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Development and Application of the New Integrated Equipment and Process of the Nine-Steam-Nine-Bask Method in the Processing of *Polygonatum cyrtonema*

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Abstract: As a traditional processing method, the Nine-Steam-Nine-Bask method has been widely used in the special processing of Chinese medicinal materials. With the highly integrated design and innovation of infiltrating equipment, steaming equipment, drying equipment, and other equipment, a new type of integrated equipment for the Nine-Steam-Nine-Bask method was finally developed and successfully applied in *Polygonatum cyrtonema* processing. Moreover, seven new processes were explored. The longer the steaming time was, the more steaming and drying cycles, the lower the product recovery rate and the higher the energy consumption. The higher the steaming pressure was, the lower the product recovery rate, the higher the energy consumption and the shorter the drying time. The longer the drying time was, the lower the product recovery rate and polysaccharide content, and the higher the energy consumption. The best new process was XGY1, which had the highest overall score. The steaming process was the most time-consuming and energy-intensive production process, followed by the drying process. The obtained results can provide knowledgeable guidance for the further optimization of the integrated equipment of the Nine-Steam-Nine-Bask method and the development and application of technology for processing characteristic Chinese medicinal materials.

Keywords: Nine-Steam-Nine-Bask; integrated equipment; *Polygonatum cyrtonema*; polysaccharide; processing

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1. Introduction

As a traditional method for processing Chinese medicinal materials, the Nine-Steam-Nine-Bask method is mainly used for repeated steaming and drying processes [1–3]. In fact, "nine" does not mean 9 times, but "multiple times". The specific processing details vary depending on the variety of medicinal materials, and the main purpose of this method is to manipulate the medicinal properties of medicinal materials or increase the effective components and reduce the toxic components [3]. The Nine-Steam-Nine-Bask method is generally used to process more precious medicinal materials, mainly supplements. The most representative species are *Polygonatum cyrtonema*, *Rehmannia glutinosa*, *Fallopia*

multiflora (Thunb.) Harald, and *Sophora japonica* Linn. in the "Big Four Nine Steamed Goods" [4,5].

At present, the process of the Nine-Steam-Nine-Bask method for Chinese herbal medicines involves mostly manual operations or is inefficiently performed using ordinary single-steaming equipment and hot-air-drying equipment. Either way, there are many problems. For example, the traditional method of Nine-Steam-Nine-Bask is time-consuming and labor-intensive. It requires the long-term supervision of experienced pharmacists, which greatly increases the production cost. Due to the need to repeat the steaming and drying process many times, workers must carry out multiple material transfers between different equipment. The completeness of the traditional processing process is judged by pure experience, resulting in poor quality and a lack of stability of the final processed products. The pressure of the traditional braising process is too low to keep the braising pressure and temperature constant. The traditional drying process requires the generation of hot air by electric heating or gas heating, which have low energy utilization efficiencies and will result in the consumption of much energy. Traditional equipment controls parameters, such as temperature, humidity, and heating time, without precision or not at all. To date, there is no real processing equipment in the Nine-Steam-Nine-Bask method, let alone processing equipment with multiple functions. However, traditional Chinese medicine products, such as *Polygonatum cyrtonema*, are not suitable for the current stage of industrial production due to their cumbersome processing process, long production cycles, high fuel consumption, poor environmental sanitation, and ease of material loss during the steaming process [6]. With the recent continuous expansion of the planting scale of Chinese medicinal materials including *Polygonatum cyrtonema*, the output is increasing year by year [7,8]. However, relying on the existing solely manual production or semiautomatic equipment for small batch production, the current production is not able to meet the needs of consumers. Therefore, there is an urgent need to develop new large-scale industrialized new equipment and new processes suitable for the characteristic application of the Nine-Steam-Nine-Bask method.

Polygonatum cyrtonema is the dried rhizome of *Polygonatum kingianum* Coll. et Hemsl., *Polygonatum sibiricum* Red. or *Polygonatum cyrtonema* Hua, a Liliaceae plant, and is a traditional Chinese medicine and food homologous plant [9]. *Polygonatum cyrtonema* usually contains compounds such as polysaccharides [10,11], steroidal saponins [12], and alkaloids [13], but its main biologically active components are polysaccharides [14–16]. Modern pharmacological studies have shown that *Polygonatum cyrtonema* has antioxidant, anticancer, anti-inflammatory, and antibacterial effects [17–24]. Research on *Polygonatum cyrtonema* mainly focuses on processing, and its purpose is to eliminate the stimulation, toxicity, and side effects of *Polygonatum cyrtonema* and ultimately achieve its medicinal effect [25]. The methods for processing *Polygonatum cyrtonema* mainly include steaming and wine steaming. The color difference of the medicinal materials before and after processing is large. After processing, the surface of the medicinal materials is mostly brown to black, the texture is soft, and the smell is sweet [26]. At present, there are many reports on the chemical composition of the polysaccharides of *Polygonatum cyrtonema* [12,27–29], and the results of each study are different, but the overall trend of polysaccharide content after processing is a decreasing trend [30]. The polysaccharide content has been used as a control index to measure the quality of *Polygonatum cyrtonema* in the "Chinese pharmacopoeia" [9], and most of its pharmacological activities are related to its polysaccharides [20,21,23,31,32]. The processing of *Polygonatum cyrtonema* is mainly affected by factors such as processing time and processing temperature. The processing technology of each region is also quite different, and different processing methods have certain effects on the resulting polysaccharide content [33]. Compared with other traditional Chinese medicines and foods, there is a serious lack of innovative research on the processing technology and equipment related to *Polygonatum cyrtonema*. The present research will have important guiding significance for the standardization of processing in the *Polygonatum cyrtonema* industry and its sustainable future development.

2. Materials, Instruments and Methods

2.1. Materials and Instruments

Polygonatum cyrtonema was harvested from the authentic Chinese herbal medicine planting base of Jiangxi Yuxia Pharmaceutical Co., Ltd., in Xiajiang County, Jiangxi Province, China, and drying and preliminary processing was performed by Jiangxi Shunfutang Traditional Chinese Medicine Piece Co., Ltd., to obtain sliced *Polygonatum cyrtonema*. Special rice wine with an alcohol volume fraction of approximately 10–19% was obtained from Jiangxi Shunfutang Traditional Chinese Medicine Piece Co., Ltd. The main reagents used in the experiment were ethanol (mass fraction: ≥99.7%), petroleum ether (boiling range: is 30–60), hydrochloric acid (mass fraction: 36–38%), phenol (mass fraction: ≥99%), and concentrated sulfuric acid (mass fraction: approximately 95–98%), obtained from Xilong Scientific Co., Ltd., Shantou, China. Glucose was purchased from Shanghai Macklin Biochemical Co., Ltd., Shanghai, China (mass fraction: ≥99%). Sodium hydroxide was purchased from Shanghai Titan Scientific Co., Ltd., Shanghai, China (mass fraction: ≥96%).

The instruments used in the experiment mainly included a vacuum-drying oven (DZF-6090, Shanghai Sheyan Instrument Co., Ltd., Shanghai, China), electronic halogen moisture analyzer (DHS20-A, Shanghai Sheyan Instrument Co., Ltd.), electric centrifuge (80-2, Changzhou Yitong Analytical Instrument Manufacturing Co., Ltd., Changzhou, China), collector-type constant temperature heating magnetic stirrer (DF-101S, Gongyi Yuhua Instrument Co., Ltd., Zhengzhou, China), rotary evaporator (RE-52AA, Shanghai Yarong Biochemical Instrument Factory, Shanghai, China), UV–Vis Spectrophotometer (TU-1810DASPC, Beijing Purkinje General Instrument Co., Ltd., Beijing, China), etc. The old processing equipment described in this article mainly included the combined use of infiltrating equipment, steaming equipment, and drying equipment. In the old process 1 (JGY1), manual infiltrating was used instead of the infiltrating equipment. Both steaming and braising were performed using steaming equipment (model SZZ-1000), and drying equipment (model HX-4) was used for drying. The equipment was manufactured by Hangzhou Fuyang Kanghua Pharmaceutical Machinery Co., Ltd., Hangzhou, China.

