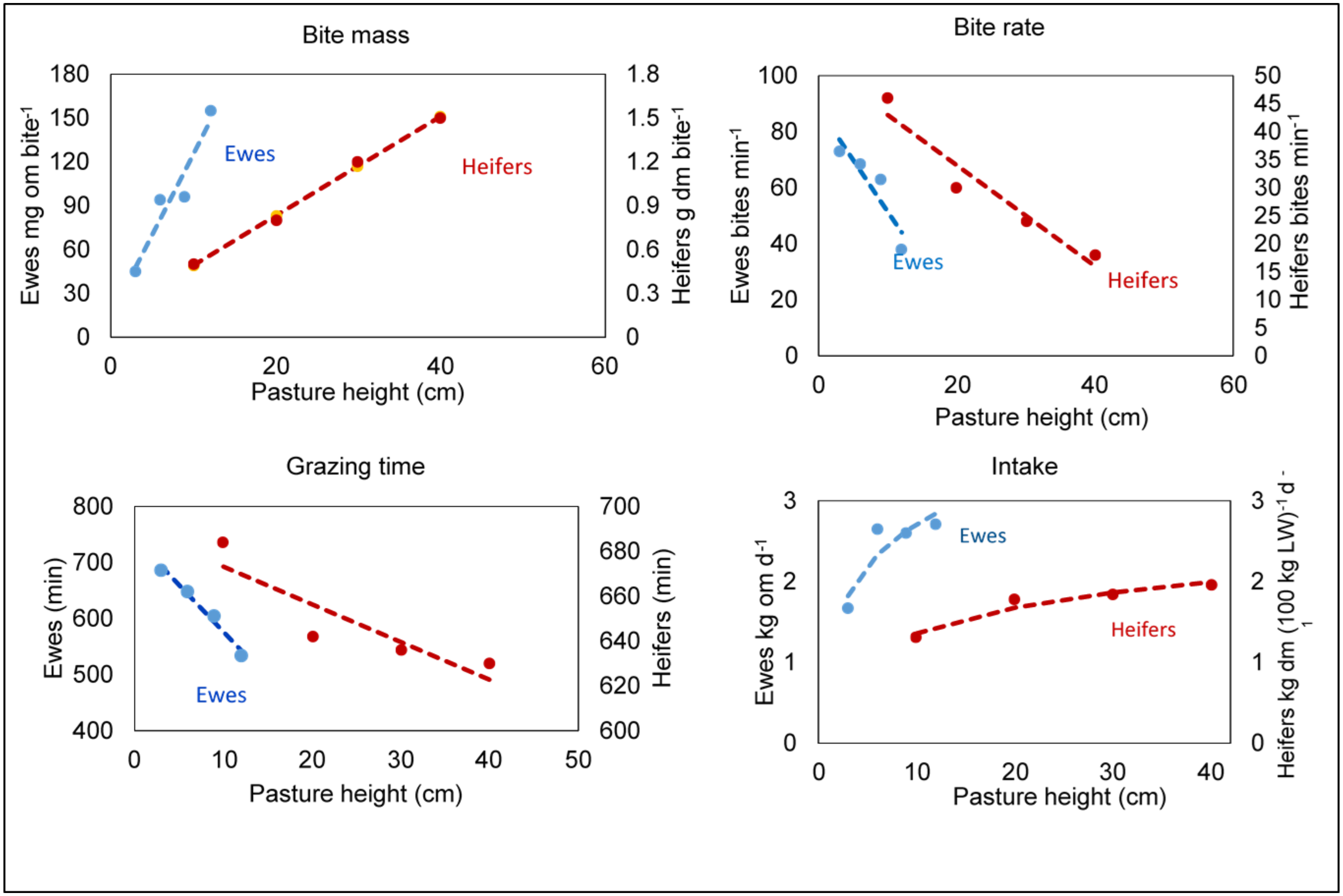

Table 1: Components of ingestion behaviour, grazing times, rumination and inactivity in dairy cows under grazing in temperate climate pastures

	Dairy cows		**Heifers**	
	English ryegrass[52]	English ryegrass[53]	English ryegrass[51]	*Trifolium repens*[51]
Forage intake, kg DM 100 kg LW^{-1}	3.3	3.0	3.0	2.4
Forage intake, kg DM d^{-1}	15.2	15.5	6.9	5.5
Grazing time, min d^{-1}	629	646	536	436
Intake rate, g DM min^{-1}	24.2	23.9	12.8	12.7
Bite rate, bites min^{-1}	62	57	61	55
Bite mass, g	0.39	0.42	0.21	0.23
Times of grazing, rumination and other activities in dairy cows				
	English ryegrass[48]	Ryegrass (80%) and clover[48]	English ryegrass[53]	Ryegrass (80%) and clover[54]
Grazing time, min d^{-1}	622	591	646	549
Grazing, sessions d^{-1}	6.5	5.6	10.0	9.6
Session duration, min $period^{-1}$	99	120	79.5	63
Rumination, min d^{-1}	431	402	426	401
Other activities, min d^{-1}	388	447	368	490