BEEF SPECIES–RUMINANT NUTRITION CACTUS BEEF SYMPOSIUM: Sustainable and economically viable management options for cow/calf production through enhanced beef cow metabolic efficiency[1]

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Abstract: Beef cow herds are expected to be metabolically and reproductively efficient in varied and ever changing environmental conditions. Therefore, selection and management of grazing beef cows provides unique and diverse challenges in achieving optimal production efficiency for any environment. Beef cows face dynamic and highly variable nutritional environments that periodically are inadequate in meeting nutrient and energy requirements. Nutritional management during high metabolically stressed and key physiological states can lead to increased or decreased metabolic efficiency. Conversely, cow metabolic efficiency may be reduced in many production systems due to surplus nutritional inputs and reduced exposure to environmental stressors. Alternatively, metabolically potent supplementation strategies targeting enhanced energy metabolism and endocrine mechanisms would increase beef cow metabolic and economic efficiency. Metabolic efficient beef cows adapt to environmental changes by adjusting their metabolic energy utilization in order to match current environmental conditions and remain reproductively competent. This mechanism involves adaptive processes that drive adjustments in nutrient partitioning and energy utilization efficiency. However, the variation in metabolic and reproductive efficiency among beef cows within cow/calf production systems is substantial, suggesting a lack of complete integration of nutrition, genetics, and reproduction with environmental constraints and conditions. Better integration and understanding of the interactions may lead to advancements in metabolic efficiency of the cowherd. Metabolic flexibility is recognized as an important trait in dairy production but has received little attention thus far in beef cattle. Overall, management and supplementation strategies in cow/calf systems from a mechanistic, targeted nutritional approach during key physiological periods would hasten improvements in metabolic efficiency.

Key words: beef cow, metabolic efficiency, nutritional management, oxidative capacity

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INTRODUCTION

Flexible and opportunistic strategies are pivotal for successful management of livestock in variable environmental climates, which include the challenges grazing livestock face and their innate ability to adapt to those challenges (Launchbaugh and Hunt, 2000). Dynamic changes in nutritional and physiological stressors create nutritional and metabolic challenges, in which failure to cope and adapt to those challenges can result in decreased

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production efficiency. Even when forage or forage quality is abundant, the production cycle in cattle is energetically demanding due to the energetic costs of lactation and gestation. Energetic costs of lactation are even more exacerbated if genetic potential exceeds the environmental capacity (Edwards et al., 2017). Furthermore, the ability to adapt and cope with the nutritional challenges varies greatly among livestock, in which genetic potential and metabolic imprinting is likely an explanation (Gross and Bruckmaier, 2015). During the production year, grazing livestock often face multiple time periods when nutrient input does not meet requirements at which body reserves are needed to be mobilized. In doing so, enhancing or selecting for increased oxidative capacity during nutrient limited and demanding time points is a key function of metabolic efficiency and increasing metabolic robustness of the cowherd. Strategic supplementation that enhances energy metabolism and oxidative efficiency during periods of nutrient and physiological stress would increase cow/calf production efficiency. Furthermore, increased longevity and resiliency within environmental constraints may be highly dependent on selection for energetic and metabolic efficiency associated with stress resistance (Parsons, 2002). With that in mind, metabolic efficiency and longevity may be reduced in beef herds due to managing to meet or exceed nutrient requirements during key physiological periods allowing for reduced exposure to moderate stress. This begs the questions of "Do our current management practices and traditional recommendations decrease the ability to adapt to nutrient challenges? and "Can we use management and strategic supplementation during nutrient challenges to enhance metabolic efficiency." This review will focus on late gestation and early lactation management practices that can increase energy metabolism and metabolic efficiency of the cowherd.

GENETIC SELECTION TO INCREASE METABOLIC EFFICIENCY

One of the largest regulators of metabolic efficiency for beef cows is genetic potential within their environment and management system. Discrepancies in environmental constraints and the animal's genetic potential can lead to increased production costs, manipulation of the environment with additional feedstuffs, and decrease metabolic efficiency (Macdonald et al., 2008). A large challenge for the cowherd, especially in limited resource environments, is an increase in selection for greater milk production. An increase in selection for milk production has resulted in beef cows under greater nutritional stress during early lactation, which ultimately reduces overall reproduction and cowherd efficiency (Edwards et al., 2017). These authors determined the impact of milk production on cow/calf performance in Angus and Angus crossbred cows with milk ranging from 6.5 to 12 kg/d at peak milk production. Although cows were in high-quality feed environments, this study reported that reproduction decreased in mature beef cows when peak milk production was greater than 9 kg/d. This study indicates that even with high-quality feed resources, increased milking ability decreases the ability of cows to adapt to the nutritional and metabolic demands of lactation, resulting in decreased reproductive performance.

