ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P83

Effect of Enzymolysis Treatment on the Quality of Freeze-Dried Meal Replacement Porridge

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Abstract: Effects of enzymolysis treatment on the quality of freeze-dried meal replacement porridge were investigated. The optimal technological parameters (59℃, α -amylase 2000 U/g, saccharase 4200 U/g, cellulase 3800 U/g, digestion time 39 min) were gained by single test, Plackett-Burman test and Box-Behnken response surface. After enzymatic hydrolysis, the instant solubility of the product was greatly improved, and the total flavone and content sensory quality of the product was increased.

Keywords: Meal replacement porridge; Enzymatic treatment; Property

1. Introduction

Meal replacement food is not only convenient when you eat it, but also quickly provides various necessary nutrients to the human body, it is easy to achieve the effect of satiety with higher dietary fiber content and lower food calories, therefore you can control your caloric intake. So, the Meal replacement becomes the new consumption trend and more and more people favor it [1]. In China, the main kind of Meal replacement is Meal replacement porridge with the drawback of short storage cycle and difficult to transport; at the same time, the product of solid powder has the shortcoming of easy agglomeration and cannot be eaten directly [2-3]. Adding enzyme preparation can improve product of sensory quality and nutrient content. The research has manifested that α-amylase, β-amylase, glycosylase and cellulase enable degrade or modify biomacromolecules in grain raw materials, which can not only heighten the digestive property of cereals, but also give special physiological functions to the products. [4]. Therefore， in order to improve the sensory quality of the product, improve the instant solubility of the product, improve the nutritional value of the product, enhance the storage of the product, the effect of enzymatic hydrolysis on product quality with the aim which is to develop a solid freeze-dried meal replacement porridge product which can be eaten directly and drunk after mixing.

2. Materials and Methods

2.1 Test Material

Raw material (grains, beans, potatoes, coarse cereals, nuts) was provided by Shandong Xifudejia Agricultural Development Co., Ltd. α-amylase, Glycosylase and Cellulase were purchased from Nanjing Xinte Biotechnology Co., Ltd.

2.2 Research Method

2.2.1 Determination of texture

Determination of texture was performed using TA.XTC-18 texture analyzer with P5 probe and TPA mode.

2.2.2 Determination of color difference

The color difference was analyzed Using the CR-10 Plus colorimeter.

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2.2.3 Determination of nutrient content

The moisture content, ash content, protein content, fat content, dietary fiber content, and carbohydrate content were determined based on GB 5009.3-2016, respectively.

2.2.4 Sensory evaluation

Sensory evaluation was performed according to the DB37T 1319-2009.

2.2.5 Determination of reducing sugar content and calculation of DE value

2.2.6 Determination of total flavone content

The total flavone content and instant solubility was analyzed reference to the method of [4].

2.2.7 Data analysis

Adopting the software of SPSS 21 was to the analysis of variance and factor and examination of Duncan according to date. ($p<0.05$).

3. Results and Analysis

3.1 Effect of Enzymatic Hydrolysis Treatment on Product Quality

3.1.1 Effect of enzyme addition amount on enzymatic hydrolysis

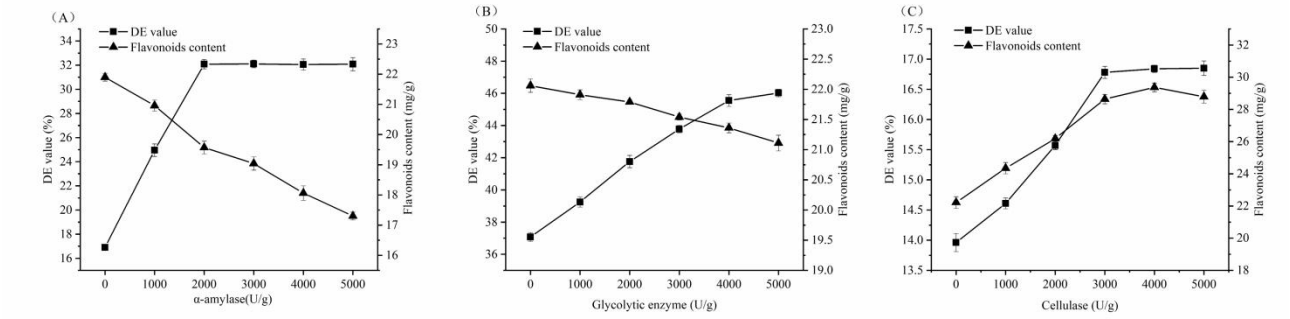

Fig.1 Effect of the amount of enzyme added on DE values and total flavonoids
(A): Effect of α -amylase plus enzyme amount on DE value and total flavonoids; (B): Effect of saccharifying enzyme amount on DE value and total flavonoids; (C): Effect of cellulase plus enzyme amount on DE value and total flavonoids.