2.2. Methods

2.2.1. Extraction of Polysaccharides

The extraction rate of polysaccharides from *Polygonatum cyrtonema* was mainly affected by the ratio of solid-to-liquid, extraction times, extraction temperature, extraction time, pH, and other factors. On the basis of analyzing and summarizing the related studies of predecessors [22,34–38], the polysaccharides of *Polygonatum cyrtonema* were extracted by the method of graded extraction. An electronic halogen moisture analyzer was used to directly measure the moisture content of *Polygonatum cyrtonema* samples. That is, 5 g of the sample was taken out and evenly spread in the stainless-steel tray, and heated at 105 °C, and the corresponding moisture content value was read after the automatic end. First, the processed wine-made *Polygonatum cyrtonema* was pulverized and passed through a 60-mesh sieve, and then 20 g of the sample powder was taken, and degreased with petroleum ether at 65 °C for 24 h. The petroleum ether was recovered, and the sample powder was evaporated to dryness. Second, 10 g of the defatted *Polygonatum cyrtonema* powder was taken and 200 mL of distilled water was added to it, extraction was carried out at 80 °C for 2 h (solid-to-liquid ratio 1:20, g: mL), centrifugation was carried out at 4000 rpm for 10 min to obtain a filtrate, which was then concentrated to 1/5 of its original volume. Then, alcohol precipitation was carried out with 4 times the volume of ethanol, and the precipitate was obtained by centrifugation after standing for 24 h. After vacuum drying at 60 °C for 12 h, water-extracted samples of *Polygonatum cyrtonema* polysaccharides were obtained. Finally, the filter residue after the water extraction in the previous step was taken, 2% of sodium hydroxide solution was added to it, extraction was carried out at 80 °C for 2 h (solid-to-liquid ratio 1:20, g: mL), and the centrifuged filtrate was adjusted to neutrality with 2 moles per litre of hydrochloric acid. After concentration, alcohol precipitation, centrifugation, and drying, alkali extraction samples of *Polygonatum*

cyrtonema polysaccharides were obtained. All samples were concentrated in vacuo on a rotary evaporator with a water-bath heating temperature of 80 °C.

2.2.2. Determination of Polysaccharide Contents

Using anhydrous glucose as the standard reference substance, absorbance values were measured at the larger stable absorption wavelength by a UV–visible spectrophotometer. In this paper, the phenol–sulfuric acid method was used for the determination. Ten milligrams of anhydrous glucose were accurately weighed, dissolved in distilled water, and increased to volume in a 100-mL volumetric flask to prepare a 0.1-mg/mL glucose standard solution. Then, 0, 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 mL of glucose standard solution were accurately pipetted into 10-mL test tubes. Each test tube was diluted to 2 mL with distilled water, and then 1 mL of 5% phenol solution (the phenol needs to be prepared and used immediately) and 5 mL of concentrated sulfuric acid were added in sequence, and then each test tube was agitated and placed at room temperature for 30 min. The test tube without glucose standard solution was used as a blank control, and its absorbance value was measured at 486 nm. Similarly, the water-extracted and alkaline-extracted samples of *Polygonatum cyrtonema* polysaccharides were crushed and passed through a 100-mesh sieve to prepare a 0.1 mg/mL solution. A total of 1.0 mL of the solution to be tested was accurately pipetted and placed in a 10-mL test tube, and configured according to the same method as above. The absorbances of the water-extracted sample and the alkaline-extracted sample were measured at 486 nm and 482 nm, respectively. According to the standard curve of glucose, the content of polysaccharides in *Polygonatum cyrtonema* was determined.

3. Results and Discussion

3.1. Development of the Integrated Equipment and Process of Nine-Steam-Nine-Bask

3.1.1. Development of the Integrated Equipment

Taking the Nine-Steam-Nine-Bask method as the ideal method to meet the actual needs of users, equipment such as infiltrating equipment, steaming equipment, and drying equipment has been optimized with a highly integrated design on the basis of the existing Nine-Steam-Nine-Bask processing technology [1,39,40]. Technologies such as infiltration enhancement, heat-transfer enhancement, heat-pump energy savings, and individual control have been integrated to develop a new type of integrated Nine-Steam-Nine-Bask equipment (model KMDJJ3-300). Its working principle and basic composition, which mainly comprises raw material → infiltrating medicine → steaming → braising → drying → multiple cycles → product, are shown in Figure 1. The equipment has fully realized the inheritance and innovation of the traditional Nine-Steam-Nine-Bask equipment and process. The equipment uses infiltration strengthening technology, which upgrades the original infiltrating method under normal temperature and pressure to spray infiltration in a vacuum state and simultaneously braises and infiltrates in a low-temperature state to shorten the time required for the infiltrating process. The equipment uses heat transfer enhancement technology to upgrade the original stacking form to a layered tiering form, which greatly enhances the heat absorption of the medicinal materials during the steaming process and the rapid water loss of the medicinal materials during the drying process to improve steaming and drying processing efficiency. The equipment uses the most advanced heat pump energy-saving technology, upgrading the original open hot-air drying form to an air-source heat-pump drying form, and has the function of electric heating to supplement heat to reduce the processing energy consumption in the drying process of Chinese herbal medicines.

The basic composition of the equipment mainly includes the air inlet KJ, the fresh air valve V01, the condenser L01, the fan F01, the air inlet valve V02, the steaming–drying integrated box M01, the dehumidification valve V03, the air outlet KC, the return air valve V04, the throttling valve J01, the evaporator Z01, the compressor C01, the fan F02, the drain valve V05, the filter G01, the circulation pump P01, the circulation valve V06, the evacuation valve V07, the check valve DV01, the steam generator Q01, the steam inlet ZJ,

the vacuum pump ZP01, etc. The working process of the equipment includes the infiltrating medicine unit, the braising unit, the steaming unit, the drying unit, the juice-collecting unit, and the cleaning unit. The infiltrating medicine unit mainly circulates through the vacuum pump ZP01, the steaming–drying integrated box M01, the drain valve V05, the filter G01, the circulation pump P01, the circulation valve V07, the check valve DV01, and the steaming–drying integrated box M01 to realize vacuum spraying. The steam generator Q01, the steam inlet ZJ, and the steaming–drying integrated box M01 are used to braise and infiltrate at a low temperature. The braising unit and the steaming unit are mainly cycled through the steam generator Q01, the steam inlet ZJ, and the steaming–drying integrated box M01. The drying unit mainly uses the air inlet KJ, the fresh air valve V01, the fan F01, the condenser L01, the air inlet valve V02, the steaming–drying integrated box M01, the dehumidification valve V03, the air outlet KC, and the return air valve V04 to dry the product in a cycle. The heating cycle work required for drying is performed through the condenser L01, the throttling valve J01, the evaporator Z01, the compressor C01, and the fan F02. The juice-collecting unit first completes part of the drying function, and then performs the circulating work from the steaming–drying integrated box M01, the drain valve V05, the filter G01, the circulation pump P01, the circulation valve V07, the check valve DV01, and the steaming–drying integrated box M01, and performs the remaining part of the drying function again, thereby completing the process of collecting juice. The cleaning unit mainly performs circulating work through the steaming–drying integrated box M01, the drain valve V05, the filter G01, the circulation pump P01, the circulation valve V07, the check valve DV01, and the steaming–drying integrated box M01.

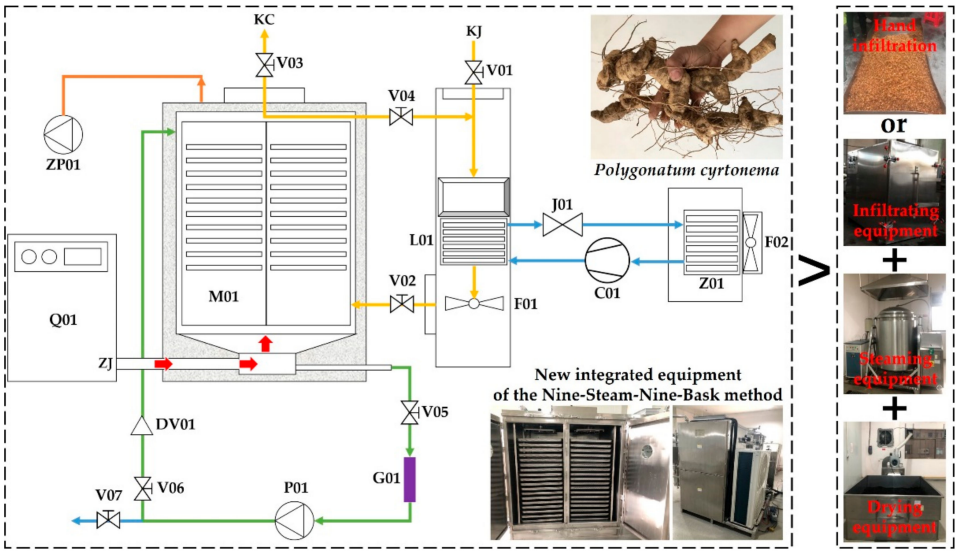

Figure 1. Working principle and basic composition of the new integrated equipment of the Nine-Steam-Nine-Bask method.

3.1.2. Development of the Integrated Process

The processing flow of process 1 of the old equipment (Old Process 1, JGY1) is shown in Figure 2, which mainly includes six steps: loading, infiltrating, steaming, braising, drying, and unloading. Loading, infiltrating, and unloading were all carried out manually. One hundred kilograms of sliced *Polygonatum cyrtonema* was removed for loading, and the medicine was manually infiltrated at room temperature for 24 h. A total of 5 alternating cycles of steaming and braising were carried out. Each steaming cycle was carried out at around 104–105 °C for 8 h, and each braising cycle involved natural cooling and lasted for 16 h. Finally, after drying at 80 °C for 8 h, the moisture content of *Polygonatum cyrtonema* reached 12%, and then unloading was carried out.

