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Enhancement of GABA content in Hongqu wine by optimisation of fermentation conditions using response surface methodology

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Abstract: γ-aminobutyric acid (GABA) is an important inhibitory neurotransmitter in the human body, but its content decreases with age. So it is suitable to supplement the body's GABA from diet. Hongqu wine is popular because of the addition of *Monascus* strains in the saccharification process, which makes the wine rich in functional ingredients such as GABA, and monacolin K. In this study, the fermentation parameters of Hongqu wine were optimised to maximise the GABA content through response surface methodology (RSM). The optimal conditions were as follows: 500 g of steamed rice was mixed with 115.4% of boiled water containing 10 g of sodium glutamate and adjusted to pH 3.8 with lactic acid, and then 32% of Hongqu seed inoculum was added. After 5 days of fermentation at 28 °C, 1.5 g of activated yeast was inoculated for ethanol fermentation at 30 °C for 5 days. Finally, the average content of GABA in Hongqu wine amounted to 710.24 mg L^{-1}, which is close to the value predicted by RSM model (692.44 mg L^{-1}), indicating the statistical fit is good. This provided technical support and theoretical guidance for the production of Hongqu wine rich in GABA by two-stage fermentation.

Keywords: γ-aminobutyric acid; Huangjiu; safety and health; response surface analysis; *Monascus pilosus* CBS 290.34

Huangjiu, also called Chinese yellow wine, Chinese rice wine or yellow wine, is a type of brewed wine prepared by cooking, adding koji (Qu), saccharification, fermentation, pressing, filtering, decoction, storage, and blending with rice, glutinous rice, maize, millet, wheat, etc. as the main raw materials (Shen et al. 2012a; Tian et al. 2016). Huangjiu has a history of more than 2 500 years, which is known as the world's three largest ancient wines along with beer and wine (Xu et al. 2018; Liang et al. 2020). Huangjiu is popular among the Chinese people because of its low alcohol content, unique aroma and subtle sweet flavour. In addition, Huangjiu contains active ingredients such as polyphenols, melanoidin, glutathione, etc., which function as scavenging

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free radicals, preventing cardiovascular diseases, and have anti-cancer and anti-aging properties (Que et al. 2006; Shen et al. 2012a; Chen et al. 2020). With thousands of years of historical and cultural accumulation, Huangjiu occupies an important position in traditional Chinese culture. In recent years, its market share has been increasing in China (Shen et al. 2012b).

Hongqu wine, also called Hongqu Huangjiu, red yeast rice wine or Hongqu rice wine, is one of the typical representatives of Huangjiu popular in central, eastern and southern China (Lu et al. 2019). It is highly praised since a *Monascus* strain is used as saccharifying agent producing special ingredients such as γ-aminobutyric acid (GABA), cholesterol lowering agent monacolin K and appealing red colour (Journoud and Jones 2004; Tian et al. 2016). GABA is a non-proteinogenic natural amino acid commonly found in animals, plants and microorganisms. It has been demonstrated that GABA possesses many physiological functions such as regulation of blood pressure, heart rate and hormone levels, reduction of blood lipid, as well as improvement of liver and kidney function and so on (Bown and Shelp 1997; Hayakawa et al. 2004; Ma et al. 2020). Body builders also use it to increase muscle growth. Given the important role of GABA promoting human health, GABA is allowed to be added to a variety of foods except for special populations by many countries and organisations (Yamatsu et al. 2016). As one grows older, the GABA content in the body gradually decreases. Therefore, supplementing GABA from the diet is a good way to maintain the body's needs. Hongqu wine rich in GABA has aroused widespread interest and has a broad market prospect (Lv et al. 2013; Wu et al. 2015).

In this study, we optimised fermentation conditions through response surface methodology (RSM), and obtained GABA-rich Hongqu wine with *Monascus pilosus* CBS 290.34 as the saccharifying agent. The GABA content in the wine reached 710.24 mg L^{-1}, which is more than the GABA content of similar products on the Chinese market. This study provides a reference for the production of GABA-rich Hongqu wine.

