Physicochemical, functional characteristics and microbiological characteristics of three Jiangxiangxing Baijiu cooling field building materials: Tabia, terracotta brick and sandstone slab

Huabin Tu [a,c,d], Mingyue Mu [a,c,d], Yanbo Cheng [a,c,d], Bo Wan [a,c], Fei Liu [b,*], Sheng Liu [a], Zongxiao Chen [a], Zongren Wang [a], Chuanwang Hu [a] , Qiaoyu Li [a,d]

[a] Kweichow Moutai Co., Ltd, Renhuai, Guizhou 564501, China
[b] School of Chemistry and Chemical Engineering, Guizhou University, Guiyang, Guizhou 550025, China
[c] Kweichow Moutai Group, Renhuai, Guizhou 564501, China
[d] Guizhou Brewing Engineering Technology Research Center, Renhuai, Guizhou 564501, China

*Corresponding author's e-mail: ce.feiliu@gzu.edu.cn

Abstract. The high-quality development of Jiangxiangxing Baijiu industry is beneficial for promoting rapid social and economic growth. Among them, the physicochemical properties of the ground building materials used in the aging cellars of Jiangxiangxing Baijiu play a crucial role in the production of this type of Jiangxiangxing Baijiu. Based on this, this article conducts a physicochemical, functional and microbiological characteristics (microbial community structure) analysis of three Jiangxiangxing Baijiu cooling field building materials (tabia, terracotta brick and sandstone slab). The results show that TA mainly consists of elements such as O, Si, Ca, Al, S, Fe, and Mg, with Si, Ca, and Al being the most abundant. Terracotta brick and sandstone slab possess similar elemental compositions, mainly containing elements such as O, Si, Al, Fe, and Mg. Compared to tabia, terracotta brick and sandstone slab have low content of Ca and S elements. Additionally, the order of specific surface area for the three materials is tabia > terracotta brick > sandstone slab. The order of thermal insulation performance is tabia > terracotta brick > sandstone slab, water absorption capacity is tabia > terracotta brick > sandstone slab, water release rate is sandstone slab > terracotta brick > tabia, and material strength is sandstone slab > terracotta brick > tabia. The analysis of microbial community structure shows that there is no significant difference in the microbial community structure of the three materials at the gate level, but there is a certain degree of difference in the genus level. The research findings in this paper provide necessary theoretical data and practical guidance for further developing better Jiangxiangxing Baijiu cooling field building materials.

Keywords: Tabia; Terracotta brick; Sandstone slab; Characteristics

Q. Gao et al. (eds.), *Proceedings of the 2024 7th International Conference on Structural Engineering and Industrial Architecture (ICSEIA 2024)*, Atlantis Highlights in Engineering 30,
https://doi.org/10.2991/978-94-6463-429-7_23

1 Introduction

Jiangxiangxing Baijiu plays an important role in promoting the high-quality development of the world liquor industry [1-6]. In the brewing process of Jiangxiangxing Baijiu, the airing process is an important link to improve the quality of Jiangxiangxing Baijiu. Among them, the cooling field is carried out in the cooling field, and the characteristics of the floor building materials used in the cooling field have a great influence on the cooling field. Because the properties or conditions of the building materials on the ground of the cooling field have an important influence on the activity and function of the air environment and functional microbial flora in the brewing workshop [7-11]. The moisture absorption rate, moisture retention rate, heat transfer coefficient, gas permeability coefficient, thermal conductivity and specific heat capacity of the material may affect the quality of liquor. In addition, cooling field as an important place in the process of brewing production, the flavor of the production of Jiangxiangxing Baijiu will be different with different cooling field materials [12, 13]. Spreading and stacking saccharification on the cooling field are two important production processes in the process of winemaking. The purpose of spreading is to cool the distiller 's grains after high temperature cooking to a suitable temperature, and to control the physical and chemical indexes of distiller 's grains to a certain extent, which provides production conditions for microbial enrichment. The purpose of stacking saccharification. The existing concrete cooling field has poor water absorption and is not conducive to microbial enrichment. It is rarely used by liquor-making enterprises. The tabia cooling field can solve the problems of water absorption and is conducive to microbial enrichment. It has been widely used by Jiangxiangxing Baijiu production enterprises. The traditional tabia cooling field is generally built with lime, clay and cinder into a tabia ground, which has certain strength, water resistance and air permeability, especially air permeability, which is more conducive to high-temperature stacking fermentation. However, because the production of the existing tabia cooling field mainly depends on the experience of the old wine masters and the production conditions of the wine enterprises, these defects lead to the unstable quality of the Jiangxiangxing Baijiu produced, and it is difficult to effectively improve the quality. Under the current technical level, the climate environment and microbial environment can be basically simulated artificially. In addition, the microbial community structure also has a significant impact on the Jiangxiangxing Baijiu cooling field building materials [7]. Therefore, it is particularly urgent and important to clarify the physical and chemical characteristics and functional characteristics of the special building materials for the ground of the liquor cooling field to promote the high-quality development of the Jiangxiangxing Baijiu cooling field process.

