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IMPROVING NUTRITIVE VALUE AND DIGESTIBILITY OF MAIZE STOVER-A REVIEW

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SUMMARY

Agricultural crop residues constitute an essential part of ruminant diets, especially during scarcity of green fodder. Maize stover is one of the most abundant crop residues available throughout the world which has good nutritive value as compared to other crop by-products. The rumen microbial utilization of maize stover is restricted by the presence of lignin, which limits the amount of total digestible energy available to ruminants. For utilization of maize stover as cattle feed, complete or partial degradation of lignocellulosic complex is therefore required. An array of treatments and feeding methods has been developed to overcome effects of lignin in order to bring improvement in digestive value of maize stover. Among various pretreatment strategies, chemical and biological treatments have significant impact on feeding value of maize stover. Biological pretreatment offers several advantages over physical and chemical processes with mild reaction conditions, low capital cost, avoidance of toxic chemicals and high product yields. The present manuscript reviewed the efficacy of different pretreatment strategies for improving the nutritive quality of lignin rich biomasses of maize stover.

Keywords : Maize stover, nutritive quality, delignification, chemical treatment, biological treatment

Livestock have worth mentioning share in agriculture and is considered as backbone of Indian agriculture for sustaining livelihood, nutritional, environmental and agricultural growth. India possesses highest livestock population in the world growing continuously. Accordingly, their feeding as well as nutritional requirements are also increasing with the same magnitude. Hence, livestock production is at the mercy of balance nutrition. This situation has also been aggravated due to increased cultivated land under major food and cash crops (Ayyadurai *et al.*, 2013). By 2025, Indian livestock has an expected deficit of 68% green fodder and about 25% dry fodder (Ayyadurai *et al.*, 2013; Singh *et al.*, 2013). Additionally, increased pressure on land for human food production leaves little available land for further fodder production. As a result, livestock predominantly depend upon straws, stover, husks and crop by-products as major feed source (Singh *et al.*, 2013), which generally have less amount of essential nutrients especially protein and energy. These issues coupled with the rise in demand for livestock products as a result of intense urbanization and exploding human population necessitate the research on better utilization of crop residues for improving animal productivity. Maize (*Zea mays* L.) popularly known as 'corn', is one of the crop having wider climatic adaptability. Globally, maize is also known as 'queen' of cereals crops. It is generally grown as *kharif* cereal crop worldwide and considered as third major food crop after wheat and rice (Katoch *et al.*, 2009). India holds second position in maize production among other maize growing Asian countries, while sixth position in the world. In the past, it was mainly confined to food in India but now it is being largely used as a source of fodder (60%) (Katoch and Kumar, 2014). Increasing demand for fodder, shortage of arable land and water together with shrinking and deteriorating common property resources is further increasing the demand for maize as a food-feed crop (Katoch *et al.*, 2009). As a dual-purpose crop, maize holds great potential to improve socioeconomic status of small hold farmer by ensuring food as well as feed security (Katoch *et al.*, 2009). The stover from maize is one of the major crop residues which are characterized by multi-source, wide distribution, high abundance, low cost and less competing usage (Li *et al.*, 2014). During the periods of green fodder shortages, maize stover in combination with wheat straw is generally used as major feed source for livestock. Among residues from cereals, maize stover is the only fodder which has excellent nutritional quality along with good quantity of biomass (Chaudhary *et al.*, 2012). However, the livestock productivity based on maize stover feeding is constrained by low voluntary intake and poor nutrient digestibility. Lignification of cell walls has been identified as major limiting factor for nutritive value and digestibility of maize stover. Looking at the vast gap between demand and supply of fodder either in term of quality and quantity, it is pertinent to improve quality and digestibility of maize stover. The present manuscript reviews available technologies to improve feeding value of maize stover.