Grazing dairy studies in New Zealand have provided evidence of the impact of increasing selection for milk yield has on overall productivity. Macdonald et al. (2008) compared 3 strains of Holstein-Friesian under different feed allowances in a grazing production system. The strains utilized in this study were 1) 1970s strain of New Zealand Friesian with high genetic potential in 1975 (NZ70); 2) 1990s strain of New Zealand origin and selected for high genetic potential (NZ90); or 3) a 1990s strain of North American origin that was selected for high genetic potential in a traditional North American dairy system (NA90). Even at increased feed allowances, NA90 cows had shorter lactations and reduced reproductive performance, leading to decreased profitability. Under the management systems of this grazing dairy study, environmental and managerial practices would have to be modified to allow the NA90 strain of cows to survive in the New Zealand grazing management system. Overall, cows with high genetic potential for milk in forage-based grazing systems may be severely affected during nutrient-restricted periods and environmental stresses compared with cows of low genetic potential selected in pasture-based grazing systems.

Genetic selection for milk increases the prioritization of nutrients to support lactation rather than realimentation of body weight (BW), causing increased metabolic challenges during early lactation. For example, in grazing dairy cows, increasing milk production increases insulin resistance (Chagas et al., 2009). Although the level of milk production and insulin resistance has been primarily studied in dairy cows, increasing selection for milk production may increase insulin resistance and metabolic challenges for beef cows, especially young, growing 2- and 3-yr-old cows by partitioning nutrients away from growth and reproduction towards milk. Increasing insulin resistance and milk production will ultimately increase mobilization of body reserves and lower reproductive performance (Mulliniks et al., 2011). For instance, Hunter and Magner (1988) compared formaldehyde-treated casein-supplemented heifers with nonsupplemented heifers. These authors reported that increased metabolizable protein supply encouraged repartitioning of nutrients away from lactation while decreasing days to resumption of estrus after calving in first-calf heifers.

ADIPOSE TISSUE MOBILIZATION AND METABOLIC FLEXIBILITY

Beef cows often go through one or more periods of BW loss through a production cycle. Traditionally, implementing a supplementation strategy during late gestation through early lactation limits body tissue mobilization by facilitating forage intake to meet cow nutrient requirements to maintain cow BW. However, supplementation strategies may not be cost effective or feasible in extensive environments. In addition, as suggested by Parsons (2002), selection for stress resistance or metabolic efficiency is reduced in populations due to adequate or high levels of nutrition while reducing exposure to environmental stress. With that in mind, BW loss or adipose tissue mobilization can be utilized as an effective supplementation strategy if incorporated correctly in a management system. Research has indicated that management strategies can be developed to encourage moderate stages of feed restriction and nutrient realimentation during periods of poor nutrient availability to improve the efficiency of nutrient utilization (Freetly and Nienaber, 1998; Freetly et al., 2008).

During times of grazing low-quality forages, livestock have the ability to adjust their nutrient requirements without affecting productivity (Petersen et al., 2014). Therefore, strategically utilizing the environmental conditions at key physiological time periods eliciting a positive or negative BW change can result in decreasing production costs while selecting for animals that are better adapted to changes in nutritional swings. For instance, Rauw et al. (2010) evaluated BW change in ewes placed on resource-poor environments during a Nevada winter. The study reported ewes who lambed the previous year where better adapted to harsh, nutrient-poor conditions resulting in less BW loss than ewes who had not lambed the year prior. Thus, livestock that have experienced homeorhetic changes are better adapted to prioritize productivity and may be more efficient at mobilizing and oxidizing adipose tissue supplies (Rhoads et al., 2013). In a 7-yr study, Mulliniks et al. (2016) categorized cows by their natural variation in BW change during late gestation as cows that lost 25 kg, maintained BW, or gained 25 kg. Cows that lost or maintained BW during late gestation had greater pregnancy rates the subsequent breeding season. Although BW change differences were not reported up to and through breeding, this improved reproductive performance may be attributed to a decrease in nutrient requirements in cows losing BW during late gestation and an overall increase in nutrient utilization. On the other hand, overconditioning cows during late gestation may have increased nutrient requirements at calving, which may have resulted in increased negative energy balance (**NEB**). In dairy cows, overfeeding during late gestation or through the dry transition period results in increased body condition scores (BCS) at calving and decreased dry matter intake (Rukkwamsuk et al., 1999). If intake is decreased postpartum in over conditioned beef cows during late gestation, cows with greater BCS at calving may exhibit a greater NEB, increased metabolic dysfunction, and decreased reproductive performance.