In summary, this article uses simple craftsmanship to prepare special materials for the drying cellar floor of Jiangxiangxing Baijiu. These materials include tabia, terracotta brick and sandstone slab. The article further analyzes the physicochemical and functional characteristics of these three materials, and provide a theoretical foundation for the development of high-performance special materials for the drying cellar floor of Jiangxiangxing Baijiu.

2 Experimental section

2.1 Materials

All materials used without further purification. Lime, coal cinder, purple red mud, dinas and abandoned ceramic jars were obtained from China Kweichow Moutai Group Co., Ltd.

2.2 Preparation of materials

Mixing lime, coal cinder and purple red mud in a certain proportion with water to form, and maintain them to obtain tabia (TA). Crushing the abandoned ceramic jars, mixing with water, mechanically form them, naturally air dry them, and calcine them at 1000°C to obtain terracotta brick (TB). After mixing and stirring the dinas and water, mechanical molding is carried out, and the sandstone slab (SS) are cut according to a certain size ratio.

2.3 Analysis of Physicochemical, functional characteristics and microbiological characteristics of materials

The elemental content of the bulk was analyzed by Malvern Panalytical Zetium X-ray fluorescence (XRF) spectrometer. The surface element of the samples were detected by Thermo Fisher K-Alpha + Xray photoelectron spectroscopy (XPS) spectrometer with Al Kα X-ray source (1486.6 eV). Micromeritics ASAP 2020 M analyzer was employed to measure the specific surface area and pore structure of the catalysts at −196 °C. Temperature programmed desorption (TPD) measurements were conducted using a Micromeritics Auto Chem II 2920 chemisorption analyzer. CO2/NH3-TPD tests were conducted with the sample being preheated at 300 °C for 1 h under He gas flow, and then cooled to 50 °C to allow CO2 or NH3 gas adsorption for 30 min. After increasing temperature to 800 °C at a heating rate of 10 °C/min, desorption was carried out.

The water absorption performance of the three materials is determined by using the Tea-bag method [14-16], and the water retention capacity of the three materials was determined according to the literature [13, 15]. The compressive strength of the three materials is tested by using a compression testing machine, and the thermal conductivity of the material is determined by using a thermal conductivity instrument. The microbial community structure of the three materials was analyzed through microbial analyzer [17].

3 Results and discussion

3.1 Analysis of the physicochemical characteristics of TA, TB and SS

The X-ray fluorescence analyzer (XRF) was used to qualitatively and quantitatively analyze the elemental composition of the TA, TB and SS. The results are shown in

Table 1. It can be seen from the table data that the TA mainly contains O, Si, Ca, Al, S, Fe and Mg, among which the content of O, Si, Ca and Al is the highest. It should be pointed out that the TB have similar elemental composition with SS, mainly containing O, Si, Al, Fe and Mg. Compared with TA, the content of Ca and S elements in TB and SS is very low, which is related to the use of lime and coal cinder as raw materials in triad soil. The XPS full spectra of the three materials further support this result (Figure 1).

Table 1. Elemental composition (wt%) of TA, TB and SS.

Samples	Si	O	Ca	Al	S	Fe	Mg	K	Ti
TA	16.330	49.051	14.425	7.703	3.546	3.451	2.480	1.559	0.678
TB	26.745	53.279	1.624	8.330	0.036	3.240	1.849	2.865	0.498
SS	28.460	50.749	1.035	8.559	0.022	3.018	2.906	1.842	0.500