Nutritional Quality of Maize Stover

The utilization of crop residues as feed source is constraint by their low voluntary intake, less protein content and poor digestibility. Maize stover has low protein, high fiber with high level of indigestible carbohydrates and polyphenolic compounds such as lignin which affects the voluntary intake and the gastro-intestinal function of the animals. Chaudhary *et al.* (2012) reported that the crude protein, cellulose, hemicellulose, ADL and ash content in maize stover ranges from 3.50-8.70%, 31.30-41.00%, 20.00-34.40%, 3.10- 5.00% and 4.20-7.50 per cent, respectively. As compared to other competitive crop residues, maize stover has high crude protein and *in vitro* dry matter digestibility (IVDMD) (Chaudhary *et al.*, 2012). The structural carbohydrates, (cellulose and hemicellulose) of maize stover are often present in lignocelluosic form. Unlike cellulose and hemicellulose, lignin cannot be easily digested and considered as greatest impedement in the breakdown of cell wall polysaccharides by rumen microbes. The nutritional composition of maize stover varies among different morphological fractions, of which leaf blade has high crude protein and low fiber content where as stem rind has low crude protein content as compare to other parts of maize plant (Li *et al.*, 2014). It has also been reported that nutritional composition and digestibility of maize stover changes with the growth stage and harvesting time (Azim *et al.*, 1989; Masood *et al.*, 2012). However, the rate of quality deterioration is more severe in leaves (Chaudhary *et al.*, 2012). Table 1 represents the nutritional composition of different morphological fractions of maize stover and changes in nutritive profile of maize stover with plant maturity.

Strategies for Enhancing Nutritive Value and Digestibility of Maize Stover

A multitude of different pre-treatment technologies have been developed during last few decades for increasing nutritional and preservative quality of crop residues. The pretreatment strategies mainly target the lignocellulosic matrix to reduce lignin content. Pretreatments are also increases the rate of enzymatic hydrolysis of cellulosic polysaccharides by ruminal microflora. A wide range of processing methods has been developed and classified into physical, thermal, chemical and biological treatments. Physical treatments increase the digestibility of crop residues by increasing the surface area of roughages. Chemical treatments, particularly alkali, acid and ammonification have been widely used for enhancing digestibility and nutritive value of maize stover. The

TABLE 1

Nutritional composition of maize stover

1. Nutritional value of maize stover (%DM basis)												Reference
		CP	CF	EE	NDF	ADF	HC	Cellulose	ADL	AIA	Ash	Aredo and Musimba (2003)
		3.60	-	-	76.00	48.40	27.60	42.90	3.00	2.80	-	
2. Nutritional composition of different morphological fractions of maize stover (% DM basis)												
Tassel		6.60	-	1.40	71.39	37.80	33.59	32.02	5.78	-	-	Li *et al.* (2014)
Leaf blade		9.95	-	1.49	62.28	31.12	31.16	26.69	4.43	-	-	
Leaf sheath		4.25	-	1.02	74.81	39.01	35.80	33.29	5.72	-	-	
Stem rind		1.94	-	0.60	71.06	47.59	23.47	39.27	8.32	-	-	
Stem pith		3.33	-	1.22	70.49	39.05	31.44	34.72	4.33	-	-	
Stem node		4.20	-	0.92	72.33	39.24	33.09	32.44	6.80	-	-	
Ear husk		2.26	-	0.87	82.69	43.34	39.35	39.74	3.60	-	-	
Whole maize plant		4.05	-	1.31	71.93	41.36	30.57	35.10	6.26	-	-	
3. Nutritional composition of maize leaves at different maturity stages (% DM basis)												
Crop I	Jun.	10.35	28.50	0.75	59.40	34.04	25.40	27.38	5.68	-	8.88	Azim *et al.* (1989)
	Jul.	7.65	35.60	2.17	61.52	34.60	26.92	28.82	6.66	-	10.26	
Crop II	Sept.	14.85	19.13	1.17	57.28	32.55	24.73	22.33	6.17	-	8.98	
	Oct.	12.53	19.54	1.44	57.88	32.42	25.46	26.17	10.08	-	10.94	

application of chemicals increases the rate of lignin solubilization and hydrolysis of cellulosic fractions. However, the adverse effects on environment and high operational cost makes these methods unsafe and non-economical. Instead of using chemicals, the application of various microorganisms has also been reported to have significant impact on nutritive value of crop residues. Various strategies which have been utilized for delignification of crop residues have been discussed below :

(i) Physical treatments

Physical treatments are easy to perform and responsible for improving the nutritive value of the crop residues without any harmful effects on ruminants and environment.