MATERIAL AND METHODS

Chemicals and strain

Monascus pilosus CBS 290.34 was purchased from Centraalbureau voor Schimmelcultures (CBS, Netherlands). GABA and 2,4-dinitrofluorobenzene (DNFB) standard with purity ≥ 99% were purchased from the Aladdin company. Other conventional chemical reagents, such as sodium glutamate, were purchased from China National Medicines Corporation Ltd. (China). Active dry yeasts were purchased from Angel Yeast Corporation Ltd. (China).

DNFB solution (1%): 0.2 g DNFB was dissolved in 20 mL of acetonitrile and mixed and stored in the dark.

Seed broth (seed medium): 50 g dextrose, 10 g peptone, 2 g $NH_4H_2PO_4$, 0.5 g $MgSO_4 \cdot 7H_2O$, and 0.1 g $CaCl_2$ in 1 000 mL of potato juice, adjusted to pH 6.0 (Sayyad et al. 2007).

Preparation of seed fermentation broth

Monascus pilosus CBS 290.34 strain was cultured on potato dextrose agar (PDA) slants at 28 °C for 7 days, and spores were washed off with sterile water to prepare the spore suspension, the concentration of which was adjusted to 1.0×10^6 spore mL^{-1}. Then, 10% spore suspension (v/v) was inoculated into 500 mL flasks containing 100 mL of seed broth, and was incubated at 28 °C for 33 h with 110 rpm in a HY-6 shaker (Ruihua Instrument Co., Ltd., China).

Fermentation process of Hongqu wine

The preparation for Hongqu wine was described as follows: 500 g of rice was soaked in tap water for 6 h and washed until no white slurry was produced. Then, the soaked rice was drained properly and steamed at 121 °C for 20 min (Zealway G154DWS; Xiamen, China) followed by spreading and cooling; later it was put into 2.5 L of ceramic tank with sterile water, sodium glutamate and seed inoculum. Lactic acid was used to adjust the pH value of this fermentation broth. After 5 days of fermentation for saccharification, activated yeast was added for ethanol fermentation. Five days later, Hongqu wine is obtained by filtration.

Optimisation of fermentation conditions of Hongqu wine rich in GABA

Screening of key fermentation parameters by Plackett-Burman design. In order to determine the parameters affecting the content of GABA in Hongqu wine, different fermentation parameters were evaluated in a two-step experimental design strategy. In the first step, a two factorial design, Plackett-Burman statistical experimental design, is used to identify the key variables, a very useful approach to optimisation of fermentation parameters. A 12-run Plackett-Burman design was achieved by Design Expert 8.06 software (Statease, USA) and six factors (Table 1) were screened by single factor experiments described by Chen and Chen (2009). The Plackett-Burman experimental design is based on the equation of the first-order polynomial model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 \quad (1)$$

where: y – predicted response (GABA yield); β_0, β_1, β_2, β_3, β_4, β_5, and β_6 – regression coefficients; x_1, x_2, x_3, x_4, x_5 and x_6 – coded levels of the independent variables.

All six variables were studied at two widely spaced levels. The low level (−1) and the high level (+1) of each factor are listed in Table 1. GABA yields were detected by high-performance liquid chromatography (HPLC) (DGU-20A; Shimadzu, Japan), and the results of Plackett-Burman design were analysed by using the Design Expert 8.06 program. If the *P*-value of a specified factor was less than 0.05, it would be considered as a significant term which can be selected as a parameter for the next RSM analysis.

Steepest ascent design. Based on the main effect factors screened by Plackett-Burman design, a series of trials was performed in the direction of the steepest ascent for high content of GABA (Table 2). Three fermentation parameters, Hongqu seed inoculum (x_2), amount of water added (x_3) and pH (x_6) were further optimised by steepest ascent experiments. The steepest ascent directions and change distance were determined by the coefficients of parameters obtained from Plackett-Burman design.