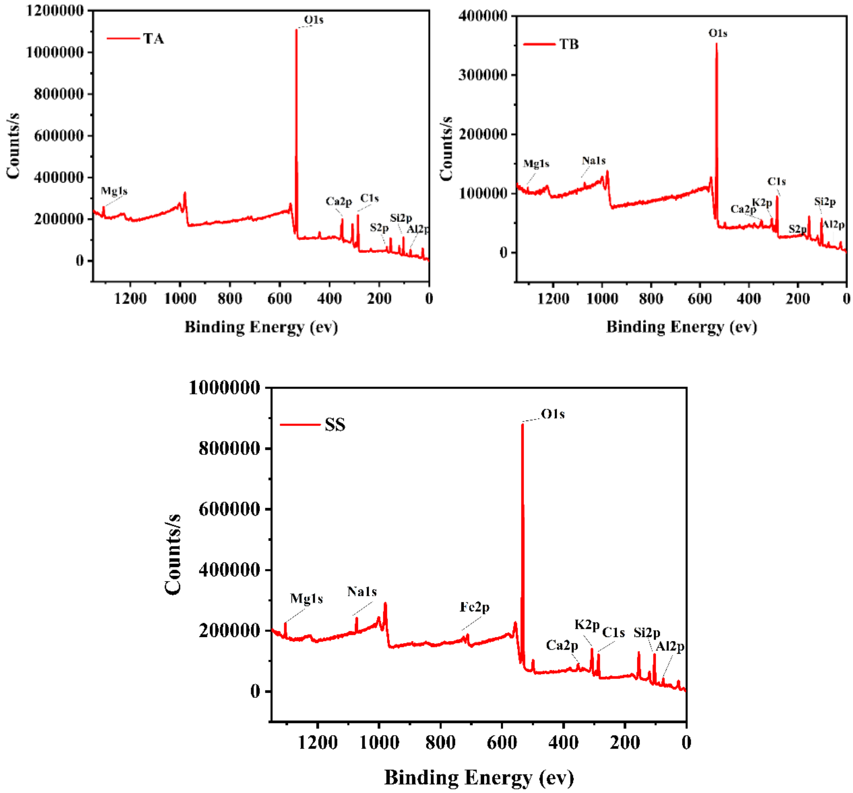


Fig. 1. XPS full spectrum of TA, TB and SS.

The specific surface area and pore structure properties of TA, TB and SS were analyzed by N_2 adsorption-desorption. The results are shown in Figure 2, and the pore structure parameters are shown in Table 2. It can be seen from the table data that the specific surface area of the TA is 19.7 $m^2 \cdot g^{-1}$, and it mainly exhibits mesoporous characteristics. It can be seen from the figure that when the relative pressure (p/p0) in the corresponding spectrum of the TA sample is 0.5-0.9, the shape and characteristics of the curve conform to the typical type IV isotherm, and the H3 hysteresis loop appears in the curve, indicating that there are mesoporous or even macroporous structures in the sample. The specific surface area of TB and SS is extremely low, and the three show the trend of TA > TB > SS. The comparative analysis shows that the TA has a larger specific surface area and pore volume, indicating better thermal insulation performance and water absorption.

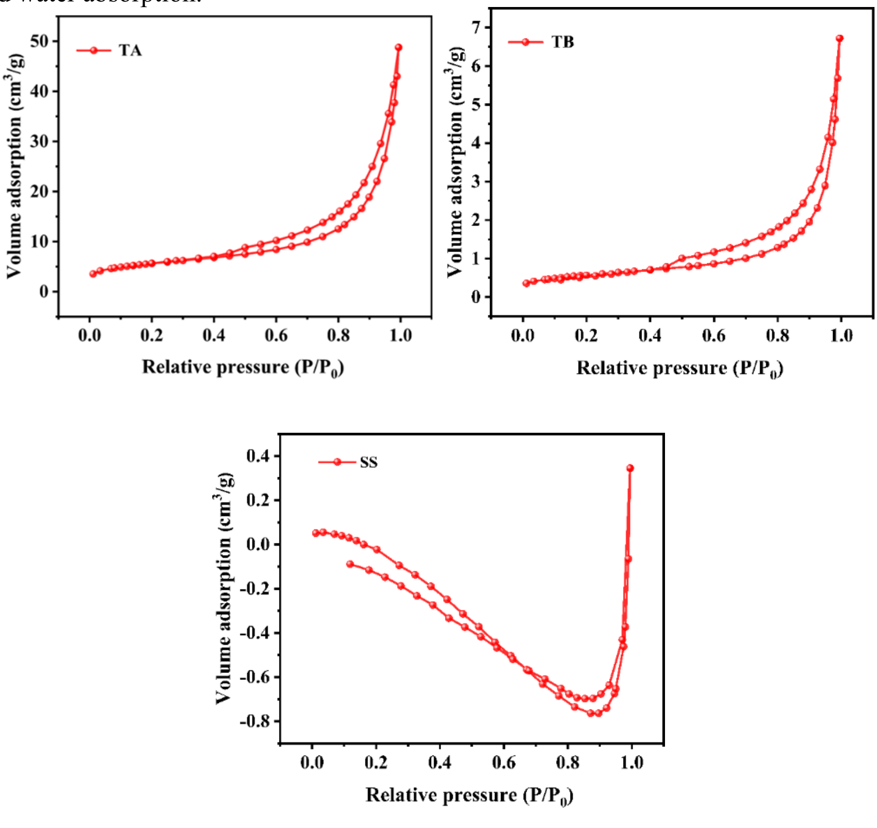


Fig. 2. N_2 adsorption-desorption isotherms of TA, TB and SS.

Table 2. Specific surface area, pore volume and average pore size of TA, TB and SS.

Samples	specific surface area ($m^2 \cdot g^{-1}$)			pore volume ($cm^3 \cdot g^{-1}$)	
	S_{BET}	S_{mic}	S_{mes}	V_t	V_{mes}
TA	19.68	3.79	15.89	0.075	0.073
TB	2.03	1.86	0.17	0.01	0.01
SS	0.0064	-	-	0.0005	-

The NH_3-TPD spectra of TA, TB and SS are shown in Figure 3 and Table 3. It can be seen from the figures and table data that compared with the TA, the acid content on the surface of the TB and SS is extremely low, indicating that the preparation process of the TB and SS is quite different from that of the TA, which further confirms the particularity of the preparation process of the TA.