Traditional recommendations suggest that cows need to be nutritionally managed at a BCS 5 or greater at breeding for optimal reproductive performance (DeRouen et al., 1994; Lents et al., 2003). This recommendation may mask cows with decreased metabolic efficiency or select for subfertile beef cows that require additional inputs to be successful. In a 6-yr study, evaluating the effect of BCS at calving on postcalving reproductive parameters, calving BCS (BCS 4, 5, or 6) did not have an influence on pregnancy rates or resumption of estrus in young range cows grazing native range with minimal feed inputs (Mulliniks et al., 2012), indicating that providing additional nutrient inputs in cows that were less than a BCS 5 would have resulted in increased costs without increased production merit. However, this does suggest that metabolic status or signals in range beef cows may have a larger role in reproductive efficiency than the subjective, insensitive measure of BCS. For instance, Mulliniks et al. (2013) illustrated that timing of conception in young range beef cows was not influenced by BCS; however, conception timing was affected by whole blood β-hydroxybutyrate (**BHB**) concentrations as cows who conceived later in the breeding season had a greater BHB concentration than cows who conceived earlier in the breeding season. In many nutritional environments, BCS may not be a sensitive enough management tool for reproductive and metabolic parameters. The uncoupled relationship between calving BCS and reproduction as reported by Mulliniks et al. (2012) may be partially due to long-term management of this herd within the environmental conditions in New Mexico. Long-term cow herd management may lower BCS thresholds for reproductive success or robustness within the environment while decreasing production costs. In addition, nutritional management practices to achieve a greater calving and breeding BCS may result in selection of metabolic inefficient and inflexible beef cows, resulting in the need for increased inputs to achieve acceptable reproductive performance.

One concern during late gestation of not meeting nutrient requirements and allowing for moderate BW loss is a negative impact on fetal growth and future performance. Previous research has established that maternal nutrient intake during gestation can alter progeny calf health and performance (Martin et al., 2007; Funston et al., 2010). However, cows that have been adapted and managed to reproduce in harsh, limited nutrient environments may have the ability to maintain normal fetal growth and development during periods of maternal nutrient restriction. For instance, late gestation BW change from losing 25 kg to gaining 25 kg had no impact on calf weaning BW, BW at feedlot entry, finishing BW, and hot carcass weight (Mulliniks et al., 2016), illustrating that moderate restriction during late gestation did not affect progeny growth from birth throughout the finishing period. Maternal undernutrition in gestating ewes adapted to nutrient restricted environments did not affect fetal plasma concentrations of glucose or fetal growth (Vonnahme et al., 2006) and were able to maintain fetal concentrations of amino acids (Jobgen et al., 2008). These studies imply that the dam and fetus may have the ability to provide a natural adjustment against nutrient restrictions when livestock are managed long term in their environment. Thus, preplanned management strategies to allow for BW loss during periods of moderate feed restriction followed by nutrient realimentation during periods of increased nutrient supply can be utilized to improve efficiency of energy utilization (Freetly et al., 2008) and decrease input and production costs.

