Brown midrib resistence (BMR) corn[1]

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ABSTRACT: This literature review was done to envestigate the research development on brown midrib resistance (BMR) variety corn that is known to have lower content of lignin in the forage yielded than those other varieties of corn. The low lignin content is associated with changes in concentration of phenolic acids and alteration of enzymes involved in lignin biosynthesis. The BMR corn have specific sign of reddish-brown coloration found in the center midrib on the underside of the leaf. The pigmentation appears in the stem with its lignifications visually associated with rind and vascular bundles. The coloration fades during maturing and may disappear on the leaves, but remains in the stalks. There were four BMR mutants were recorded naturally, namely: *bm1*, *bm2*, *bm3*, and *bm4* , and the lesser lignin content were observed in *bm3.* Harvesting of corn plant generally at about 60 to 70 days after planting (milking stage of kernel), where more energy will be provided. The dry matter (DM) production approximately 2.5 t/ha lower or about 10 to 15% lesser than the conventional one. And after harvested the corn forages generally preserve as silage and given to the animals mostly for dairy cows in the stall. The BMR corn silage (BMRCS) fed to dairy cows usually resulted in increase of body weight and milk yield, reduce rumen pH, increase microbial synthesis therefore increases N content in milk, but no effect on fat content when it is compare to conventional corn. The lower rumen pH of cows fed BMRCS can be attributed to the lower pH of corn silage.

Key words: BMR, silage, lignin, digestibility, dairy cows, body weight, milk yield

INTRODUCTION

Corn ranks third, after wheat and rice, in the world production of cereal crops, and according to Martin et al., 1976, about 45% of the world corn crop was grown in the United States of America (USA). Miller, 1984, stated that corn considered as a supplementary forage crop for silage to carry animals through the winter, and if the summer yield of forages has been deficient, corn is probably one of the best silage crops in the USA. In Indonesia, corn crop can be grown in a very wide of land classifications, and very adaptable to a wide range of environmental conditions, and it is well known either for food and also for feed.

Corn or maize (*Zea mays*) can be considered as the most completely domesticated of all field crops. The most likely center of origin of corn is Mexico or Cental of America, with a possible secondary origin in South America (Martin et al, 1976). This crop depended wholly upon the care of human, and cannot exist as a wild plant.

Maize has a remarkable diversity of vegetative types. The small type, early sorts only about 60cm tall bear 8 to 9 leaves and are able to produce mature grain in 50 days. Others with 42 to 44 leaves and growing about 6 m tall require as many as 330 days to be came mature (Martin et al, 1976). The corn hybrids or varieties generally has typical height of about 90 cm to about 2.4 m, mature in 90 to 120 days, and maybe develop several tiller. In Indonesia, as in US at present for feeding animal purposes especially for dairy cattle the corn plant generally harvested when the kernel at milking stage or at about 60 to 70 days after planting, where more energy from corn forage will be provided due to some soluble carbohydrates content in the kernel. But, mostly the forages given to the cows freshly after harvesting (cut and carry or zero grazing method), very seldom farmers conserve the forages as a silage.

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Brown midrib resistant corn is a corn variety that is known to have lower lignin content than the ordinary varieties. In recent decade, some scientists have paid attention to do research on the use of BMR corn for feeding animals.

HISTORY OF BMR CORN

The first BMR corn plant seems to be observed in northwestern USA at the University of Minnesota Farm, St. Paul, Minnesota in 1924. The BMR corn plants exhibited a reddish brown pigmentation of the leaf midrib that became visible in plants at the 4-6 leaf stage (Jorgenson, 1931). The name BMR was attributed to this trait because of the reddish-brown coloration of the center midrib on the underside of the leaf. The pigmentation appears in the stem with its lignifications visually associated with rind and vascular bundles. The coloration fades during maturing and may disappear on the leaves, but remains in the stalks. Four BMR mutants have been indentified naturally, namely: *bm1*, *bm2*, *bm3*, and *bm4* (Barrière and Argillier, 1993). Brown midrib hybrids are usually characterized by low lignin concentrations and high fiber digestibility. The lower lignin content will increase digestibility of the forage, thereby resulting in forage with higher energy concentration. It has been of interest for many years to be studied as animals feed. The BMR gene has little effect on the concentrations of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and ash in corn plants (Weller et at., 1984). The low lignin content is associated with changes in concentration of phenolic acids and alteration of enzymes involved in lignin biosynthesis (Cherney et al., 1991).