Box-Behnken design (BBD). RSM design was formulated according to the Box-Behnken tool using Design Expert 8.06 software. Three fermentation parameters including Hongqu seed inoculum, amount of water added and pH were optimised in the Box-Behnken experiments, and the GABA yield in Hongqu wine was regarded as the response value in this design. Statistical analysis of the model was performed to evaluate the analysis of variance. The coefficient of determination, R^2, was used to judge the quality of the polynomial model equation, and *F*-test was used to determine its statistical significance (Tan et al. 2012; Feng et al. 2014). The results of RSM were analysed using the Design Expert 8.06 program.

Table 1. Experimental independent variables at two levels used for improving GABA in Hongqu wine with *Monascus* strain CBS 290.34 by using Plackett–Burman design

Factor		Level	
Variable	parameter	low (−1)	high (+1)
x_1	yeast addition time (d)	3	5
x_2	Hongqu seed inoculum (%, v/w)	10	20
x_3	amount of water added (%, v/w)	150	300
x_4	sodium glutamate (%, w/w)	1	2
x_5	amounts of yeast addition (%, w/w)	0.15	0.30
x_6	pH	4	6

GABA – γ-aminobutyric acid

Table 2. Experimental design and results of steepest ascent experiments

Run	Variable			GABA (mg L^{-1})
	x_2	x_3	x_6	
1	20	150	4.0	560.54
2	30	120	3.8	673.32
3	40	90	3.6	629.37
4	50	60	3.4	321.84

GABA – γ-aminobutyric acid; the symbols of the coded variables are the same as those used in Table 1

GABA analysis. GABA was detected by HPLC following the previous description with minor modification (Li et al. 2016). Firstly, GABA was subjected to derivatisation reaction. GABA standard solution or Hongqu wine (0.2 mL) was mixed with 0.2 mL of DNFB solution (1%, w/v) and 0.2 mL of $NaHCO_3$ (0.5 mol L^{-1}, pH 9.0) in a 2-mL centrifuge tube (round bottom; Axygen, China). The mixture was placed in a water bath at 60 °C for 1 h in the dark. After returning to room temperature, the volume was adjusted to 2 mL with KH_2PO_4 (0.01 mol L^{-1}, pH 7.0). The reaction solution was filtered through a membrane filter (0.22 μm; Jinteng, China) before HPLC analysis.

HPLC was performed on a Shimadzu LC-20AT system with a diode array ultraviolet detector (Japan). The Inertsil ODS-3 C18 column (4.6 mm × 250 mm, 5 μm; Shimadzu, Japan) was employed and the column temperature was set at 35 °C. The mobile phase was a mixture of 50% ACN and 0.01 mol L^{-1} KH_2PO_4 (40 : 60, v/v); the flow rate was maintained at 1.0 mL min^{-1}. The injection volume was 20 μL.

RESULTS AND DISCUSSION

Results of Plackett–Burman design. In our previous study, *Monascus pilosus* CBS 290.34 produced

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high GABA and had strong saccharification ability, but it did not produce any mycotoxin (citrinin). These features are very suitable for producing Hongqu products rich in GABA. Six fermentation parameters were employed in Plackett-Burman design (Table 3). The results (Table 4) indicated that model terms could be recognised as significance based *P*-value (0.018 < 0.05). Three parameters, namely Hongqu seed inoculum (x_2), the volume of water added (x_3) and pH (x_6), were considered to be significant model terms because all of their *P*-values were less than 0.05. Therefore, these three parameters were assessed as key factors in the

Table 3. Results of Plackett-Burman design

Run	Coded variable level						GABA (mg L^{-1})
	x_1	x_2	x_3	x_4	x_5	x_6	
1	–1	1	–1	–1	–1	1	83.14
2	1	1	1	–1	1	1	13.29
3	–1	–1	1	1	1	–1	2.65
4	–1	1	1	1	–1	1	30.79
5	1	–1	1	1	–1	1	104.54
6	1	–1	1	–1	–1	–1	60.89
7	–1	1	1	–1	1	–1	34.52
8	–1	–1	–1	–1	–1	–1	163.49
9	1	1	–1	1	–1	–1	593.64
10	–1	–1	–1	1	1	1	171.37
11	1	–1	–1	–1	1	1	142.09
12	1	1	–1	1	1	–1	570.80