During early lactation, the animal's energy requirement for lactation and maintenance can exceed energy intake, resulting in mobilization of stored resources from adipose tissue to meet energy demands. This time period in beef cows provokes a NEB, characterized by elevated concentrations of BHB, which is associated with a metabolic dysfunction resulting from inadequate adaptation to NEB and incomplete oxidation of energy substrates (Herdt, 2000). The adaptive responses to high metabolic demands, such as lactation, vary among animals even with the same nutrient requirement. For example, postpartum cows prioritize metabolizable energy first towards milk production, then growth, and finally the regaining of adipose tissue (Lucy, 2003). Under the same metabolic load of lactation, cows will partition nutrients and adapt to metabolic demands differently (Sundrum, 2015). Days to BW nadir, lowest BW after calving, can be a good measure of adaptability and has been shown to have a strong relationship with reproduction (Canfield and Butler, 1990). In primiparous beef cows, Spitzer et al. (1995) reported that increasing BW gain after calving increases luteal activity by the start of breeding and increases percentage of early pregnancies. Increasing postpartum BW gain and decreased days to BW nadir may be an important factor in increasing reproductive efficiency. However, Mulliniks (2008) reported young cows in New Mexico achieving BW nadir at day 111 postpartum, returned to estrus at day 70, and had a 96% pregnancy rate during a drought year (76% of annual rainfall) with cows grazing low-quality native range (3.3% CP and 78.6% NDF). Achieving a positive energy balance or BW nadir occurred 7 d prior to the end of the breeding season. In addition, circulating BHB concentrations and breeding BCS (BCS of 4) were lower with increased circulating serum nonesterified fatty acids (NEFA) than other years of that study, illustrating the ability for cows to metabolically adapt to the environmental conditions and remain reproductively efficient. The capacity for animals to cope with acute and chronic environmental changes depends on the degree of metabolic flexibility (Hofmann and Todgham, 2010). Therefore, early lactation for a range beef cow is a period characterized by the cow's coping ability, resulting in either reproductive competence or overall failure to adapt to the increased metabolic demands of lactation (Mulliniks et al., 2013; Hobbs et al., 2017).

To test metabolic robustness of dairy cows during early lactation, Gross and Bruckmaier (2015) retrospectively ranked cows according to their greatest NEFA concentration in weeks 1 to 4 postpartum classifying cattle with a low or high response. These authors reported that the greater amplitude of adaptive responses or increased plasma concentrations of NEFA, BHB, and insulin-like growth factor-I in high-response cows may indicate a rapid ability for the sufficient supply of mobilization-derived nutrients. However, these authors did not include the effect of mobilization rate on reproductive efficiency. Mulliniks et al. (2013) measured the altered metabolic responses of cattle grazing variable quality of nutrients in forage in correlation to their time of conception. These authors reported that beef cows with elevated blood ketone concentrations, manifested from metabolic imbalance prior to breeding season, had a prolonged interval from calving to conception. This delay in conception date may be explained by studies in rats (Iwata et al., 2011) and sheep (Cope, 2018), which suggest that BHB suppresses luteinizing hormone concentration and acts as a negative energy signal inhibiting gonadal function. Therefore, ketone concentrations may be one useful indicator of adaptive capacity during metabolically challenging periods as failure to efficiently adapt cellular metabolism to oxidize fatty acids, which may compromise a cow's ability become pregnant in a timely manner in a breeding season. Overall, beef cow metabolic efficiency can be enhanced during demanding physiological periods when nutrients are sparse by increasing oxidative capacity and energy metabolism.

STRATEGIC SUPPLEMENTATION TO INCREASE METABOLIC FLEXIBILITY

Selecting for animals that have enhanced metabolic flexibility during nutrient challenges occurs after the challenge, and animals either adapt or fail to adapt to the challenges such as culling open females. However, supplementation strategies may be utilized to improve metabolic efficiency during nutrient and environmental challenges. Supplementation or additional nutritional inputs can improve livestock productivity. However, in a profit model, increases in feed costs and inputs result in decreased profit due to an uncoupled and proportional linear response in increased production (Ramsey et al., 2005). Thus, supplementation should be utilized strategically to elicit a metabolic response, which can positively alter important economic production traits such as conception date and overall pregnancy rates.

