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A Study on Drying Kinetics of Rhubarb Medical Plant by an Infrared Dryer

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ABSTRACT

Rhubarb is a mountain plant that contains many antioxidants and various vitamins, including A, B1, B2 and C, and is an extremely healthy product and a rich source of antioxidants and dietary fibers. Today, it is important to dry medicinal plants and agricultural products in order to achieve better product quality, so that minimal physical, chemical and biological changes made in the product. In this research, the drying kinetics of rhubarb medicinal plant with an infrared dryer conducted at three temperature levels of 50, 60, and 70 ℃ in the skin and without skin for 2 and 5 cm pieces of the product. By increasing the drying temperature and reducing the length of the parts and removing the skin of the samples, the drying speed and mass transfer increased and the drying time decreased. The values of activation energy ranged from 32.18 to 45.09 kJ/mol and the values of moisture diffusion coefficient ranged from 2.45 x 10-9 to 5.97 x 10-10 square meters per second. The overall color change of the product at all three temperatures was insignificant and the color of the rhubarb product changed little during the drying process. Using the intensity of low infrared radiations kept the color characteristics of rhubarb samples .Due to the low cost and high speed of drying, infrared dryer recommended as an economic method with high productivity for drying rhubarb medicinal plant.

INTRODUCTION

Rhubarb with the scientific name *Rheum ribes* L is a plant from the sorrel family (seven plants) with 70 different species native to Asian regions including Iran, Pakistan, India and China (Turkmen *et al.*, 2005). Rhubarb is a mountain plant that looks like celery, but is pink in color and tastes sour and sweet. Rhubarb contains many antioxidants and various vitamins including A, B1, B2 and C. In addition, rhubarb preserves various elements such as potassium, magnesium, calcium and some organic acids such as citric acid and malic acid (Öztürk *et al.*, 2007). Rhubarb is an extremely healthy product and a rich source of antioxidants and dietary fibers. This plant consists of up to 93% water and has the highest moisture content among all common vegetable products (Rubina *et al.*, 2019). According to the principles of traditional Chinese medicine, rhubarb is an herbal medicine with many therapeutic properties, including catharsis, heat-clearing effects, detoxification, and blood stasis removal (Hu *et al.*, 2014). The water in food is the most important factor determining the type and rate of degradation. Drying is the process of removing moisture through the simultaneous transfer of heat and mass. When the heat is transferred to the surface of the material, the water in the food material turns into steam by receiving the latent heat of evaporation and is transferred to the outside through a boundary layer (Shahidi, 2011). There are different types of rhubarb preservation methods that increase the "storage life" of rhubarb with removing moisture from rhubarb and preventing the growth of microorganisms, including canning, pickling, preparing sauce, jam or gel, drying, freezing and fermentation to Wine. In this research, infrared drying of rhubarb will be considered due to its popularity in food processing and the benefits provided (Rubina *et al.*, 2019). One of the most important and effective parameters in the drying process is temperature changes which have harmful effects on the medicinal plant. Because with temperature increasing, the tissues of the material are damaged and in addition to the color change, the amount of wrinkling on the surface increases. This phenomenon hinders the process of drying and reabsorption of water. Nowadays, in order to achieve better quality of the product, drying of medicinal plants done at a lower temperature and with modern methods so that minimal physical, chemical and biological changes made in the product. In most medicinal plants, mechanism of infrared radiation heat transfer works better than hot air flow and many researchers recommend this method. Hot air drying is the most commonly used commercial method for drying vegetables and fruits, but its major disadvantages are long drying time and reduced product quality (Ebadi *et al.*, 2011). In contrast, infrared heating has many advantages such as high heat transfer rate, uniform heating, shorter process time, less energy consumption, lower energy cost and improved quality of the final product (Salehi, 2020). Among the applications of infrared radiation in drying, we can mention the