GABA – γ-aminobutyric acid; the symbols of the coded variables are the same as those used in Table 1; "–1" and "1" levels are shown in Table 1

Table 4. Coefficients and *P*-values calculated from Plackett-Burman design

Source	Coefficient	SE	*F*	*P*
Model	104.51	56.10	10.89	0.018*
x_1	53.17	25.09	4.49	0.1014
x_2	86.87	25.09	11.99	0.0258*
x_3	–136.14	26.61	26.18	0.0069**
x_4	51.26	25.09	4.17	0.1105
x_5	6.80	23.47	0.084	0.7865
x_6	–88.67	23.47	14.28	0.0195*

SE – standard error; the symbols of the coded variables are the same as those used in Table 1; the *P*-term is used to confirm factors that have significant effects on the response; if a factor has a *P*-value of less than 0.05, it is a significant factor; **P* < 0.05, ***P* < 0.01, *** *P* < 0.001

steepest ascent experiment. The fitted first-order model equation for GABA yield in Hongqu wine could be written as follows:

$$y = 104.51 + 53.17x_1 + 86.87x_2 - 136.14x_3 + 51.26x_4 + 6.80x_5 - 86.67x_6 \quad (2)$$

where *y* – response values (GABA yield); x_1, x_2, x_3, x_4, x_5 and x_6 – yeast addition time, Hongqu seed inoculum, the volume of water added, sodium glutamate, the amounts of yeast and pH, respectively.

As shown in Table 4, the coefficients of some factors are positive, such as the yeast addition time (x_1), Hongqu seed inoculum (x_2), sodium glutamate (x_4) and the amounts of yeast (x_5), so we can improve GABA yields by increasing or extending these factors. On the contrary, the volume of water added (x_3) and pH (x_6) exhibited negative effects. The model *P*-value was 0.018, indicating this model is significant.

Results of steepest ascent experiments. The results of steepest ascent experiments are shown in Table 2. The maximum yield of GABA in steepest ascent experiments was obtained when 2.5 L of ceramic tank containing 500 g of steamed rice, with 54.55% moisture content of the substrate (the sum of rice and water), 10 g of sodium glutamate and at pH 3.8 with 30% of seed inoculum were incubated at 30 °C for 5 days, and followed by addition of 1.5 g yeast for further 5-day fermentation at 28 °C. The yield of GABA reached the maximum (673.32 mg L^{-1}) in the fermenting system. Therefore, volume of seed inoculum (x_2), amount of water added (x_3), and pH (x_6), these three factors and their levels were selected for the second-order experiment, that is, Box–Behnken design.

Results of Box-Behnken design (BBD) experiment. To achieve the optimum levels of fermentation parameters that influenced GABA yield in the preparation of Hongqu wine, amount of water added, pH and volume of Hongqu seed inoculum were further optimised by RSM experiments [Table S1, see electronic supplementary material (ESM)]. An experimental design of 17 runs, containing 5 central points, was achieved according to the Box--Behnken design (BDD). The yield of GABA was set as the response value. Figure 1 clearly suggested that most points were nearby the line adjustment, meaning that the experimentally determined values were similar to those predicted by the model. Data in each run were analysed by Design Expert 8.06 software and shown in Table S2 (see ESM). Accordingly, the second-order model equation for GABA yield could be written as follows:

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$$y(G) = 689.39 - 17.80A - 5.64B + 14.17C - 4.70AB + 3.05AC + 5.88BC - 56.24A^2 - 22.85B^2 - 31.33C^2 \quad (3)$$

where: *y(G)*, *A*, *B*, and *C* – GABA yield, the amounts of water added, pH and the volume of Hongqu seed inoculum, respectively.

