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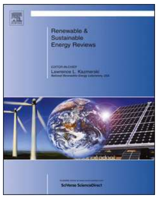

Energy and cost analyses of kombucha beverage production

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ABSTRACT

Kombucha is a traditional fermented beverage and it is produced by the fermentation of tea and sugar. Many beneficial effects to the human body can be achieved using substances with antioxidative properties. Substrates for kombucha fermentation contain antioxidants which originated from tea leaves. This study is conducted by kombucha beverage production device that has been invented by authors, located in the Tehran province, Iran. Data is collected from a kombucha beverage production device, performed by 23 replications in capacity of 4.5 L during January–December 2014. Total energy inputs and outputs were calculated as 2.77 MJ L^{-1} and 8.69 MJ L^{-1}, respectively, therefore the energy productivity and net energy value are estimated as 0.38 kg MJ^{-1} and 5.92 MJ L^{-1}, respectively. The results show that the highest share of energy is consumed by sugar (40.9%) and kombucha beverage (29%). The ratio of energy outputs to energy inputs is approximately 3.14. The shares of renewable and direct energy were 15.7% and 91.5%, respectively from the total energy input. The net return and productivity from kombucha beverage production were found to be 0.38$ L^{-1} and 1.03 kg $\$^{-1}$, respectively. The results showed that by increasing volume of kombucha beverage production device, input costs (kombucha fungus, electricity, machinery and rent land expense) will decrease because of proration costs.

Contents

1. Introduction

A large amount of information has been published concerning the effects of tea and its major constituents on human health. Kombucha is a traditional fermented beverage with a history of several thousand years in the East and remains quite popular in the West. It is typically prepared by fermenting sweetened black tea or green tea with a popularly culture known as a “tea fungus”, at room temperature for about 14 days [1,2].

Kombucha is produced by the fermentation of tea and sugar by a symbiotic association of bacteria and yeasts forming a"tea fungus". It also originated in China where the"Divine Che" was prized 220 BC during the Tsin Dynasty for its detoxifying and energizing properties [3]. In 414, Doctor Kombu brought the tea fungus to Japan from Korea to cure the digestive troubles of the Emperor. "Tea Kvass" was introduced into Russia by oriental merchants and then into Eastern Europe and Europe around the turn of this century.

Kombucha is prepared under aerobic conditions by fermenting sweetened black or green tea with tea fungus. The product is a slightly sweet and carbonated acidic beverage resulting from numerous compounds that are produced by the symbiotic culture

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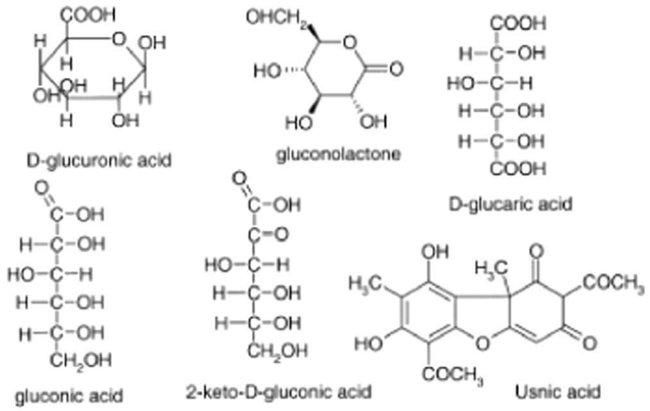

Fig. 1. Chemical structure of some kombucha constituents.

Table 1
Comparison of relevant published results on sucrose fermentation by kombucha.

Refs.	Ferment, conditions		pH	Content of acids (g/L)		
	Day	Sucrose (g/L)		Total	Acetic	L-Lactic
[19]	14	70	2.5	6.9	4.1	–[a]
[8]	15	70	> 2	–[b]	5	> 0.6
[20]	14	70	2.9	–[a]	–[a]	–[a]
[21]	14	95	–[b]	10	8	–[b]
[22]	14	70	2.5	8	5.8 (volatile)	–[a]
[23]	14	70	3.1	13.6	5.6	0.3
[24]	10	70	3.3	2.7	–[a]	–[a]
[25]	15	100	3.3	–[b]	6.2	0.33
[26]	14	70	5.3	1.15	0.53	0.05

[a] Not tested for the presence.
[b] Not available.

of bacteria and yeasts [4,5]. The kombucha fermentation process also leads to the formation of cellulose pellicles floating at the surface of the growth medium, due to the activity of some strains such as *Acetobacter xylinum* [6,7].