(a) Mechanical comminution

In this process, the particle size of solid material is reduced by crushing, grinding, cutting or other processes. The main purpose of this process is to reduce crystallinity of lignocellulose in order to increase surface area and reduce the degree of polymerization and ultimately increase the accessibility of ruminal microbes for enzymatic hydrolysis of lignocelluloses (Saritha *et al.,* 2012).

(b) Extrusion

This method is used to produce objects with fixed cross-sectional profile. In this process heating, mixing and shearing of crop residues disrupts lignocellulose structure and increases the accessibility of carbohydrates for enzymatic hydrolysis by ruminal microbes (Saritha *et al.,* 2012).

(c) Silage formation

Silage is produced by controlled fermentation of crop residues. By this process, crop residues can be stored for longer periods with significantly improved nutritional composition. The ensiling of maize stover with molasses (5%) resulted in 7.29%, 7.15% and 28.57% increase in crude protein, ether extract and ash content, respectively (Wattanaklang *et al.,* 2016). It has been also reported that silage production with the leaves from leguminous fodder trees could serve as an alternative for commercial feed supplements (Titterton, 2001).

(d) Hot water treatment

Treatment with hot water maximizes the solubilization of the hemicellulose fraction and minimizes the formation of monomeric sugars. Mosier *et al.* (2005) reported that corn stover treated with water at 190°C for 5 min, convert 90% of cellulose into glucose. Zhou *et al.* (2010) recovered 100% cellulose in solid fraction and highest glucose yield (89.20%) from corn stover, treated with water at 210°C for 3 min.

(ii) Chemical pre-treatments

The application of chemicals improves the digestibility and voluntary intake of low quality roughages by solubilizing lignin and hemicellulose fractions in cell wall (Saenger *et al.,* 1982). Among different chemicals, sodium hydroxide, calcium hydroxide, urea, ammonia and dilute acid have been widely used for this purpose. Treatment with alkali involves solvation and saphonication processes by which it causes swelling of biomass and makes it more digestible to grazing animals (Hendriks and Zeeman, 2009). In acid treatment, the solubilized lignin gets quickly condensed and precipitated. The effect of various chemicals on nutritive quality of maize stover has been reviewed under following subheads:

(a) Urea pre-treatment

For improving the feeding quality of various crop residues *via* increasing the non protein nitrogen content, feed grade urea has been widely employed as major source of ammoniation. The positive effects of urea application on nutritive value of crop residues are result of two processes: a) conversion of urea into ammonia by urease and b) effect of ammonia on the cell wall of residues. Various studies have been conducted to study the effect of urea on nutritional quality of maize stover. It has been reported that pretreatment with urea (0-8%) increases the crude protein content from 6 to 131% and decreases the NDF content from 8 to 9.83% in maize stover (Woyengo *et al.,* 2004; Aregherore, 2005; Oji *et al.,* 2007; Ramirez *et al.,*2007; Elias and Fulpagare, 2015). A fall in NDF content has been showed to increase animal intake of urea treated maize stover as compared to normal stover (Chaudhary *et al.,* 2012). The increase in crude protein content is mainly due to addition of non-protein nitrogen which destabilizes the protein complexes with antinutrients.