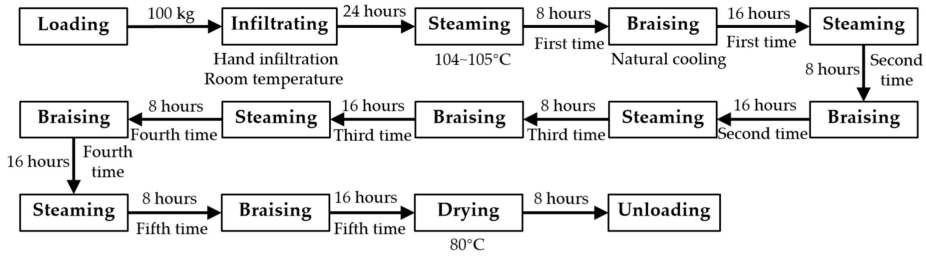

Figure 2. Processing flow of process 1 of the old equipment (Old Process 1, JGY1).

The processing flow of process 1 of the new equipment (New Process 1, XGY1) is shown in Figure 3, which mainly includes five steps: loading, infiltrating, steaming, drying, and unloading. Similarly, 100 kg of the sliced *Polygonatum cyrtonema* was removed for loading, and the vacuum spraying infiltration at room temperature was carried out and maintained for 4 h. It was then braised and infiltrated for 8 h at around 40–60 °C, followed by five consecutive steaming cycles. Each steaming cycle was carried out at around 95–100 °C for 8 h. Finally, after drying at 60 °C for 29 h, the moisture content of *Polygonatum cyrtonema* reached 12%, and then unloading was carried out.

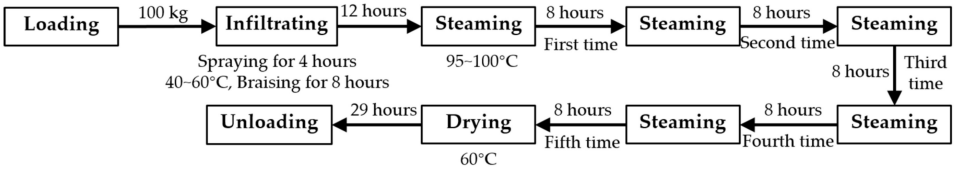

Figure 3. Processing flow of process 1 of the new equipment (New Process 1, XGY1).

The processing flow of process 2 of the new equipment (New Process 2, XGY2) is shown in Figure 4, which mainly includes five steps: loading, infiltrating, steaming, drying, and unloading. The raw material and infiltrating and unloading conditions were exactly the same as those of XGY1, followed by a total of five alternating cycles of steaming and drying. Each steaming cycle was carried out at around 95–100 °C for 8 h. Each drying cycle was performed at 60 °C for 8 h, while the drying time of the fifth cycle was 27 h.

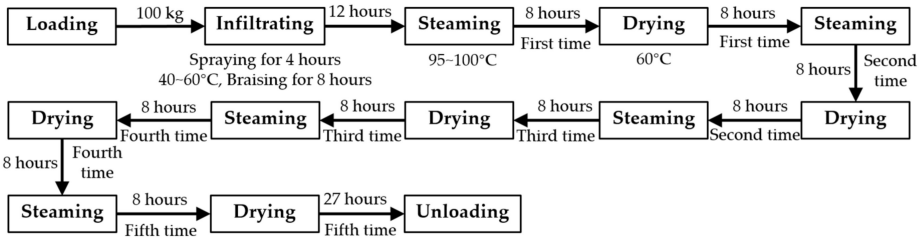

Figure 4. Processing flow of process 2 of the new equipment (New Process 2, XGY2).

The processing flow of process 3 of the new equipment (New Process 3, XGY3) is shown in Figure 5, which mainly includes five steps: loading, infiltrating, steaming, drying, and unloading. The raw material and infiltrating and unloading conditions were exactly the same as those of XGY1, followed by five consecutive steaming cycles. Each steaming cycle was carried out at around 120–125 kPa for 8 h. Finally, drying was carried out at 60 °C for 24 h.

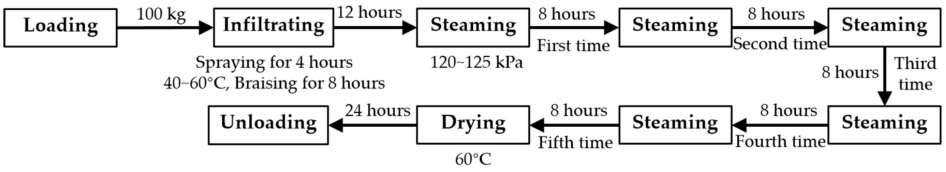

Figure 5. Processing flow of process 3 of the new equipment (New Process 3, XGY3).

The processing flow of process 4 of the new equipment (New Process 4, XGY4) is shown in Figure 6, which mainly includes six steps: loading, infiltrating, steaming, braising, drying, and unloading. The raw material and infiltrating and unloading conditions were exactly the same as those of XGY1, followed by a total of three alternating cycles of steaming and braising. Each steaming cycle was carried out at around 120–125 kPa for 10 h. Each braising cycle involved natural cooling and lasted for 14 h. Finally, drying was carried out at 60 °C for 25 h.

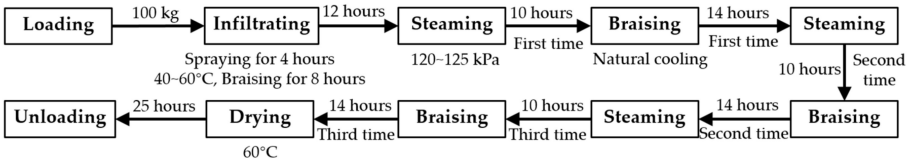

Figure 6. Processing flow of process 4 of the new equipment (New Process 4, XGY4).

The processing flow of process 5 of the new equipment (New Process 5, XGY5) is shown in Figure 7, which mainly includes six steps: loading, infiltrating, steaming, braising, drying, and unloading. The raw material and infiltrating and unloading conditions were exactly the same as those of XGY1, followed by a total of 3 alternating cycles of steaming and braising. Each steaming cycle was carried out at around 120–125 kPa for 16 h. Each braising cycle involved natural cooling and lasted for 8 h. Finally, drying was carried out at 60 °C for 26 h.

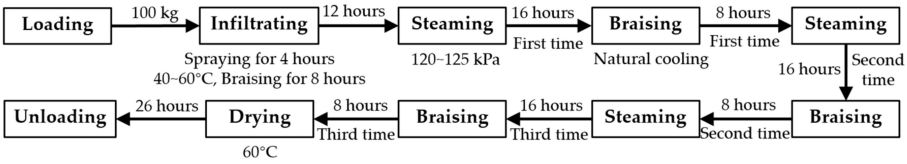

Figure 7. Processing flow of process 5 of the new equipment (New Process 5, XGY5).

The processing flow of process 6 of the new equipment (New Process 6, XGY6) is shown in Figure 8, which mainly includes five steps: loading, infiltrating, steaming, drying, and unloading. The raw material and infiltrating and unloading conditions were exactly the same as those of XGY1, followed by five consecutive steaming cycles. Each steaming cycle was carried out at around 80–85 °C for 12 h. Finally, drying was carried out at 60 °C for 34 h.

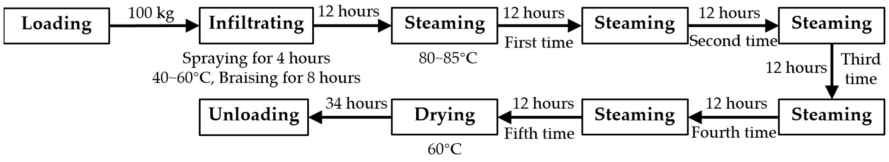

Figure 8. Processing flow of process 6 of the new equipment (New Process 6, XGY6).

The processing flow of process 7 of the new equipment (New Process 7, XGY7) is shown in Figure 9, which mainly includes five steps: loading, infiltrating, steaming, drying, and unloading. The raw material and infiltrating and unloading conditions were exactly the same as those of XGY1, followed by five consecutive steaming cycles. Each steaming cycle was carried out at around 80–85 °C for 12 h. Finally, drying was carried out at 50 °C for 44 h.

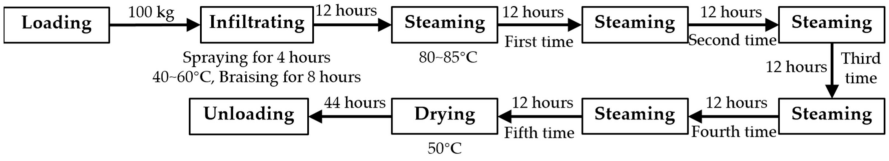

Figure 9. Processing flow of process 7 of the new equipment (New Process 7, XGY7).

It should be noted here that the steaming process of JGY1 of the old equipment was high-pressure steaming. The steaming processes of XGY1 and XGY2 were micro-positive pressure steaming. The steaming processes of XGY3, XGY4 and XGY5 were high-pressure steaming. The steaming processes of XGY6 and XGY7 were atmospheric steaming. The order of high to low steaming pressure is high-pressure steaming > micro-positive pressure steaming > atmospheric steaming.

