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Results of optimization of technological parameters for aaruul drying equipment

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Abstract
Mongolia has a large nomadic culture which has existed for thousands of years. Nomadic herders spend much of their time producing milk and dairy products, including Aaruul, or dried yogurt curd, which is a local dairy product unique to Mongolia. A drying device was designed to dry aaruul made by traditional methods to a moisture content no more than 20% in a short period of time, and the optimum values of drying temperature, drying time, and air flow speed were determined by multi-factored model and step-by-step decomposition method. As a result of the experiment, curd with a moisture content of 60% is dried at a temperature of 44^0C with an air flow speed with 3m/s for 7 hours, and the moisture content becomes 19.8%. It takes 4-5 days to dry curd naturally, and by using this device, curd drying time can be reduced by 10-17 times and the productivity of curd production can be increased. The electricity consumption of the device for drying 1kg of curd is 1.5 kWh.

Keywords: temperature, air flow, moisture, drying time, distance between shelves

Introduction
Mongolians have a long history of developing and passing down the knowledge of how to process the milk of the five kinds of livestock in accordance with the characteristics of nomadic livestock farming, natural and climatic conditions. Mongolians use aaruul, cheese and curds cheese. Aaruul is a globally recognized product due to its unique health and biological worth [1].

A sampling of the research work of foreign researchers, the Japanese researcher [2] studied the chemical and biochemical composition of Mongolian five-horned cattle's milk and dairy products; Mongolian and Japanese researchers [3] collaborated on the probiotic effect of Mongolian semolina dairy products; Swedish researchers [1] studied the features and characteristics of milk and curd of five-horned cattle in Mongolia; Korean and Japanese researchers [4] conducted studies on the effects of traditional Mongolian yogurt on high-fat rats. Concluding from the research work on dairy products, many foreign researchers have determined technological research on the benefits of milk and dairy products in Mongolia, however there is a dearth of research on dairy product manufacturing equipment.

Mongolians extract the raw material of aaruul - curd in the following three ways. It includes Pot-distilled curd, Yoghurt curd, and Curd produced by enzyme-acid technology.

Aaruuls are made from pot-distilled curds and yoghurt curds, and the technological basis of the curd production method is explained by the theory of heat-acid fermentation [5]. In Mongolian knowledge, there are two main types of heat-acid fermentation, firstly, milk is heated up to 85-90^0C, sour yogurt and yellow water are added to create an acidic environment (pH 4.7-5.0), and secondly, once fermented yogurt, and distillate are boiled and proteins are filtered. When straining the curd, put it in a cloth bag and hang it to release the whey by its own weight. After that, the mouth is closed and the remaining whey is released by pressure. At this time, curd is 60% moist. The compressed curd is removed from the bag and put into the cutting and molding process, after which it is dried to a moisture content of at least 20%. These operations take a total of 4-5 days and are interdependent processes [6]. In order to increase the efficiency of the pressing operation and save time, a curd pressing device was designed and the moisture

content of the curd was determined depending on the weight of the curd, pressing pressure, and time, and their optimal values were determined [7].Aaruuls are dried by natural or hot drying methods, and dried aaruuls must meet hygienic requirements. At any drying stage, the curd with a moisture content of no more than 75% is dried to a moisture content of 10 - 20% [5]. Aaruul is dried at a temperature of 50-55^{0}C for 20-24 hours by hot drying [8]. A sample of the research work of foreign researchers on the drying of agricultural products with solar energy is used in many countries of the world to dry fruits, vegetables, grains, fish, meat, and wood [9]. Drying vegetables with a solar collector not only protects them from insects, rain, dust, and dirt, but also has the advantage of not requiring an additional source of energy. At the temperature of 35 - 65^{0}C, food products with moisture content of 85 - 90% are dried to 9 - 54%. The air flow rate of the drying process is 1 – 3 m/s, and the air flow consumption is between 1.8 – 15.1 m^3/min [9]. In North African countries, 0.5 kg of precious plums are dried for 1-9 hours and 2 kg of potatoes for 5.5-11.5 hours respectively [10]. It is suitable if the thickness of aaruul dried by hot drying is not more than 1cm [8]. Since the uniformity of the aaruul size is good for the smooth drying process, the authors determined the distance between the threads of the aaruul cutting device depending on the linear shrinkage coefficient of the Aaruul. In Mongolia, the aaruul is dried in direct sunlight and wind from June to October. This method takes a lot of time, as the curds are exposed to dust and are eaten by insects. For this reason, in order to solve these problems, a device working in hot drying mode was designed, and the technological parameters of the curd drying process were experimentally determined and optimized. Simplification of milk processing and aaruul drying, will contribute to the increase of dairy production and consumption, market sales, increase in profits, and the support of family business.