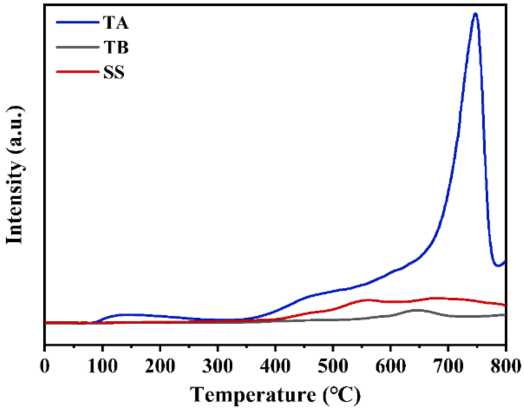


Fig. 3. NH_3-TPD of TA, TB and SS.

Table 3. Acidity of TA, TB and SS.

Samples	total acid content(mmol·g^{-1})
TA	2.602
SS	0.547
TB	0.168

The CO_2-TPD spectra of TA, TB and SS are shown in Figure 4 and Table 4. It can be seen from the diagram and the table data that the three surfaces all show certain alkali properties, but compared with the TA, the alkali content on the surface of the TB and SS is relatively low, which is related to the presence of a certain amount of Ca^{2+} in the TA. This provides more excitation centers for the alkaline sites, which in turn produces a richer amount of alkali.

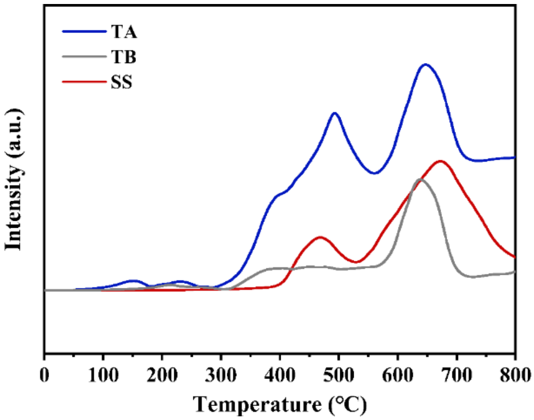


Fig. 4. CO_2-TPD diagram of the samples.

Table 4. Alkali amount of different catalysts.

Samples	total alkali（mmol·g^{-1}）
TA	0.111
SS	0.106
TB	0.083

3.2 Analysis of the functional characteristics of TA, TB and SS

The thermal conductivity of the special TA, TB and SS for the cooling field was measured by the thermal conductivity meter. The results are shown in Table 5. According to the table data, the thermal conductivity of the TB is the largest, which is 0.71 W/(m*K), while the thermal conductivity of the TA is the lowest, which is only 0.13 W/(m*K), indicating that the TA has the best thermal insulation performance, which is closely related to its maximum pore volume. The thermal insulation performance of the three is : TA > TB > SS, which is completely consistent with the trend of pore volume between the three.

Table 5. Thermal conductivity of TA, TB and SS.

Samples	Thermal conductivity W/（m*K）
SS	0.71
TB	0.32
TA	0.13

The water absorption data of TA, TB and SS are shown in Table 6. It can be seen from the table data that the TA showed the largest water absorption rate, which was 17.6 %. The water absorption of TB and SS is only 3.8 % and 7.06 %, respectively. The water absorption rate is TA > TB > SS, which is also completely consistent with the trend of pore volume between the three.

Table 6. Water absorption rate of TA, TB and SS.

Samples	Water absorption rate（%）
SS	3.84
TB	7.06
TA	17.60

Four temperature points of 25 °C, 35 °C, 45 °C and 55 °C were selected to determine the change of water release rate with time of TA, TB and SS. The results are shown in Figure 5. It can be seen from the figure that before the water release rate reaches 70 %, the slope of the water release curve of the TA sample at all test temperature points is the lowest, showing the best water retention function, which is consistent with the previous analysis and discussion results. Because of the largest pore volume and specific surface area, the TA also shows the best water retention characteristics on the basis of the maximum water absorption. When the water release rate reaches 70 %, the water release rate of the SS becomes slower, which may be related to the adsorption of a small amount of water on the dense pores of the SS.