3.2. Application, Evaluation and Analysis of the Integrated Equipment in the Processing of Polygonatum cyrtonema

As a typical representation of the traditional products of the Nine-Steam-Nine-Bask method, *Polygonatum cyrtonema* can be used in the application research of the corresponding integrated equipment. The evaluation and analysis of the processing performance of the integrated equipment and the quality of the processed products will have important guiding significance for the further optimization of the integrated equipment and the development and application of the processing technology of characteristic Chinese medicinal materials. The comprehensive evaluation indicators of products processed by the integrated equipment mainly include color, odor, taste, recovery rate, polysaccharide content, processing time, processing energy consumption, etc., of which color, odor and taste are sensory qualities. The recovery rate, polysaccharide content, processing time, and processing energy consumption of the products processed by the integrated equipment are judged and scored through their experimental results. In the adopted scoring standard, the highest score is 95 points, the lowest score is 60 points, the scores are scored at a five-point interval, and the same score is scored in the same situation. Then, the average total score of each evaluation index is calculated and ranked accordingly, and finally, the best new process among all processes is determined.

3.2.1. Evaluation and Analysis of the Product Recovery Rate

In general, if the product grade of *Polygonatum cyrtonema* does not change, the higher the product recovery rate of *Polygonatum cyrtonema*, the higher the economic value it produces, and the process by which it was produced should be optimal. If the product grade of *Polygonatum cyrtonema* is changed, then the economic value cannot be determined solely by the product recovery rate of *Polygonatum cyrtonema*, but should be determined by the comprehensive evaluation index of *Polygonatum cyrtonema*. The product recovery rate of *Polygonatum cyrtonema* under different processing conditions can be calculated using the following formula:

$$RT_{HS} = (M_{HS}/M_{YL}) \times 100\% \quad (1)$$

In the above formula, RT_{HS} is the product recovery rate of *Polygonatum cyrtonema* in %. M_{YL} is the raw material quality of *Polygonatum cyrtonema* before each batch of processing in kg. M_{HS} is the final mass of *Polygonatum cyrtonema* recovered after each batch of processing in kg.

The product recovery rates of *Polygonatum cyrtonema* under different processing conditions are shown in Figure 10, and the order of size was XGY6 > XGY7 > XGY1 > XGY4 > JGY1 > XGY2 > XGY3 > XGY5. The results show that the different processing conditions have a great influence on the product recovery rate. If you only look at the product recovery rate, the products processed by XGY6 are the most economical, and XGY5 is the worst. Compared with XGY1, the product recovery rate of XGY2 is lower, mainly due to the greater loss of *Polygonatum cyrtonema* caused by multiple steaming and drying cycles and longer drying conditions. This also shows that after many cycles of steaming and drying, the product recovery rate of *Polygonatum cyrtonema* will not be very high, and the loss will be relatively large. The infiltrating and drying conditions of XGY1, XGY3, and XGY6 were exactly the same, but the steaming temperature and time were different. Among them, the steaming pressure or temperature of XGY1 and XGY3 were different. The reason why the product recovery rate of XGY1 was higher than that of XGY3 is that XGY3 caused a greater loss of *Polygonatum cyrtonema* under a higher steaming pressure. The product recovery

rate of XGY6 was higher than that of XGY1 for similar reasons. In the three kinds of the high-pressure steaming, the product recovery rate of XGY4 was greater than that of XGY3 and XGY5, which may be related to the length of steaming time. The steaming time of XGY5 was the longest, and the steaming time of XGY4 was the shortest. The steaming and braising times of XGY4 and XGY5 were different. The reason why the product recovery rate of XGY4 was higher than that of XGY5 was that XGY5 caused a greater loss of *Polygonatum cyrtonema* at longer steaming time. The drying temperatures of XGY6 and XGY7 were different. The reason why the product recovery rate of XGY6 is higher than that of XGY7 is that XGY7 leads to greater loss of *Polygonatum cyrtonema* at a longer drying time. Among all the new processes, XGY6 and XGY7 had the lowest steaming pressure, which was implemented during atmospheric steaming. However, the product recovery rates of XGY6 and XGY7 were higher than those of micro-positive pressure steaming and high-pressure steaming, and most of the product recovery rates of micro-positive pressure steaming are also higher than those of high-pressure steaming. Indirectly, the level of steaming pressure has a serious impact on the product recovery rate of *Polygonatum cyrtonema*, which should be steamed at as low a pressure as possible to obtain a higher product recovery rate. This result also suggests the unique advantages of upgrading the original stacking form to the layered tiering form, which reduces the steaming pressure and also improves the product recovery rate of *Polygonatum cyrtonema*.

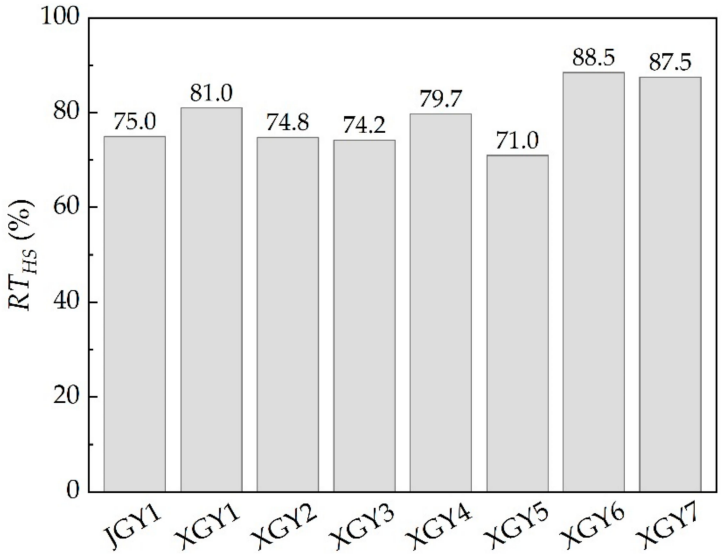

Figure 10. Product recovery rate of *Polygonatum cyrtonema* under different processing conditions.

In summary, the higher the steaming pressure is, the longer the steaming time, and the longer the drying time, and the more steaming and drying cycles there are, the lower the product recovery rate of *Polygonatum cyrtonema*. These conclusions provide guidance for the future development and further optimization of the integrated equipment and process of the Nine-Steam-Nine-Bask method.

3.2.2. Evaluation and Analysis of Polysaccharide Contents

Polysaccharides are the most abundant component and an important active ingredient in *Polygonatum cyrtonema*. It is the most intact among the various chemical components of *Polygonatum cyrtonema*. Because of its importance, it is often listed as one of the measures of the quality of *Polygonatum cyrtonema* [9,30,34,37]. The extraction rate of polysaccharides extracted by water or alkali can be calculated by the following formula:

$$PT_{WE/AE} = (m_{WE/AE}/m_t) \times 100\% \quad (2)$$

In the above formula, PT_{WE} and PT_{AE} are the polysaccharide extraction rates of the water-extracted and alkaline-extracted samples of *Polygonatum cyrtonema*, respectively, in %. M_{WE} and m_{AE} are the masses of the final obtained water-extracted sample and alkali-extracted sample, respectively, in g. m_t is the mass of raw materials used for the extraction of *Polygonatum cyrtonema* in g.

By using a spectrophotometer to measure the absorbance of glucose at different wavelengths, the results show that the maximum absorption peak position of glucose is located at 486 nm. Therefore, the absorbance value (OD value) was measured at a wavelength of 486 nm using a spectrophotometer, the absorbance value was plotted against the concentration of the standard solution of glucose (mg/mL), and the standard curve of glucose was constructed. The standard curve of glucose is shown in Figure S1 in the Supplementary Material. The linear regression equation is $y = 0.07805 + 53.7206x$, the maximum linear correlation coefficient (R^2) reaches 0.9999, and the linear range is around 0.00125–0.0125 mg/mL, which indicates good linearity. According to the final obtained glucose standard curve and by measuring the absorbance values of the samples, the mass fraction of polysaccharides in the water-extracted or alkaline-extracted samples of *Polygonatum cyrtonema* can be calculated:

$$M_{WE/AE} = \left(C_D V_D / C_Q V_Q\right) \times 100\% \quad (3)$$

$$M_t = \left(m_{WE} M_{WE} + m_{AE} M_{AE}\right) \times 100\% / m_t \quad (4)$$

In the above formula, M_{WE} and M_{AE} are the mass fractions of polysaccharides in the water-extracted and alkaline-extracted samples of *Polygonatum cyrtonema* in %. C_D is the polysaccharide solution concentration of the test sample determined by the phenol-sulfuric acid method in mg/mL. V_D is the final constant volume of the test sample in mL. C_Q is the sampling concentration of the test sample in mg/mL. V_Q is the sampling volume of the test sample in mL. M_t is the total mass fraction of polysaccharides in the water-extracted and alkaline-extracted samples of *Polygonatum cyrtonema* in %.

