Fruit-and-berry mash fermentation rate research

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Annotation

Based on the Delle's theory of preserving effect of sugar-alcohol solutions, obtained differential equation of mash fermentation. Decision of differential equation determines the alcohol content during fermentation and the rate of mash fermentation. Theoretical results are confirmed experimentally during fermentation of fruit-and-berry mash.

Key words: fermentation, differential equations, extract, ethyl alcohol concentration, fruit wine, malt.

Over 100 years ago, P. Delle researched preserving effect of ethanol and sugar in the mash [1]. Preserving effect of a mass-volume percent (1 g/100 cm^3) sugar is taken as a preservative unit (unit Delle). Mash is not fermented if there is sugar in the amount of 80 g per 100 cm^3 or more. On the other hand, the mash is not fermented if there is ethanol in the amount of 18% of volume or more. Dividing that data we receive approximately 4.5 Delle units for preserving action of one volume percent of ethanol.

Each type of yeast has its limit number of preserving units when the activity of the yeast and the fermentation process both stop down. For most yeast this limit number of preserving units is 70-78 ones.

In order to obtain the differential equation of mash fermentation, it is necessary to introduce the concept of free preserving units. The number of free preserving units is the difference between the limit number of preserving units and the existing number of preserving units in the mash. For example, if the yeast limit number of preserving units is 78 units, and there are 8% alcohol and 12 g/100 cm^3 sugar in mash , then the number of free preserving units is $78 - 12 - 4{,}5 \bullet 8 = 30$.

During mash fermentation the number of free preserving units is decreasing constantly. We can determine the number of free preserving units using the volume of alcohol. Let the limit number of preserving units is A, the content of sugar in the mash is B before fermentation, so the number of free preserving units at that time is $A–B$. During fermentation, the alcohol content increases and sugar content reduces. Content of fermented over sugar is equal to alcohol volume part divided by 0.6. Then the number of free preserving units is:

$$A–B–4{,}5c + c:0{,}6=A–B–2{,}83c, \qquad (1)$$

where c – volume of alcohol.

In the first approximate rate of mash fermentation is proportional to the number of free preserving units directly, which leads to the differential equation:

$$\frac{dc}{dt}=\frac{k}{2.83}(A-B-2.83c), \tag{2}$$

where c - volume of alcohol; t - time; k - coefficient of proportionality, which depends on the temperature, chemical composition of the mash, kind of yeast. This quotient increases with temperature increasing.

Let divide variables in the differential equation:

$$\frac{2.83dc}{A-B-2.83c}=kdt. \tag{3}$$

By integrating the differential equation we obtain the result:

$$A-B-2.83c=De^{-kt}, \tag{4}$$

where D – integration constant. At the initial time t = 0, the concentration of alcohol is zero, c = 0, and integration constant is equal to D = A-B. Then the decision of the differential equation has the form:

$$c=\frac{A-B}{2.83}(1-e^{-kt}). \tag{5}$$

The coefficient k can be determined from experimental data of fermentation. Decision of differential equation (5) describes the process of mash fermentation when sugar was added one time only before fermentation. When the quantity of sugar is 29 g/100 cm^3 and above the equation (A-B) / 2.83 = Cmax is equal to the maximum possible quantity of fermented over alcohol and decision of differential equation (5) can be written in the form:

$$c=c_{\max}(1-e^{-kt}). \tag{6}$$

When the quantity of sugar is less than 29 g/100 cm^3 decision of differential equations is described by the formula (6) as well, but $c_{\max}=0,6B$.

In general, the fermentation process is divided into three periods: starting fermentation, rapid fermentation and finishing fermentation, when fermentation is going on slowly. Increasing of alcohol content during periods of rapid fermentation and finishing fermentation is going on according to the formula (6). During starting fermentation that lasts for several hours, the process of yeast reproduction takes place. In this period, the alcohol content is much lower than follows from formula (6). Therefore it is necessary to clarify the decision, taking into account the process of reproduction of yeast. In this case quantity of yeast should be set of in relative manner, considering the maximum quantity of yeast as a unit.