(b) Alkali pre-treatment

Among chemical pre-treatments, alkali treatment has been reported to have significant impact on the nutritive value of maize stover (Table 2). Sodium hydroxide is the most commonly used chemical for alkali pretreatment (Ololade et al., 1970; Klopfenstein et al., 1972). The application of sodium hydroxide (8%) on maize stover cause 4.88, 6.25 and

7.25% increase in ADF, lignin and cellulose content, respectively, (Ololade et al., 1970). Klopfenstein et al. (1972) reported 47.43% increase in organic matter digestibility and 7.30, 6.30 and 24.27% decrease in ADF, ADL and cell wall constituents, respectively in maize stover treated with 5% solution of sodium hydroxide. When chopped corn stover treated with 2% NaOH, 46% increase in organic matter intake and 16% increase in cellulose digestibility was observed by Oji *et al.* (1977). Chen et al. (2009) observed 73.90% reduction in lignin content and 65.63% and 13.36% increase in cellulose and hemicelluloses content with 2% NaOH. Beside sodium hydroxide, the application of calcium hydroxide has also been recommended, as it removes the amorphous substances present in lignocellulosic biomass. Kim and Holtzapple (2005) reported that corn stover treated with an excess of calcium hydroxide in non-oxidative and oxidative conditions at different temperature (25-55°C) caused 87.50% reduction of lignin content. Chen et al. (2009) also reported that treatment of lime hydrolysed 14.80% of hemicellulose to soluble sugar and removed 34.80% of lignin from corn stover. The enzymatic hydrolysis of alkali treated corn stover resulted in conversion of glucan (91.30%) and xylan (51.80%) into glucose and xylose, respectively (Kim and Holtzapple, 2005).

(c) Ammonia pre-treatment

Anhydrous ammonia increases the nutritive value of low quality forages like corn stover and advocated as an effective alternative to alkali pre-treatment (Saenger *et al.*, 1982; Kim *et al.*, 2003). Ammonification of crop residues breaks the bond between cell wall constituents resulting in swelling and flexibility of fiber content. It has been reported that treating corn stover with ammonia (3 to 5%) increases the cellulose digestibility and IVDMD upto 18-19% and 15%, respectively (Oji *et al.*, 1977). Sankat and Bilanski (1980) reported 89% increase in crude protein content and 21.50% increase in IVDMD of corn stover after 30 days ammoniation. Chen *et al.* (2009) reported that ammoniation of corn stover with aqueous ammonia hydrolyzed 67.80% of hemicellulose content, removed 41% of lignin and increased the cellulose content up to 69.76%. The ammonia recycled percolation (ARP) process is an efficient method as it removes 70-85% of the total lignin without any adverse effect on cellulose content. Longer ARP process resulted in more delignification rate as well as increased enzymatic digestibility (Kim *et al.*, 2003).

(d) Acid pre-treatment

The dilute sulfuric acid treatment primarily affects the sugar content (glucose and xylose) in maize

TABLE 2
Effect of chemical pretreatments on nutritional value of maize stover

Pretreatment		Nutritional composition of maize stover before and after the chemical pre-treatment (%)											Reference
NaOH		CP	CF	EE	NDF	ADF	HC	Cellulose	ADL	AIA	NFE	IVDMD	Ololade *et al.* (1970)
	Control	-	-	-	73.10	38.90	-	33.10	4.80	-	-	-	
	2%	-	-	-	74.00	39.60	-	34.00	4.90	-	-	-	
	4%	-	-	-	73.10	39.80	-	34.30	5.00	-	-	-	
	8%	-	-	-	65.70	40.80	-	35.50	5.10	-	-	-	
	Control	-	-	-	81.70	48.90	-	-	7.90	-	-	66.00	Klopfenstein *et al.* (1972)
	3%	-	-	-	67.80	48.40	-	-	8.00	-	-	67.30	
	5%	-	-	-	61.50	45.30	-	-	7.40	-	-	74.00	
Urea	Control	7.10	-	-	82.40	-	38.40	40.30	5.70	-	-	-	Woyengo *et al.* (2004)
	4%	9.00	-	-	74.30	-	23.70	40.60	8.40	-	-	-	
	Control	7.40	-	-	75.40	46.70	28.70	36.80	8.90	1.00	-	-	Ramirez *et al.* (2007)
	4.5%	12.30	-	-	66.00	43.00	23.00	34.60	7.30	1.10	-	-	
	6.5%	15.60	-	-	69.30	44.00	25.30	36.50	6.10	1.40	-	-	
	Control	4.31	43.81	1.98	-	-	-	-	-	-	40.98	-	Elias and Fulpagare (2015)
	8%	9.98	41.02	3.78	-	-	-	-	-	-	35.94	-	
	Control	-	-	-	-	-	21.70	38.70	19.30	-	-	-	Chen *et al.* (2009)
NH4OH	10%	-	-	-	-	-	12.90	65.70	21.00	-	-	-	
$Ca(OH)_2$	0.4 g/g	-	-	-	-	-	27.30	53.30	18.60	-	-	-	
Dil. H_2SO_4	1.5%	-	-	-	-	-	8.50	61.90	28.40	-	-	-	