The extraction rates and polysaccharide mass fractions of JGY1 at different processing stages are shown in Figure 11a. PT-WE, PT-AE, PT-TE, PT-WE-PM, PT-AE-PM, and PT-TPM represent the extraction rate of the water-extracted polysaccharide, the extraction rate of the alkali-extracted polysaccharide, the extraction rate of the total polysaccharide, the mass fraction of the water-extracted polysaccharides, the mass fraction of the alkaline-extracted polysaccharides, and the mass fraction of the total polysaccharides, respectively. PT represents percentage. YL, RY, and HG represent raw materials, infiltrating and drying, respectively. ZM1–ZM5 represent the first to fifth steaming and braising cycles. ZZ1–ZZ5 represent the first to fifth steaming cycles. ZH1–ZH5 represent the first to fifth steaming and drying cycles. With the continuous progress of each processing stage of *Polygonatum cyrtonema*, PT-WE gradually decreased, from 33.04% of raw materials to 10.81% of dried. Compared with the raw materials of *Polygonatum cyrtonema*, in the process of medicine infiltration, the decrease in PT-WE was smaller. After the first steaming and braising cycle, the decrease in PT-WE was the largest. The decreases for the subsequent processing stages are all small, and the overall trend tends to be balanced. PT-AE has a completely similar trend to PT-WE in each processing stage, from 35.88% of raw materials to 14.80% of dried, and each processing stage was higher than that of PT-WE, mainly because the dilution lye can dissolve more acidic polysaccharides and macromolecular neutral polysaccharides, while the water extract can only dissolve small molecular neutral polysaccharides. PT-TE is the sum of PT-WE and PT-AE, so it also had a similar change trend, from 68.93% of raw materials to 25.61% of dried. Similar to PT-WE and PT-AE, PT-WE-PM finally decreased from 90.39% of raw material to 50.03% of dried, and PT-AE-PM finally decreased from 38.26% of raw material to 13.54% of dried. PT-TPM finally decreased from 43.60% of raw material to 7.72% of dried. This again proves that the polysaccharide content of *Polygonatum cyrtonema* after processing was generally decreasing. PT-WE-PM was much larger than PT-AE-PM, which indicates that there were more impurities in the alkaline-

extracted polysaccharides, while the availability of the water-extracted polysaccharides was higher. It is necessary to use the graded extraction of polysaccharides for *Polygonatum cyrtonema*, and related utilization research can be carried out in the future.

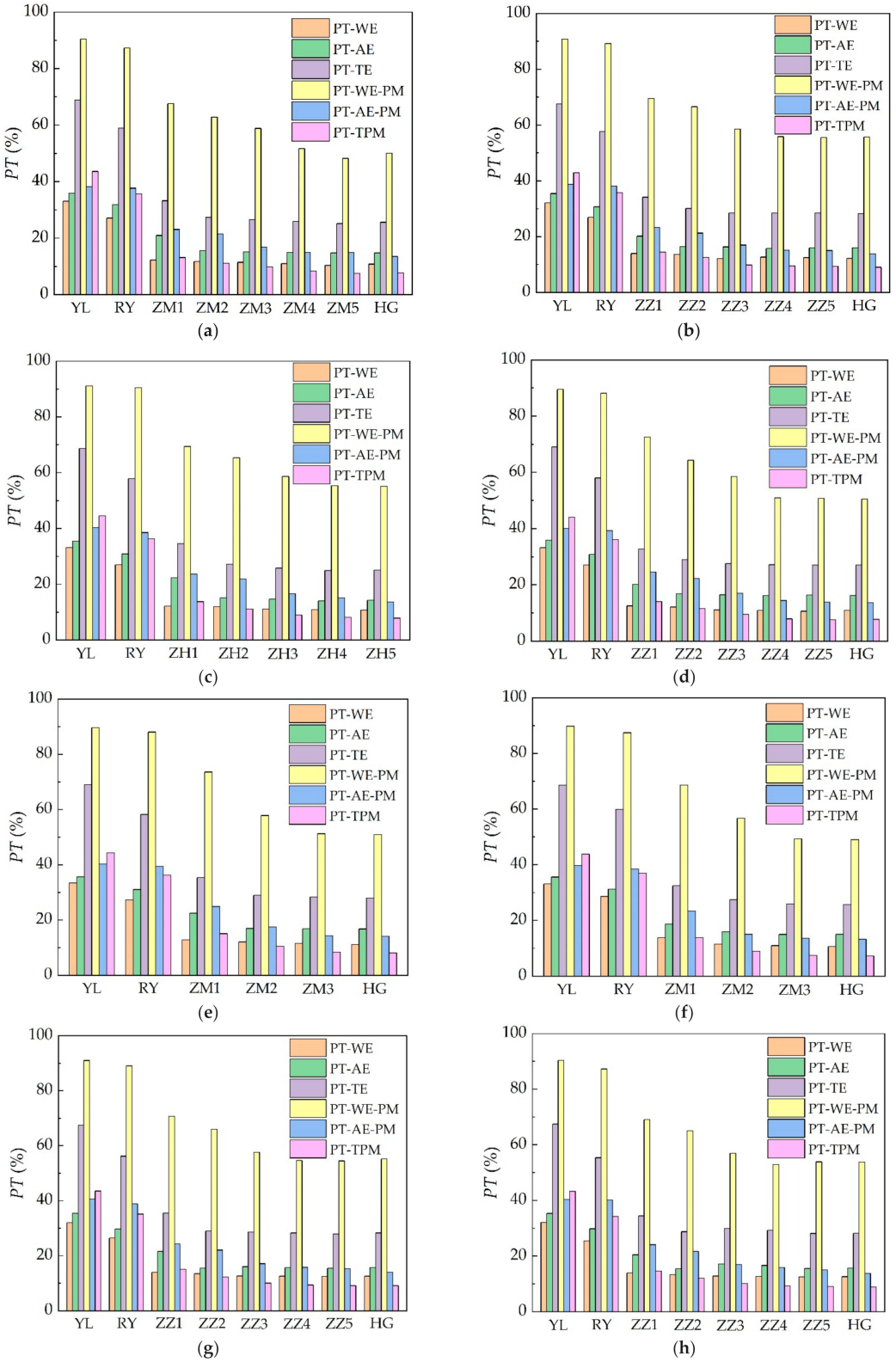

Figure 11. Extraction rate and polysaccharide mass fraction of JGY1 (**a**), XGY1 (**b**), XGY2 (**c**), XGY3 (**d**), XGY4 (**e**), XGY5 (**f**), XGY6 (**g**), and XGY7 (**h**) at different processing stages.

The extraction rates and polysaccharide mass fractions of XGY1 at different processing stages are shown in Figure 11b, which are completely similar to those of JGY1, showing a trend of decreasing at first and then tending to balance. PT-WE finally decreased from 32.14% of raw material to 12.24% of dried. PT-AE decreased from 35.48% of raw material to 16.07% of dried. PT-TE decreased from 67.62% of raw material to 28.32% of dried. PT-WE-PM decreased from 90.83% of raw material to 55.69% of dried. PT-AE-PM decreased from 38.71% of raw material to 13.84% of dried. PT-TPM finally decreased from 42.93% of raw material to 9.04% of dried. PT-WE-PM was also much larger than PT-AE-PM.

The extraction rates and polysaccharide mass fractions of XGY2 at different processing stages are shown in Figure 11c. PT-WE finally decreased from 33.19% of raw material to 10.77% of dried. PT-AE decreased from 35.50% of raw material to 14.31% of dried. PT-TE decreased from 68.69% of raw material to 25.08% of dried. PT-WE-PM decreased from 91.13% of raw material to 55.09% of dried. PT-AE-PM decreased from 40.35% of raw material to 13.69% of dried. PT-TPM finally decreased from 44.57% of raw material to 7.89% of dried. Similar to JGY1 and XGY1, XGY2 shows a trend of decreasing at first and then tending to balance, and PT-WE-PM is much larger than PT-AE-PM. The steaming processes of XGY1 and XGY2 were both micro-positive pressure steaming. The infiltrating and drying conditions of both raw materials are the same, but the additional multiple drying process of XGY2 do not bring any benefits but reduce PT-WE, PT-AE, PT-TE, PT-WE-PM, PT-AE-PM, and PT-TPM. This shows that the polysaccharide extraction rate and mass fraction of *Polygonatum cyrtonema* will be seriously decreased after the repeated steaming and drying cycles, which is the real reason why many processed products of *Polygonatum cyrtonema* on the market are unqualified.

The extraction rates and polysaccharide mass fractions of XGY3 at different processing stages are shown in Figure 11d. PT-WE finally decreased from 33.24% of raw materials to 10.89% of dried. PT-AE decreased from 35.85% of raw material to 16.24% of dried. PT-TE decreased from 69.09% of raw material to 27.14% of dried. PT-WE-PM decreased from 89.49% of raw material to 50.48% of dried. PT-AE-PM decreased from 40.05% of raw material to 13.69% of dried. PT-TPM finally decreased from 44.11% of raw material to 7.72% of dried. Compared with those of XGY1, the raw materials, infiltrating, and drying conditions of both are the same, except PT-AE, PT-WE, PT-TE, PT-WE-PM, PT-AE-PM, and PT-TPM are all lower for XGY1, which may be due to the high-pressure steaming of XGY3 resulting in more polysaccharides for conversion.

