THE EFFECT OF PLASMA-ACTIVATED WATER TREATMENT ON THE FERMENTATION QUALITY OF WHEAT STRAW SILAGE

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Abstract

Plasma-activated water (PAW) is a novel green functional water rich in reactive oxygen and nitrogen, while with no residues, and it has been widely used in food preservation and other fields. This study apply PAW to the pretreatment of wheat straw ensiling to investigate its effect on silage. In the research, PAW-treated and untreated control groups were set up, and the fermentation quality, chemical composition and microbial population at different ensile stages were measured. The results showed that after ensiling, PAW treatment could improve fermentation characteristics of wheat straw silage, with promoting lactic acid accumulation, optimizing nutritional composition, and reducing crude fiber loss; it also regulated microbial population dynamics by inhibiting the proliferation of molds and spoilage bacteria, and drove the microbial community towards targeted succession by silage-functional bacteria such as lactobacilli. This study confirmed the significant effect of PAW in enhancing the quality of straw silage, providing a new technical pathway for the green innovation and upgrading of silage fermentation technology.

Keywords: plasma-activated water, fermentation quality, silage

INTRODUCTION

Straw, as an agricultural by-product with an annual output of over 1 billion tons, has significant importance for sustainable agricultural development through efficient feed utilization. PAW, as a novel green treatment technology, shows broad application prospects in agriculture and the food sector. This study applied PAW to the pretreatment of wheat straw silage innovatively, revealing its effects on silage fermentation and nutrient retention by comparing key indicators at different fermentation stages and aerobic exposure stages. It provides referencer for developing low-cost, green, and efficient silage regulation technologies.

MATERIAL AND METHODS

Wheat straw irrigated with plasma-activated water (PAW) and ordinary water (CK) was selected as experimental material. The moisture content of each group was adjusted to about 65%. They were placed in fermentation plastic bags and sealed with a vacuum sealer. Each treatment was prepared in triplicate. Fermentation was carried out at room temperature (16~35 °C) for 3 and 30 days (d), followed by aerobic exposure for 3, 5, and 7 d after 30 d of fermentation. After each opening, the samples were tested for fermentation quality, chemical composition, and other related indicators.

RESULTS AND DISCUSSION

The experimental results showed that at 3 d of ensiling, the PAW group had acetic acid, DM, and CP of 23.00 g/kg DM, 0.37%, and 35.50 g/kg DM, respectively, all higher than the CK group‘s 21.96 g/kg DM, 0.34%, and 31.90 g/kg DM, while NDF and ADF decreased to 556.7 and 493.3 g/kg DM, lower than the CK group, indicating that PAW treatment is beneficial for nutrient preservation and fiber composition improvement at the early stage of fermentation. At 30 d of ensiling, the NH_3-N in the PAW group decreased to 0.07 g/kg DM, significantly lower than the CK group‘s

0.29 g/kg DM; meanwhile, WSC, acetic acid, and CP contents increased to 11.01, 30.53, and 29.21 g/kg DM, respectively, and NDF and ADF further decreased to 540.0 and 487.4 g/kg DM.indicating that PAW treatment can improve fermentation characteristics and optimize nutritional composition.

Microbial analysis results show that PAW pretreatment has little effect on bacterial communities, only maintaining higher community diversity and richness during fermentation. In contrast, it has a significant impact on fungal communities, markedly changing their initial composition, reducing species richness in the later stages of fermentation, optimizing community structure, and improving feed aerobic stability.

Tab. 1: Dynamic changes of fermentation quality during wheat straw silage

Item		Treatment	Days of ensiling (day, d)					SEM	P value		
			3	30	30–3	30–5	30–7		T	E	T×E
pH		CK	7.05^{aA}	5.38^{aCD}	5.32^{aD}	5.44^{aC}	5.71^{aB}	0.010	<0.01	0.039	0.043
		PAW	7.03^{aA}	5.37^{aD}	5.48^{bC}	5.44^{aCD}	5.81^{aB}				
WSC (g/kg DM)		CK	12.13^{aA}	7.30^{aA}	8.23^{aA}	8.78^{aA}	9.35^{aA}	0.439	0.029	0.559	0.194
		PAW	11.25^{aA}	11.01^{bA}	7.80^{aB}	5.81^{aB}	8.76^{aAB}				
NH_3-N (g/kg DM)		CK	0.13^{aA}	0.29^{aA}	0.17^{aA}	0.13^{aA}	0.25^{aA}	0.023	0.764	0.210	0.415
		PAW	0.16^{aA}	0.07^{aA}	0.09^{aA}	0.17^{aA}	0.19^{aA}				
Organic acid	Lactic acid	CK	7.74^{aB}	78.48^{aA}	39.09^{aAB}	40.34^{aAB}	58.33^{aA}	1.687	<0.01	0.909	<0.01
		PAW	6.94^{aC}	151.40^{bA}	38.61^{aB}	22.35^{aBC}	8.39^{bC}				
(g/kg DM)	Acetic acid	CK	21.96^{aB}	17.75^{aBC}	45.82^{aA}	ND	12.07^{aBC}	1.361	<0.01	0.224	<0.01
		PAW	23.00^{aB}	30.53^{aA}	8.58^{bC}	8.87^{bc}	9.53^{aC}				

Indices with different superscript letters indicate significant differences (P<0.05).