In grazing production systems, forage-based diets have an increased ruminal production of acetate compared with propionate that can lead to an imbalance in acetate:propionate ratio (McCollum, 1985; Cronjé et al., 1991). Disproportion in the acetate:propionate ratio can have negative modifications in energy metabolism. For efficient and complete oxidative metabolism to occur in ruminants, cellular oxaloacetate is essential for the conversion of acetyl-CoA resulting from ruminal acetate or fatty acid catabolism, to be converted to adenosine triphosphate in the tricarboxylic acid cycle. Therefore, oxaloacetate supply derived from glucose directly or indirectly via glucogenic precursors, such as ruminally produced propionate, glycerol, and glucogenic amino acids, is essential in oxidative capacity of forage-based production systems. This may be even more essential during early lactation. Cows consuming low-quality and low-glucogenic diets have negative consequences such as the potential acetate clearance rates, leading to increased circulating BHB or ketone concentrations from incomplete fatty acid oxidation. Inadequate cellular glucose has also been shown to negatively affect insulin sensitivity by increasing adipose mobilization and reducing clearance of insulin-dependent intermediates, ultimately inhibiting acetate clearance rate and utilization (Waterman et al., 2006; De Koster and Opsomer, 2013). For example, Waterman et al. (2007) reported as forage quality declines, tissues become less responsive to insulin, resulting in longer glucose half-life. In addition, enhanced energy metabolism in young range cows identified by faster glucose and acetate clearance rates has been reported to increase reproductive performance in beef cows (Waterman et al., 2006; Mulliniks et al., 2011). Therefore, during key physiological periods such as late gestation and early lactation when nutrient requirements increase and cattle are often grazing limited nutrients supplementation strategies could target improving energy utilization of both forage (i.e. acetate) and fatty acids from lipolysis.

Decreased nutrient intake can further exacerbate energetic challenges associated with pregnancy and nutrient demands of lactation, thus creating the most difficult periods in managing beef cows. During early lactation, cows experience a NEB and will mobilize both protein and fat storage to offset the energy deficiency. Research in dairy cows has established a large variation in the amount and duration of protein and fat mobilization (van der Drift et al., 2012); however, this mobilization during the early postpartum period is important for the animal's ability to adapt to the demands of lactation. In environments where metabolizable protein supply is deficient, range beef cows may have to catabolize lean protein reserves to be able to meet the increased demand to glucogenic precursors to oxidize ruminal acetate and fatty acids from lipolysis. For instance, in Nebraska, May-calving cows are estimated to be deficient in both energy and metabolizable protein balances at the start of breeding, which is further exacerbated through the breeding season (Mulliniks and Adams, 2019). Depending on level of milk production, estimated metabolizable protein balance can be as low as –300 g/d. Coming into the breeding season in a NEB creates a scenario that cows have to have the ability to mobilize and oxidize stored body fat effectively to reproduce, which may require catabolism of lean tissue. In a review, Bell et al. (2000) states that in high-producing dairy cows, protein catabolism is greater than 1,000 g/d to meet the need for amino acids and glucose. In addition, insulin resistance during early lactation in beef cows may inhibit protein synthesis and increase protein catabolism (Bell et al., 2000). Lactating, young range cows have been shown to be highly insulin resistant during early lactation, conducting a glucose tolerance test indicating glucose half-lives ranged 65 (Waterman et al., 2011) to 97 min (Mulliniks et al., 2011), which are up to 3 times greater than glucose half-lives in some high-producing dairy cows (Chagas et al., 2009; Lohrenz et al., 2010). The degree and extent of lean tissue mobilization during negative energy balance situations in response to grazing low-quality, extensive rangelands may need to be further investigated.

Strategic supplementation with increased rumen undegradable protein (RUP) can modify proportions of the type tissue being mobilized promoting the utilization of fat tissue over muscle protein (Leng et al., 1978; Soenen et al., 2013). Fattet et al. (1984) demonstrated how strategic use of RUP supplements during periods of increased weight loss could potentially have a positive influence on body protein tissue stores. An energetic interaction occurs during tissue mobilization when RUP supplements are fed with adequate dietary supply of glucose for efficient oxidative metabolism, especially when low-quality diets are consumed. In addition, research during late gestation and early lactation indicates that RUP supplementation becomes more effective when animals are in a negative energy balance. For instance, Dhuyvetter et al. (1993) and Lalman et al. (1993) reported that young beef cows consuming low-quality forage lost less BW when supplemented with RUP supplements compared with rumen degradable protein supplements. Overall, the above studies indicate that supplementing RUP to ruminants in grazing low-quality forages minimizes muscle catabolism and may increase protein deposition during late gestation and early lactation when cows are in a negative energy balance.