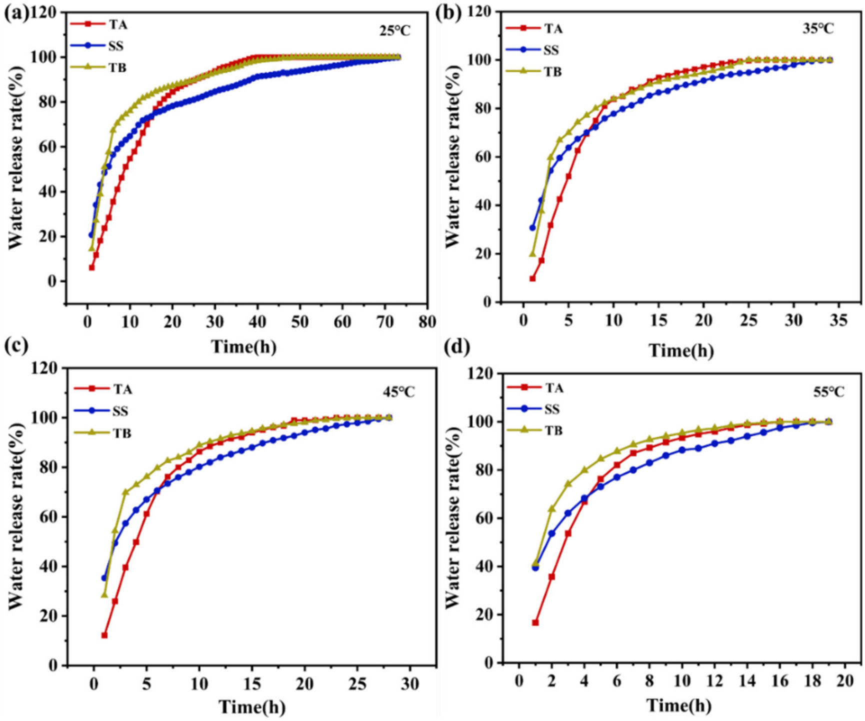


Fig. 5. Water release rate of TA, TB and SS at different temperatures.

It can be seen that the TA has the best thermal insulation performance and maximum water absorption due to its largest specific surface area and pore volume, and also has the best water retention characteristics.

The compressive strength data of TA, TB and SS are shown in Table 7. From the data listed in the table, it can be seen that the TA has the lowest compressive strength, while the SS show higher compressive strength. Unsurprisingly, the material strength trend is just the opposite, SS > TB > TA.

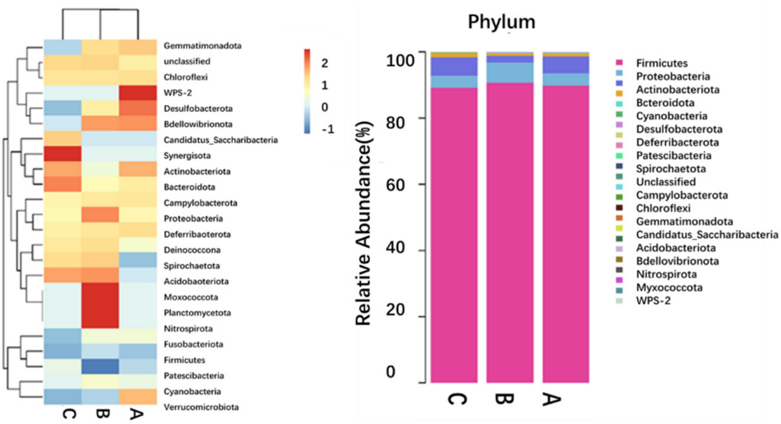
Table 7. Compressive strength of samples.

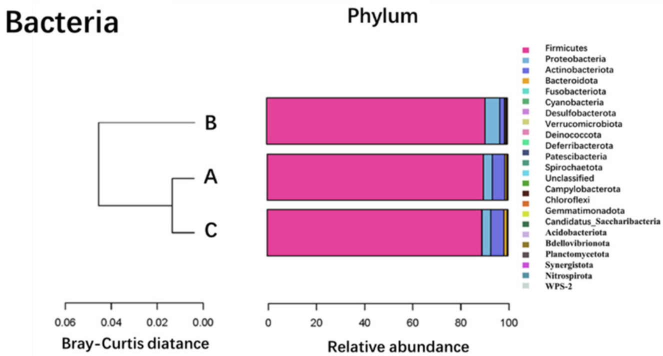
Samples	Compressive strength（MPa）
SS	17.23
TB	9.67
TA	2.74

3.3 Analysis of the microbiological characteristics of TA, TB and SS

The bacterial and fungal community structure was analyzed at the phylum level and genus level (Figure 6 and Figure 7). Firmicutes, Proteobacteria, Actinobacteria and Bacteroidetes were the dominant phyla, of which Firmicutes reached more than 85 %.

There was no significant difference between the samples at the phylum level. Marine Bacillus, Cladosporium and Bacillus were the dominant genera of the three cooling field materials, and there was no significant difference. In addition, Cronobacter was the dominant genus of the TA cooling field samples, and Lactobacillus was the dominant genus of the SS cooling field samples. Cluster analysis showed that the bacterial community structure of TA and TB samples was more similar.





