Influence of drying methods on quality of *Zanthoxylum armatum* DC. and mathematical modelling of the drying kinetics

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Abstract. In order to evaluate different drying methods on the quality of *Zanthoxylum armatum* DC and the change of moisture content of *Z armatum* during the drying process, the quality change was analyzed under three drying methods: Greenhouse drying equipment, Hot-air drying and Open sun-drying. The moisture loss was systematically recorded, converted to moisture ratio, and fitted to four semi-theoretical drying mathematical models: Lewis, Page, Henderson and Pabis, Avhad and Marchetti models. Comparisons of model fitness were using the coefficient of determination (R2), root mean square error (RMSE), mean bias error (MBE) and absolute error (MAE). The results showed that the color of *Z armatum* obtained by the greenhouse drying equipment was bluish green, which was significantly different from the other two drying methods (p<0.05). The numb degree difference of *Z armatum* obtained by the three methods was not significant(p>0.05). The opening rate is better in greenhouse drying equipment and hot air 40°C drying. The content of linalool can reach 45.5738~55.3898% of the volatile oil. The drying mathematical models fitting results showed that Avhad and Marchetti models fitted best, and the R2 of the curve ranged from 0.9677 to 0.9967, which could accurately predict the change trend of moisture ratio of *Z armatum* in three drying methods with drying time.

1 Introduction

Zanthoxylum armatum DC also called "Qinghuajiao" in Chinese, belongs to family Rutaceae and is native to southeast and southwest China [1]. The peel contains a large amount of essential oil, which is usually used in flavoring food, traditional medicine and pharmaceutical industry and has a unique aroma similar to lemon, and can be used to prepare a variety of dishes to impart natural flavor [2], and has become a major feature of Chinese spices. Z armatum is mainly used in Sichuan cuisine, and it is required to retain its unique color, numb, and aroma. So the indicators in this article will consider color, numb, and aroma. In addition, due to the high moisture content of the freshly picked Z armatum are susceptible to microbial degradation and the oil cell of Z armatum is easily broken during transportation, which reduces the quality [3]. Fresh Z armatum is not suitable for long-term storage. Therefore, Z armatum should be dried for safe storage [4]. Drying is the most important process in the processing of fresh Z armatum, which not only needs to reduce the moisture content of Zarmatum, but also needs to effectively control the browning of Z armatum.

Z armatum currently on the market is mainly dried in the form of natural and hot air. Research on drying has shown that it is a good alternative to producing high quality drying products [5]. The traditional open sun drying method is commonly used to produce Z armatum because it is low input cost. However, the quality of dried products in the open air is low due to the contamination of foreign matter (garbage, dust, soil and sand) and the long time required for drying [6]. Hot air drying requires high investment and high energy consumption. Greenhouse drying is considered as a promising alternative to fruit and vegetable drying in developing countries because it has the lowest operating cost in terms of fuel costs [7]. It is also a more convenient option for rural areas and other areas where electricity supplies are scarce or unstable [8]. Studies have shown that the highest temperature of the greenhouse can reach 49°C, which is far higher than the maximum temperature of the air outside the greenhouse, which is 32.8°C. The time of drying pepper in the greenhouse is shorter [9]. Panwar [10] designed a dryer that could dry 600 kilograms of cotton in a day, reducing the water content from 40% to 5%.

In the process of drying, it is necessary to understand the internal law of drying. Mathematical model is an important aspect of simulating drying process in drying technology. Existing mathematical models used to predict the drying process of different biomaterials include Lewis model [11]. Page model [12], Henderson and Pabis model [13], Avhad and Marchetti model [14]. The Lewis model is the simplest model because it contains only one model constant and now widely used to describe the drying behavior of different agricultural products [15]. Page model is a modification of Lewis model that contains two model constants. Henderson and

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Pabis model is related to Fick's second law, also known as two-parameter exponential models [16]. Avhad and Marchetti improved the Page and the Henderson and Pabis model to get the Avhad and Marchetti model [17]. Dissa used Lewis model, Page model, Henderson and Pabis model to fit the drying dynamics of mango slices, and found that Page model was the most suitable model to describe the thin layer drying characteristics of mango slices. Henderson and Pabis model produced a good fit in predicting citrus seed drying [18]. Keneni [19] used Lewis model, Page model, Henderson and Pabis model, Avhad and Marchetti model to fit the mathematical model of Jatropha seed drying kinetics, and the results showed that Avhad and Marchetti model provided more reliable experimental data fitting.