As can be seen from Fig. 1: the DE value of meal replacement porridge increased with the increase of the three enzyme additions in a gradient, and the DE value tended to stabilize after the addition of more than a certain value of enzyme, which was due to the fact that the starch and cellulose in the raw materials had been almost completely decomposed, and the reducing sugar content was no longer increased, so that the DE value tended to be stabilized [5-6]. The total flavonoid content of the meal replacement porridge showed a tendency to increase and then decrease with the increase of enzyme addition, which is because cellulase can act on the cell wall and decompose the cellulose in it, which makes the cell wall deformed or ruptured, thus facilitating the leaching of flavonoids [7]. In addition, α-amylase has a destructive effect on flavonoids, while glycolytic enzymes can hydrolyze some of the isoflavonoids into the form of isoflavone glycosides, which in turn leads to a reduction in the total flavonoid content [8-10]. Therefore, this experiment was chosen as the addition of α-amylase, saccharase and cellulase at 2000 U/g, 4000 U/g and 4000 U/g, respectively.

3.1.2Effect of enzyme addition on instant solubility

As can be seen from Table 1, with the increase of enzyme addition, the quick-solubility of the meal replacement porridge was obviously enhanced, and the dispersion time and wetting time were obviously shortened, among which the addition of saccharification enzyme had the best effect on

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the quick-solubility enhancement. As can be seen from Fig. 2, with the increase of enzyme addition, the spatial structure of the meal replacement porridge gradually became uniform honeycomb from irregular holes, and the pores increased. This is because the enzymatic degradation of insoluble substances, water fully into the interior of the meal replacement porridge, ice crystals, ice crystals sublimation during vacuum freeze-drying to form a honeycomb spatial structure, which makes the product brewing hot water can quickly enter the interior of the meal replacement porridge, thus improving the quick solubility.

Table 1 Effect of α -amylase plus enzyme amount on instant solubility

Additive amount（U/g）	α -amylase		saccharifying enzyme		cellulase plus enzyme	
	Dispersibility（s）	Wettability（s）	Dispersibility（s）	Wettability（s）	Dispersibility（s）	Wettability（s）
0	53.36±0.73^{a}	321.56±2.02^{a}	51.42±0.82^{a}	322.35±1.71^{a}	53.52±0.72^{a}	317.63±1.16^{a}
1000	40.16±1.11^{b}	159.68±1.74^{b}	44.01±0.71^{b}	202.91±1.93^{b}	43.11±0.34^{b}	185.38±1.02^{b}
2000	21.71±1.86^{c}	89.33±0.85^{c}	24.33±0.62^{c}	99.55±1.02^{c}	31.77±0.39^{c}	125.36±0.79^{c}
3000	17.91±0.49^{d}	71.85±1.31^{d}	18.68±0.63^{d}	69.09±0.72^{d}	20.77±0.58^{d}	81.99±0.78^{d}
4000	17.81±0.38^{d}	71.19±0.40^{d}	15.84±0.21^{e}	52.45±0.34^{e}	19.76±0.31^{e}	67.13±0.19^{e}
5000	17.51±0.47^{d}	71.02±0.49^{d}	15.42±0.19^{e}	51.43±0.44^{e}	19.24±0.19^{e}	66.94±0.40^{e}

The same alphabets in right side of the same list show no significance ($p>0.05$), on the contrary, having significance ($p<0.05$).