Both the amounts of water added and the volume of Hongqu seed inoculum were significant factors (*P* < 0.05) (Table 5). Coefficient analysis of the regression equation of fermentation parameter model is summarised in Table S3 (see ESM). We can see that the *P*-value of the test model was 0.0002 (< 0.01), which means that the regression model is extremely significant. The lack of fit was not significant relative to the pure error (*P* > 0.05). Moreover, the coefficient of determination R^2 is 0.9669 (Table S4; see ESM), indicating that 96.69% of the variability in the response can be explained by the model. The adjusted R^2 value of 0.9242 (Table S4) was also high enough to advocate for a high significance of the model. Adequate precision measures the signal-to-noise (S/N) ratio, and the ratio > 4 is desirable (Yolmeh and Jafari 2017). The ratio of 14.112 (Table S4) in this study indicated an adequate signal. From the data above, there was a good fit between

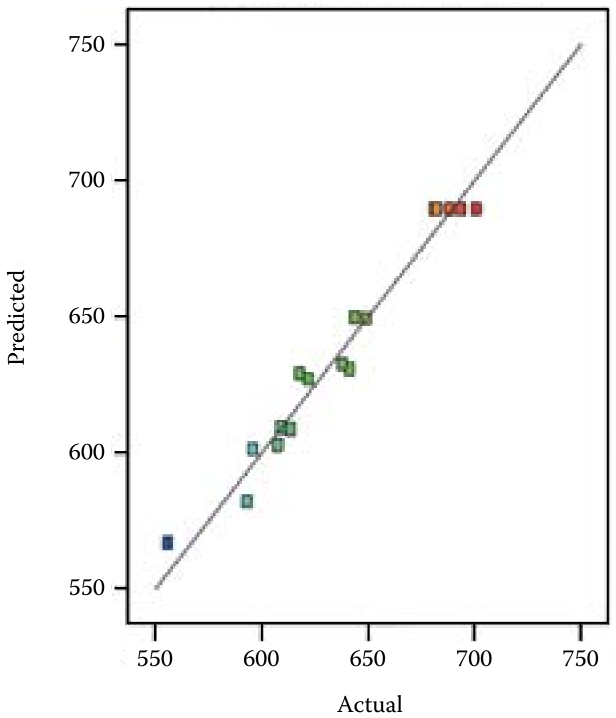

Figure 1. Plot of predicted *vs.* actual values for GABA yield

GABA – γ-aminobutyric acid

Table 5. Analysis of variance of model parameters

Model parameters	*df*	*F*	*P*
A	1	19.76	0.0030**
B	1	1.98	0.2019
C	1	12.52	0.0095**
AB	1	0.69	0.4340
AC	1	0.29	0.6063
BC	1	1.08	0.3341
A^2	1	103.80	< 0.0001***
B^2	1	17.13	0.0044**
C^2	1	32.21	0.0008***

If a factor has a *P*-value of less than 0.05, it is a significant factor; **P* < 0.05, ***P* < 0.01, *** *P* < 0.001

the measured and predicted GABA yields, and this model is sufficient to approximate the response surface of the experimental design. The interactions between different investigation factors and the 3D response surface curves (Figure 2) were obtained through Design Expert 8.06. As shown in Figure 2A, there is an intersection between the three selected factors, and the opening direction of the curve is downward, indicating that there is a negative interaction between all parameters. Moreover, as shown in Figure 2B–2D, the profiles of the response surfaces between the amount of water added and pH, the amount of water added and Hongqu seed inoculum, as well as Hongqu seed inoculum and pH are all convex with an open downward direction, indicating the optimal fermentation conditions of GABA yield exist within the designed level of factors. Maximum GABA yield (692.44 mg L^{-1}) was predicted for 500 g of steamed rice in 2.5 L of ceramic tank containing 115.4% water, 10 g sodium glutamate and 32% seed inoculum precultured for 33 h at 28 °C at pH value 3.8, fermented for 5 days followed by addition of 1.5 g yeast for further fermentation. To verify the reliability of the model, it was validated under these conditions, and an average GABA yield of 710.24 mg L^{-1} was obtained, which is far more than that of other Chinese rice wines (Wu et al. 2015; Qian et al. 2016).