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drying of many chemicals, pharmaceuticals and food in the industry and performing laboratory tests to determine the drying characteristics of different materials. In a study, the drying of laurel plant done. The results showed that drying by air with infrared rays at a temperature of 45 ℃ has a significant effect on increasing the essential oil content. In addition, the compound 8,1-cineole, which was one of the main compounds of the essential oil of this plant, was reduced in the most of the treatments compared to the control, but an increasing in the amount of this compound was reported in two treatments, infrared and oven (Sellami *et al.*, 2011). Many medicinal plants and roots including ginseng root, mint (Ashtiani *et al.*, 2017), aloe vera (Sriariyakul *et al.*, 2016), black tea (Qu *et al.*, 2019) and etc., which were dried with an infrared dryer, the maximum retention of their active pharmaceutical ingredients has been reported compared to other methods.

In this research, the drying kinetics of rhubarb medicinal plant with an infrared dryer at three temperature levels of 50, 60, and 70 ℃, with and without skin, for 2 and 5 cm pieces investigated.

MATERIALS AND METHODS

Plant preparation

Rhubarb obtained from the mountains of the Soma region of Broadost, located in the west of West Azerbaijan province, in the border heights with Turkey. After cleaning, the samples manually cut into four shapes: 5 cm pieces with skin and without skin and 2 cm pieces with skin and without skin. AOAC (AOAC, 1990) method used to measure initial moisture. For this purpose, 50 grams of 5 cm rhubarb pieces without skin and with skin measured with a laboratory scale model (DJ-V320A) with an accuracy of 0.001 g, and then the samples placed inside the oven at a temperature of 105 ℃ for 24 h. After removing the sample from the oven, the samples immediately weighed and their secondary weight obtained, and the initial moisture content of rhubarb was calculated based on the weight of dry matter.

Infrared dryer

To dry the samples, an infrared dryer model GC400, Grok Engineering and Design Company, Iran was used. The temperature range of this dryer is from 35 ℃ to 90 ℃, its humidity range is up to 90%, and the power consumption is 3 kW to 9 kW. In this research, the infrared temperature was kept at three levels of 50, 60, and 70 ℃ and the distance of the sample from the lamp was kept constant at 20 cm. Then the mass and time data measured during the drying process until reaching the final moisture content.

Calculate the humidity ratio

In this research, the moisture ratio and drying rate of rhubarb were calculated using Equations (1) and (2) (Doymaz, 2012).

$$MR=\frac{m_e-m_t}{m_o-m_t} \tag{1}$$

$$DR=\frac{M_{t+dt}-M_t}{\Delta t} \tag{2}$$

Where, m_t is the amount of moisture in time, m_0 is initial humidity, m_e is equilibrium humidity, M_t is the amount of moisture at time t, M_{t+dt} is the amount of humidity at time t+dt, Δt is the time interval between two consecutive humidity (s).

Calculation of effective diffusion coefficient of moisture

Describing the process of moisture infiltration in fruits during drying is very complicated. This process may include molecular diffusion, capillary flow, product moisture, hydrodynamic flow of moisture, Knudsen diffusion (in conditions where the drying process takes place at low temperature and pressure, the moisture transfer process is under Knudsen diffusion, such as freeze drying) or Surface diffusion of moisture. By considering and combining these phenomena, the effective diffusion coefficient of moisture can described by Fick's second law. This rule does not depend on the power source used in the drying process and is used in different drying methods. The moisture diffusion coefficient is an important factor for describing the rate of moisture flow inside the material, which actually describes the degree of difficulty for moisture to pass through the product.