In order to solve the shortcomings of the above methods, this work designed a greenhouse drying equipment, using forced convection mode of solar energy to dry *Z armatum*. Greenhouse drying equipment can use solar energy more efficiently, low investment, and can be used to dry a variety of fruits, thereby bringing better economic benefits [20]. The effect of greenhouse drying equipment compares with traditional natural drying and hot air drying, studies the effects of different drying methods on *Z armatum* quality, and combines four mathematical models to fit the drying process under different drying conditions to fit the most suitable mathematical model to predict the drying kinetics of *Z armatum* under three treatments.

2 Materials and methods

2.1 Materials and equipment

2.1.1 Raw Materials

Fresh fruit of *Z armatum*, collected from Santai County, Mianyang City, Sichuan Province in July 2019. Methanol was purchased from Chengdu CHRON CHEMICALS co. LTD.

2.1.2 Instruments and equipment

101-2EBS Air Circulation Oven from Beijing ever bright medical treatment instrument co., LTD; Greenhouse drying equipment; HZY-A320Electronic scales from Connecticut HZ electronic technology co., LTD; CS-10 Colorimeter from CHN Spec co., LTD; UV-Vis spectrophotometer measurement from Shanghai Mepi instrument Co., LTD. Agilent 7890A-575C Gas Chromatography-Mass Spectrometer:

The dimension of the designed even span roof type greenhouse dryer is 35 cm*35 cm *65 cm. Trays are fabricated with stainless steel wire meshed having the dimension 24 cm*30 cm. These are placed on the runner at 17 cm height. There are 4 and 1 fans with a diameter of 12 cm and a power of 21 W at the bottom and top of the device, respectively, to ensure sufficient air exchange under and around Z armatum fruit. Figure 1 shows greenhouse drying equipment.



1-Air outlet fan, 2- Outer wall of greenhouse, 3, 4, 5, 6- Air inlet fan, 7- Tray place Figure 1. Greenhouse drying equipment

2.2 Methods

The moldy and diseased fruit in the fresh Z armatum picked out, weigh the selected Z armatum samples and dry them according to different drying conditions (Greenhouse/Open sun/ Hot air 40, 45, 50, 55, 60°C) for 680 minutes. After the drying, Z armatum was seeded and debranched, and stored in a sealed bag at 4°C for future use.

2.3 Determination of quality index

2.3.1 Color measurement

The color difference was determined according to Al-Ismaili method [4]. Take an appropriate amount of dried *Z armatum* and crush it through a 100 mesh sieve. Make sure that the *Z armatum* powder is spread on the white paper, and then use the color difference meter to determine the L\a\b value of the sample (Because basically want to see the green circumstance of cane Z armatum, notice to see a value, did not calculate E). Repeat twice and average.

2.3.2 Numb degree

The numb degree of *Z armatum* was determined by UV-Vis spectrophotometer measurement (UV-1800PC, Shanghai Mepi instrument Co., Ltd, China). Samples were taken every two hours during the drying period,

and numb degree was determined by spectrophotometry. The hydroxyl- α -sanshool weighed precisely was dissolved and diluted with methanol, and then formulated into 1, 2, 3, 4, 5, 6µg/ml standard solution, the absorption of which were survived at 268nm with methanol as the blank, respectively. The linear regression of absorption on concentration was made and the regression equation was calculated. The standard curve was drawn and its equation was y = 7.1554x + 0.0254, $R^2 = 0.9997$. Ten samples were randomly selected each time. The seeds were deseeded to retain the Z armatum peel. After grinding, 0.02 g of the sample was placed in a centrifuge tube, 3mL of methanol was added, and the mixture was centrifuged for 10 minutes after sonication for 20 minutes. After the supernatant was removed, methanol was added again. Ultrasonic and centrifugation again, mix the supernatant with the previous supernatant in a constant volume of 10ml. After the solution was diluted 500 times, the absorbance A was measured at a wavelength of 268nm. Each experiment was repeated twice to take the average value. The formula for calculating the numb *K* is as follows:

$$K = \frac{(7.1554 * A + 0.0254) * n}{1000 * m}$$

where, *K* is numb degree; *A* is the absorbance at 268 nm of the hydroxy- α -sanshool; n is dilution factor; m is the sample mass(g).