To produce kombucha, tea ingredients and sucrose undergo progressive modification by the action of the tea fungus. The main metabolites identified in the fermented beverage are: acetic, lactic, gluconic and glucuronic acids, ethanol and glycerol [4,8]. Some chemical structures of important ingredients reported in kombucha are given in Fig. 1.

It has been reported that the kombucha beverage helps digestion, gives relief from arthritis, acts as a laxative, prevents microbial infections, helps in combating stress and cancer and vitalizes the physical body, etc. It is believed that this beverage enhances immunity [9]. Prevention of microbial infections has been demonstrated against broad spectra of microorganisms, such as *Escherichia coli*, *Helicobacter pylori*, *Staphylococcus aureus*, *Salmonela cholerasius* serotype typhymurium and *Bacillus cereus* [10,11].

Activity of kombucha on the traditional carbon source sucrose was investigated by several authors [5,9,12,13] and main pathways of conversion of sucrose into numerous products were determined. In addition to sucrose, the application of any other sugar (lactose, glucose or fructose) is possible.

Many beneficial effects to the human body can be achieved using substances with antioxidative properties. Substrates for kombucha fermentation contain antioxidants which originated from tea leaves. These are mainly polyphenols, especially catechins, which belong to the flavanols group [14,15]. Beside polyphenols, kombucha beverage contain metabolites, like vitamin C, B2, B6, and catalase, which have a free-radicals trapping ability [16] or can act synergistically with antioxidants like citric acid [17,18].

In this study, the best time for harvesting at acidic level (pH) is reported. Comparison of relevant published results on sucrose fermentation by kombucha has been shown in Table 1.

Energy, economics, and the environment are mutually dependent. Efficient use of energy is one of the principal requirements of sustainable agriculture. Continuous demand in increasing food production resulted in intensive use of energy inputs and natural resources. However, intensive use of energy causes problems threatening public health and environment. Efficient use of energy in agriculture will minimize environmental problems, prevent destruction of natural resources, and promote sustainable agriculture as an economical production system [27]. Economic production is a function of many factors such as human labor, capital, natural resources, availability of energy and technology. Therefore, both the natural resources are rapidly decreasing and the amount of contaminants is considerably increasing. The best way to lower the environmental hazard of energy use is to increase the energy use efficiency [28]. Energy input–output analysis is usually used to evaluate the efficiency and environmental impacts of production systems. It is also used to compare the different production systems.

Energy has a key role in economic and social development but there is a general lack of rural energy development policies that focus on agriculture; since, has a dual role as user and supplier of energy. Energy is a fundamental ingredient in the process of economic development, as it provides essential services that maintain economic activity and the quality of human life. Thus, shortages of energy are a serious constraint on the development of low income countries. Shortages are caused or aggravated by widespread technical inefficiencies, capital constraints and a pattern of subsidies that undercut incentives for conservation [29].

The main objective of this study is to perform the energy and economic analyses of kombucha beverage production. This study is particularly important because there has not been any previous study focusing on energy and cost assessment of kombucha beverage production.

2. Materials and methods

This study is conducted by kombucha beverage production device that has been invented by authors, located in the Tehran province, Iran. Data is collected from a kombucha beverage production device, performed by 23 replications in capacity of 4.5 L during January–December 2014.

In this study in kombucha beverage production, energy inputs are human labor, sugar, water, green tea, kombucha beverage, kombucha fungus and electricity and the energy outputs include kombucha beverage and kombucha fungus.

The energy equivalent of human labor is the muscle power used in field operations of kombucha beverage production where the muscle power is the ability to exert an average energy in 1 h of activities [30]. To aim this, the number of required workers for any particular practice was inquired as well as the working duration for an individual worker. Accordingly, the corresponding energy equivalent was extracted to determine the human labor energy.

Based on the energy equivalents of the inputs and output (Table 2), the surveyed data including various energy and economic indicators can be computed. Specifically, energy ratio (energy use efficiency), specific energy, energy productivity, net energy and energy intensiveness are calculated. For the economic analyses, net profit, gross return, net return, benefit to cost ratio and productivity are also computed.