Fick's second law expressed as follows by assuming the one-dimensional movement of the moisture flow and the constant effective diffusion coefficient of moisture.

$$\frac{\partial M}{\partial t}=D_e\frac{\partial^2 M}{\partial x^2} \tag{3}$$

The general solution of Fick's second law in Cartesian coordinates is expressed by Crank (1975) for a blade-shaped body as follows (Crank, 1975):

$$MR=\frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left[\frac{-(2n+1)^2\pi^2D_{eff}}{4L^2}\right] \tag{4}$$

Where, *MR* is moisture ratio (dimensionless), *t* is drying time (s), D_e is the effective diffusion coefficient of moisture (m^2/s), *L* is the thickness of rhubarb pieces (m)

If the drying time is long, Equation (5) can simplified as follows and only the first sentence of the series is considered

$$MR=\frac{8}{\pi^2}exp\left(-\frac{\pi^2D_{eff}}{4L^2}t\right) \tag{5}$$

Now, the effective diffusion coefficient of moisture calculated from the slope method. In this method, by plotting the logarithmic value of the humidity ratio obtained from the laboratory data against time, a constant line with a slope of K is obtained (Doymaz, 2012).

$$LnMR=Ln\frac{8}{\pi^2}-\frac{\pi^2D_{eff}}{4L^2}t \tag{6}$$

$$K=\frac{\pi^2D_{eff}}{4L^2} \tag{7}$$

Finally, by using equation (7) and using linear regression, the amount of effective diffusion coefficient of moisture can be obtained.

Estimating activation energy

Activation energy is the minimum energy needed to start a drying process (Aghbashlo and Samimi-Akhijahani, 2008). The Arrhenius equation used to calculate the activation energy. In the Arrhenius equation, the relationship between temperatures, diffusion coefficient and activation energy is expressed as follows (Sahin and Öztürk, 2016).

$$D_{eff}=Aexp\left(\frac{-E_a}{RT}\right) \tag{8}$$

Where, E_a is activation energy (kJ/mol), *A* is constant number and the same unit as the diffusion coefficient, *R* is the general gas constant (kJ/mol K), *T* is the absolute temperature (K)

This relationship can be calculated according to linearly equation (7) and the activation energy can be calculated by plotting *Ln* D_{eff} in terms of 1/T (equation9).

$$LnD_{eff}=LnA-\frac{E_a}{RT} \tag{9}$$

Color changes

Color is an important factor in agriculture and food industry and is the first factor that buyers consider when buying a product (Arabhosseini *et al.*, 2011). The L index is the brightness index or the degree of color transparency, which ranges from L= 0 (darkness) to L=100 (brightness). A decrease in the L index means that the color of the samples is dark. +a index indicates increased redness and -a indicates increased greenness. The more negative this index is the better and it is the closer to the color of the fresh sample. +b index indicates increased yellowness and -b indicates increased blueness. (Roozdar *et al.*, 2014) The color of the samples was measured by a WR10 colorimeter made by FRU China. The difference amount of color (ΔE) between the dried samples and the original sample was calculated using color indices by equation (10). In addition, in this research, to describe the color changes, the Chroma index of product color purity (C*) according to equation (11) which indicates the closeness of the color to its original and the browning index (BI). according to equation (12) which indicates the product color and its tendency is towards darkness and Hue angle according to equation (13) was calculated (Chisari *et al.*, 2007).

$$\Delta E=\sqrt{(L_0^*-L^*)^2+(a_0^*-a^*)^2+(b_0^*-b^*)^2} \tag{10}$$

$$C^*=[a^{*2}+b^{*2}]^{\frac{1}{2}} \tag{11}$$

$$x=\frac{a^*-1.75L^*}{5.645L^*+a^*-0.301b^*}\ ,\quad BI=\frac{100(x-0.31}{0.17} \tag{12}$$

$$h^*=tan\left(\frac{b^*}{a^*}\right) \tag{13}$$

Where, L^*, a^* and b^* are the average color components of the product after drying and L_0^*, a_0^* and b_0^* are the average color components of the product before drying.

RESULTS AND DISCUSSIONS

The effect of changes in temperature and length of rhubarb samples with skin and without skin on changes in moisture content and drying rate of the product with respect to time is shown in Fig.1 at three temperature levels of 50, 60, and 70 ℃. As can be seen, by increasing the drying temperature and reducing the length of the pieces, and removing the skin of the samples, the drying speed increased, so the rate of moisture removal from rhubarb increased. In addition, increasing the temperature increased the mass transfer and decreased the length of the samples, and the exit of moisture was accelerated, therefore, the drying time was reduced.