BMR CORN COMPARED TO CONVENTIONAL CORN HYBRIDS

The unique difference in BMR compared to conventional corn hybrids comes from the mutation of certain enzymes involved in lignin biosynthesis. One mutation in *bm3* involves low concentration of *o*-methyl transferase activity to complete methylation reaction of caffeic acid to ferulic acid, which is a lignin precursor (Cherney et at., 1991). Goto et al. (1994) showed lower concentrations of *p*-coumaric (4.3 vs. 7.4 g/kg DM) and ferulic acids (2.7 vs. 3.8 g/kg DM) for *bm3* compared to normal whole plant corn silage, respectively. Similarly, Hartley and Jones (1978) reported lower total concentration of phenolic compounds (10 vs. 16 mg/g of cell wall) for *bm*3 compared to normal whole plant corn silage.

Most BMR hybrids currently used by the hybrid seed industry have the *bm3* allele, which characteristically have low lignin content, but higher NDF digestibility than the other *bm* genes. Allen (1997) stated that the *bm3* mutation in corn hybrids decreased lignin content by 1.1 units and increased in vitro NDF digestibility after 30 h of incubation by 8.4 units compared with conventional control hybrids. The BMR corn hybrids have been reported produce lower whole-plant DM than conventional corn. Miller et al. (1983) reported that *bm3* corn produce silage of about 77% of the grain yield and only 90% of the stover yield compared to CCS. Similarly, Barrière et al. (1998) reported 2.5 t/ha reduction in total DM yield for BMR compared to conventional corn plants, while Miller et al, (1983) calculated the DM yield of BMR hybrids was about 10 to 15% less their the conventional one.

PERFORMANCE OF DAIRY CATTLE DUE TO BMR CORN FEED

Effect on Rumen pH

Oba and Allen (2000b) observed depressed ruminal pH in cows fed BMRCS compared to cows fed CCS (5.68 vs. 5.84), although chewing activity and organic matter (OM) truly fermented in the rumen were similar between the treatments. Similarly, Greenfield et al. (2001), Taylor and Allen (2005a), and Gehman et al. (2008) observed lower ruminal pH for BMRCS treatment compared with CCS treatment by 0.52, 0.22, and 0.28 pH units, respectively. In contrast, Qiu et al. (2003) and Weiss and Wyatt (2006) reported no effects of feeding between BMRCS- and CCS-based diets on ruminal pH.

In an attempt to explain ruminal pH differences by salivary buffering capacity without measuring saliva flow to the rumen directly, Oba and Allen (2000b) measured chewing activity and OM truly fermented in the rumen. In their study, no explanation for the depressed ruminal pH was evident. The authors speculated that factors other than chewing time, which may affect rate of absorption and passage along with the neutralization of fermentation acids, may explain the decreased ruminal pH with the BMRCS diet (Oba and Allen, 2000b).

Gehman et al. (2008) performed a lactation study using 20 cows in midlactation to investigate effects of type of corn silage and ionophore in a 4 × 4 Latin square design with a 2 × 2 factorial arrangement. Dietary treatments included BMRCS and CCS at two concentration of monensin (0 and 300mg/d). It was found, that the inclusion of monensin in BMRCS-based diets increased ruminal pH by 0.14 units. The monensin supplementation had no effect on DMI, digestibility of any nutrients, and N metabolism, and there were no interactions between type of corn silage and monensin supplementation. However, treatments with BMRCS appeared to have negatively effect on N digestibility. The BMRCS-based diet tended ($P = 0.08$) to increase DMI, but did not affect the NDF digestibility and nor on milk production. Digestibility reduction of nutrient when cows fed BMRCS-based diet may have been caused by increased DMI and possibly increased digestions in the lower gut.

Effect on Microbial in the Rumen

Wells and Russel (1996) mentioned, that as retention time increase, microbial autolysis and predation by protozoa would also increases, resulting in reduced efficiency of microbial protein synthesis (EMPS). Oba and Allen (2000b) reported that, despite a decrease in ruminal pH, BMRCS increased EMPS, possibly because of faster ruminal passage rate reduced microbial turnover. Conversely, lower ruminal pH might have reduced EMPS for BMRCS compared with CCS when DMI, and presumably rate of passage, was not affected by treatment (Greenfield et al., 2001). Because feeding BMRCS often reduces ruminal pH, its potential to increase EMPS might depend on the extent to which ruminal passage rate increases, resulting in a greater amount of N to be excreted into the feces (Gehman et al. 2008).

