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A new approach to automation of black tea fermentation process with electronic nose

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ABSTRACT

Manufacturing of black tea is a complex process consisting of plucking, withering, curling, fermenting, drying, determining of quality, and packaging stages. Nowadays, tea quality is determined by two methods. Either chemical analysis method is used or tea tasters give quality scores by tasting, smelling, and visual inspection. By means of recent studies, tea quality can also be determined by electronic nose technology. The quality of tea is generally related with the fermentation stage. In this work, an electronic nose, which determines the quality of tea during the fermentation process in real time from only its odour, was made, and the fermentation band was controlled by this electronic nose. Fermentation bands of a tea factory in the Çayeli District of Rize, Turkey have been simulated and controlled via LabVIEW simulation software by using real odour values measured in the factory with the electronic nose. In the study, a new fermentation band system has been designed to function with the electronic nose. This section of the study has been performed in the simulation environment due to the high cost of physical system setup. With the method proposed in this study, tea factories will be able to increase their production capacity with higher quality.

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KEYWORDS
Black tea production; electronic nose; black tea quality classification; fermentation band automation

1. Introduction

Tea is the most consumed beverage in the world after water and there are six types of processed tea today: namely green, black, oolong, yellow, dark and white teas [1]. Black tea is the most consumed tea comprising 78% of total tea consumption [2].

In black tea manufacturing, required processes are performed in the following order: picking up leaves from (tea) trees, the withering of plucked tea leaves, breaking faded tea leaves into small pieces by heavily rolling (curling), fermenting curled leaves by exposing into water vapour, drying fermented wet leaves [3]. Black tea manufacturing is completed after these processes and then, the tea is named as "finished tea". To obtain the commercial product, tea has to be packaged. Tea companies sell teas according to their quality. Therefore, finished teas are classified into groups according to their quality before packaging.

The quality of finished tea is determined by chemical analysis [4] or experts' (tea taster) tasting [5]. Quality is generally determined by human test panels in tea factories due to the high cost and time consumption of chemical analysis.

An electronic tongue is a new device to determine the quality of black tea, and electronic visualization is also a new method for classifying tea quality [6,7]. Besides, an electronic nose (e-nose) is another new technology for classifying foods [8–10] and beverages [11,12] by quality.

A number of studies have been made on the classification of tea quality with e-nose. In one study, black tea that had previously been classified according to its quality based on tea tasters' marks was classified with an electronic nose by putting 0.3 ml fermented tea in a 100 ml sample box during fermentation and generating a headspace [13,14]. The same researchers conducted another study in which they put 50 g of fermented tea in a sample box, and they obtained a more than 90% classification rate by using 60% training and 40% testing of all data [15].

An electronic nose was made to directly determine the quality of black tea during the fermentation process without using a sample box in this study. Firstly, tea samples whose odours were sniffed by the e-nose have been sorted into three subgroups as low–medium–high quality according to tea tasters' scores, and they were classified with 75% accuracy using 50% training data and 50% testing data with the kNN-3 classification method [16]. Secondly, the same tea samples were sorted into the same subgroups according to the results of chemical analysis, and they were classified with 74.19% accuracy [17]. Afterwards, a new fermentation line working via decision of e-nose that can detect the quality of black tea according to results of the chemical

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analysis in real time was built. This paper suggests a new approach for black tea manufacturing in tea factories by classifying tea quality in real time.

2. Production of black tea

Black tea manufacturing is a hierarchical process consisting of plucking, withering, rolling (curling), fermenting, and drying stages. Fresh tea leaves are plucked from tea plants in three, or sometimes four, flushing periods in Turkey.

Plucked tea leaves are withered for 6–8 h by blowing hot air until their humidity decreases to 60–65%. It is much more quickly than withering naturally. After that, withered leaves are broken into small pieces by rolling for 45 min. Meanwhile, fermentation (oxidation) starts when the leaves crumble in the curling process. Fermentation process continues by sending hot water vapour to broken leaves from the bottom of a perforated band. This process continues 2 h and 15 min traditionally in tea factories in Turkey.

In the factory where this study was carried out, the fermentation temperature and humidity were tried to be maintained at 25–30°C and 90–95%, respectively, to provide ideal fermentation conditions.