Table 2
Energy equivalents of inputs and output in kombucha beverage production.

Particulars	Unit energy	Equivalent (MJ unit^{-1})	Refs.
A. Inputs			
1. Human labor	h	1.96	[31]
2. Sugar	kg	15.76	[32–34]
3. Water	L	0.01	[35]
4. Green tea	kg	8.34	[9]
5. Kombucha beverage	L	8.39	[9]
6. Kombucha fungus	kg	6.62	[36]
7. Electricity	kW h	11.93	[37]
B. Outputs			
1. Kombucha beverage	L	8.39	[9]
2. Kombucha fungus	kg	6.62	[36]

Energy demand is divided into direct and indirect energies or renewable and non-renewable energies. Direct energy (DE) covers human labor and electricity, while indirect energy (IDE) includes energy embodied in sugar, water, green tea, kombucha beverage and kombucha fungus used in kombucha beverage production. Renewable energy (RE) consists of human labor, sugar, green tea, kombucha beverage and kombucha fungus, whereas non-renewable energy (NRE) includes water and electricity.

The economic inputs of this system contain expenses of human labor, sugar, water, green tea, kombucha beverage, kombucha fungus, electricity, machinery and rent land. Kombucha beverage, kombucha fungus could be considered as economic outputs.

Basic information on energy inputs and energy outputs is entered into Excel spreadsheets and SPSS 19 spreadsheets. Expressions, such as the energy use efficiency, the energy productivity, the specific energy, the net energy gain and the energy intensiveness were given by Mohammadshirazi et al. [38]. Other expressions stated as energy intensity cost, energy intensiveness value and energy ratio cost, were given by Mohammadshirazi et al. [39]:

$$\text{Energy use efficeincy} = \frac{\text{Output Energy}(\text{MJL}^{-1})}{\text{Input Energy}(\text{MJL}^{-1})} \tag{1}$$

$$\text{Energy Productivity} = \frac{\text{Yield}(\text{kg L}^{-1})}{\text{Input Energy}(\text{MJL}^{-1})} \tag{2}$$

$$\text{Net Energy} = \text{Output Energy}(\text{MJL}^{-1}) - \text{Input Energy}(\text{MJL}^{-1}) \tag{3}$$

$$\text{Energy intensiveness} = \frac{\text{Input Energy}(\text{MJL}^{-1})}{\text{Total production cost}(\$\text{L}^{-1})} \tag{4}$$

Net profit, gross return, net return, benefit to cost (BC) ratio and productivity were calculated by [38]:

$$\text{Grossproductionvalue} = \text{Yeild}(\text{kg L}^{-1}) \times \text{Price of Commodity}(\$\ \text{kg}^{-1}) \tag{5}$$

$$\text{Grossreturn} = \text{Gross production value}(\$\ \text{L}^{-1}) - \text{Variable production cost}(\$\ \text{L}^{-1}) \tag{6}$$

$$\text{Netreturn} = \text{Gross production value}(\$\ \text{L}^{-1}) - \text{Total production cost}(\$\ \text{L}^{-1}) \tag{7}$$

$$\text{BC} = \frac{\text{Gross Production value}(\$\ \text{L}^{-1})}{\text{Total production cost}(\$\ \text{L}^{-1})} \tag{8}$$

$$\text{Productivity} = \frac{\text{Yeild}(\text{kg L}^{-1})}{\text{Total production cost}(\$\ \text{L}^{-1})} \tag{9}$$

Table 3
Energy use pattern for kombucha beverage production.

Quantity (inputs and outputs)	Unit	Quantity per unit volume of kombucha beverage (L)	Total energy equivalent (MJ L^{-1})	Percentage of the total (%)
A. Inputs				
1. Human labor	(h)	0.11	0.21	7.54
2. Sugar	(kg)	0.07	1.13	40.91
3. Water	(L)	0.96	0.01	0.35
4. Green tea	(kg)	0.03	0.24	8.66
5. Kombucha beverage	(L)	0.10	0.80	29.05
6. Kombucha fungus	(kg)	0.02	0.15	5.31
7. Electricity	(kW h)	0.02	0.23	8.19
Total energy input			2.77	
B. Outputs				
1. Kombucha beverage	(L)	1.00	8.39	96.61
2. Kombucha fungus	(kg)	0.04	0.29	3.39
Total energy output			8.69	