Weiss and Wyatt (2006) evaluated the effect of corn silage hybrid and metabolizable protein (**MP**) supply on N metabolism using 8 cows fed low (4.5%) or high concentration (7.1%) of RUP. The different RUP concentrations were achieved by the addition of fish meal and treated soybean meal. Diets contained 55% CCS or BMRCS on DM basis. Increasing the supply of MP greatly increased urine output and tended ($P = 0.13$) to increase total manure output, whereas diets with BMRCS tended ($P = 0.09$) to reduce manure output. At equal N intake, feeding BMRCS reduced N excretion by about 4%. The authors concluded that feeding BMRCS rather than CCS would have the same effect on manure N excretion as would feeding approximately 22 g/d less N. Although cows on the low MP treatments consumed an average of 125 g/d less N than those on the high MP treatments, average ruminal ammonia concentrations were not affected by treatment. Ruminal ammonia concentrations are dependent on supply of RDP and rate of bacterial growth. Oba and Allen (2000b) reported that rumen ammonia concentrations were reduced ($P < 0.09$) when BMRCS was fed, which they attributed to increased bacterial protein synthesis. A similar, albeit weak ($P < 0.15$), trend was observed by Weiss and Wyatt (2006).

Effect on Milk Yield

Oba and Allen (1999b) showed that increased NDF digestibility observed for BMRCS in vitro did not necessarily correspond to similar NDF digestibility in vivo. Thirty two cows averaging 89 ± 27 DIM were fed BMR and CCS-based diets in a single crossover design with 28-d period. The digestibility of NDF that was estimated by 30 h of in vitro fermentation was 9.7 units higher for BMRCS than CCS (49.1 vs. 39.4%). However, when the corn silages were included in total mixed ration (TMR) diets at 45% of the diet DM, cows fed the BMRCS had only 2.2 percentage units greater apparent total tract NDF digestibility compared with cows fed the CCS-based diet ($P = 0.02$). Intake of DM was greater for cows fed the BMRCS diet compared with cows fed the CCS (25.6 vs.

23.5 kg/d). The authors hypothesized that the discrepancy of NDFD improvement between in vitro and in vivo to the two corn silage hybrids was a result of the increased DMI observed for the cows fed the BMRCS. The relationship between DMI and total tract NDF digestibility showed a negative correlation ($P < 0.01$); as DMI increased, NDF digestibility decreased. The authors speculated that this was because of faster passage from the rumen for the BMRCS as DMI increased (Oba and Allen, 1999b). Because a constant retention time was used to determine in vitro digestibility, the differences in NDF digestibility between BMRCS and CCS may have been inflated when the two corn silages were compared in vivo.

The increases in DMI and NDF digestibility observed by Oba and Allen (1999b) for cows fed the BMRCS treatment was accompanied by a milk yield response compared with cows fed the CCS treatment. Specifically, cows fed the BMRCS treatment yielded 2.8 kg/d more milk than cows on the CCS treatment and 2.6 kg/d more 3.5% FCM. Because this study was performed in a crossover design, the authors evaluated each animal's response to the BMRCS treatment. They plotted each animal's pre-trial milk yield against their milk yield responded to the BMRCS treatment and observed a positive correlation. This means cows that had the higher milk yields pre-trial had better response to the BMRCS treatment, and greater increases in DMI ($P = 0.06$) and milk yield ($P = 0.03$), whereas cows that had lower milk yields pre-trial had little or no responses to the BMRCS treatment. It is more challenging for high producing dairy cows to meet their energy requirement, and these results suggest that DMI of high producing cows is limited by ruminal fill to a greater extent than is that of low producing cows (Oba and Allen, 1999b).