The values of effective diffusion coefficient of moisture were calculated according to Fick's second law and using equations 4 to 7. The values of the effective diffusion coefficient of moisture and the slope of Ln (MR) curves against time were obtained for the experimental treatments. The values of this coefficient vary from 2.45 x 10-9 to 10-10 x 5.97 square meters per second. The amount of moisture diffusion coefficient in 82% of food and agricultural products is in the range of 1×10^{-8} to 1×10^{-11} m^2/s (Marinos-Kouris and Maroulis, 2020). The calculated values of the effective coefficient of moisture infiltration in the present research were also within the mentioned range.

The amount of activation energy, which represents the minimum energy required to remove moisture from the product, was calculated in different test conditions. In order to calculate the activation energy, different values of Ln (D_e) were plotted against the inverse of the absolute temperature inside the product in the drying process (1/T). The values of activation energy ranged from 32.18 to 45.09 kJ/mol. The values obtained for the activation energy in the current research were within an acceptable range because according to Duimaz (2012), the activation energy values for all food and agricultural products are in the range of 12.7 to 110 kJ/mol.

The results of the color analysis of the samples showed that the value of L^* in the dried sample of 2 cm with the skin at a temperature of 50 ℃ is higher than that of the fresh sample. While the dried sample at temperatures of 60 and 70 ℃ has a smaller L^* value than the fresh sample. In the 5 cm sample with the skin, the same result was obtained, with the difference that at 60 ℃, the value of L^* in the dry sample is higher than in the fresh sample (Tables 1, 2, and 3). The a^* component expresses the amount of redness of the product. The data in tables 1, 2, and 3 show that with increasing temperature, the value of this parameter is higher in fresh samples than in dried samples. Of course, this result was not observed in the 5 cm samples with skin, and with the increase in temperature, the a^* component in the dried sample is higher than in the fresh sample. The reason for this can be the longer length and the presence of skin on the sample. The component b^* expresses the yellowness of the product. Table (1) shows that the amount of this component for the sample with the skin at 50 ℃ is not different from the dried sample to the fresh sample. In dry skinless samples, the value of this parameter is higher than in fresh samples, and with the increase in temperature, the value of b^* also increases in fresh samples. However, in skinless samples, the amount of this component is higher than in fresh samples.