2.3.3 Opening rate

100 samples were randomly selected from the dried Z armatum samples. Recorded the sufficient number of openings n, that is the number of particles that are completely separated from the peel and seeds[21]. The calculation formula of opening rate η is as follows:

$$\eta = \frac{n}{100} \times 100\%$$

where, η is opening rate; n is the number of open particles.

2.3.4 Moisture content

The initial moisture content was obtained by constant temperature drying at $105^{\circ}C[22]$. The samples were taken out and weighed at intervals of 20 min during the drying period, and the samples were quickly put into the drying equipment. Repeat the operation until the end of drying. The moisture content M_t is calculated according to the following formula.

$$M_t = \frac{m_t - m}{m}$$

where, m_t is the mass of the sampled material at a certain time t(g); m is the equilibrium mass of the material(g).

Z armatum moisture content ratio MR calculation formula is as follows:

$$MR = \frac{M_t}{M_0}$$

where, M_0 is the initial moisture content of the sample.

2.3.5 Volatile oil

Steam distillation method [23]: accurately weigh 20g of *Z armatum*, crushed to 40 mesh, placed in a 1000 mL flat-bottomed flask, added 500 mL of ultra-pure water, heated boiling, adjust the electric furnace power to maintain reflux 4 h, after distillation is finished, the extracted volatile oil with chromatographic pure hexane diluted 50 times over 0.22 μ m of microporous filter membrane for use.

The chromatographic conditions were as follows: HP-5MS ($30m \times 0.25\mu m \times 0.25\mu m$) elastic quartz capillary column; The programmed temperature was as follows: the initial column temperature was 50° C for 3 min, then increased to 120° C at a rate of 10° C/min for 2 min, and finally increased to 260° C at a rate of 5° C/min for 5 min. The carrier gas was high purity HE, and the flow rate was 1.0mL/min. The injector temperature was 250° C, the detector temperature was 260° C, the injection volume was 1 μ L.

Mass spectrometric conditions: electron bombardment ion source, electron energy 70 eV; Ion source temperature 230 °C; Interface temperature 280 °C; Four bar temperature 150 °C; Solvent delay of 4 min; The scanning range was 20-600 amu, and the scanning interval was 0.5 s. Then, the components with a matching rate greater than 85 % were counted through NIST11.1 spectrum database retrieval.

2.4 Statistical Analysis

Table 1 shows the mathematical dynamic model: Lewis model, Page model, Henderson and Pabis model, Avhad and Marchetti model. In this experiment, the weight loss data measured by Z armatum samples under different drying methods and drying times were converted into moisture content data for the study of drying kinetics fitting. Fitting mathematical model of Z armatum moisture content ratio as a function of time.

Microsoft Excel 2010 software was used to organize the data, MATLAB 2014 software was used to process experimental data and statistical analysis including Duncan test (differences considered significant at p <0.05), and Origin 9.0 software was used to plot.

3 Results and discussion

3.1 Influence of *Z* armatum fruit color with different drying conditions

Dried Z armatum obtained under different conditions including greenhouse drying, open sun drying, hot air drying. Figure 2 shows that the color of Z armatum in the drying oven gradually deepens with the rise of temperature. Value a^* is an important indicator for evaluating whether Z armatum is still green after drying. It can be known from Table 2 that as the drying temperature of the oven increases, the value of a^* increases, and the color development gradually changes from green to yellowish brown, so the drying temperature has a greater impact on the color and luster of Z armatum. Comparison of greenhouse drying, Open sun drying and hot air drying, there was a significant difference in a * value (p < 0.05). The sorting according to a* is: 55°C (4.65) > 60°C (2.77) > Open sun (0.13) >50°C (-1.44) >45°C (-1.64) >40°C (-6.46) >Greenhouse (-7.27). The a * value of greenhouse drying equipment is the smallest (-7.27) and the color is turquoise. The Z

armatum color obtained by drying at higher temperature tends to be yellow and gradually darkens with the increase of temperature, Sriwichai has a similar phenomenon in Z *armatum* study of microwave drying [23]. Indicating that the use of the greenhouse drying equipment has no significant on the color of Z *armatum*, and the color quality of dry Z *armatum* was better.