Energy intensity cost, Energy intensiveness value and Energy ratio cost were calculated by [40]:

$$\text{Energy intensity cost} = \frac{\text{Total energy cost}(\$\text{L}^{-1})}{\text{Yeild}(\text{kgL}^{-1})} \tag{10}$$

$$\text{Energy intensiveness value} = \frac{\text{Input energy}(\text{MJL}^{-1})}{\text{Gross production value}(\$\text{L}^{-1})} \tag{11}$$

$$\text{Energy ratio cost} = \frac{\text{Total energy cost}(\$\text{L}^{-1})}{\text{Total production cost}(\$\text{L}^{-1})} \tag{12}$$

3. Results and discussion

3.1. Analysis of input–output energy used in the kombucha beverage production

The amounts of energy consumption of input and output for production of kombucha beverage are shown in Table 3. Optimum combination of kombucha beverage inputs comprise green tea 3 g per L water, sugar 75 g per L water, kombucha beverage 100 cc per L water and one kombucha fungus for 1 L kombucha beverage production. At the beginning of the process pH is 3.2 and when the kombucha beverage is harvested, pH meter will show 2.5. It takes 10 to 14 days to complete the kombucha beverage production process [26].

To obtain total energy equivalent of kombucha beverage production, equivalent of input and output (Table 2) is multiplied to quantity per unit volume of kombucha beverage (L) (Table 3). The total energy input and output are calculated as 2.77 and 8.96 MJ L^{-1}, respectively, with the highest contribution of sugar (40.91%), followed by kombucha beverage (29.05%), and green tea (8.66%) (Fig. 1). NER (energy input/energy output) is 0.32 and Rajaeifar et al. [41] have come up with 0.33 for olive oil production. Result revealed that the average sugar energy usage is 1.13 MJ L^{-1}. Energy consumption for kombucha beverage is 0.80 MJ L^{-1} while water energy usage is 0.01 MJ L^{-1}. According to the results, 0.11 h of human labor, 0.07 kg of sugar, 0.96 L of water, 0.03 kg of green tea, 0.10 L of kombucha beverage, 0.02 kg of kombucha fungus and

Table 4
Energy input–output ratio in kombucha beverage production.

Items	Unit	Kombucha beverage
Energy input	MJ L^{-1}	2.77
Energy output	MJ L^{-1}	8.69
Energy use efficiency	–	3.14
Specific energy	MJ kg^{-1}	2.65
Energy productivity	kg MJ^{-1}	0.38
Net energy	MJ L^{-1}	5.92
Energy intensiveness	MJ \$$^{-1}$[a]	2.84
Energy intensity cost	\$ kg^{-1}	0.03
Energy intensiveness value	MJ \$$^{-1}$	2.05
Energy ratio cost	–	0.03

[a] Convert Rial to Dollar [42].

Table 5
Total energy input in the form of direct, indirect, renewable and non-renewable for kombucha beverage production (MJ L^{-1}).

Form of energy (MJ L^{-1})	Kombucha beverage	(%)
Direct energy[a]	0.44	15.73
Indirect energy[b]	2.33	84.27
Renewable energy[c]	2.53	91.47
Non-renewable energy[d]	0.24	8.53

[a] Includes electricity, human labor.
[b] Includes sugar, water, green tea, kombucha beverage, kombucha fungus.
[c] Includes human labor, sugar, green tea, kombucha beverage, kombucha fungus.
[d] Includes water, electricity.

0.02 kW h of electricity, are used for one liter of kombucha beverage production.

The energy use efficiency, specific energy, energy productivity, net energy, energy intensiveness, energy intensity cost, energy intensiveness cost and energy ratio cost of kombucha beverage production, are presented in Table 4.