TABLE 3

The effect of biological treatments on nutritive quality of maize stover

Biological species	Nutritional composition of maize stover before and after the biological treatment (%)												Reference
	Treatments		CP	CF	EE	NDF	ADF	HC	Cellulose	ADL	AIA	Ash	
Trichoderma sp.	Control		7.65	-	-	78.93	46.71	32.22	34.10	8.09	4.52	-	Islamiyati *et al.* (2013)
Incubation		1 week	8.35	-	-	74.60	49.50	25.10	35.23	7.84	6.43	-	
		2 weeks	9.76	-	-	73.27	51.03	22.24	37.20	7.84	5.99	-	
		3 weeks	9.13	-	-	72.66	49.60	23.06	34.34	8.70	6.56	-	
Phanerochaete chrysosporium		1 week	8.13	-	-	74.62	48.53	26.09	36.56	7.89	4.08	-	
		2 weeks	8.92	-	-	72.78	51.58	21.20	37.49	8.28	5.81	-	
		3 weeks	8.44	-	-	71.26	48.48	22.78	34.03	8.26	6.19	-	
Pleurotus ostreatus													
	Control		-	-	-	66.03	55.66	8.11	13.60	43.31	-	-	Adenipekun and Okunlade (2012)
	Incubation	1 month		-	-	-	32.99	25.57	5.42	4.49	23.09	-	-
		2 months	-	-	-	24.83	20.33	4.49	4.30	15.76	-	-	
		3 months	-	-	-	22.28	23.43	2.85	4.17	14.65	-	-	
	Control		3.60	42.15	0.52	-	-	26.01	41.00	11.49	-	13.57	Darwish *et al.* (2011)
Pleurotus ostreatus	Incubation	1 week	6.30	41.80	1.33	-	-	24.36	38.90	10.49	-	9.41	
P. ostreatus and S. cerevisiae			8.97	39.11	1.20	-	-	18.94	35.70	10.30	-	8.51	
Pleurotus ostreatus		2 weeks	6.52	39.37	0.84	-	-	20.68	36.64	10.27	-	6.30	
P. ostreatus and S. cerevisiae			10.81	29.01	0.71	-	-	14.31	31.88	9.41	-	6.54	
Pleurotus ostreatus		3 weeks	9.90	37.37	0.67	-	-	19.12	31.36	8.94	-	3.74	
P. ostreatus and S. cerevisiae			10.20	27.10	0.32	-	-	18.86	22.40	9.00	-	3.72	
Pleurotus ostreatus		4 weeks	8.15	29.61	0.76	-	-	17.10	25.66	8.00	-	3.21	
P. ostreatus and S. cerevisiae			8.20	27.20	0.49	-	-	17.52	20.08	6.20	-	3.21	
Pleurotus ostreatus	Control		3.44	-	-	70.64	-	-	-	-	-	2.74	Ramirez-Bribiesca *et al.* (2010)
	Incubation	15 days	4.80	-	-	60.37	-	-	-	-	-	7.90	
Pleurotus ostreatus	Control		3.44	-	-	70.64	-	-	-	-	-	2.74	Diaz-Godinez and Sanchez (2002)
	Incubation	8 Days	3.36	-	-	62.79	-	-	-	-	-	6.44	
	Control		4.40	-	-	76.16	45.65	30.01	36.46	8.68	-	-	Chen *et al.* (1995)
Cyathus stercoreus	Incubation	4 weeks	5.58	-	-	69.48	52.86	16.65	42.73	9.50	-	-	
Phlebia brevispora			5.85	-	-	68.37	51.36	17.01	41.92	8.74	-	-	
Phanerochaete chrysosporium			9.34	-	-	60.14	40.65	19.49	26.05	12.88	-	-	