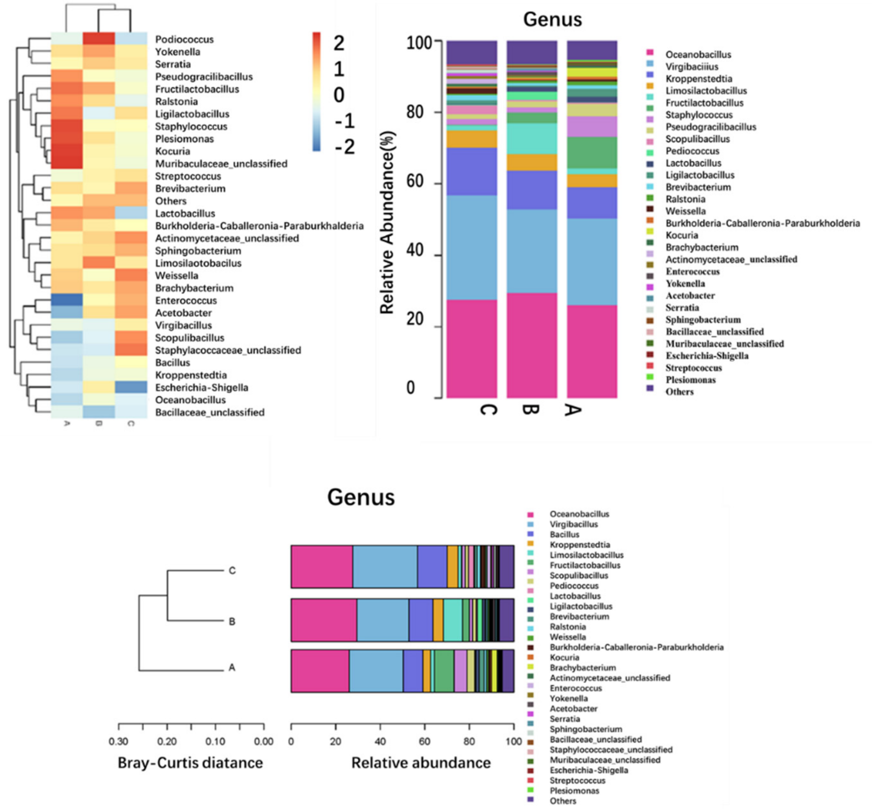
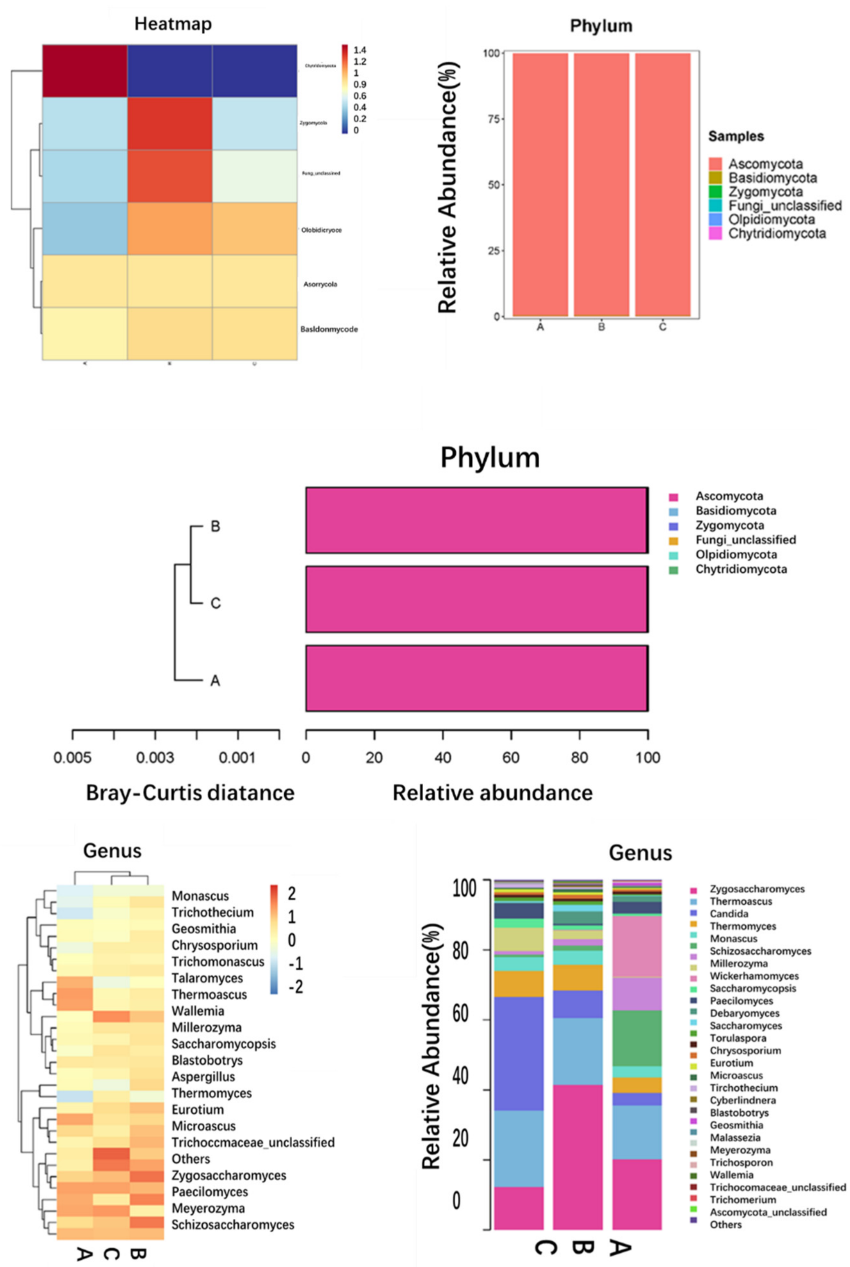