Theoretical analysis

Moisture content

Moisture content is a measure of the relative humidity (RH) in the product, expressed on a wet and dry basis. Moisture content in accordance with the wet and dry basis was determined using the following equations (1) and (2) [11]:

$$M_{wb} = \frac{M_w}{M_T} \quad (1)$$

$$M_{db} = \frac{M_w}{M_k} \quad (2)$$

where M_w is the water weight of the product, M_T is the total weight of the product, and M_k is the dry weight of the product.

Dimensionless moisture ratio

The ratio of the moisture content of the dried material at any time t to the initial moisture content is called the moisture ratio. The moisture ratio is determined by:

$$W_s = \frac{M_t - M_e}{M_0 - M_e} \quad (3)$$

where M_t is the weight of the dried material at time t, M_e – the equilibrium moisture weight, and M_0 is the initial weight of the dried material.

Materials and methods

We used yogurt curd in the aaruul drying experimen [5] and it was carried out according to the following scheme.

Prepare the aaruul according to the sequence of technology shown in the diagram above, press the curd filtered in a coarse calico bag until it has a moisture content of 60% [7].

After the pressed curds are cut by the curd cutter, they are numbered and placed evently spaced on the racks of the drying equipment. During the drying process, the weight of each sample is measured every hour with an electronic balance with an accuracy of 0.01 g. Continue the test until the moisture content of the air inside the dryer is below 20%.

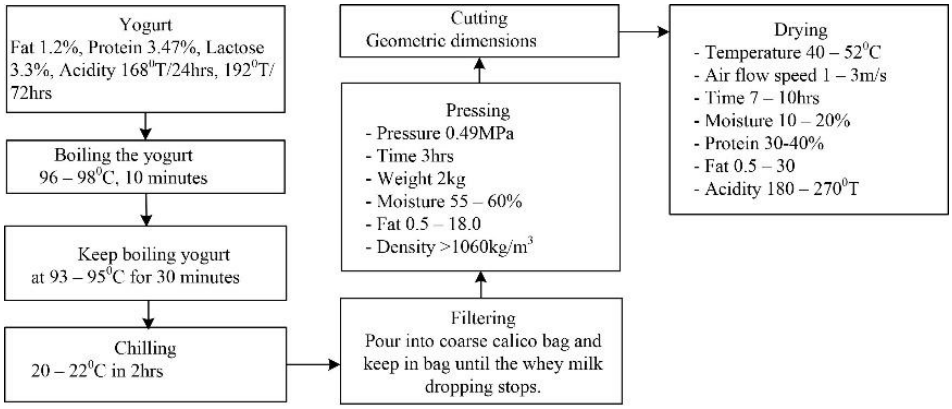

Figure 1. Technological scheme of traditional method of making aaruul with yoghurt

Drying equipment is designed to remove moisture from products by a flow of heated air, adjustable temperature, air flow speed and space between shelves (Fig.).

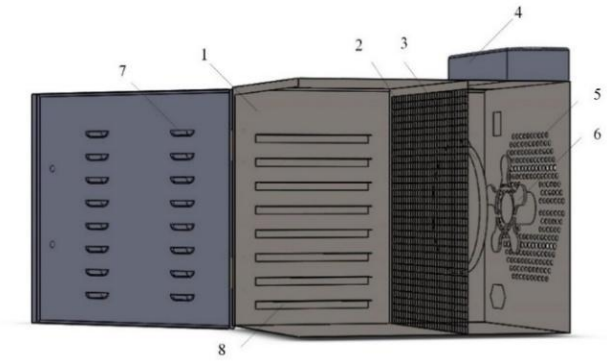

Figure 2. Aaruul drying equipment
1-drying chamber, 2-mesh, 3-electric heater, 4-control system, 5-air inlet, 6-fan, 7-air outlet, 8-shelf

The experiment will be conducted using a multi-factored experimental design. The Design of experiments of the input and output factors affecting the aaruul drying process is shown in the following figure.