Increase in milk yield has also been observed with cows fed BMRCS diets without increase in DMI. Keith et al. (1979) randomly assigned 12 lactating Holstein cows past peak lactation to one of 4 treatments in a double switchback design. The dietary treatments were BMRCS and CCS fed at two F:C ratios (75:25 and 60:40). Cows received their assigned diet for 5 wk, were randomly switched to a second treatment diet for 5 wk, and then were switched back to the originally assigned diet for 5 wk. Although both genotype of corn silage and F:C ratio did not affect DMI, milk yield was higher for cows fed the BMRCS treatment. Cows on the BMRCS treatment had 1.3 and 1.6 kg/d greater milk yield and 0.9 and 1.0 kg/d greater 4% FCM yield than cows fed the CCS treatment at F:C ratio of 75:25 and 60:40, respectively.

Oba and Allen (2000a) also fed cows BMRCS and CCS diets at two different dietary NDF concentrations (29 and 38% dietary NDF) and noted increase in DMI at both concentrations of fiber for cows on the BMRCS treatment. Along with the increased DMI, cows fed the BMRCS-based diets also had higher SCM yields regardless of the forage concentration. However, because no milk fat depression was observed for cows on the high forage BMRCS diet and SNF concentration was also greater for these cows compared with the BMRCS in low forage diet and CCS diet, the authors stated that the feeding of BMRCS was more beneficial in high forage diets when fed to high producing cows.

Frenchick et al. (1976) observed increase in milk yield for cows past peak lactation for a BMRCS-based diet than cows fed a CCS diet (22.5 vs. 21.7 kg/d) ($P = 0.05$). But, because of cows fed the BMRCS had a lower milk fat percentage, therefore the FCM yield between the two treatments were similar. Body weight gain was greater for cows fed the BMRCS treatment (+3.1 kg) compared to CCS treatment (-0.6 kg).

Sommerfeldt et al. (1979) theorized that BW gains of cows fed BMRCS were due to partitioning of energy from milk production. In their study, cows (averaging 42 DIM) fed BMRCS-based diet had no advantages in DMI and milk yield compared with cows fed CCS diet, but cows fed the BMRCS did have greater daily BW gain (+58.4 vs. -47.3 g/d). Rook et al. (1977) also observed increased BW gain with cows fed BMRCS-based diet from 42 to 91 DIM (49.6 vs.7.1 g/d), but there were also increase in DMI compared with cows fed CCS-based diet (20.2 vs. 18.6 kg/d).

The apparent partitioning of energy toward BW gain rather than milk production for cows fed BMRCS was also observed by Block et al. (1981). Cows fed BMRCS from 18 to 74 DIM increased BW (+10.2 kg), whereas cows fed CCS lost BW (-26.6 kg). Cows fed the BMRCS treatment produced more milk throughout the study, but this was not significant. The authors, however, noted that when the milk yield of the two groups were analyzed by week, cows receiving the BMRCS treatment produced more milk in wk 5, 6, and 8 compared to cows receiving the CCS treatment.

Effects of BMRCS on lactational performance have also been compared with other specialty hybrids. Ballard et al. (2001) fed late lactation cows (204 ± 104 DIM) corn silages from either leafy, BMR, or high grain yield corn hybrids. Because the leafy and BMR hybrids are considered as ones for making corn silage, they were compared with the grain hybrid and to each other. Direct contrast between the grain hybrid and either of the silage hybrids was not performed. They found that cows fed the silage hybrids produced 1.1 kg/d more milk compared with cows fed the grain hybrid, and that the BMRCS treatment increased milk yield over the leafy hybrid by 2.3 kg/d. Yield of 3.5% FCM was also greater for cows fed the BMRCS treatment compared with the leafy treatment (35.8 vs. 33.5 kg/d), but cows receiving the silage hybrids had similar 3.5% FCM yield compared to cows fed the grain hybrid treatment (34.7 vs. 33.3 kg/d). In a study using growing dairy heifers (Ballard et al., 2001), the silage hybrids allowed greater consumption of DM compared with the grain hybrid as a percent of BW (2.13 vs. 2.02%), but body condition and BW gain were similar between the treatments.

Transition cows have benefited by BMRCS-based diets. Santos et al. (2001) fed primiparous and multiparous dairy cows 3 different diets: 2 CCS-based diets at either 55:45 or 65:45 F:C ratios, and a BMRCS-based diet at a 65:45 of F:C ratio. The dietary treatments began an average of 23 d prior to calving and continued for 33 d postpartum. Post calving health and DMI were similar between treatments, but a tendency (P = 0.09) for increased milk yield was observed for muliparous cows receiving the BMRCS treatment (+ 2.2 kg/d).