A number of factors effect black tea quality; such as the soil in which tea trees grow, amount of rain fall throughout a year, altitude, ambient temperature, and plucking, withering, curling, fermenting, drying processes. However, the fermentation stage is one of the most important stages in determining black tea's quality [18,19].

Due to the different characteristics mentioned above, the ideal fermentation time of each tea varies. However, because of the impossibility of determining the quality of black tea during the fermentation process with the current technology, it has been determined by experience that the most suitable fermentation time is 2 h and 15 min after 45 min of curling process.

The current flowchart and the production flow diagram of the factory where this study was carried out are shown in Figure 1(a,b), respectively.

The quality of tea cannot be monitored during fermentation in the present production method; it can only be determined in the finished tea.

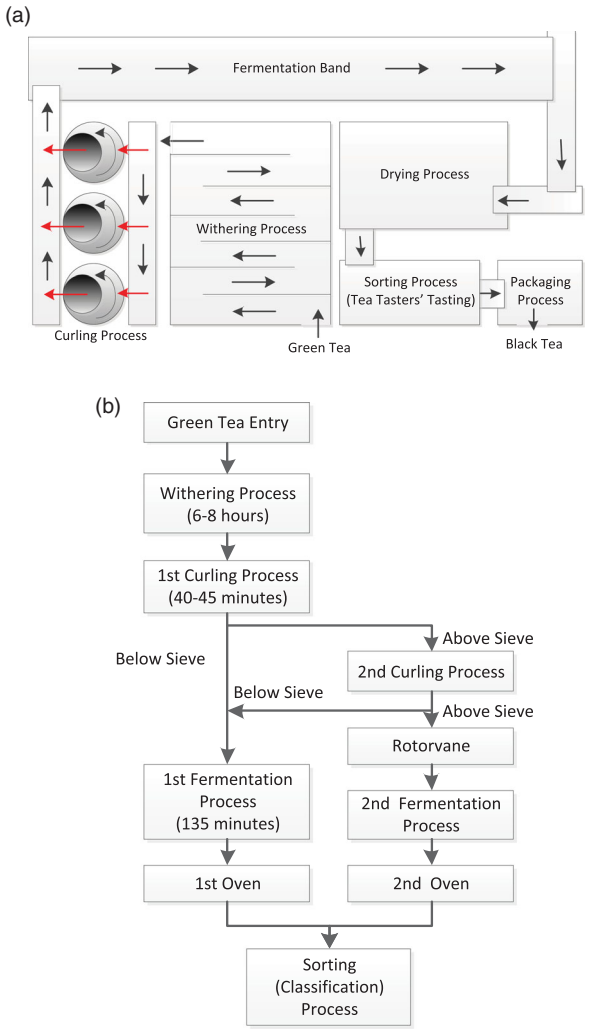

Figure 1. (a) The flowchart of the present production method in tea factories. (b) Flow diagram of production of black tea.

3. Quality classification and electronic nose

Quality analysis is generally done with tea tasting because of the costliness and difficulty of time-consuming chemical analysis.

The quality of black tea is determined by the experts called "Tea Tasters" in the tea factories by looking at the taste of infused tea samples, which are infused with certain standards. "Tea Tasters" in Turkey express the quality of tea with a score of 0–20. Tea tasting is done for two purposes. The first is the tasting of tea samples taken at regular intervals (10–15 min) from the oven during production. Thus, by commenting about production, some necessary interventions, such as increasing or decreasing humidity or temperature of fermentation, can be made on the production lines. The second tea tasting is done after the drying process for the purpose of classification. By this means, quality levels of teas are determined, and they are packed according to their quality levels by making the necessary blending.

In black tea, 5–12% of flavonoids, which provide the antioxidant properties of tea, are theaflavin (TF) and 63–72% of them are thearubugins (TR) [20]. In the chemical analysis method, the quality of black tea is determined by calculating the ratio of theaflavins to thearubigins (TF/TR) in infused tea. This ratio is accepted worldwide as 1:10 for the ideal black tea [21], but it is lower due to plucking standards in Turkey [22]. The chemical analysis is more objective compared to tea taster's analyses. However, chemical analysis is quite costly and more difficult to determine the quality of finished black tea.