Model	Mode equation	Dry conditions	Parameter	\mathbb{R}^2	RMSE	MBE	MAE
Lewis		Greenhouse	k=0.00135	0.9661	0.0317	0.0292	0.0292
		Open sun	k=0.00135	0.9348	0.0433	0.0398	0.0398
	MR = exp(-kt)	40°C	k=0.0016	0.9035	0.0545	0.0503	0.0503
		45℃	k=0.0016	0.9309	0.0563	-0.0520	0.0520
		50℃	k=0.00185	0.9104	0.0681	-0.0635	0.0635
		55℃	k=0.0036	0.9048	0.0773	0.0744	0.0744
		60°C	k=0.00425	0.9189	0.0682	0.0571	0.0571
Handerson & Pabis	MR = aexp(-kt)	Greenhouse	a=1.059 k=0.0012	0.9637	0.0328	-0.0307	0.0307
		Open sun	a=1.004 k=0.001	0.9517	0.0373	-0.0244	0.0303
		40°C	a=1.02 k=0.001201	0.9543	0.0375	-0.0367	0.0367
		45℃	a=1.015 k=0.0017	0.9526	0.0467	-0.0444	0.0444
		50℃	a=1.004 k=0.002	0.9574	0.0469	-0.0435	0.0435
		55℃	a=1.016 k=0.0024	0.9516	0.0551	-0.0513	0.0513
		60℃	a=1.007 k=0.0032	0.9514	0.0528	-0.0248	0.0471
Model	Mode equation	Dry conditions	Parameter	R ²	RMSE	MBE	MAE
	$MR = exp(-kt^N)$	Greenhouse	k=0.0068 N=0.699	0.9136	0.0507	-0.0006	0.0453
		Open sun	k=0.0067 N=0.7	0.9154	0.0493	0.0078	0.0446
		40℃	k=0.012 N=0.63	0.9213	0.0493	0.0081	0.0430
Page		45℃	k=0.015 N=0.66	0.9326	0.0557	0.0203	0.0494
		50°C	k=0.014 N=0.67	0.9105	0.0680	-0.0347	0.0602
		55℃	k=0.0137 N=0.7	0.9030	0.0780	-0.0427	0.0690
		60°C	k=0.024 N=0.69	0.9233	0.0664	0.0531	0.0531
Avhad & Marchetti	$MR = aexp(-kt^N)$	Greenhouse	a=1.02 k=0.0009 N=1.05	0.9967	0.0099	-0.0017	0.0083
		Open sun	a=1.02 k=0.0009 N=1.044	0.9902	0.0168	0.0002	0.0130
		40°C	a=1.02 k=0.001 N=1.052	0.9939	0.0138	-0.0052	0.0115
		45℃	a=1.02 k=0.001 N=1.113	0.9854	0.0259	-0.0091	0.0207
		50°C	a=1.03 k=0.014 N=0.7	0.9710	0.0387	0.0045	0.0328
		55℃	a=1.08 k=0.018 N=0.697	0.9677	0.0450	0.0053	0.0400
		60°C	a=1.08 k=0.021 N=0.7	0.9801	0.0338	0.0006	0.0291

Table 2. Quality of Z armatum in different drying conditions

Quality	Greenhouse	Open sun	40°C	45°C	50°C	55℃	60°C
L*	45.62±1.265ª	$31.28{\pm}0.62^d$	$37.94{\pm}0.025^{b}$	35.36±0.17°	$30.52{\pm}1.165^{d}$	25.77±0.47e	25.40±0.365e
a*	-7.27 ± 0.285^{f}	0.13±0.215°	-6.46±0.135 ^e	-1.64 ± 0.075^{d}	-1.44±0.225 ^d	4.65±0.26ª	2.77±0.01 ^b
b*	32.63±0.84ª	24.76 ± 0.15^{d}	31.76±0.905ª	$28.16{\pm}0.285^{b}$	26.79 ± 0.32^{bc}	$25.45{\pm}0.57^{cd}$	22.82±0.235e
Opening rate	98.67 %	96.67 %	99.00%	93.00 %	93.33 %	90.33 %	90.00 %