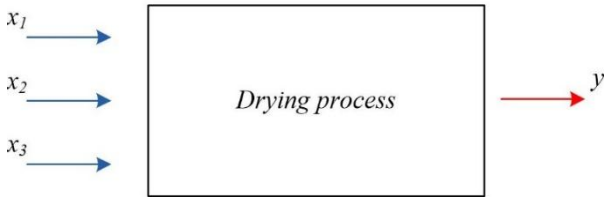

Figure 3. Design of experiments

Inlet parameters: x_1 – air flow speed, m/s; x_2 – temperature, ^{0}C; x_3 – distance between shelves, cm; outlet parameter: y – aaruul moisture, %

$$y = f(x_1, x_2, x_3) \rightarrow 10 - 20\%$$

Parameter levels that represent y-value are determined not only by the values of X_{imax}, X_{imin}, but by box planning or second-order rotatable planning with 3rd and 5th grade changes [11]. Optimum values of the inlet parameters are defined by the preliminary tests as demonstrated in Table 2.

Table 1.

Factors and levels of combination experiment

Effective parameters	Changed values of effective parameters					J_i
	$-x_a$	x_{imin}	x_{i0}	x_{imax}	$+x_a$	
	-1.682	-1	0	+1	+1.682	
Air flow speed X_1, m/s	0.318	1	2	3	3.682	1
Temperature X_2, ^{0}C	33.272	36	40	44	46.728	4
Distance between shelves X_3, cm	1.11	3.5	7	10.5	12.88	3.5

The moisture content of dried aaruul should be 10 - 20% [12]. The amount of moisture of dried aaruul is determined according to the method of determination of moisture and dry matter of milk and dairy products MNS 401:75 standard [13].
Under the condition that the moisture content of the dried aaruul is the lowest, the optimum value of air flow rate, drying temperature, and the distance between the racks, which are the technological parameters of the aaruul drying equipment, are found by the step-by-step decomposition method.

Results

Table 2 shows the results of experiments that determined that aaruul moisture depends on air flow speed, temperature, and distance between shelves.

Table 2.

Test results of aaruul moisture

№	Standard matrix			Experimental matrix			Outlet parameters
	Inlet parameters			Real values of inlet parameters			
	x_1	x_2	x_3	X_1	X_2	X_3	$\bar{y}$
1	-	-	-	1	36	3.5	25.80
2	+	-	-	3	36	3.5	23.85
3	-	+	-	1	44	3.5	22.77
4	+	+	-	3	44	3.5	20.93
5	-	-	+	1	36	10.5	25.68
6	+	-	+	3	36	10.5	23.92
7	-	+	+	1	44	10.5	22.42
8	+	+	+	3	44	10.5	20.57
9	-1.682	0	0	0.318	40	7	24.92
10	+1.682	0	0	3.682	40	7	20.42
11	0	-1.682	0	2	33	7	24.18
12	0	+1.682	0	2	46	7	19.20
13	0	0	-1.682	2	40	1.11	21.67
14	0	0	+1.682	2	40	12.88	23.62
15	0	0	0	2	40	7	22.10
16	0	0	0	2	40	7	20.83
17	0	0	0	2	40	7	21.65
18	0	0	0	2	40	7	20.17
19	0	0	0	2	40	7	21.83
20	0	0	0	2	40	7	20.20

When the numerical values of the measurements were checked for outliers using Student's test, the condition that the calculated value was lower than the table value ($t_T < t_X$) was met, and there were no outliers. Therefore the numerical values of the measurements were governed by the Law of normal distribution, and the calculated value of the Shapiro and Wilka W criteria was W_T = 42.81, which allowed the value in the table to be greater than W_X = 0.014. Regression coefficients for factor dependence has been determined and a multivariate regression model (eq.2) for dependence has also been obtained.

$$y = 21.073 - 1.096x_1 - 1.533x_2 + 0.729x_1^2 + 0.719x_3^2 \quad (2)$$

When the regression model was tested by Fisher's test, the calculated value of the test was $F_T = 1.63$, and $F_T < F_X = 2.71$, so our model proved to be similar.