Abbreviations : CP–Crude protein, CF–Crude fiber, EE–Ether extract, NDF–Neutral detergent fiber, ADF–Acid detergent fiber, HC–Hemicellulose, ADL–Acid detergent lignin, AIA–Acid insoluble ashes, NFE–Nitrogen free extract and IVDMD–In vitro dry matter digestibility.

stover. Previous studies reported that subsequent digestion of the cellulose and hemicellulose with sulfuric acid maximized the sugar content in corn stover (Lloyd and Wyman, 2005). The highest xylose yield from corn stover has been observed at 140°C temperature, digested with 0.98% of sulfuric acid (Lloyd and Wyman, 2005). Chen *et al.* (2009) observed that when corn stover treated with dilute sulfuric acid (1.5%), it converted 76.60% of hemicellulose to soluble sugar and removed 12.20% of lignin from raw material.

(iii) Biological treatments

Although, the nutritive value of lignin rich crop residues could also be improved by chemical and physical treatments, but these treatments are constrained by their high cost, safety and potentially their negative effect on environment and animal health (Chen *et al.*, 1995). Treatment of crop residues with different microorganisms (fungi, bacteria) is an effective alternative to physical and chemical treatments. Biological processing of crop residues is more efficient in increasing the nutritive value and digestibility of crop residues without any negative effect on environment and animal health. Biological treatments increase the accessibility of hydrolytic enzymes on cellulosic polysaccharides by disrupting the lignocelluloses complex in crop residues (Ramirez Bribiesca *et al.*, 2010). Various studies have been conducted to emphasizing the role of microorganisms in improving the quality of maize stover. Treatment of maize stover with oyster mushroom (*Pleurotus ostreatus)* resulted in significant increase in CP content (39.50-171.89%) (Ramirez-Bribiesca *et al.*, 2010; Adenipekun and Okunlade, 2012) and decrease in NDF content (11 to 14.50%) (Diaz-Godinez and Sanchez, 2002; Ramirez-Bribiesca *et al.*, 2010). The fiber content (NDF and ADF) in maize stover also decreases significantly when treated with white rot fungi (*Phanerochaete chrysosporium, Cyathus stercoreus* and *Phlebia brevispora*) while the *in-vitro* digestibility significantly increased upto 27.87% (Chen *et al.*, 1995). Darwish *et al.* (2011) have shown that treatment with *Saccharomyces cerevisiae* caused 227.77% increase in crude protein, 20.36% and 12.00% decrease in lignin and crude fiber content, respectively after the 7 days of incubation at 28°C. A period of 2 weeks incubation of maize stover with 5% *Trichoderma sp.* resulted in improved crude protein content and fiber quality in maize stover (Islamiyati *et al.*, 2013). The effect of biological treatments on nutritive quality of maize stover has been presented in Table 3.

CONCLUSION

Crop residues are one of the important component of ruminants feed and their role become evident especially during the scarcity of green fodder. The stover from maize is one of them which have far better nutritive quality as compared to other crop residues. However, the utilization of maize stover in animal feeding system is constrained by poor voluntary intake and low digestibility. Various strategies have been developed to bring significant improvement in nutritive value and digestibility of maize stover. However, these approaches need further refinement to develop simpler and economically viable methods to small and marginal farmers, whereby they can easily enhance the production of their cattle. The advancement in pretreatment strategies will also help in value addition, utilization of lignin rich biomasses and agro-industrial by products and also solve the problem of scarcity of quality fodder in the countries which are in developing phase.

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