Within the same column, values with different letters indicate significant differences (p < 0.05).



a~e. Hot air at 40°C, 45°C, 50°C, 55°C and 60°C respectively; f. Open sun drying; g. Greenhouse drying **Figure 2.** *Z armatum* products under different drying conditions

3.2 Influence of numb degree on Z armatum with different drying conditions

From Figure 3, the *Z* armatum numb degree under 7 dry conditions increased first and then gradually decreased with the extension of time. Ten hours before drying, the *Z* armatum numb degree under various conditions gradually increased from 9.2182, and began to decrease after reaching the peak (Greenhouse: 132.5042; Open sun: 118.6005, Hot air 40°C: 115.4150; 45°C: 132.3197; 50°C: 117.5039; 55°C: 100.5753; 60°C: 101.6222). The results showed that in the early stage of drying, with the rapid decrease of water content of *Z* armatum, the proportion of numb flavor substances was larger when

equal quality Z armatum was taken, and the numb degree increased in the later stage. However, the main numb flavor substance of Z armatum is hydroxy zanthoxylin, which is not stable to heat. The numb flavor substance is damaged by heating for a long time and at a higher temperature [24,25]. Therefore, the numb degree of Z armatum is relatively low in the later stage of drying, especially in the oven at 55°C. According to Figure 3, with the increase of oven temperature, the Z armatum numb degree at the end of drying shows a decreasing trend: 117.16^a (45°C) > 112.07^a (40°C) > 101.98^{ab} (50°C) > 81.06^b (60°C) > 77.96^b (55°C), but there is no significant difference in the Z armatum numb degree of oven at 40°C, 45°C and 50°C, Open sun and greenhouse drying equipment (p < 0.05).



Figure 3. Numb degree variation of Z armatum with drying time

3.3 Influence of opening rate of *Z* armatum with different drying conditions

The opening rate was more than 90% under the 7 conditions, and there was no significant difference

between oven 40°C and greenhouse (p < 0.05); moreover, the opening rate decreased with the increase of temperature. The opening rate of *Z* armatum dried at 40°C was the highest, which was higher than other temperature gradients. Therefore, the opening rate of *Z* armatum dried at 40°C is better than other temperature conditions, as shown in Table 2.

3.4 Influence of moisture ratio of *Z* armatum with different drying conditions

Dry the Z armatum with a laying thickness of 3 cm under different conditions to obtain the relationship between moisture content ratio and time (MR / T), as shown in Figure 4. With the increase of drying time, the moisture ratio gradually decreases. MR decreased from 1 to 0.4463 (Greenhouse), 0.0.4964 (Sun), 0.4019 (40°C), 0.2689 (45°C), 0.2337 (50°C), 0.1781 (55°C), 0.1920 $(60^{\circ}C)$, respectively. And the slope of the MR~T graph in the initial drying stage is higher than that in the latter half. The reason is that the dry medium -- hot air, in the case of higher temperature, increases the temperature difference between air and Z armatum surface, increases the heat transfer impetus, resulting in faster heat transfer speed; when the ambient water content is constant, the higher the air temperature, the relative humidity of the air will decrease, which increases the humidity difference with the sample, and accelerates the mass transfer driving force, which accelerates mass transfer; In addition, the increase of temperature will accelerate the

thermal movement of water molecules, causing the water molecules to diffuse faster in the sample [26]. The higher the drying temperature, the faster the rate of decrease of the moisture ratio. The reason is that the increase in temperature increases the vapor pressure difference between the dry air and Z armatum. When the drying time reaches 680 min, the Z armatum moisture content ratio in the open sun is higher than that in the greenhouse drying equipment, because when the short-wavelength solar radiation passes through the greenhouse drying equipment, it is absorbed by the Zarmatum placed in the equipment, resulting in the Zarmatum heating. The heated Z armatum will emit radiation with a longer wavelength, which cannot penetrate the greenhouse wall, thus increasing the temperature of the enclosed air and causing the temperature inside the greenhouse to be higher than that outside the greenhouse [27]. Therefore, when the moisture content ratio of Z armatum in sunlight tends to be gentle, the moisture content ratio of Z armatum in greenhouse will continue to decline. The three types of Zarmatum drying process are directly from the speed-up phase to the speed-down phase without a constant-speed drying process, which also conforms to the drying characteristic curve of porous materials.