It is well established that propionate is the predominate precursor for glucose in ruminant animals. However, the need to supplement propionate in grazing beef cattle diets as a limited nutrient may be overlooked compared with dairy cattle. For instance, Schei et al. (2007) indicated that dairy cows in NEB had limited glucogenic precursors such as propionate. Available evidence indicates that postruminal supply of glucogenic precursors may increase nutrient utilization of forages, especially when cattle are grazing low-quality forages. This may be critical in extensive rangeland production systems where livestock graze low-quality forage up to 9 mo out of the year and as mentioned above is insufficient in glucogenic precursors. In a study with growing lambs consuming low-quality feed, Leng et al. (1978) reported on the magnitude of diet utilization efficiency when an increased supply of glucose was made available via duodenal infusion in sheep fed oat chaff. The treatment design used a factorial approach with fish meal as a protein source. The combination of fish meal and glucose infusion improved feed efficiency by nearly 50%. In a similar designed study with growing lambs, Kempton et al. (1978) fed lambs a basal diet of a low-protein mix of sugar and oat chaff (50:50). Lambs received treatments in a factorial design using 1 of 4 levels of fishmeal and within each level of fishmeal, lambs received 1 of 3 levels of glucose postruminally. Supplementation of fishmeal increased feed intake, average daily gain, and reduced feed conversion ratio (feed:gain) from 6:1 to 4:1 with increasing levels of fishmeal. However, average daily gain and feed conversion ratio were improved by the addition of glucose to the diet, indicating once the requirement for RUP is met, additional postruminal supply of glucose is needed to optimize nutrient utilization. Therefore, increasing propionate supply has an amino acid sparing effect, replacing amino acids from being catabolized for gluconeogenesis, resulting in increased efficiency of propionate conversion to glucose (Agarwal et al., 2015). Increasing postruminal supply of propionate has been shown to increase fatty acid and acetate uptake to the hindlimb in growing lambs (Majdoub et al., 2003).

Cronjé et al. (1991) evaluated supplementation of low-quality roughage diets and acetate clearance rate in sheep. This study fed urea-treated wheat straw with increasing amount of high RUP supplement to supply additional glucogenic precursors and compared this basal diet with a diet that supplied 46 g of propionate fed as sodium propionate. Acetate clearance increased with increasing amounts of fed protein supplement, but further increased when propionate was fed in addition to the bypass supplement. Waterman et al. (2006) showed improved tissue response to insulin, weight gain, and reproductive performance when glucogenic precursors in the form of RUP plus 100 g/d of calcium propionate were added to range supplements to young range cows. Cows supplemented with RUP with 100 g/d of calcium propionate had a decreased glucose half-life after a glucose tolerance test, returned to estrus 9 d sooner, and had greater average daily gain from the end of supplementation to the end of breeding than cows fed traditional cottonseed meal-based supplement with no additional glucogenic precursors. In a similar study, Mulliniks et al. (2011) reported that increasing glucogenic precursors with RUP and 40 g/d calcium propionate–enhanced energy metabolism by increasing the rate acetate is metabolized and decreasing BHB concentration in young range beef cows grazing dormant forage. These authors also reported a decrease in days to resumption of estrus after calving and an increase in pregnancy rates in 2- and 3-yr-old range cows. Diets that supply additional glucogenic precursors may decrease serum ketone concentrations and increase acetate disappearance rate, indicating more efficient energy metabolism, improved use of forage energy, and a reduction in inhibitory reproductive signals.

CONCLUSION

Traditional management practices such as managing for certain BCS or meeting and (or) exceeding nutrient requirements may decrease overall metabolic efficiency and long-term longevity of the cowherd. Due to nutritional constraints of the environment for cow/calf production, management and selection of animals must focus on animals that are highly adaptable and metabolically flexible to dynamic changes in nutrient quality. The ability for beef cows to cope with nutritional challenges from environmental and physiological stresses may be dependent on the adaptive ability to have increased oxidative capacity of fatty acids from lipolysis during nutrient-restricted periods. In addition, supplementation strategies such as increasing postruminal glucogenic supply may allow cows to have an increased energy utilization, allowing cows to be more metabolically flexible during key physiological periods.

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