Energy use efficiency (energy ratio) is calculated as 3.14, showing the inefficiency of input energy in kombucha beverage production. It is shown that the energy ratio can be increased by decreasing energy use, which means that for each MJ of energy consumed to produce kombucha beverage, 3.14 MJ of energy is obtained. The average energy productivity of kombucha beverage is 0.38 kg MJ^{-1} which means that 0.38 unit output is obtained per unit energy. Calculation of energy productivity rate is well documented in the literature such as; orange (0.35) [40], garlic (0.42) [43] and cucumber (0.55) [44]. The specific energy, net energy and energy intensiveness of kombucha beverage production are 2.65 MJ kg^{-1}, 5.92 MJ L^{-1} and 2.84 MJ \$$^{-1}$, respectively. Since the net energy is positive, it is concluded that in kombucha beverage production, energy is saved. Total energy cost is calculated by converting energy input to other commodities such as: barrel of oil and dollar in indices of energy intensity cost and energy ratio cost for production of kombucha beverage. Energy intensity cost, energy intensiveness value and energy ratio cost of kombucha beverage production are 0.03\$ kg^{-1}, 2.05 MJ \$$^{-1}$ and 0.03, respectively. Similar ratios have been reported for different production such as: 0.05\$ kg^{-1}, 4.14 MJ \$$^{-1}$ and 0.01 for orange production [40]; 0.04\$ kg^{-1}, 7.41 MJ \$$^{-1}$ and 0.21 for tangerine production [38].

Total mean energy input for kombucha beverage production as direct, indirect, renewable and nonrenewable forms is illustrated in Table 5. The total energy input consumption could be classified as direct energy (15.7%), indirect energy (84.3%), renewable energy (91.5%) and non-renewable energy (8.5%). For more energy saving use of solar energy and heat energy as electrical renewable energies are recommended.

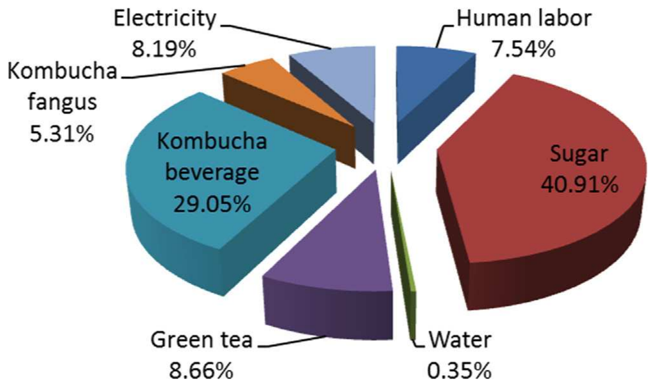

Fig. 2. Distribution of energy use from different inputs in kombucha beverage production.

Table 6
Energy equivalents of inputs and output in kombucha beverage production.

Particulars	Unit energy	Equivalent (\$ unit^{-1})	(\$ L^{-1})	Percentage of the total (%)
A. Inputs				
1. Human labor expense	h	1.66	0.18	18.13
2. Sugar expense	kg	0.81	0.06	5.98
3. Water expense	L	0.00004	0.00004	0.004
4. Green tea expense	kg	1.66	0.05	4.89
5. Kombucha beverage expense	L	1.84	0.18	18.13
6. Kombucha fungus expense	kg	5.53	0.12	12.61
7. Electricity expense	kW h	0.04	0.001	0.09
8. Machinery expense	h	0.00	0.23	23.36
9. Rent land expense	m^2	44.26	0.16	16.82
Total costs			0.97	
B. Outputs				
1. Kombucha beverage	L	1.11	1.11	81.82
2. Kombucha fungus	kg	5.53	0.25	18.18
Total incomes			1.35	

With respect to the obtained results, shown in Fig. 2, shares of energy consumption in kombucha beverage production consist of 40.9% sugar, 29% kombucha beverage, 8.7% green tea, 8.2% electricity, 7.5% human labor, 5.3% kombucha fungus and 0.3% water. The results reveal that consumption of sugar, kombucha beverage and green tea; are the highest energy input for kombucha beverage production.

3.2. Economic analysis of kombucha beverage production

Input costs for kombucha beverage production are presented in Table 6 and Fig. 3. Total cost and total income are 0.97\$ L^{-1} and 1.35\$ L^{-1} for kombucha beverage production, respectively. By increasing volume of kombucha beverage production device, input costs will decrease because of proration costs. Increasing device volume causes reduction of kombucha fungus, electricity, machinery and rent land expense. The highest share of cost is machinery with 23.36%, and the second and third highest costs are for human labor and kombucha beverage each with 18.13%.