Nowadays, the electronic nose method also can be used for determining the quality of black tea. The

electronic nose is a system that recognizes the odours previously introduced to it. It consists of an electronic circuit which converts the gas information into electrical information via its chemical gas sensor array (sensor unit) and a software that interprets this information with its prepared algorithm.

In this study, 13 Figaro (Figaro Engineering, Inc.) gas sensors, which can be purchased commercially, were used to generate the sensor block. Only 5 of these 13 gas sensors which have 14 outputs reacted to the black tea fermentation odour. TGS-826, TGS-2104, TGS-2201-I output, TGS-2602, and TGS-2620 sensors reacted to the tea odour, and the data of these sensors have been used for classification. The sensor list and their detection ranges, which are obtained from sensor datasheets, are given in Table 1.

The sensor block and odour capturing system (hardware schematic of the e-nose system), which were used in this study, are shown in Figures 2 and 3, respectively.

Odour was converted to electrical signals through the use of gas sensors, and these signals were transmitted to a computer by converting it to data via a DAQ card.

Table 1. The sensors which were used.

Model	Target Gas	Range (ppm)
TGS 813–A00	Combustible Gases, HC	500–10,000
TGS 825	Hydrogen Sulphide	5–100
TGS 826	Ammonia/Amine/Odour	30–300
TGS 830	Chlorofluorocarbons	200–3000
TGS 880	Ethanol	50–300
TGS 2104	Carbonmonoxide(CO), hidrogen(H_2)	10–100
TGS 2180	Methane, hydrogen, ethanol	1–150 (g/m^3)
TGS 2201 (dual sensor element)	1. Output 1: NO, NO_2,	1–30
	2. Output 2: CO, H_2, HC	0.3–0.7
TGS 2602	Hydrogen, ethanol, ammonia, toluene	1–30
TGS 2610-D00	Propane, Butane, LPG	300–10,000
TGS 2611-C00	Methane, Natural Gas	300–10,000
TGS 2620	Alcohol, Organic Vapour	50–10,000
TGS 5042	Carbon Monoxide (CO)	0–10,000

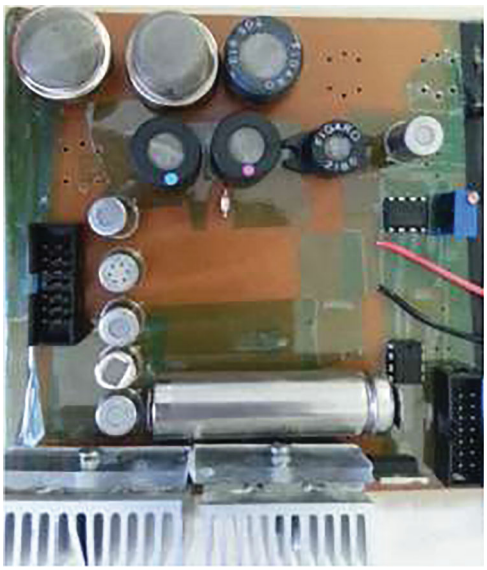

Figure 2. Sensor block of e-nose.

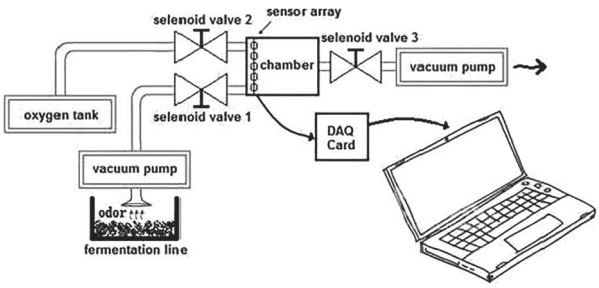

Figure 3. Odour capturing system.

The smell of tea was sniffed from 10 cm above the 25 cm height of the tea on the fermentation band, which has a 1.80 m width, a 30 m length, and a 1 m side wall height.

Teflon tubes were used in the e-nose system to prevent previous odours from influencing next odour. Oxygen, taken from an oxygen tank, was used to clean the sensors' data with the aim of capturing the same reference value in all cycles. The capture of different values due to a difference in ambient air at different times has therefore been prevented.