Influenced by cultural customs and dietary habits, there is a slight difference in the process of making Hongqu wine. In this study, a two-stage fermentation process was adopted to brew Hongqu wine rich in GABA. First, Hongqu seed inoculum was blended with steamed rice to saccharify the materials at 28 °C for 5 days, then, highly active yeast used in Huangjiu production was added for ethanol fermentation. This

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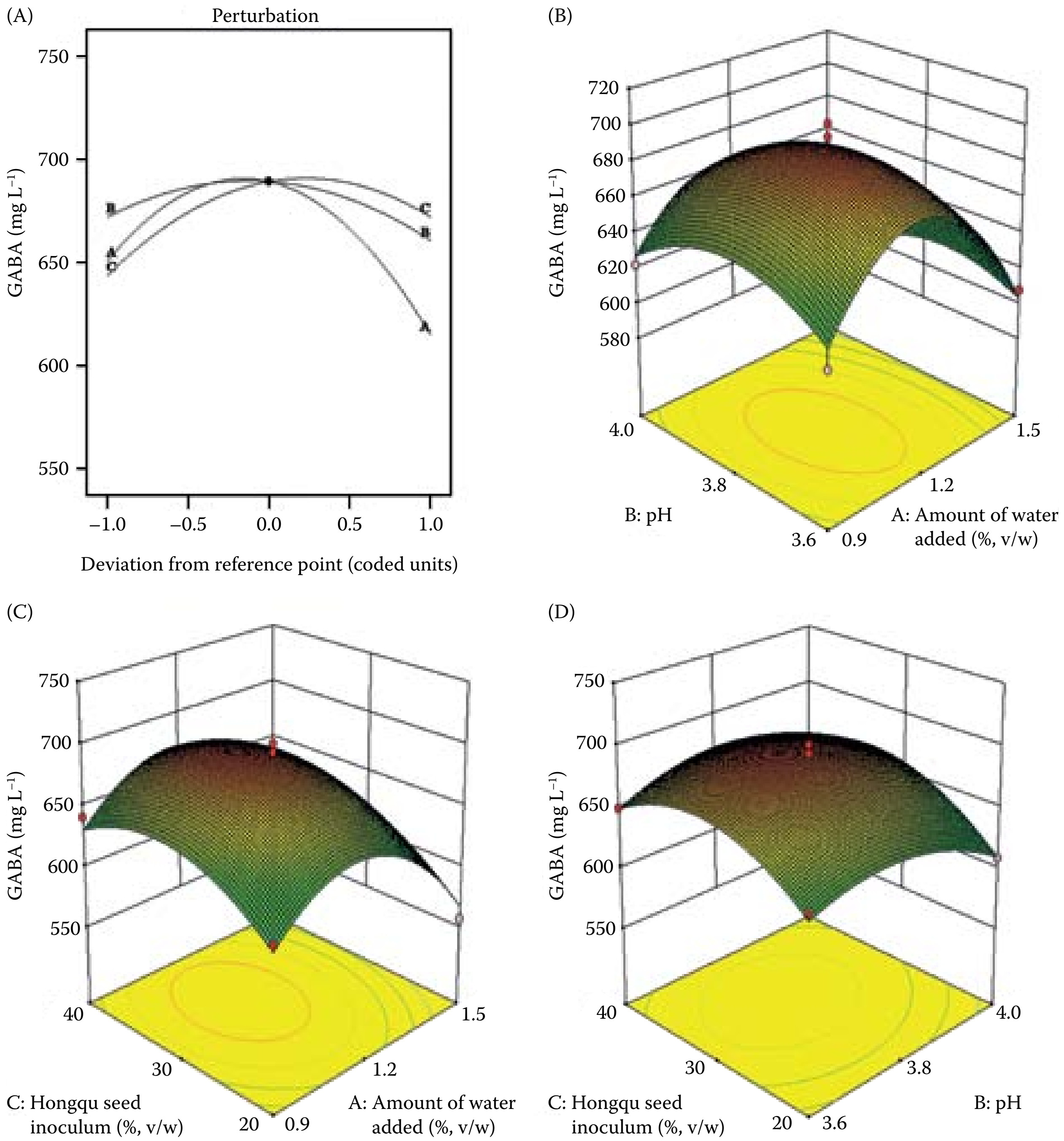