Economic analysis of kombucha beverage production is shown in Table 7. According to the results of the research, the total expenditure for kombucha production is 0.97\$ L^{-1} while the gross production value is found to be 1.35\$ L^{-1}. About 40% is fixed expenditures (machinery expense and rent land expense),

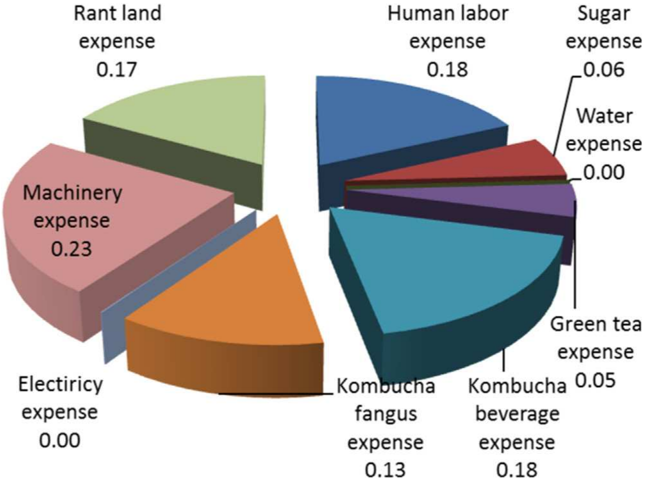

Fig. 3. Distribution of expenses use from different cost inputs in kombucha beverage production.

Table 7
Economic analysis of kombucha beverage production.

Cost and return components	Unit	Value
Gross production value	$\$ L^{-1}$	1.35
Variable production cost	$\$ L^{-1}$	0.58
Fixed production cost	$\$ L^{-1}$	0.39
Total production cost	$\$ L^{-1}$	0.97
Total production cost	$\$ kg^{-1}$	0.93
Gross return	$\$ L^{-1}$	0.77
Net return	$\$ L^{-1}$	0.38
Benefit to cost ratio	–	1.39
Productivity	$kg \$^{-1}$	1.03

whereas 60% of the total expenditure is variable costs which comprises other expenses. Based on these results, the gross return, net return, benefit to cost ratio, productivity from kombucha beverage production are calculated as 0.77$ L^{-1}, 0.38$ L^{-1}, 1.39 and 1.03 kg $\$^{-1}$, respectively. Other researchers have reported similar results on benefit to cost ratio, such as: 2.11 for olive oil [41], 1.68 for greenhouse cucumber, 3.28 for greenhouse tomato [45], 1.4 for orange [40] and 1.62 for tangerine [38].

4. Conclusions

Based on the presented paper, the following conclusions are drawn:

1. Optimum combination of kombucha beverage inputs comprise green tea 3 g per L water, sugar 75 g per L water, kombucha beverage 100 cc per L water and one kombucha fungus for 1 L kombucha beverage production. At the beginning of the process pH is 3.2 and when the kombucha beverage is harvested pH will be 2.5 that pH is measured by pH meter.
2. The total energy consumption in kombucha beverage production is 2.77 MJ L^{-1}. Sugar (40.9% of total energy) is found to be the most energy consuming commodity among all energy sources. Within the total energy inputs, the energy input of kombucha beverage and green tea has the secondary and tertiary share. Energy output is calculated as 8.69 MJ L^{-1} in which indirect (2.33 MJ L^{-1}) and renewable (2.53 MJ L^{-1}) energies are rather high, accordingly. To reduce the total energy input, since jam energy is lower than sugar energy, it is recommended that in the process jam is used rather than sugar.
3. Energy use efficiency, energy productivity, specific energy, net energy and energy intensiveness of kombucha beverage production are 3.14, 0.38 kg MJ^{-1}, 2.65 MJ kg^{-1}, 5.92 MJ L^{-1}, and 2.84 MJ $\$^{-1}$; respectively.
4. The total cost and total income are 0.97$ L^{-1} and 1.35$ L^{-1}, respectively. By increasing volume of kombucha beverage production device, input costs (kombucha fungus, electricity, machinery and rent land expense) will decrease because of proration costs. The highest share of cost input is machinery with 23.36% of total cost followed by human labor (18.13%) and kombucha beverage (18.13%).
5. According to the results of this research, the total expenditure for the production is 0.97$ L^{-1} while the gross production value is found to be 1.35$ L^{-1}. Based on the result of economic analysis of kombucha beverage production, the benefit-cost ratio is found to be 1.39. The net return and productivity from kombucha beverage production is obtained as 0.38$ L^{-1} and 1.03 kg $\$^{-1}$, respectively.

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