The extraction rates and polysaccharide mass fractions of XGY4 at different processing stages are shown in Figure 11e. PT-WE decreased from 33.39% of raw material to 11.14% of dried. PT-AE decreased from 35.64% of raw material to 16.75% of dried. PT-TE decreased from 69.03% of raw material to 27.89% of dried. PT-WE-PM decreased from 89.64% of raw material to 50.92% of dried. PT-AE-PM decreased from 40.20% of raw material to 14.14% of dried. PT-TPM finally decreased from 44.26% of raw material to 8.07% of dried. Compared with JGY1, both involve the processes of infiltrating, steaming, braising, and drying. The steaming process was high-pressure steaming, but the infiltrating and drying conditions and processing time were different. The PT-WE, PT-AE, PT-TE, PT-WE-PM, PT-AE-PM, and PT-TPM of XGY4 were higher than those of JGY1. Compared with XGY3, both the steaming processes were high-pressure steaming, but XGY4 had a braising process. The PT-WE, PT-AE, PT-TE, PT-WE-PM, PT-AE-PM, and PT-TPM of XGY4 were higher than those of XGY3.

The extraction rates and polysaccharide mass fractions of XGY5 at different processing stages are shown in Figure 11f. PT-WE decreased from 33.10% of raw material to 10.70% of dried. PT-AE decreased from 35.58% of raw material to 15.02% of dried. PT-TE decreased from 68.68% of raw material to 25.73% of dried. PT-WE-PM decreased from 89.79% of raw material to 48.99% of dried. PT-AE-PM decreased from 39.75% of raw material to 13.25% of dried. PT-TPM finally decreased from 43.86% of raw material to 7.23% of dried. The steaming processes of XGY3, XGY4 and XGY5 were high-pressure steaming. Compared with XGY3, XGY5 had a braising process. Compared with XGY4, the processing times

were different. The PT-WE, PT-AE, PT-TE, PT-WE-PM, PT-AE-PM, and PT-TPM of XGY5 were all lower than those of XGY3 and XGY4, while those of XGY4 were higher than those of XGY3. The results show that the reductions in the extraction rate and mass fraction of polysaccharides may be more related to the steaming process or steaming time, and less related to the braising process or braising time. In addition, in terms of the polysaccharide content of the product, that of XGY1 was better than that of XGY4; while XGY1 had no braising process, which also indicates that the reductions in the extraction rate and mass fraction of polysaccharides may be more related to the steaming process. This provides future optimization directions of reducing the braising process and increasing the steaming process.

The extraction rates and polysaccharide mass fractions of XGY6 at different processing stages are shown in Figure 11g. PT-WE decreased from 32.05% of raw material to 12.60% of dried. PT-AE decreased from 35.40% of raw material to 15.72% of dried. PT-TE decreased from 67.44% of raw material to 28.32% of dried. PT-WE-PM decreased from 90.98% of raw material to 55.24% of dried. PT-AE-PM decreased from 40.65% of raw material to 13.99% of dried. PT-TPM finally decreased from 43.54% of raw material to 9.16% of dried. Compared with XGY1 and XGY3, the steaming temperatures and times were different. The total polysaccharide mass fraction of XGY6 was greater than that of XGY1.

The extraction rates and polysaccharide mass fractions of XGY7 at different processing stages are shown in Figure 11h. PT-WE decreased from 32.13% of raw material to 12.62% of dried. PT-AE decreased from 35.35% of raw material to 15.66% of dried. PT-TE decreased from 67.47% of raw material to 28.27% of dried. PT-WE-PM decreased from 90.39% of raw material to 53.75% of dried. PT-AE-PM decreased from 40.35% of raw material to 13.84% of dried. PT-TPM finally decreased from 43.30% of raw material to 8.95% of dried. The drying temperatures of XGY6 and XGY7 are different, which indicates that reducing the drying temperature will lead to slight decreases in PT-WE-PM, PT-AE-PM, and PT-TPM, mainly due to the longer drying time leading to more polysaccharide loss, which is similar to the product recovery rate of *Polygonatum cyrtonema*. The longer the drying time was, the lower the polysaccharide content of *Polygonatum cyrtonema*. Compared with JGY1, the drying time is still relatively long, which provides a future optimization direction of shortening the drying time.

3.2.3. Evaluation and Analysis of Processing Time

The processing time of *Polygonatum cyrtonema* directly affects the production cost and efficiency of the product, mainly in the use of manual labor and the labor input for frequent operations. Therefore, under the premise of ensuring product quality, the shorter the processing time of the product is, the lower the production cost and the higher the production efficiency. The processing time of *Polygonatum cyrtonema* mainly includes the times of infiltrating, steaming, braising, drying, and other steps, as well as the total time of each link. The following formula can be used to calculate the total processing time percentage of the product for infiltrating, steaming, braising, and drying under different processing conditions and the percentage of time saved compared with JGY1:

$$\sum T = T_{RY} + T_{ZZ} + T_{MZ} + T_{HG} \tag{5}$$

$$PT_{RY/ZZ/MZ/HG} = \frac{T_{RY/ZZ/MZ/HG}}{\sum T} \times 100\% \tag{6}$$

$$PT_{JS} = \frac{\left|\sum T_{XGY} - \sum T_{JGY1}\right|}{\sum T_{JGY1}} \times 100\% \tag{7}$$

In the above formula, T_{RY}, T_{ZZ}, T_{MZ}, and T_{HG} represent the times of infiltration, steaming, braising, and drying, respectively, in hours. $\sum T$ is the total time of the product processing in hours. PT_{RY}, PT_{ZZ}, PT_{MZ}, and PT_{HG} represent the total processing time percentages of the product for infiltrating, steaming, braising, and drying under different processing conditions, respectively, in %. $\sum T_{XGY}$ is the total processing time of each new

process in hours. $\sum T_{JGY1}$ is the total processing time of JGY1 in hours. PT_{JS} is the percentage of time saved compared with JGY1 in %. RY, ZZ, MZ, HG, and JS represent infiltrating, steaming, braising, drying, and time saving, respectively.

The total processing time percentages of the product for infiltrating, steaming, braising, and drying under different processing conditions and the percentages of time saved compared with JGY1 are shown in Figure 12. In the process of medicine infiltration, the total processing time percentages of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 15.79%, 14.81%, 10.81%, 15.79%, 11.01%, 10.91%, 11.32%, and 10.34%, respectively. The total processing time percentage of XGY7 was the smallest, while the percentages of JGY1 and XGY3 were the largest. In general, the optimized processing time of infiltration was very reasonable. Compared with JGY1, all new processes do not require manual infiltration. By using the infiltration strengthening technology, the original infiltrating method under normal temperature and pressure was upgraded to spray infiltration in a vacuum state, and moreover, braising and infiltrating in a low-temperature state were carried out, which greatly shortens the time required for medicine infiltration. During the steaming process, the total processing time percentages of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 26.32%, 49.38%, 36.04%, 52.63%, 27.52%, 43.64%, 56.6%, and 51.72%, respectively. The total processing time percentage of JGY1 was the smallest, while that of XGY6 was the largest. During the braising process, the total processing time percentages of JGY1, XGY4, and XGY5 were 52.63%, 38.53%, and 21.82%, and the order of size was JGY1 > XGY4 > XGY5. The polysaccharide content of the product also indicated that the braising process could be reduced. This provides a future optimization direction for shortening the braising time. In the drying process, the total processing time percentages of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 5.26%, 35.8%, 53.15%, 31.58%, 22.94%, 23.64%, 32.08%, and 37.93%, respectively. The total processing time percentage of JGY1 was the smallest, while that of XGY2 was the largest.

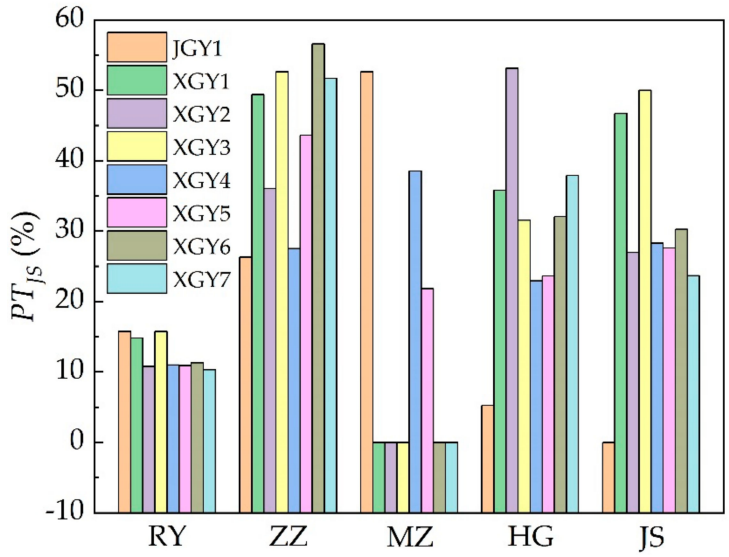

Figure 12. Total processing time percentage of the product for infiltrating, steaming, braising, and drying under different processing conditions and the percentage of time saved compared with JGY1.