A sniffing cycle, which is shown in Figure 3, takes 60 s in total and a flow chart of this cycle is described in Figure 4.

The classification of data, which was gathered from sensors to a computer, is made by algorithms and takes very short periods of time, such as 1 or 2 s. These algorithms compare the data with data which were introduced to the computer beforehand by extracting some eigenvalues. Thus, the quality of the tea is determined from the smell of the tea.

In the study, a total of 64 different tea odours in 8 different fermentation cycles were recorded on a computer, and 200 g samples of these teas were obtained by drying immediately.

Process time	Process
10 second	Sensor Cleaning Process: Sensors' data were cleaned with oxygen for 10 seconds. Selenoid valve 1 was closed and selenoid valves 2 and 3 were opened.
30 second	Sniffing Process: Tea smell was transmitted to the sensor block by vacuum pumps. Selenoid valve 2 was closed and selenoid valves 1 and 3 were opened.
10 second	Odor Locking Process: The tea smell, which was filled to the smell chamber for 30 seconds, was kept in this room for 10 seconds by closing the entrance and exit of the room, against the possibility of the sensor's late reacting. All valves were closed.
10 second	Sensor Cleaning Process: This process was done the same with first cleaning process.

Figure 4. Flow chart of a sniffing cycle of the e-nose.

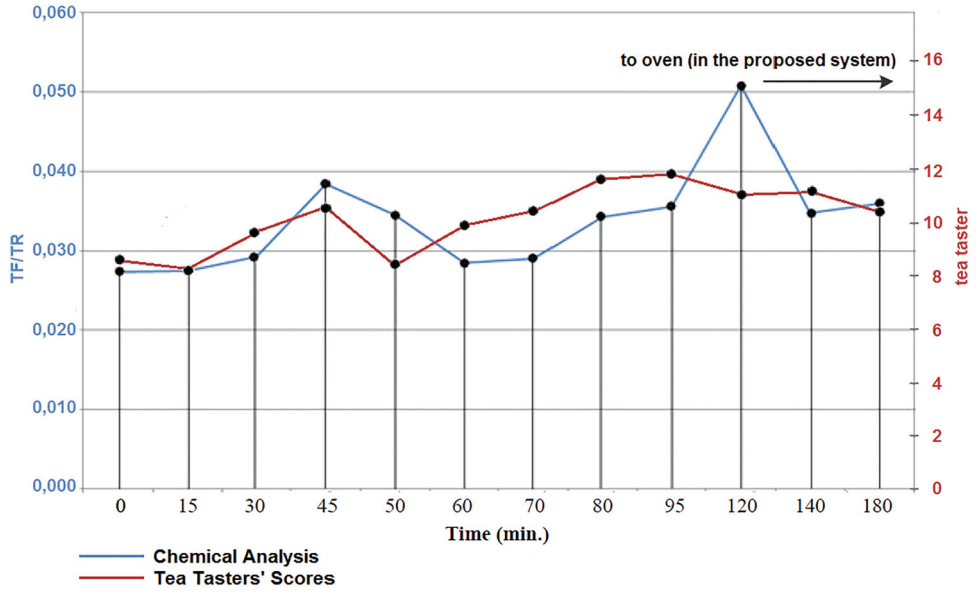

Figure 5. Superposition of TF/TR ratios and tea tasters' average scores.

Later on, to determine qualities according to two different methods, these teas were tasted by eight different tea tasters, and chemical analyses were performed.

The average of the tea tasters' scores and chemical analysis results were superposed on the same graph in Figure 5 for one fermentation period of tea.

Although the decrease and increase of the quality are not on the same slope, there is a general harmony on the graph in which teas' quality lowered and which teas' quality rose. Only in a few samples, chemical analysis expressed a high score while the average of tea tasters' scores specifies a medium or low score.

Similarly, the quality scores given by 8 different tea tasters were generally consistent, but it is seen that sometimes very contrasting quality scores can be given. For example, one of the tea tasters gave a score of 17, which is the highest of all given by the tea tasters, to a tea sample in 64 samples, while another taster gave the lowest tasting score of 7 to the same tea sample. It shows that although tea tasters are trained, sometimes the understanding of quality is relative to the person. A device which is made for this job, will always give the same result.