First, after adding some yeast component concentration of yeast grows exponentially as well as alcohol content. Then the growth slows down and the yeast concentration tends to a constant value. Mathematically, this dependence can be described by the formula:

$$\frac{N}{N_{\max}} = \frac{C_0 e^{\alpha t}}{1 + C_0 e^{\alpha t}}, \tag{7}$$

where N – concentration of yeast; $N_{\max}$ – maximal concentration of yeast; N / Nmax – starting fermentation coefficient, C_0 – part of adding yeast, which is 0,03-0,05 in most cases; α - constant that is determined experimentally ; t - time. Taking into account formulas (6) and (7) the alcohol content increases in the mash as follows:

$$c = c_{\max}(1 - e^{-kt})\frac{C_0 e^{\alpha t}}{1 + C_0 e^{\alpha t}}. \tag{8}$$

Thus, if the mash starting fermentation period is investigated you should use the formula (8), and when this period is not analyzed, then you can use the formula (6) which is simpler one.

To determine the speed of mash fermentation during rapid fermentation and finishing (or slow) fermentation we should calculate the derivative from formula (6):

$$\frac{dc}{dt} = c_{\max} k e^{-kt}. \tag{9}$$

Formula (9) can be written in the form:

$$\frac{dc}{dt} = v_{\max} e^{-kt}, \tag{10}$$

where $v_{\max}$ - the maximum rate of fermentation.

Obtained theoretical results were checked experimentally during fermentation fruit-and-berry wine materials with adding sugar or honey as well.

Juice was obtained by pressing of apples Kalvil snow sort, pears Glek sort, and cherries Podbyelska sort. Juices were scalded at 85°C temperature for five minutes. After pasteurization juice was cooled to room temperature and honey or sugar was added to it.

Mash was fermented periodically with pure culture yeast L 29406 Best before: 06/2005 oeroferm at a temperature of 20°C. Total extract was found by gravimetric (weight) method, and alcohol volume part was determined by distillation (areometric) method [2].

Table 1 shows the content of ethyl alcohol and rate of cherry mash fermentation with adding sugar or honey. Rate of fermentation is proportional to growth of alcohol content per day. When the alcohol content reaches a maximum value, then the rate of fermentation becomes zero. The table indicates the total mass concentration C_o of extract at the beginning of mash fermentation.

Table 1.Content of ethanol and rate of cherry mash fermentation

Duration of fermentation, days	Mash with adding sugar, C_o=28,8 g/100 cm^3		Mash with adding honey, C_o=28,8 g/100 cm^3	
	thanol, % vol.	Rate of mash fermentation, % vol./day	thanol, % vol.	Rate of mash fermentation, % vol./day
0	0	0	0	0
1	0,7	0,7	0,8	0,8
2	3,4	2,7	3,9	3,1
3	7,0	3,6	6,7	2,8
4	8,0	1,0	8,9	2,2
6	9,0	0,50	11,2	1,15
8	9,9	0,45	12,2	0,50
10	10,9	0,50	12,8	0,30
14	11,9	0,25	13,0	0,05
18	12,8	0,23	13,1	0,03
25	13,6	0,11	13,2	0,01
33	13,7	0,01	13,2	0
127	13,7	0	13,1	0

Based on the data of Table 1 we obtain the regression equation, which determines the alcohol content during rapid mash fermentation period and slow one. Calculating the derivative from the alcohol content, we can get rate of mash fermentation. Alcohol content and the rate of cherry mash fermentation with added sugar are determined by the formulas:

$$c = 13.7(1 - e^{-0.17t}). \tag{11}$$

$$\frac{dc}{dt} = 2.3e^{-0.17t}. \tag{12}$$

Alcohol content and the rate of cherry mash fermentation with added honey have the next forms:

$$c = 13.2(1 - e^{-0.29t}). \tag{13}$$

$$\frac{dc}{dt} = 3.8e^{-0.29t}. \tag{14}$$

Table 2 shows the content of ethanol and fermentation rate of pear mash with adding sugar or honey.