Figure 2. Perturbation plot and 3D graphs of the response surface model: (A) effects of selected factors on GABA yield, (B), (C), (D) effects of two factors on GABA yield, where A, B, and C are the amount of water added, pH and Hongqu seed inoculum, respectively

fermentation process is also helpful to avoid the problem of high alcohol content inhibiting GABA production (Wang et al. 2003; Cai et al. 2019). Moreover, this process is in line with the natural growth characteristics of *Monascus* strain secreting GABA. In addition, the pH was adjusted to 3.8, which not only inhibits the growth of other bacteria, but also allows the sodium glutamate to be partially converted to glutamate (Alamäe and Järviste 1995; Kono and Himeno 2000). The statistical model also demonstrated that pH was a very important factor affecting the GABA yield of Hongqu wine. Another factor with a significant effect on GABA yield is the amount of water added because the moisture content of the culture substrate will

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affect the permeability, the diffusion of heat generated by the fermentation process, and whether *Monascus* can better penetrate into the rice to produce GABA. The Hongqu seed inoculum also had a significant effect on GABA. When the nutrition is adequate, the accumulation of metabolites is proportional to the inoculum of Hongqu seed solution, but too much inoculum will lead to mycelial propagation and slow down the production of metabolites.

CONCLUSION

In this study, the optimised fermentation parameters of Hongqu wine rich in GABA were established by RSM. Under the optimum conditions, the mean GABA value of this Hongqu wine reached 710.24 mg L^{-1}. The ethanol concentration of final product was 12.8% (v/v). This inspiring result provides a reference for the application of *Monascus pilosus* CBS 290.34 in fermented food industries to produce GABA-rich food.

REFERENCES

Alamäe T., Järviste A. (1995): Permeabilization of the methylotrophic yeast *Pichia pinus* for intracellular enzyme analysis: A quantitative study. Journal of Microbiological Methods, 22: 193–205.

Bown A.W., Shelp B.J. (1997): The metabolism and functions of gamma-aminobutyric acid. Plant Physiology, 115: 1–5.

Cai Q.Q., Zhou K.X., Liu Z.B., Zhang C., Zhang W., Ni L. (2019): Studies on growth inhibitory factors of *Monascus* in the brewing process of Hongqu rice wine. Journal of Chinese Institute of Food Science and Technology, 19: 143–149.

Chen C.X., Chen F.S. (2009): Study on the conditions to brew rice vinegar with high content of γ-amino butyric acid by response surface methodology. Food and Bioproducts Processing, 87: 334–340.

Chen T., Qi X.P., Chen M.J., Lu D.L., Chen B. (2020): Discrimination of Chinese yellow wine from different origins based on flavor fingerprint. Acta Chromatographica, 32: 139–144.

Lu F.J., Peng B., He S.G., Wu Z.Q. (2019): Effect of Hongqu rice addition on polyphenol components and antioxidant properties of Hongqu rice wine. China Brewing, 38: 113–118. (in Chinese)

Que F., Mao L.C., Zhu C.G., Xie G.F. (2006): Antioxidant properties of Chinese yellow wine, its concentrate and volatiles. LWT – Food Science and Technology, 39: 111–117.

Feng Y.L., Shao Y.C., Zhou Y.X., Chen F.S. (2014): Production and optimization of monacolin K by citrinin-free *Monascus pilosus* MS-1 in solid-state fermentation using non-glutinous rice and soybean flours as substrate. European Food Research and Technology, 239: 629–636.

Hayakawa K., Kimura M., Kasaha K., Matsumoto K., Sansawa H., Yamori Y. (2004): Effect of a gamma-aminobutyric acid-enriched dairy product on the blood pressure of spontaneously hypertensive and normotensive Wistar-Kyoto rats. British Journal of Nutrition, 92: 411–417.

Journoud M., Jones P.J.H. (2004): Red yeast rice: A new hypolipidemic drug. Life Sciences, 74: 2675–2683.

Kono I., Himeno K. (2000): Changes in γ-aminobutyric acid content during beni-koji making. Bioscience, Biotechnology, and Biochemistry, 64: 617–619.