Sixty-four tea samples were sorted into three subgroups according to their TF/TR ratios. Groups are shown in Table 2.

The MATLAB software package has been used for classification. Half of the samples were used as training data, and the other half were used as test data.

The LDA, Bayes, and KNN-3 methods were used for classification. The KNN-3 method has given the best classification accuracy with 74.19% between these methods [17].

Table 2. The quality groups of tea samples.

Quality	TF/TR Ratio	No of Samples
Low quality	0.026–0.035	24
Medium quality	0.035–0.039	21
High quality	0.039–0.051	19

4. Simulation of the production system

In the current production, fermentation is being carried out according to a traditional duration, not to quality. That is because there is no technology which can determine the quality during the course of the fermentation process. In the factory where current work was carried out, this duration was taken as 2 h and 15 min.

With the e-nose system used in this study, tea quality can be determined from only its smell during fermentation in real time. Consequently, a tea that reaches a high level of quality at any time during the fermentation will not have to ferment for 2 h and 15 min. However, in the current fermentation band system, e-nose won't interfere with the tea even if it is detected to have high quality due to the teas that are in front of and behind it.

Since the quality of tea can now be determined by only its odour during fermentation, it is believed that instead of a single and long fermentation band, a lot of short bands would be much more useful in terms of system intervention.

It is also hard to keep the temperature and humidity values of a long fermentation band at the desired values, because when the new tea doesn't come from the curling process to the fermentation band, the entry of fermentation band will be empty. Therefore, the hot steam which provides the fermentation by penetrating to the tea from under the band will escape from this empty part of the band. This situation prevents the fermentation of tea, which has to continue to the fermentation to get the desired quality. A fermentation band with an empty entrance is shown in Figure 6.

Thus, fermentation bands that are independent from each other were designed. In a designed system, all

Figure 6. A fermentation band without curled tea in its entrance during the fermentation process.

e-noses sniff the bands for every 5 min, consecutively. They determine the band's tea quality, and the system sends the tea to the suitable drying process based on its defined quality. By this way, the factory can produce higher quality tea with a higher manufacturing capacity. The new system for the fermentation process proposed in this study is shown in Figure 7.

Thus, only an empty fermentation band's temperature and humidity will change when the band isn't fed by the curling unit. The temperature and humidity values of the other fermentation bands will not change, and the quality of all teas will not be negatively affected.

The proposed system has been simulated in LabVIEW. A screen shot of the LabVIEW interface is shown in Figure 8. In the simulation, each band has its own fermentation duration, temperature, and humidity value. The tea in a band will only be evaluated according to its own quality, and the tea will be produced at the best quality possible which can be caught. In the simulation system, the temperature and humidity values of the bands are kept in the desired range. The actual information about the quality of tea and the continuous process information about the band are given in the information lines on the bottom-right corner of the screen.

In this system, the tea brought from 45 min of curling, will not be fermented for 2 h and 15 min in the fermentation band standardly. It will be sent to the high-quality oven when the quality reaches a high level. As a result of evaluations done with tea tasters, the following comments were made about the fermentation process of tea which is sniffed by e-nose:

- If the quality is high, the tea will be immediately sent to the high-quality oven and the fermentation for

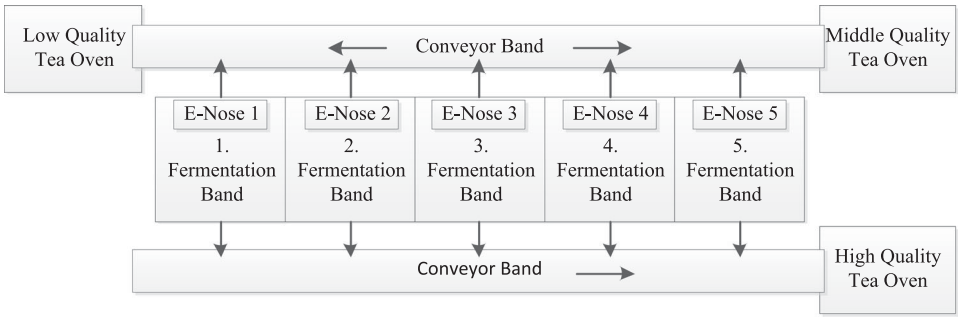

Figure 7. Proposed fermentation system.