Table 2.Content of ethanol and rate of pear mash fermentation

Duration of fermentation, days	Mash with adding sugar, C_o=30,2 g/100 cm^3		Mash with adding honey, C_o=29,1 g/100 cm^3	
	thanol, % vol.	Rate of mash fermentation, % vol./day	thanol, % vol.	Rate of mash fermentation, % vol./day
0	0	0	0	0
1	0,9	0,9	1,0	1,0
2	2,5	1,6	2,9	1,9
3	4,1	1,6	4,8	1,9
4	6,8	2,7	7,2	2,4
6	7,9	0,55	10,2	1,5
8	8,9	0,50	12,0	0,9
10	9,8	0,45	13,3	0,65
12	10,6	0,40	13,9	0,30
15	11,8	0,40	14,3	0,13
19	13,2	0,35	14,5	0,05
26	14,7	0,21	14,6	0,01
34	15,2	0,06	14,7	0,01

Based on the data of Table 2 we obtain the regression equation, which determines the alcohol content during rapid mash fermentation period and slow one.

Alcohol content and the rate of pear mash fermentation with added sugar are determined by the formulas:

$$c = 15.2(1 - e^{-0.11t}). \tag{15}$$

$$\frac{dc}{dt} = 1.7e^{-0.115t}. \tag{16}$$

Alcohol content and the rate of pear mash fermentation with added honey are determined by the formulas accordingly:

$$c = 14.7(1 - e^{-0.21t}). \tag{17}$$

$$\frac{dc}{dt} = 3.1e^{-0.21t}. \tag{18}$$

Table 3 presents content of ethanol and fermentation rate of apple mash with adding sugar or honey.

Table 3.Content of ethanol and rate of apple mash fermentation

Duration of fermentation, days	Mash with adding sugar, C_o=28,8 g/100 cm^3		Mash with adding honey, Co=29,7 g/100 cm^3	
	thanol, % vol.	Rate of mash fermentation, % vol./day	thanol, % vol.	Rate of mash fermentation, % vol./day
0	0	0	0	0
1	0,3	0,3	0,4	0,4
2	1,4	1,1	2,3	1,9
3	2,4	1,0	3,4	1,1
4	3,4	1,0	4,6	1,2
6	5,7	1,15	6,6	1,0
8	7,3	0,80	8,0	0,70
11	9,4	0,70	10,0	0,66
15	10,7	0,33	12,1	0,53
18	12,0	0,43	12,8	0,23
21	12,7	0,23	13,5	0,23
24	13,2	0,17	14,0	0,17
28	13,8	0,15	14,6	0,15
33	14,3	0,10	15,3	0,14
41	14,6	0,04	15,5	0,03
50	14,9	0,03	15,7	0,02
66	15,2	0,02	15,7	0
83	15,4	0,01	15,6	0
112	15,4	0	15,7	0

Based on the data of Table 3 we obtain the regression equation, which determines the alcohol content during rapid mash fermentation period and slow one.

Alcohol content and the rate of apple mash fermentation with added sugar are determined by the formulas:

$$c = 15.4(1 - e^{-0.07t}). \tag{19}$$

$$\frac{dc}{dt} = 1.1e^{-0.07t}. \tag{20}$$

Alcohol content and the rate of apple mash fermentation with added honey have the next forms:

$$c = 15.7(1 - e^{-0.10t}). \tag{21}$$

$$\frac{dc}{dt} = 1.6e^{-0.10t}. \tag{22}$$

The highest rate of fermentation has cherry mash, and the lowest rate of fermentation has apple mash respectively. Rate of fermentation of fruit-and-berry mash with added honey is higher than the corresponding rate of fermentation of fruit-and-berry mash with added sugar. This is due to the fact that honey contains nitrogenous substances, and that are essential for yeast.

Literature:

1. Справочник по виноделию /Под ред. Г.Г.Валуйко, В.Т.Косюры.–2-е изд., перераб. и доп. – Симферополь: Таврида, 2005. – 624 с.
2. Валуйко Г.Г. Технология виноградных вин. – Симферополь: Таврида, 2001. – 624 с.
3. Охременко Н.С. Номограмма прочности вин. Виноделие и виноградарство СССР, 1961, № 2 (201), с. 14-16.
4. Остапчук Н.В. Основы математического моделирования процессов пищевых производств. – К.: Вища школа, 1991. – 368 с.
5. Ribereau-Gayon P., Peunaud E. Traite d'oenologie – Paris, 1960. – Vol. 1. – 40 p.