Figure 4. Moisture ratio change of Z armatum with drying time

3.5 Model fitting of moisture reduction during drying process

Four semi-theoretical thin-layer drying models were used to fit the MR and T data under different drying treatment methods, and the model parameters and evaluation indexes R^2 and RMSE, MBE, and MAE were obtained, as shown in Table 1.

Four fitting statistical parameter results of different drying methods can be obtained from Table 1, R^2 value changes from 0.9030 to 0.9967. The R^2 fitted by Avhad and Marchetti models are between 0.9677 and 0.9967, which is higher than the other three dynamic models. The

average RMSE values of the four models are 0.0571, 0.0596, 0.0328, 0.0263, and the average RMSE values fitted by the Avhad and Marchetti models is the smallest. The range of MBE of Lewis model, Page model, Henderson and Pabis model, Avhad and Marchetti model are $-0.0635 \sim 0.0744$, $-0.0427 \sim 0.0531$, $-0.0513 \sim -0.0244$, $-0.0091 \sim 0.0053$, among which Avhad, Marchetti model fits. The average MBE is -0.0018, which is lower than the other 3 drying models. The average MBE of the four models were 0.0193, 0.0016, -0.0366, and 0.0008, respectively. The average MBE of the Avhad and Marchetti models, the fitting effect of the Avhad and Marchetti model is the

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best description of the drying process of Z armatum. Table 1 is a comparison of the experimental values with the predicted values of the Avhad and Marchetti models. It can be seen that the Avhad and Marchetti models fit the greenhouse drying equipment best.

3.6 Volatile oil analysis

According to the analysis results of the essential oil from the NST11.1 standard library search, the composition and content of essential oil from different drying methods are different, mainly including alkenes, alcohols, esters and aldehydes, as shown in Table 3. There are 28 alkenes, 14 alcohols, 2 esters and 2 aldehydes. The results showed that there were 28 kinds of volatile oil in equipment drying, 32 kinds of volatile oil in sunlight drying, 28 kinds of volatile oil in oven drying at 40°C, 28 kinds of volatile oil in oven drying at 45°C, 25 kinds of volatile oil in oven drying at 50°C, 26 kinds of volatile oil in oven drying at 55°C and 31 kinds in oven drying at 60°C. The common components are: linalool, 1-4-Terpineol, p-Menth-2-en-1-ol, stereoisomer (8CI), (+)-Dipentene, l-Caryophyllene, g-Terpinene, 2-Thujene (7CI, 8CI). The content range of linalool is $42.6226 \sim 46.3660$, the content range of 1-4-Terpineol is $1.1467 \sim 4.0092$, the content range of p-Menth-2-en-1-ol is $0.1271 \sim 0.2283$, the content range of stereoisomer (8CI) is 16.7101 ~ 19.8515, the content range of (+)-Dipentene is $0.7450 \sim 1.9778$, the content range of 1-Caryophyllene, g-Terpinene is 0.5078 ~ 1.9247, the content range of 2-Thujene (7CI,8CI) is 0.13359 ~ 0.3301. the content of linalool can reach 45.5738 \sim 55.3898% of the volatile oil, which is the main substances of the Z armatum volatile oil [28].