Effect on Milk Composition

Effects of BMRCS-based diets on milk composition and yield have given mixed results. Several studies have shown no effect on concentration or yield of milk components with BMRCS diets (Tine et al., 2001; Ebling and Kung Jr., 2004; Gehman et al., 2008). In other studies, milk fat yield was not affected by corn silage hybrid, but milk fat percentage was reduced when BMRCS was fed (Oba and Allen, 2000a; Qiu et al., 2003; Weiss and Wyatt, 2006).

Oba and Allen (2000a) conducted a lactation study to test 2 concentrations of dietary NDF with BMRCS and CCS hybrids fed to lactation cows in a 4 × 4 Latin square design with a 2 × 2 factorial arrangement of treatments. The authors observed lower milk fat concentration for cows fed BMRCS diet compared with CCS diet at low (29% DM), but not high (38% DM) NDF concentration. Milk fat concentration was depressed greatly for the BMRCS treatment compared with CCS treatment for the low NDF concentration diet (3.28 vs. 3.67%), but not for the high NDF concentration diet (3.86 vs. 3.90%). However, milk fat yield was similar among treatments (average of 1.24 kg/d). The milk fat depression observed for the BMR treatment in the low NDF concentration diet was hypothesized by the authors to be a dilution effect resulting from a greater rate of milk fluid synthesis relative to milk fat synthesis.

Taylor and Allen (2005b) reported that milk fat percentage was positively correlated with ruminal pH (r = 0.58; $P < 0.01$), and ruminal pH was greater for CCS-based diets compared with BMRCS-based diets (6.12 vs. 5.97). The decrease in milk fat concentration by BMRCS-diets might be because of increased ruminal biohydrogenation and lower flux of trans $C_{18:1}$ fatty acids from the rumen with higher ruminal pH (Taylor and Allen, 2005b). Many studies have shown a negative relationship between milk trans $C_{18:1}$ fatty acids and milk fat concentration (Bauman and Griinari, 2003), and higher ruminal pH might result in more complete biohydrogenation of $C_{18:1}$ fatty acids in the rumen. Acetate to propionate ratios of less than 2.0 are often associated with milk fat depression, and a positive relationship exists between ADF concentration and milk fat percentage (Erdman, 1988).

The effects of WPCS processing with CCS-based diets on milk fat are mixed. Bal et al. (2000) reported a 0.07 percentage unit and 0.07 kg/d increases ($P < 0.01$) in milk fat because of WPCS processing. Schwab et al. (2002) reported that processing BMRCS reduced milk fat percentage ($P < 0.01$) and yield ($P < 0.01$) by 0.25% and 0.08 kg/d, respectively. In contrast, Weiss and Wyatt (2006) reported that milk fat concentration in BMRCS-based diets increased by 0.23 percentage unit because of WPCS processing. No increases in milk fat percentage have been reported for an increase in WPCS chop length (Clark and Armentano, 1999; Bal et al., 2000; Schwab et al., 2002).

Several studies have shown no effect on protein and lactose concentration of milk by feeding

BMRCS-based diets (Schwab et al. 2002; Taylor and Allen, 2005b; Gehman et al., 2008). However, Oba and Allen (1999a) observed increases in milk protein concentration and yield with cows fed BMRCS diets by 2.4 and 8.1%, respectively compared with cows fed CCS diets. In a subsequent study, Oba and Allen (2000a) noted increased in milk protein yield for cows fed the BMRCS diet compared with those fed CCS diet, but not for milk protein concentration. According to Oba and Allen (2000c), the increased milk protein yield in these two studies were due to the greater microbial N production..

CONCLUSIONS

Based on the literature studies, it can be concluded that BMR corn fed to dairy cows resulted in increase milk yield, reduced rumen pH, increase microbial synthesis therefore increases N content in milk, but no effect on fat content when it is compare to conventional corn. The lower rumen pH of cows fed BMRCS can be attributed to the lower pH of corn silage.

Study of BMR corn in Indonesia have to be done, since under tropical condition the result on the animal performances maybe will be different. The writer believe that there should be available cultivar of BMR crops, both corn and sorghum varieties in Indonesia.

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