Compared with JGY1, the time saving percentages of XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 46.71%, 26.97%, 50%, 28.29%, 27.63%, 30.26%, and 23.68%, respectively, of which the time saving percentage of XGY7 was the smallest, and the time saving percentage of XGY3 was the largest. The results show that all the new processes using new equipment can result in saved processing time for *Polygonatum cyrtonema*, and the steaming and drying processes are the most correlated to the total processing time, which provides a future optimization direction of shortening the processing time. This also shows that the investment in new equipment improves production efficiency and reduces

the use of labor, thus reducing production costs. The steaming pressures or temperatures of XGY1 and XGY3 were different, and finally, the drying time of XGY1 was 5 h longer than that of XGY3. This may be because XGY3 caused more damage to the internal structure of *Polygonatum cyrtonema* under higher steaming pressure, which is more conducive to the rapid moisture escape during the drying process, thereby shortening the drying time. For similar reasons, the final drying time of XGY6 was 5 h longer than that of XGY1. These results provide a future optimization direction of shortening the drying time. The drying temperatures of XGY6 and XGY7 were different, and finally, the drying time of XGY7 was 10 h longer than that of XGY6, which indicates that the water loss rate is slower at lower temperatures. In short, the higher the drying temperature is, the faster the water loss rate. Moreover, the higher the steaming pressure is, the shorter the drying time.

3.2.4. Evaluation and Analysis of Processing Energy Consumption

The processing energy consumption of *Polygonatum cyrtonema* will also affect the production cost of the products, which is mainly reflected in the consumption of energy. Under the premise of ensuring product quality, the energy consumption per unit mass of *Polygonatum cyrtonema* during processing should be reduced as much as possible. The processing energy consumption of *Polygonatum cyrtonema* mainly includes the energy consumption of infiltrating, steaming, braising, drying, and other steps, as well as the total energy consumption of eachstep. The following formula can be used to calculate the total processing electric energy percentage of the product for infiltrating, steaming, braising, and drying under different processing conditions and the percentage of electric energy savings compared with JGY1:

$$\sum E = E_{RY} + E_{ZZ} + E_{MZ} + E_{HG} \tag{8}$$

$$PE_{RY/ZZ/MZ/HG} = \frac{E_{RY/ZZ/MZ/HG}}{\sum E} \times 100\% \tag{9}$$

$$PE_{JN} = \frac{\left|\sum E_{XGY} - \sum E_{JGY1}\right|}{\sum E_{JGY1}} \times 100\% \tag{10}$$

In the above formula, E_{RY}, E_{ZZ}, E_{MZ}, and E_{HG} represent the energy consumption of infiltrating, steaming, braising, and drying, respectively, in kW·h. $\sum E$ is the total energy consumption of the product processing in kW·h. PE_{RY}, PE_{ZZ}, PE_{MZ}, and PE_{HG} are the percentages of the total energy consumption of the product processing for infiltrating, steaming, braising, and drying under different processing conditions, respectively, in %. $\sum E_{XGY}$ is the total processing energy consumption of each new process in kW·h. $\sum E_{JGY1}$ is the total processing energy consumption of JGY1 in kW·h. PE_{JN} is the percentage of electricity savings compared with JGY1 in %. JN represents energy savings.

The total processing electric energy percentage of the product for infiltrating, steaming, braising, and drying under different processing conditions, and the percentage of electric energy savings compared with JGY1 are shown in Figure 13. In the process of medicine infiltration, the total processing electric energy percentages of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 0%, 5.24%, 4.08%, 4.42%, 5.71%, 3.72%, 6.89%, and 6.4%, respectively. JGY1 did not require electric energy but required labor, while the total processing electric energy percentage of XGY6 was the largest. It should be noted here that the infiltrating conditions of all new processes were the same, and the energy consumption fluctuated in the range of around 23.5–25 kW·h, which is relatively normal. Due to the differences in the total processing electric energies, the total processing electric energy percentages of the infiltrating process of the new processes will be quite different. During the steaming process, the total processing electric energy percentages of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 61.94%, 76.02%, 64.32%, 82.51%, 76.34%, 85.13%, 51.21%, and 47.77%, respectively. The total processing electric energy percentage of XGY7 was the smallest, while that of XGY5 was the largest. The total processing electric energy percentages of the steaming process of all new processes were in the range of around 47.77–85.13%, and the fluctuation range was large. This shows that the steaming process

directly affects the overall energy consumption, which indicates that the steaming process is the most energy-consuming production step among all of the processing steps, and the future optimization of energy conservation and emission reduction should focus on this step. All braising processes of JGY1, XGY4, and XGY5 involve a natural cooling process and no energy consumption, so their energy consumption is zero. However, other new processes have no braising process, so their energy consumption is also zero. Therefore, the braising process will not affect the energy consumption. In the drying process, the total processing electric energy percentages of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 38.06%, 18.74%, 31.61%, 13.06%, 17.95%, 11.15%, 41.9%, and 45.83%, respectively. The total processing electric energy percentage of XGY5 was the smallest, while that of XGY7 was the largest. The total processing electric energy percentages of the drying process of all new processes were in the range of around 11.15–45.83%, and the fluctuation range was also large. This shows that the drying process will also affect the overall energy consumption. The drying process is the second most energy-consuming link after the steaming process, and the future optimization of energy conservation and emission reduction should also be focused on this link.

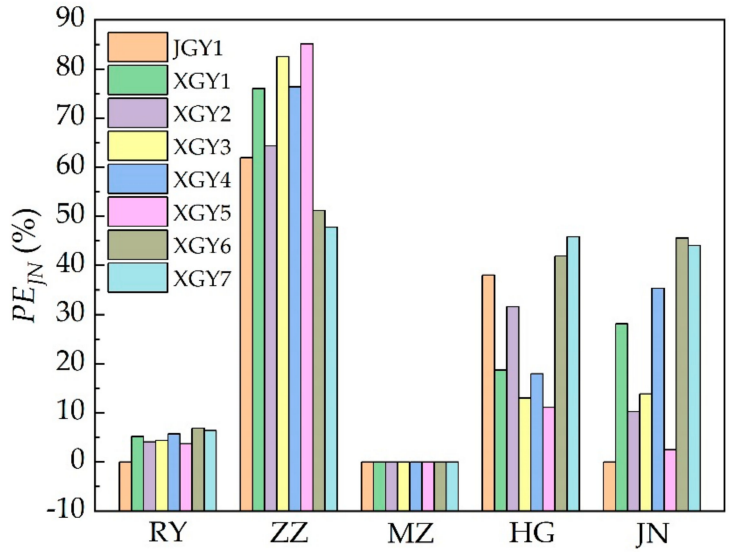

Figure 13. Total processing electric energy percentage of the product for infiltrating, steaming, braising, and drying under different processing conditions and the percentage of electric energy savings compared with JGY1.

Compared with JGY1, the energy saving percentages of XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were 28.13%, 10.26%, 13.85%, 35.36%, 2.49%, 45.59%, and 44.04%, respectively. The energy saving percentage of XGY5 was the smallest, and the energy saving percentage of XGY6 was the largest. The results show that all new processes using new equipment can save energy and reduce consumption, and the steaming and drying processes are the most energy-consuming production steps, which provides a future optimization direction of reducing the processing energy consumption per unit mass of *Polygonatum cyrtonema*. Thus, the investment in the research and development of new equipment is very important for saving energy and reducing emissions and production costs.

The steaming processes of JGY1, XGY3, XGY4, and XGY5 were high-pressure steaming, so the energy consumption is high. Those of XGY6 and XGY7 were atmospheric steaming, so the energy consumption is low. Those of XGY1 and XGY2 were micro-positive pressure steaming, so the energy consumption lies between that of atmospheric pressure steaming and high-pressure steaming. This shows that the steaming pressure has a great influence on the energy consumption per unit mass of *Polygonatum cyrtonema*, and upgrading the original stacking form to the layered tiering form reduces the steaming pressure and the energy consumption per unit mass. Compared with XGY1, the multiple steaming and

drying cycles of XGY2 will greatly increase the energy consumption. The total processing electric energy percentage of the steaming process of XGY2 was less than that of XGY1, mainly because the increase in multiple-cycle drying steps led to increases in the drying energy consumption and total energy consumption, which reduced the total processing electric energy percentage of the steaming process of XGY2. In fact, the total energy consumption of the steaming process of XGY2 was higher than that of XGY1, mainly because the temperature of the material decreased due to the increase in the multiple-cycle drying steps, and the energy consumption required for steaming again increased. Compared with XGY1, because the high-pressure steaming of XGY3 greatly damages the internal structure of *Polygonatum cyrtonema*, the drying time was shortened, and the drying energy consumption was also reduced. Compared with XGY1, because the low-pressure steaming of XGY6 causes less damage to the internal structure of *Polygonatum cyrtonema*, its drying time increased, and thus the drying energy consumption also increased. Since the steaming time order was XGY5 > XGY3 > XGY4, the steaming energy consumption order was also XGY5 > XGY3 > XGY4. The drying temperatures of XGY6 and XGY7 were different, resulting in different energy consumption for drying. Low-temperature drying prolongs the drying time and increases the energy consumption. In summary, the steaming process was the most energy-intensive production step, and the drying process was the next most energy-intensive, and the future optimization of unit energy consumption should start from these two aspects. The higher the steaming pressure is, the longer the steaming time, the longer the drying time, the more steaming and drying cycles, and the higher the energy consumption.