 Table 3. Components of volatile oils

Component	Greenhouse	Open sun	40°C	45℃	50℃	55°C	60°C
.alphaGuaiene	0	0	0.1511	0.1189	0	0.1583	0
Bicyclogermacrene	0.8793	0	0	0	0.9595	0.4733	1.7199
(+)-4-Carene	0.3111	0.4196	0.6447	0.4009	0.6787	0.7092	0
(+)-b-Selinene	0	0.5816	0	0	0.33	0	0.6595
(+)-epi-Bicyclosesquiphellandrene	0	0	0.2004	0.1936	0	0	0
6-Octenal, 3,7-dimethyl-, (R)-	0.1412	0	0.1356	0.1519	0	0	0
1,3,6-Octatriene, 3,7-dimethyl-, (Z)-	0	1.2681	0	0.9221	0	0	1.0841
Naphthalene, 1,2,4a,5,6,8a-hexahydro-4, 7-dimethyl-1-(1-methylethyl)-	0.1748	0	0.1252	0.1431	0	0	0.1376
1,5,5-Trimethyl-6-methylene-cyclohexe ne	0.1684	0.2834	0.1069	0.1145	0.1664	0	0.2651
1,6-Octadien-3-ol, 3,7-dimethyl-, 2-aminobenzoate	0.5601	0.5502	0.4041	0.5412	0	0.4434	0
α-Patchoulene	0	0.3027	0	0	0	0	0
1H-Cyclopenta [1,3] cyclopropa [1,2] benzene, octahydro-7-methyl-3- methylene-4-(1-methylethyl)-,[3aS-(3a.a lpha.,3b.beta.,4.beta.,7.alpha.,7aS*)]-	0	0	0	0	0	1.1221	3.0322
1-Hydroxy-1,7-dimethyl-4-isopropyl-2, 7-cyclodecadiene	0	0.1759	0	0.1471	0	0	0
Caryophyllene	1.2117	1.7663	0.785	0.8759	1.0848	0.745	1.9778
Bicyclo[3.1.0]hex-2-ene, 4-methyl-1-(1-methylethyl)-	0.154	0.1359	0.2422	0.2261	0.242	0.3301	0.1544
Nerolidol 2	0	0	0	0	0	0	0.1767
(+)-2-Carene	0	0	0	0	0	1.3213	0.6703
.betaPhellandrene	4.0817	9.897	0	0	5.2166	4.3867	0
3-Cyclohexen-1-ol, 4-methyl-1- (1-methylethyl)-, (R)-	1.1467	1.5824	2.1676	1.4219	2.6955	4.0092	2.3761
Azulene, 1,2,3,3a,4,5,6,7-octahydro-1, 4-dimethyl-7-(1-methylethenyl)-, [1R-(1.alpha.,3a.beta.,4.alpha.,7.beta.)]-	0	0	0	0	0.145	0	0.3051
Bicyclo[3.1.1]hept-2-ene-2-methanol, 6,6-dimethyl-	0	0.1218	0	0.1476	0	0.1297	0
LalphaTerpineol	0	0	0	0	0.5939	0	0.6628
.betaHumulene	0.2557	0	0	0	0	0	0
Cyclohexanecarboxylic acid, pentadecyl ester	0	0.238	0	0	0	0	0
Cyclohexanemethanol,4-ethenylalpha., .alpha.,4-trimethyl-3-(1-methylethenyl)-	0.3785	0.2289	0.2474	0.2298	0	0	0.1542