Li N.N., Liu Y., Zhao Y., Zheng X.Q., Lu J.L., Liang Y.R. (2016): Simultaneous HPLC determination of amino acids in tea infusion coupled to pre-column derivatization with 2,4-dinitrofluorobenzene. Food Analytical Methods, 9: 1307–1314.

Liang Z.C., Lin X.Z., He Z.G., Li W.X., Ren X.Y., Lin X.J. (2020): Dynamic changes of total acid and bacterial communities during the traditional fermentation of Hong Qu glutinous rice wine. Electronic Journal of Biotechnology, 43: 23–31.

Lv X.C., Huang R.L., Chen F., Zhang W., Rao P.F., Ni L. (2013): Bacterial community dynamics during the traditional brewing of Wuyi Hong Qu glutinous rice wine as determined by culture-independent methods. Food Control, 34: 300–306.

Ma W.Y., Zhang J., Shu L., Tan X.Q., An Y., Yang X.D., Wang D.P., Gao Q. (2020): Optimization of spray drying conditions for the green manufacture of γ-aminobutyric acid-rich powder from *Lactobacillus brevis* fermentation broth. Biochemical Engineering Journal, 156: 107499.

Qian M., Liu J.X., Mo Y.C., Zhu H., Zhao W.H., Bai W.D. (2016): Process optimization of Guangdong Hakka rice wine containing GABA. China Brewing, 35: 123–126. (in Chinese)

Sayyad S.A., Panda B.P., Javed S., Ali M. (2007): Optimization of nutrient parameters for lovastatin production by *Monascus purpureus* MTCC 369 under submerged fermentation using response surface methodology. Applied Microbiology and Biotechnology, 73: 1054–1058.

Shen F., Li F.Z., Liu D.L., Xu H.R., Ying Y.B., Li B.B. (2012a): Ageing status characterization of Chinese rice wines using chemical descriptors combined with multivariate data analysis. Food Control, 25: 458–463.

Shen F., Yang D.T., Ying Y.B., Li B.B., Zheng Y.F., Jiang T. (2012b): Discrimination between Shaoxing wines and other chinese rice wines by near-infrared spectroscopy and chemometrics. Food and Bioprocess Technology, 5: 786–795.

Tan J., Chu J., Shi W.J., Lin C., Guo Y.X., Zhuang Y.P., Zhang S.L., Imanaka T. (2012): High-throughput screen-

https://doi.org/10.17221/47/2021-CJFS

ing strategy used for enhanced production of pigment by *Monascus purpureus* D39-4. Food Science and Biotechnology, 21: 1603–1610.

Tian Y.T., Huang J.M., Xie T.T., Huang L.Q., Zhuang W.J., Zheng Y.F., Zheng B.D. (2016): Oenological characteristics, amino acids and volatile profiles of Hongqu rice wines during pottery storage: Effects of high hydrostatic pressure processing. Food Chemistry, 203: 456–464.

Wang J.J., Lee C.L., Pan T.M. (2003): Improvement of monacolin K, γ-aminobutyric acid and citrinin production ratio as a function of environmental conditions of *Monascus purpureus* NTU 601. Journal of Industrial Microbiology and Biotechnology, 30: 669–676.

Wu Z.Z., Xu E.B., Long J., Wang F., Xu X.M., Jin Z.Y., Jiao A.Q. (2015): Rapid measurement of antioxidant activity and γ-aminobutyric acid content of Chinese rice wine by Fourier-transform near infrared spectroscopy. Food Analytical Methods, 8: 2541–2553.

Xu J.L., Wu H.J., Wang Z.W., Zheng F.P., Lu X., Li Z.P., Ren Q. (2018): Microbial dynamics and metabolite changes in Chinese rice wine fermentation from sorghum with different tannin content. Scientific Reports, 8: 4639.

Yamatsu A., Yamashita Y., Pandharipande T., Maru I., Kim M. (2016): Effect of oral gamma-aminobutyric acid (GABA) administration on sleep and its absorption in humans. Food Science and Biotechnology, 25: 547–551.

Yolmeh M., Jafari S.M. (2017): Applications of response surface methodology in the food industry processes. Food and Bioprocess Technology, 10: 413–433.

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