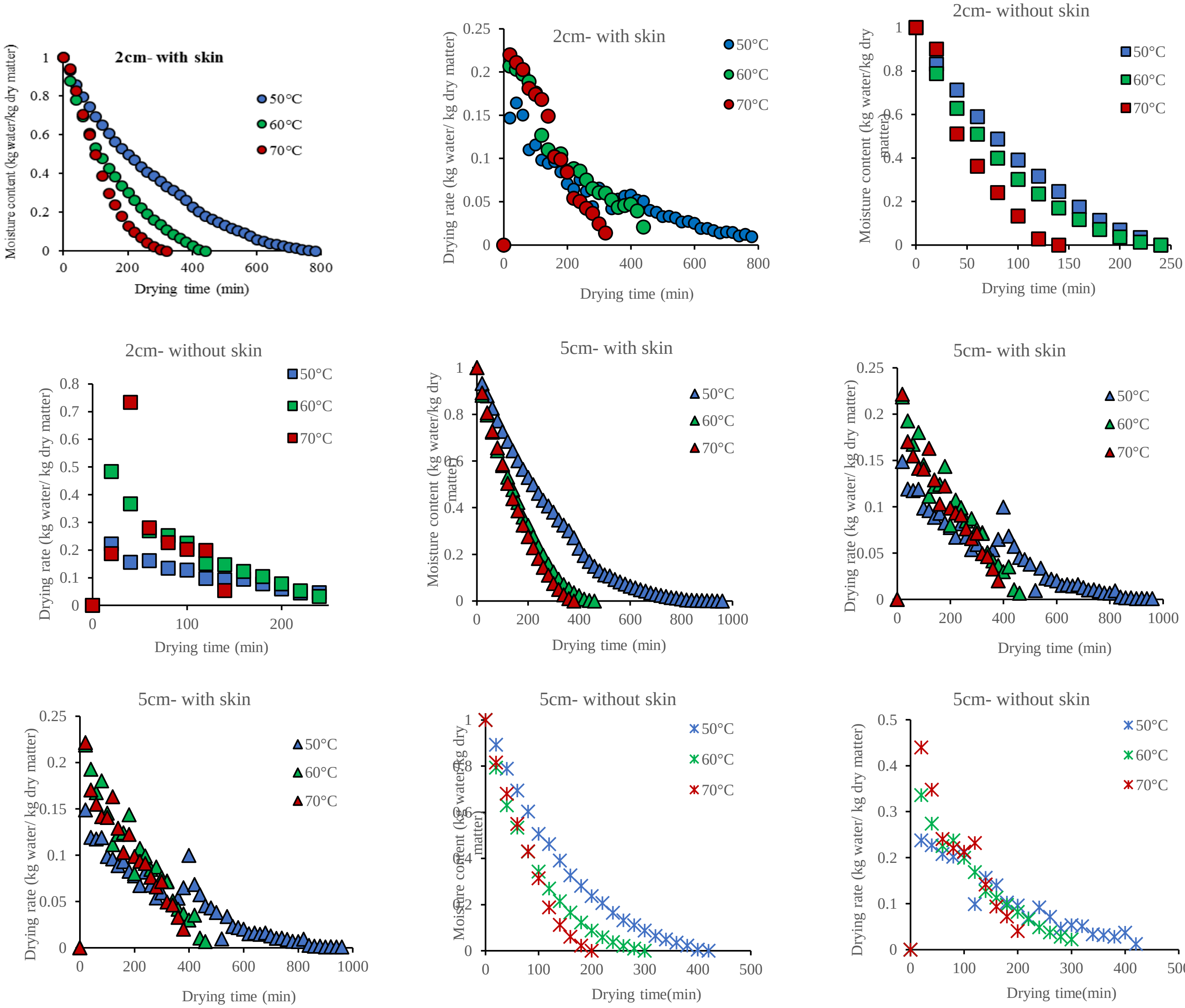

Fig 1. Moisture content and drying rate of rhubarb at different temperatures and dimensions in with skin and skinless conditions

The overall color change of the product (ΔE), which is a combination of changes in the values of parameters L*, a*, and b*, is widely used to describe color changes during the processing of food products. According to the data in tables (1), (2), and (3), the values of this parameter in samples dried at temperatures of 50, 60, and 70 ℃ are almost the same. The reason for this is the low overall color changes during the rhubarb drying process. Because this product contains a low percentage of sugar and is less affected by browning reactions. Chroma actually expresses the degree of purity of color and is proportional to the intensity of that color. Therefore, its higher values mean preserving the natural color of the rhubarb product. The value of this parameter in 2 and 5 cm fresh samples with skin and dried at 50 ℃ is almost the same, and in the skinless state, dried samples have higher Chroma than fresh samples. At the temperature of 60 ℃, the amount of Chroma in the samples is almost constant, and at the temperature of 70 ℃, the dried samples have almost lower values than the fresh samples. Therefore, the small changes in the Chroma index also indicate insignificant changes in the color of the product, and as mentioned before, the color of the rhubarb product had little changes during the drying process. The brownness index indicates the purity of the brown color. Tables (1) and (2) and (3), show that the value of this index for samples dried at 60 ℃ is higher than fresh samples at the same temperature. The reason for this is the high purity of the brown color in the rhubarb product and the amount of the red component on which the browning index depends is more. At the temperature of 70 ℃, this index remained unchanged and at the temperature of 50 ℃, except for the 5 cm sample with skin, it was higher in fresh samples than in dried samples.