, [1R- (1.alpha.,3.alpha.,4.beta.)]-							
Cyclohexene, 1-methyl-3-(1-methylethenyl)-, (.+/)-	0.7866	0	0.8527	0	0	0	0
d-Cadinene	0.1294	0.1614	0	0	0	0	0.1729
.gammaElemene	0	1.6535	0	0.5632	0	0	0
p-Menth-8-en-1-ol, stereoisomer	0.6589	0	0	0	0.2096	0	0
1,4,7,-Cycloundecatriene, 1,5,9,9-tetramethyl-, Z,Z,Z-	0	0.5862	0	0	0.3457	0	0.6247
.alphaCadinol	0	0.4191	0	0	0.1012	0	0.3354
.alphaPhellandrene	0.5481	0	0.5399	0.5677	0	0.5178	0
.alphaTerpineol	0	0.6869	0	0	0	1.0888	0
.betaPinene	0	4.6945	0	0	0	0	0
.gammaMuurolene	0	0.1313	0	0	0	0	0
2,6-Octadien-1-ol, 3,7-dimethyl-, (Z)-	0	0	0	0	0	0.1676	0
1,6,10-Dodecatrien-3-ol, 3,7,11-trimethyl-	3.0139	0	2.2478	0	0	1.3672	0
1,6-Cyclodecadiene,1-methyl-5-methyle ne-8- (1-methylethyl)-, [S-(E,E)]-	2.2548	3.0524	1.5344	1.7074	1.868	0	0
Humulene	0.777	0	0.509	0.5524	0	0.4086	0
.tauCadinol	0	0	0	0	0	0	0.1747
trans-p-Menth-2-en-1-ol	0	0	0.1267	0	0.128	0.1531	0.1303
1,6,10-Dodecatrien-3-ol, 3,7,11-trimethyl-, (E)-	0	0	0	2.4416	0.1409	0	0
1,6-Octadien-3-ol, 3,7-dimethyl-	43.9334	43.2281	43.7481	42.6226	45.0256	44.3101	46.366
Decanal	0.1153	0.1467	0.1165	0.1235	0.15	0	0.1818
Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methyleth	0.4557	2.5614	0.2255	0.1775	1.5121	0	2.6963
Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methyleth	0	0.1404	0	0	0	0.3292	0.1766
enyl)-, [1S-(1.alpha.,2.beta.,4.beta.)]-							
.betaOcimene	0.8362	0	0.8876	0	1.2512	0.8515	0
(1R)-2,6,6-Trimethylbicyclo[3.1.1]hept- 2-ene	0	0	0	1.2388	0	0	0.3782
Cyclohexene, 4-methylene-1-(1-methylethyl)-	12.0852	0	12.948	0	0	8.9335	0
Hexadecane	0	0	0	0	0	0	0.1106
Pentadecane	0	0	0	0	0	0	0.1127
Cyclohexanol,	0	0.2121	0 (072	0 (520	0	0 10 49	0 4105
1-methyl-4-(1-methylethenyl)-, cis-	0	0.2121	0.6072	0.0529	0	0.1948	0.4105
.gammaTerpinene	0.5078	0.6851	0.9679	0.623	1.0387	1.9247	1.0785
Cyclohexene, 1-methyl-4-(1-methylethylidene)-	0	0.4273	0.4553	0.3861	0.506	0	0.4906
2-Cyclonexen-1-ol, 1-methyl-4-(1-methylethyl)-, trans-	0.1271	0.1363	0.1942	0.1483	0.1868	0.2283	0.1829
acetate. (Z)-	0	0.1	0	0	0	0	0
D-Limonene	18.2342	18.178	19.1363	19.8515	19.5087	19.558	16.7101
(1S)-2,6,6-Trimethylbicyclo[3.1.1]hept- 2-ene	0.9894	0.4032	1.2295	0	0.6496	1.0772	0

4 Conclusion

Z armatum obtained in the seven drying conditions in this paper. In terms of color, the color of dried Z armatum at 40°C is the best under hot wind conditions, but it is lower than the greenhouse. The Z armatum obtained by the greenhouse drying equipment is cyan-green, which can prevent the browning of Z *armatum* during the drying process. Drying Z armatum numb degree in 45°C conditions is the highest. The numbness of Z armatum in greenhouse was low, which may be because the high temperature in greenhouse destroyed the numbness of Z armatum. The numb degree of Z armatum increased first and then decreased slowly. Therefore, the drying process of Z armatum should not be too long, so as to prevent the thermal sensitive hydroxy - zanthoxylin from being broken and reduce the numb feeling strength of Z armatum. The opening rate of Z armatum under the greenhouse was slightly lower than that of hot wind 40°C, but higher than that under other conditions. Compared with the results of other drying conditions, although the numb degree of Z armatum dried by the greenhouse drying equipment is low, but the color and opening ratio are higher than other conditions. The fitting results of models show that the R² fitted by the Avhad and Marchetti models are larger than those fitted by other models, and the RMSE is lower than those fitted by other models, which can accurately predict the change trend of the moisture ratio with drying time in the Z armatum drying process under the three drying modes.

Credit authorship contribution statement

Dong Xia: Methodology, Software, Validation, Investigation, Writing original draft preparation, Visualization. Lingyan Jiang: Methodology, Software, Formal analysis, Investigation, Data curation. Jinxi Cheng: Software, Formal analysis, Investigation, Data curation, Visualization. Xiaoyan Hou: Methodology, Software, Formal analysis, Investigation, Data curation, Visualization. Shanshan Li: Conceptualization, Validation, Writing review and editing, Supervision. Qingying Luo: Writing review and editing, Supervision, Project administration, Funding acquisition. Guanghui Shen: Methodology, Supervision, Project administration. Hejun Wu: Formal analysis, Resources, Funding acquisition. Anjun Chen: Resources, Funding acquisition, Conceptualization. Zhiqing Zhang: Conceptualization, Validation, Resources, Writing review and editing, Project administration, Funding acquisition.

Conflicts of interest

The authors declare no conflicts of interest.

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