3.2.5. Evaluation and Analysis of *Polygonatum cyrtonema* Quality

Sensory quality evaluation is mainly conducted by the processing experts of *Polygonatum cyrtonema*. Huian Liao, a master craftsman from Zhangbang Luling in Jiangxi Province, China, was hired to make corresponding judgements and scores for each batch of samples. The color changes in the processing of *Polygonatum cyrtonema* mainly include golden yellow, light yellow, brown yellow, dark brown, tan, black brown, dark black and so on. The odor changes during the processing of *Polygonatum cyrtonema* mainly include slight fragrance, fragrance, sweetness, and strong fragrance. The taste changes during the processing of *Polygonatum cyrtonema* mainly include a throat piercing taste, slightly sweet bitterness, sweet bitterness, and slightly bittersweetness. Huian Liao evaluated and scored the color, odor and taste of *Polygonatum cyrtonema*, and the product recovery rate, polysaccharide content, processing time, and processing energy consumption were judged and scored through the specific experimental results. The final scores of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 are summarized in Table 1. It can be seen from the table that in terms of color quality, the order of scores was XGY1 = XGY4 > XGY3 > XGY5 > JGY1 > XGY2 > XGY6 > XGY7, where XGY1 and XGY4 had the same color quality, while XGY7 had the worst. In terms of odor quality, the order of scores was XGY1 > XGY4 > XGY3 > XGY5 > JGY1 > XGY2 > XGY6 > XGY7, where XGY1 had the best odor quality and XGY7 had the worst. In terms of taste quality, the order of scores was XGY1 > XGY6 > XGY7 > JGY1 > XGY4 > XGY3 > XGY5 > XGY2, where XGY1 had the best taste quality and XGY2 had the worst. These results show that the specific processing technology of *Polygonatum cyrtonema* has a great influence on the quality of its color, odor and taste.

In terms of the product recovery rate, the order of scores was XGY6 > XGY7 > XGY1 > XGY4 > JGY1 > XGY2 > XGY3 > XGY5. In terms of polysaccharide content, the order of scores was XGY6 > XGY1 > XGY7 > XGY4 > XGY2 > XGY3 = JGY1 > XGY5. In terms of processing time, the order of scores was XGY3 > XGY1 > XGY6 > XGY4 > XGY5 > XGY2 > XGY7 > JGY1. In terms of processing energy consumption, the order of scores was XGY6 > XGY7 > XGY4 > XGY1 > XGY3 > XGY2 > XGY5 > JGY1. According to the average value of the total scores of each evaluation index, it can finally be determined that the optimal process sequence in all processes is XGY1 > XGY6 > XGY4 > XGY3 > XGY7 > JGY1 > XGY5 > XGY2. XGY1 has the best processing with the highest overall score. XGY2

has the worst processing with the lowest overall score. Therefore, we should try to use a processing method of XGY1 or better in the processing of *Polygonatum cyrtonema*. Since the original stacking form of JGY1 was changed to the layered tiering form of the new process, the heat and mass transfer in the steaming process of *Polygonatum cyrtonema* were greatly strengthened, and the demand for steaming pressure (actually steaming temperature) was reduced. This process can also meet the original quality requirements and ultimately improve the sensory quality of *Polygonatum cyrtonema*, the product recovery rate and the polysaccharide content and reduce the processing time and energy consumption per unit mass.

Table 1. Scores of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7.

Process Name	Scoring Standard, with 5-Point Intervals; the Highest Score is 95 Points, and the Lowest Score is 60 Points.							Total Score	
	Color	Odor	Taste	Recovery Rate	Polysaccharide Contents	Processing Time	Processing Energy Consumption	Average	Ranking Order
JGY1	75	75	80	75	65	60	60	61.25	6
XGY1	90	95	95	85	85	90	80	77.50	1
XGY2	70	70	60	70	70	70	70	60.00	8
XGY3	85	85	70	65	65	95	75	67.50	4
XGY4	90	90	75	80	75	80	85	71.88	3
XGY5	80	80	65	60	60	75	65	60.63	7
XGY6	65	65	90	95	90	85	95	73.13	2
XGY7	60	60	85	90	80	65	90	66.25	5

The drying temperature in the process with new equipment was 60 °C, mainly because some samples of *Polygonatum cyrtonema* had a burnt smell in the later stage of drying at 80 °C, which decreased the product quality. However, in the process with the old equipment, an open oven was used for drying at 80 °C with no recovery of hot air, only a small part of *Polygonatum cyrtonema* samples would produce a burnt smell, and the effect was relatively small. In the process with the new equipment, a decrease in drying temperature would significantly increase the drying time, which would increase the energy consumption. Since all new processes adopted the most advanced heat pump energy-saving technology, the new equipment still consumed much less energy than the old equipment, which indicates the very obvious energy-saving advantages of the new equipment. The original open hot-air drying form was upgraded to an air source heat pump drying form, and this new form can supplement heat by electric heating, which greatly reduces the processing energy consumption in the drying process of *Polygonatum cyrtonema*.

The final products of JGY1, XGY1, XGY2, XGY3, XGY4, XGY5, XGY6, and XGY7 were all sweet and black as lacquers. The color changes of *Polygonatum cyrtonema* at different processing stages in XGY1 are shown in Figure 14, and the color changes at different processing stages were golden yellow (YL) → light yellow (RY) → brown yellow (ZZ1) → dark brown (ZZ2) → tan (ZZ3) → dark brown (ZZ4) → dark black (ZZ5) → dark black (HG). However, the odor changes of *Polygonatum cyrtonema* at different processing stages in XGY1 were in the order of slightly fragrant (YL) → slightly fragrant (RY) → slightly fragrant (ZZ1) → light fragrance (ZZ2) → light fragrance (ZZ3) → sweet (ZZ4) → strong fragrance (ZZ5) → strong fragrance (HG). The taste changes at different processing stages were in the order of thorn throat (YL) → thorn throat (RY) → bitter and slightly sweet (ZZ1) → bitter and slightly sweet (ZZ2) → bitter and sweet (ZZ3) → bitter and sweet (ZZ4) → sweet and slightly bitter (ZZ5) → sweet and slightly bitter (HG).

Figure 14. Color changes of *Polygonatum cyrtonema* at different processing stages in XGY1 (YL (**a**), RY (**b**), ZZ1 (**c**), ZZ2 (**d**), ZZ3 (**e**), ZZ4 (**f**), ZZ5 (**g**), HG (**h**)).

4. Conclusions

Completely different from the traditional equipment of the Nine-Steam-Nine-Bask method, the integrated equipment of the Nine-Steam-Nine-Bask method is based on the functions of infiltrating, steaming, braising, drying, juice-collecting, and cleaning. It has the advantages of a closed operating environment, thin layer, short heating time, controllable constant temperature and pressure, good spray and infiltration effect, reduced loss of the medicinal components, low energy consumption, and high degree of automation. It can be used in the Nine-Steam-Nine-Bask process for *Polygonatum cyrtonema*, which can realize the automatic continuous production of the products, effectively reduce the frequent operation of workers, improve the quality, production efficiency and energy utilization rate of the processed products, and greatly save labor costs. All use clean electricity, which is more environmentally friendly and energy saving. The incorporation of this new integrated equipment has a great influence on the color, odor, taste, recovery rate, polysaccharide content, processing time, processing energy consumption, and other indicators of *Polygonatum cyrtonema* products under different processing conditions. The extraction rate and polysaccharide mass fraction of different processing stages generally show a trend of decreasing first and then tending to balance, and the mass fraction of the water-extracted polysaccharide is much larger than that of the alkaline-extracted polysaccharide. The reductions in the polysaccharide extraction rate and mass fraction may be more related to the steaming process, and they can be considered to reduce the braising process and increase the steaming process. The research and development of, and investment in, new equipment not only improves production efficiency but also reduces the use of labor, thereby reducing production costs. This is crucial for improving the quality, efficiency, cost reduction, energy saving, and emission reduction of Nine-Steam-Nine-Bask products related to the traditional Chinese medicine pieces or food companies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/pr10061044/s1, Figure S1: Standard curve of glucose.

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