Fig. 6. Phylum level and genus level analysis of bacterial community structure of samples.

At the phylum level, Ascomycota was the dominant phylum of the three cooling field samples, and there was no significant difference. At the genus level, Zygosaccharomyces, Thermoascomycetes, Candida and Monascus were the dominant genera of the three samples, and Schizosaccharomyces, Miller's yeast and Hymenomyces were the dominant genera of the SS cooling field, which caused significant differences in the species and abundance of yeasts between the SS samples and the other two samples. Through cluster analysis, the fungal community structure of TA and TB samples was more similar.


Heatmap
1.4
1.2
1
0.9
0.6
0.4
0.2
0
Phylum
Relative Abundance(%)
100
75
50
25
0
A
B
C
Samples
Ascomycota
Basidiomycota
Zygomycota
Fungi_unclassified
Olpidiomycota
Chytridiomycota
Phylum
B
C
A
0.005
0.003
0.001
0
20
40
60
80
100
Bray-Curtis diatance
Relative abundance
Ascomycota
Basidiomycota
Zygomycota
Fungi_unclassified
Olpidiomycota
Chytridiomycota
Genus
Monascus
Trichothecium
Geosmithia
Chrysosporium
Trichomonascus
Talaromyces
Thermoascus
Wallemia
Millerozyma
Saccharomycopsis
Blastobotrys
Aspergillus
Thermomyces
Eurotium
Microascus
Trichoccmaceae_unclassified
Others
Zygosaccharomyces
Paecilomyces
Meyerozyma
Schizosaccharomyces
2
1
0
-1
-2
A
C
B
Genus
Relative Abundance(%)
100
80
60
40
20
0
C
B
A
Zygosaccharomyces
Thermoascus
Candida
Thermomyces
Monascus
Schizosaccharomyces
Millerozyma
Wickerhamomyces
Saccharomycopsis
Paecilomyces
Debaryomyces
Saccharomyces
Torulaspora
Chrysosporium
Eurotium
Microascus
Tirchothecium
Cyberlindnera
Blastobotrys
Geosmithia
Malassezia
Meyerozyma
Trichosporon
Wallemia
Trichocomaceae_unclassified
Trichomerium
Ascomycota_unclassified
Others

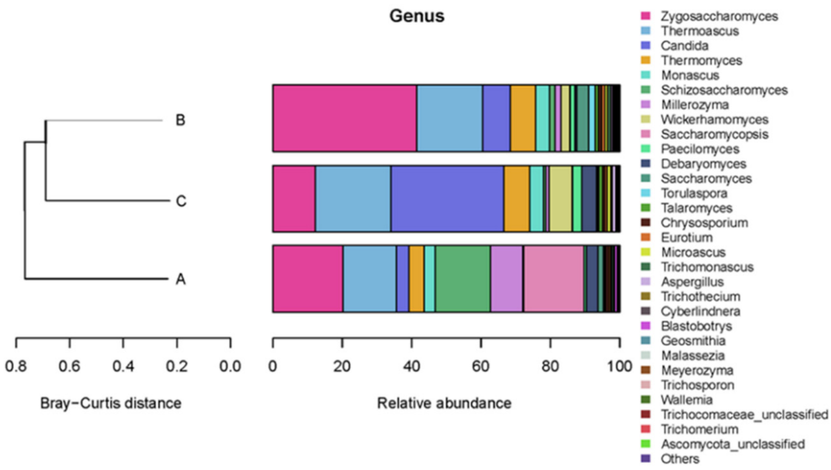


Fig. 7. phylum level and genus level analysis of fungal community structure of samples.

The significant difference analysis of bacterial phylum and genus at the gate level and genus level (Table S1-S4) showed that at the gate level, there was no significant difference among the three cooling field samples. At the genus level, there was no significant difference in the dominant genera of more than 4 %.