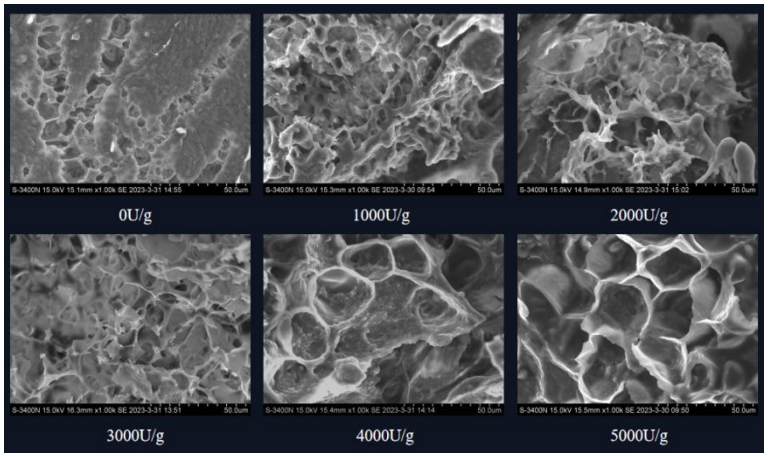

Fig.2 SEM of meal replacement porridge sections with different enzyme amounts

3.1.3Effect of enzymatic hydrolysis temperature on enzymatic hydrolysis effect

As shown in Fig. 3, the DE value of the meal replacement porridge showed a trend of first increasing and then decreasing with the increase of enzymatic temperature, which is due to the fact that temperature can regulate the activity of the enzyme, the activity of the enzyme increases with the increase of temperature when the temperature is lower, and the substrate decomposition rate is accelerated, and the DE value rises; when the enzymatic temperature is higher than its optimal temperature, the activity of the enzyme is inhibited, resulting in a decrease in the DE value [11]. The total flavonoid content decreased continuously with the rise of liquefaction temperature and saccharification temperature, and increased after exceeding the optimal temperature of α-amylase. This is because when the temperature was lower than the optimal temperature of the enzyme, the total flavonoid was continuously reduced by the decomposition of α-amylase and saccharification enzyme, and when the temperature was greater than its optimal temperature, the high temperature

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made the enzyme activity reduce, and the total flavonoid content rebounded, and the total flavonoid content increased continuously with the rise of the enzymatic digestion temperature of cellulose The total flavonoid content increased with the rise of cellulose enzymatic digestion temperature, and then continue to increase the temperature of total flavonoid content decreased. Therefore, 65℃ was finally selected as the liquefaction temperature, 60℃ as the saccharification temperature and 55℃ as the cellulolytic temperature.

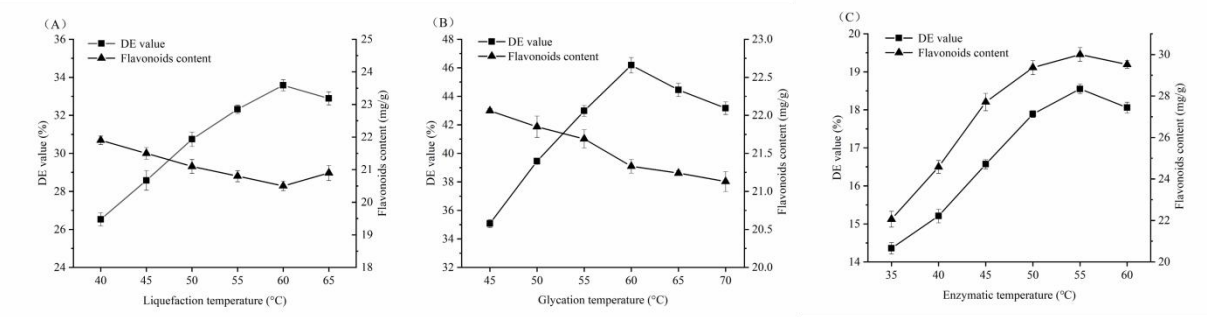

Fig.3 Effects of enzymatic digestion temperature on DE values and total flavonoids
(A): Effect of liquefaction temperature on DE value and total flavonoids; (B): influence of saccharification temperature on DE value and total flavonoids; (C): Effect of enzymatic digestion temperature on DE value and total flavonoids.

3.1.4 Effect of enzymatic hydrolysis temperature on instant solubility

As can be seen from Table 2, with the increase of enzymatic temperature, the quick-solubility of meal replacement porridge showed a trend of increasing and then decreasing, and the dispersion time and wetting time were shortened with the increase of temperature under the lower than optimal temperature, and the quick-solubility was decreased after exceeding the optimal temperature of the enzyme. As can be seen from Fig. 4, with the increase of enzymatic temperature, the spatial structure of meal replacement porridge gradually became regular and loose and porous from disordered, but when exceeding the optimal temperature of the enzyme, the diameter of the pores decreased, which affects the rehydration of the brewing, which is in line with the results of the data of the quick solubility.