We put following values to obtain regression model and defined the real model (eq.3):

$$x_1 = \frac{X_1 - 2}{1};\ x_2 = \frac{X_2 - 40}{4};\ x_3 = \frac{X_3 - 7}{3.5}$$

$$y = 44.387 - 4.012X_1 - 0.383X_2 - 0.821X_3 + 0.729X_1^2 + 0.058X_3^2 \quad (3)$$

Figure 4 shows the correlation of the Aaruul moisture (y) from the air flow speed (X_1) and the temperature of the dried Aaruul X_2.

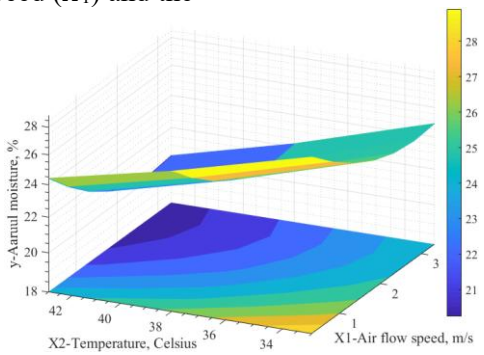

Figure 4. Correlation on the 3D surface graph

$$\boldsymbol{y = f(X_1, X_2)}$$

It shows that when the temperature (X_2) and air flow speed (X_1) increases, the Aaruul moisture (y) declines. The maximum value of the air flow speed (X_1) and temperature (X_2) can be seen in Figure 4 to hold the Aaruul moisture (y) at a value less than 20%. The Aaruul was dried at the optimal values of inlet parameters and the drying curve was derived.

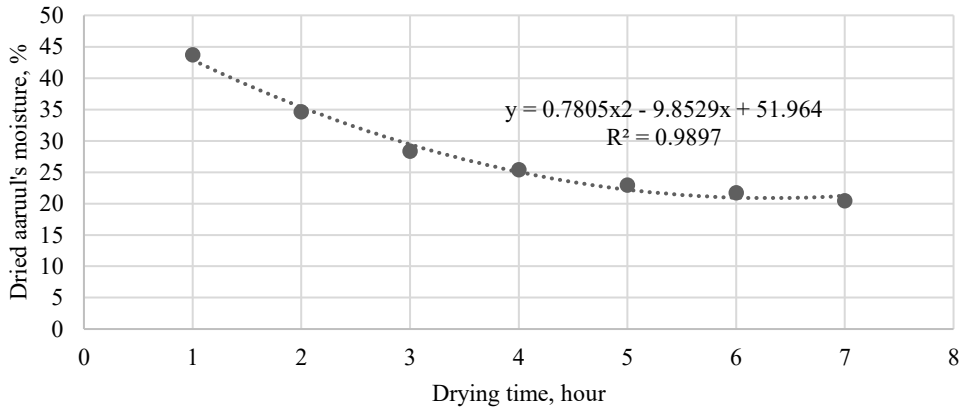

Figure 5. The change moisture of aaruul in the drying process

When curd with a moisture content of 60% is dried by heat drying, the moisture content of the curd decreases to 25% in the first 4 hours, and the drying process is intensive. But in the last 3 hours, the intensity of drying stabilized, 5.2% of the aaruul's moisture was lost, and the aaruul's moisture content was 19.8%. When transferring the traditional method of making aaruul with curd to production technology, it is mentioned that aaruul is dried at a temperature of 55-60^{0}C in the first stage, and at a temperature of 80-90^{0}C in the second stage [5]. Our joint research investigated the curd drying process in one step depending on the air flow speed and the distance between the shelves in addition to temperature. In the future, it was considered necessary to continue the aaruul drying experiment, perform it in 2 stages, and shorten the time.

Conclusion

Based on the specific aaruul moisture content, the values of air flow speed, temperature and distance between shelves using the aaruul drying equipment have been optimized and the mathematical model has been defined. The air flow speed and temperature values were determined as the most effective parameters during the experiments.

The optimal values of the inlet parameters of the aaruul drying process are calculated as 3m/s of air flow speed, 44^0C of temperature and 10.5cm of distance between shelves to have 19.8% of the Aaruul moisture content. The moisture content of the aaruul is 19.8%, which meets the requirement for moisture content of protein dairy products. It takes 7 hours to dry curd with 60% moisture using a drying device, and the cost of electricity to dry 1 kg of curd is 0.12$.

Conflict of interests

The authors declare no conflict of interests.

Authors' contribution

AJ writing original draft preparation, performed all experimetn and BD supervision, review and editing. All authors have read and approved the final manuscript.

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