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Tab. 2: Dynamic changes of chemical composition during wheat straw silage

Item	Treatment	Days of ensiling (day, d)					SEM	P value		
		3	30	30–3	30–5	30–7		T	E	T×E
DM	CK	0.34^{aD}	0.37^{aD}	0.42^{aC}	0.53^{aB}	0.68^{aA}	0.004	<0.01	<0.01	<0.01
	PAW	0.37^{bD}	0.35^{aD}	0.47^{aC}	0.56^{aB}	0.80^{bA}				
NDF (g/kg DM)	CK	597.3^{aA}	577.7^{aA}	612.0^{aA}	652.3^{aA}	561.0^{aA}	4.447	0.075	0.199	0.363
	PAW	$556.7b^{AB}$	540.0^{aB}	611.3^{aA}	596.0^{aAB}	595.0^{aAB}				
ADF (g/kg DM)	CK	531.0^{aA}	523.0^{aA}	643.3^{aA}	542.0^{aA}	510.7^{aA}	4.764	0.064	0.161	0.362
	PAW	493.3^{bB}	484.7^{aB}	542.3^{aA}	537.7^{aA}	522.7^{aAB}				
CP (g/kg DM)	CK	31.90^{aA}	21.60^{aC}	25.12^{aB}	21.61^{aC}	21.45^{aC}	1.687	<0.01	<0.01	0.738
	PAW	35.50^{bA}	29.21^{bAB}	28.89^{bAB}	25.24^{aB}	25.63^{bB}				

Indices with different superscript letters indicate significant differences (P<0.05).

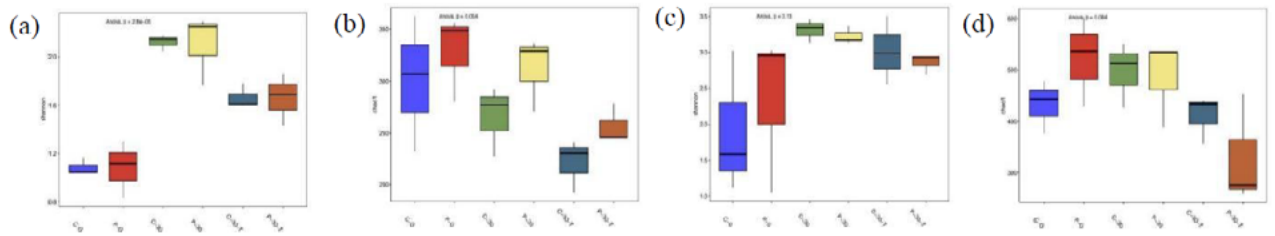

Fig. 1: The alpha-diversities at the OTU level (a and b, Shannon and Chao1 indexes of bacterial community, respectively; c and d, Shannon and Chao1 indexes of fungi community, respectively)

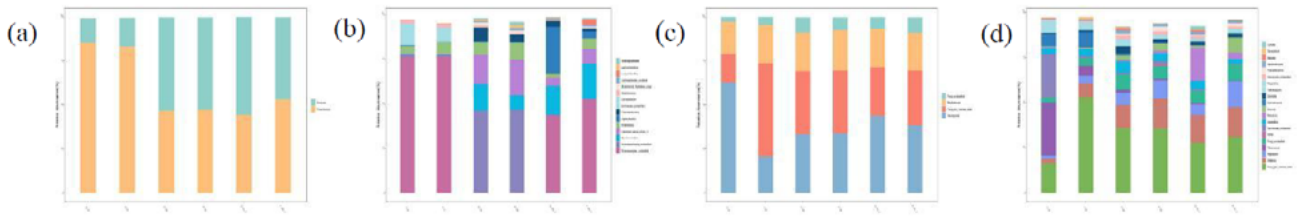

Fig. 2: The structure of the bacterial community at the phylum (a) and genus levels (b) and the structure of the fungi community at the phylum (c) and genus levels (d)

CONCLUSION

PAW treatment can effectively improve the silage quality of wheat straw, with higher acetic acid, DM and CP content, lower NDF and ADF content, NH3-N levels, and better aerobic stability and Microbial community regulation ability. Overall, PAW has good potential for improving the silage quality and aerobic stability of wheat straw.

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