Table 2 Effect of enzymatic lysis temperature on instant solubility

Enzymatic hydrolysis temperature (℃)	cellulase		α -amylase		saccharifying enzyme	
	Dispersion (s)	Wettability (s)	Dispersion s)	Wettability (s)	Dispersion (s)	Wettability (s)
35	48.97±0.47^{a}	216.45±1.01^{a}	-	-	-	-
40	42.24±0.79^{b}	168.59±0.53^{b}	47.56±0.62^{a}	194.46±0.92^{a}	-	-
45	30.28±0.40^{c}	107.64±1.37^{c}	37.03±0.60^{b}	145.02±0.90^{b}	46.79±0.46^{a}	186.56±1.09^{a}
50	21.02±0.59^{d}	73.23±0.66^{d}	23.44±0.49^{c}	88.19±0.98^{c}	34.32±0.39^{b}	123.02±0.31^{b}
55	18.38±0.44^{e}	63.80±0.43^{e}	19.75±0.52^{d}	64.17±0.39^{d}	23.87±0.95^{c}	79.85±0.56^{c}
60	20.72±0.35^{d}	72.12±0.20^{d}	16.44±0.25^{f}	59.65±0.71^{f}	15.41±0.40^{d}	53.35±0.27^{d}
65	-	-	18.45±0.42^{e}	62.36±0.49^{e}	18.18±0.45^{f}	59.49±0.46^{f}
70	-	-	-	-	21.53±0.29^{e}	64.50±0.47^{e}

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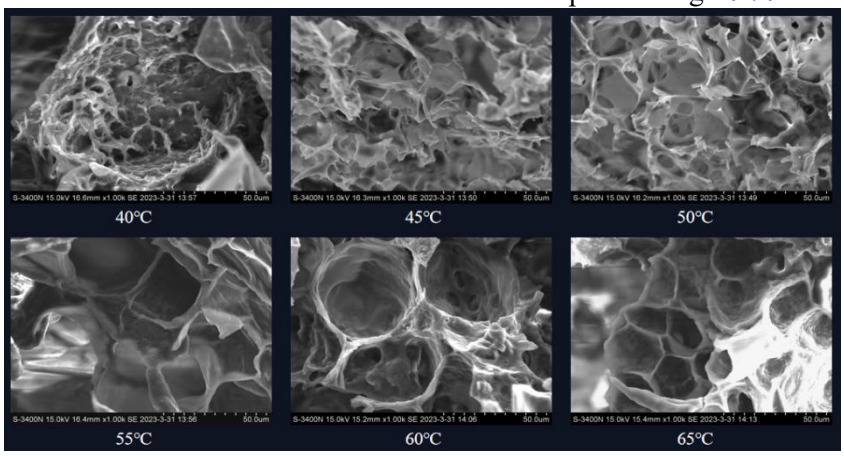

Fig.4 SEM map of meal replacement porridge sections at different enzymatic temperatures

3.1.5 Effect of enzymatic hydrolysis time on enzymatic hydrolysis effect

As can be seen from Fig. 5, the DE value of the meal replacement porridge increased with the increase of the enzymatic time of the three enzymes, because the longer the enzymatic time the enzyme activity was fully utilized, the enzyme contact with the substrate increased, and the starch was converted into small molecules of glucose to a greater extent, and the DE value increased [12]. As can be seen from Fig. 5, the total flavonoid content decreased with the increase of liquefaction time and saccharification time, because the degree of destruction of flavonoids by α-amylase and saccharification enzymes increased with the increase of enzymatic digestion time, and thus the total flavonoid content continued to decrease. The total flavonoid content firstly increased and then decreased with the enzyme digestion time, which is because the enzyme digestion time affects the amount of active ingredients dissolved, and the shorter enzyme digestion time does not allow the active ingredients to be fully dissolved [13]. Therefore, the liquefaction time of 30 min, saccharification time of 50 min, and cellulose enzymatic digestion time of 40 min were selected in this experiment.