4 Conclusions

In this work, the physicochemical and functional characteristics of three Jiangxiangxing Baijiu cooling field building materials (TA, TB and SS) were analyzed. The results show that TA mainly consists of elements such as O, Si, Ca, Al, S, Fe, and Mg, with Si, Ca, and Al being the most abundant. TB and SS possess similar elemental compositions, mainly containing elements such as O, Si, Al, Fe, and Mg. Compared to TA, TB and SS have low content of Ca and S elements. Additionally, the order of specific surface area for the three materials is TA > TB > SS. The order of thermal insulation performance is TA > TB > SS, water absorption capacity is TA > TBs> SS, water release rate is SS > TB > TA, and material strength is SS > TB > TA. The analysis of microbial community structure shows that there is no significant difference in the microbial community structure of the three materials at the gate level, but there is a certain degree of difference in the genus level.

Acknowledgments

This work was supported by the Key Laboratory of Carbon-based Energy Molecular Chemical Utilization Technology in Guizhou Province (NO. 2023008).

References

1. Liu, H., Yang, X., Su, X., Li, S., Du, Q., Peng, Y., et al. (2022) Quality Identification of Sauce-Flavor Liquor Based on the Tyndall Phenomenon. Appl. Sci., 12: 53.
2. Zheng, Y., Sun, B., Zhao, M., Zheng, F., Huang, M., Sun, J., et al. (2016) Characterization of the Key Odorants in Chinese Zhima Aroma-Type Baijiu by Gas Chromatography–Olfactometry, Quantitative Measurements, Aroma Recombination, and Omission Studies. J Agric Food Chem., 64: 5367-74.
3. Ge, J., Qi, Y., Yao, W., Yuan, D., Hu, Q., Ma, C., et al. (2023) Identification of Trace Components in Sauce-Flavor Baijiu by High-Resolution Mass Spectrometry. Molecules., 28: 1273.
4. Fang, C., Du, H., Jia, W., and Xu, Y. (2019)Compositional Differences and Similarities between Typical Chinese Baijiu and Western Liquor as Revealed by Mass Spectrometry-Based Metabolomics. Metabolites., 9: 2.
5. Zhang, H., Tan, Y., Wei, J., Du, H. and Xu, Y. (2022) Fungal Interactions Strengthen the Diversity-Functioning Relationship of Solid-State Fermentation Systems. mSystems., 7: e00401-22.
6. Jin, G., Zhu, Y. and Xu. Y. (2017) Mystery behind Chinese liquor fermentation. Trends Food Sci Technol., 63: 18-28.
7. Zhang, H., Wang, L., Tan, Y., Wang, H., Yang, F., Chen, L. et al.(2021) Effect of Pichia on shaping the fermentation microbial community of sauce-flavor Baijiu. Int J Food Microbiol., 336: 108898.
8. Wang, L., Huang, Y., Hu, X. and Li, Y. (2021) The impact of environmental factors on the environmental bacterial diversity and composition in the Jiang-flavoured Baijiu production region. LWT., 149: 111784.
9. Li, Y., Cheng, Y., Wang, H., Hu, X., Wang, L. and Huang, Y. (2022) Diverse structure and characteristics of the fungal community during the different rounds of Jiang-flavoured Baijiu production in Moutai town. LWT., 161: 113313.
10. James A. M. (2018) Optimise the microbial flora with milk and yoghurt to prevent disease. Med Hypotheses., 114: 13-17.
11. Ramya S. B., Ajay P. K, Divakar K. (2021) Metagenomic Bioprospecting of Uncultivable Microbial Flora in Soil Microbiome for Novel Enzymes. Geomicrobiolo J., 2017079.
12. Xu, Y., Zhao, J., Liu, X., Zhang, C., Zhao, Z., Li, X., et al. (2022) Flavor mystery of Chinese traditional fermented baijiu: The great contribution of ester compounds. Food Chem., 369: 130920.
13. Wei, Y., Zou, W., Shen, C.-H and Yang, J.-G. (2020) Basic flavor types and component characteristics of Chinese traditional liquors: A review. J Food Sci., 85: 4096-107.
14. Li, L., Chen, M., Zhou, X., Lu, L., Li, Y., Gong, C., et al. (2017) A case of water absorption and water/fertilizer retention performance of super absorbent polymer modified sulphoaluminate cementitious materials. Constr. Build. Mater., 150: 538-46.
15. Li, L., Zhou, X., Li, Y., Gong, C., Lu, L., Fu, X., et al. (2017) Water absorption and water/fertilizer retention performance of vermiculite modified sulphoaluminate cementitious materials. Constr. Build. Mater., 137: 224-33.
16. Liu, Z., Pan, Y., Shi, K., Wang, W., Peng, C., Li, W., et al. (2016) Preparation of hydrophilic luffa sponges and their water absorption performance. Carbohydr Polym., 147: 178-87..
17. Xiao, X.-y., Wang, M.-w., Zhu, H.-w., Guo, Z.-h., Han, X.-q. and Zeng, P. (2017) Response of soil microbial activities and microbial community structure to vanadium stress. Ecotoxicol Environ Saf., 142: 200-6.