Fig 2. Image of dried rhubarb samples

Table 1. Color changes in rhubarb samples dried at 50 ℃

50°C		Fresh	Final
	L	24.42	44.28
	a	-6.32	3.42
	b	14.33	16.37
2 cm (with skin)	ΔE	_	22.21
	Hue	-1.16	1.36
	Chroma	15.66	16.72
	BI	-9.85	6.24
	L^*	24.77	54.10
	a^*	-6.00	-2.91
	b^*	14.26	25.28
2 cm (without skin)	ΔE	_	31.49
	Hue	-1.17	-1.46
	Chroma	15.47	25.45
	BI	-8.51	-4.41
	L^*	25.67	50.17
	a^*	-5.36	5.36
	b^*	13.72	13.90
5 cm (with skin)	ΔE	_	26.74
	Hue	-1.20	1.20
	Chroma	14.73	14.90
	BI	-5.80	8.61
	L^*	25.99	51.46
	a^*	-5.16	-0.09
	b^*	13.33	16.58
5 cm (without skin)	ΔE	_	26.18
	Hue	-1.20	-1.57
	Chroma	14.30	16.58
	BI	-5	-0.13

Table 2. Color changes in rhubarb samples dried at 60 ℃

60°C		Fresh	Final
	L^*	56.20	46.93
	a^*	-5.13	3.96
	b^*	25.72	19.80
2 cm (with skin)	ΔE	_	14.27
	Hue	-1.37	1.37
	Chroma	26.23	20.19
	BI	3.40	16.43
	L^*	59.50	55.95
	a^*	-6.00	-2.91
	b^*	14.26	25.28
2 cm (without skin)	ΔE	_	5.26
	Hue	-1.43	1.54
	Chroma	22.12	21.24
	BI	6.39	11.25
	L^*	25.67	50.17
	a^*	-5.36	5.36
	b^*	13.72	13.90
5 cm (with skin)	ΔE	_	18.30
	Hue	-1.30	1.36
	Chroma	28.31	23.65
	BI	-0.56	18.84
	L^*	25.99	51.46
	a^*	-5.16	-0.09
	b^*	13.33	16.58
5 cm (without skin)	ΔE	_	12.48
	Hue	-1.29	1.50
	Chroma	26.40	21.81
	BI	0.25	12.83

Table 3. Color changes in rhubarb samples dried at 70 ℃

70°C		Fresh	Final
	L^*	54.39	45.32
	a^*	-7.68	3.94
	b^*	27.87	18.44
2 cm (with skin)	ΔE	_	17.51
	Hue	-1.30	1.36
	Chroma	28.91	18.86
	BI	0.00	0.17
	L^*	59.86	60.42
	a^*	-6.95	0.80
	b^*	24.73	23.72
2 cm (without skin)	ΔE	_	7.84
	Hue	7.84	-1.30
	Chroma	25.69	23.74
	BI	0.01	0.11
	L^*	56.83	40.32
	a^*	-0.49	6.12
	b^*	28.75	19.58
5 cm (with skin)	ΔE	_	20.02
	Hue	20.02	-1.55
	Chroma	28.76	20.51
	BI	0.10	0.21
	L^*	25.99	51.46
	a^*	-5.16	-0.09
	b^*	13.33	16.58
5 cm (without skin)	ΔE	_	26.18
	Hue	-1.26	1.47
	Chroma	32.06	21.80
	BI	-0.03	0.13

CONCLUSIONS

In this study, the drying kinetics of rhubarb slices in pieces with different lengths in the skin and skinless conditions studied in an infrared dryer. Increasing the duration of heat application and decreasing the length of the rhubarb sample increased the drying speed and decreased its duration. In addition, the diffusion coefficient and activation energy of the product were calculated and reported. In general, the results of the research showed that the use of low intensity of infrared radiation preserves the color characteristics of rhubarb samples. Due to the low cost and high speed of drying in the infrared dryer, it is recommended as an economic method with high productivity for drying the rhubarb medicinal plant.

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