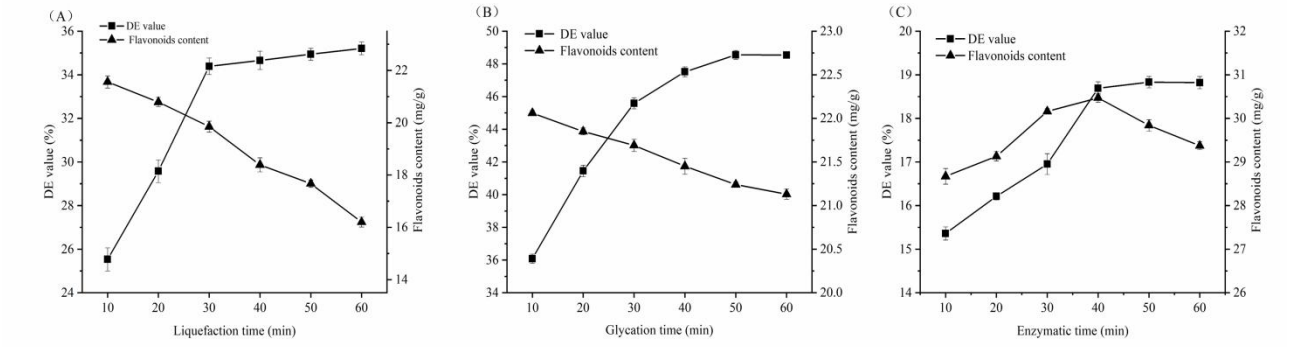

Fig.5 Effect of enzymatic digestion time on DE values and total flavonoids
(A): Effect of liquefaction time on DE value and total flavonoids; (B): Effect of saccharification time on DE value and total flavonoids; (C): Effect of digestion time on DE value and total flavonoids.

3.1.6 Effect of enzymatic hydrolysis time on instant solubility

From Table 3, the quick solubility of the meal replacement porridge was elevated with the increase of the enzymatic digestion time of the three enzymes. From Fig. 6, the pore space was irregular in the short time of enzyme digestion, and with the increase of time to the optimal enzyme digestion time, the spatial structure of the meal replacement porridge gradually became regular and loose and porous, which improved the instant solubility of the product when it was brewed.

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Table 3 Effect of enzymatic digestion time on instant solubility

Time（min）	α-amylase		saccharifying enzyme		cellulase	
	Dispersion（s）	Wettability（s）	Dispersion（s）	Wettability（s）	Dispersion（s）	Wettability（s）
10	43.95±0.50^{a}	184.61±1.14^{a}	45.23±0.87^{a}	202.14±1.72^{a}	50.87±0.51^{a}	223.06±1.87^{a}
20	31.91±0.68^{b}	137.70±0.79^{b}	34.64±0.47^{b}	149.63±0.49^{b}	43.16±0.75^{b}	160.34±0.83^{b}
30	19.68±0.43^{c}	81.74±0.56^{c}	22.85±0.44^{c}	83.63±0.47^{c}	32.76±0.48^{c}	102.02±0.34^{c}
40	17.16±0.67^{d}	62.59±0.31^{d}	18.55±0.35^{d}	60.92±0.54^{d}	18.26±0.49^{d}	64.55±0.84^{d}
50	16.44±0.17^{d}	60.75±0.61^{e}	14.56±0.14^{e}	50.62±0.61^{e}	18.26±0.60^{d}	65.52±0.34^{d}
60	16.19±0.18^{d}	59.58±0.22^{e}	14.13±0.17^{e}	51.23±0.34^{e}	18.01±0.72^{d}	64.37±0.14^{d}

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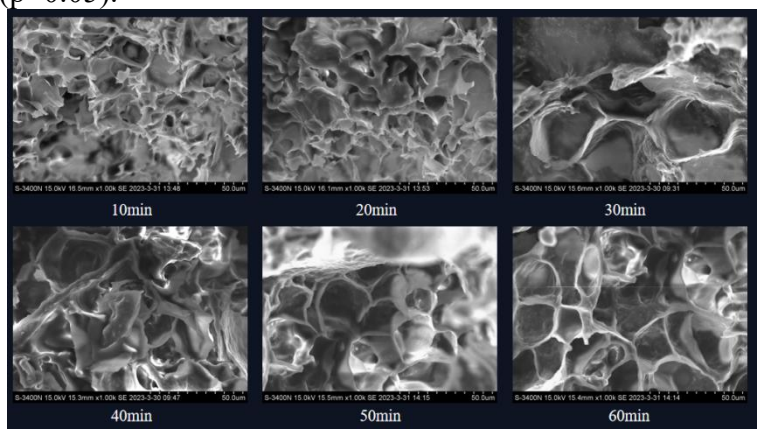

Fig.6 SEM map of meal replacement porridge sections at different enzymatic digestion times

4. Conclusion

After enzymatic hydrolysis, the instant solubility of product had been largely improved, and the content of total flavonoids also had enhanced. The Design-Expert 13 Software analysis was used to attain the optimal parameter of complex enzymatic hydrolysis process: the enzymatic hydrolysis temperature was 59℃, the addition amount of α-amylase was 2000 U/g, the addition amount of saccharase was 4200 U/g, the addition amount of cellulase was 3800 U/g, and the enzymatic time was 39 min. The instant solubility and nutrient content of meal replacement porridge were improved.

Acknowledgments

This research was financially supported by Key R&D Program of Shandong Province, China (2024TZXD004, 2023TZXD030)

References

[1] Hwang H. J., Hwang G. H., Ahn S. M., Kim Y. Y., Shin H. S. Risk assessment and determination of heavy metals in home meal replacement products by using inductively coupled plasma mass spectrometry and direct mercury analyzer[J]. Foods, 2022, 11(4): 504

ISSN:3007-9640 DOI: https://doi.org/10.70114/acmsr.2025.3.1.P83
[2] Kempf K., Röhling M., Niedermeier K., Gärtner B., Martin S.. Individualized meal replacement therapy improves clinically relevant long-term glycemic control in poorly controlled type 2 diabetes patients[J]. Nutrients, 2018, 10(8): 1022

[3] Yang Biying, Zhou Qiong. Research and development of selenium-rich black rice meal replacement powder [J]. Preservation and Processing, 21, 21(06): 66-71

[4] Chen Yue. Study on Effects of enzymatic hydrolysis and fermentation treatment on Quality characteristics and microstructure of multigrain meal replacement powder [D]. Shenyang Normal University, 2022

[5] Ge Jian. Study on high efficiency saccharification of corn starch milk by double enzymatic method [D]. Nanchang University, 2020

[6] Chen Qing，Jiang Biyin,，Mao yue，Wang Jun，Wang Wei，Bai Weidong. Study on preparation of butter milk flavor base material by complex enzymatic hydrolysis [J]. Chinese Journal of Food Additives, 2002, 33(07): 117-125

[7] Chen Wen, Wang Xiangjun, Chen Wenjing, Chen Yan, Sun Hongyuan, He Hongyuan. Optimization of the extraction process of red flavone from cellulase by Design-Expert [J]. Food Industry, 2002, 43(09): 1-8

[8] Setchell K. D., Brown N. M., Zimmer-Nechemias L., Brashear W. T., Wolfe B. E., Kirschner A. S., Heubi J. E. Evidence for lack of absorption of soy isoflavone glycosides in humans, supporting the crucial role of intestinal metabolism for bioavailability[J]. The American journal of clinical nutrition, 2002, 76(2): 447-453

[9] Braune A., Gütschow M., Engst W., Blaut M. Degradation of quercetin and luteolin by Eubacterium ramulus. [J]. Applied and environmental microbiology, 2001, 67(12): 5558-5567

[10] Schneider H., Blaut M. Anaerobic degradation of flavonoids by Eubacterium ramulus[J]. Archives of microbiology, 2000, 173: 71-75

[11] Zhang Tianshuang, Zhao Hua. Study on Saccharification technology of Chinese yam [J]. Shanxi Chemical Industry, 201, 41(02): 16-18+20

[12] Chen Yizen, Li Ying, Zhao Xu, Yang Ning, Wei Zhongping, Feng Liangshan. Research on the optimization of parameters of enzymatic digestion process of oil saxifrage tuber-almond instant powder[J]. Liaoning Forestry Science and Technology, 2022, (05):20-22+26

[13] Li Mengmeng, Lyu Changxin, Lu Yu, Jiao Tianhui, Zhao Lihong, Zhang Xuefei, Kang Yuanxie, Li Jianrong. Cellulase assisted extraction of flavonoids from red raspberry seeds and its inhibitory effect on α-glucosidase and α-amylase [J]. Chinese Journal of Food Science, 2017,17 (11): 99-107