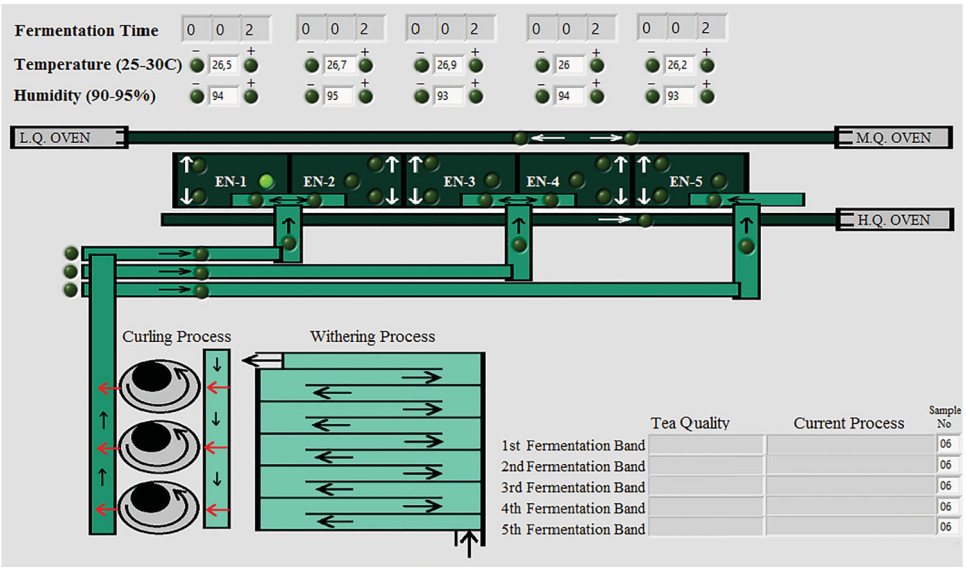

Figure 8. Simulation interface while e-nose-1 is sniffing.

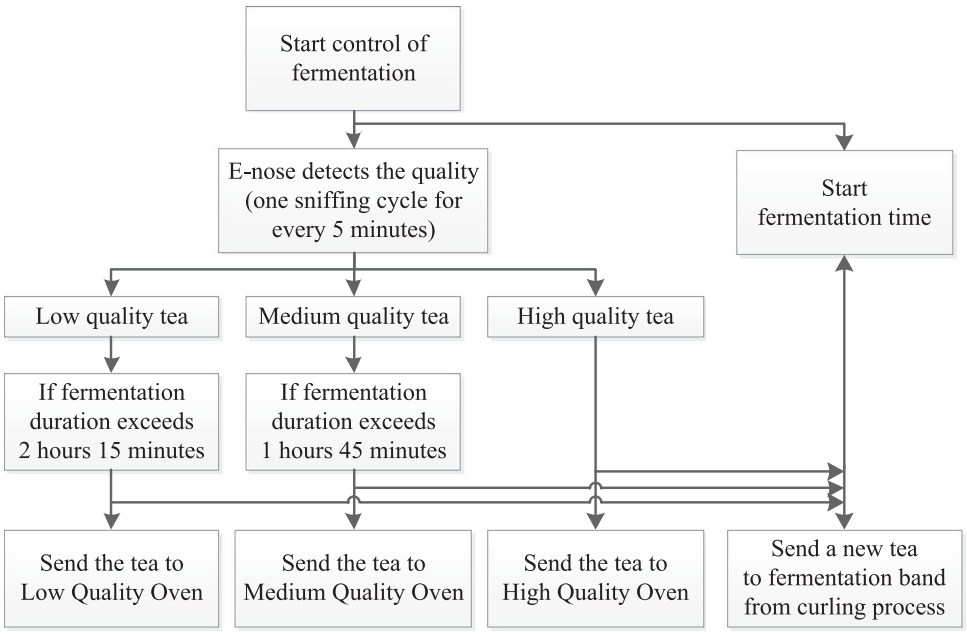

Figure 9. Flow diagram of proposed fermentation system.

this band will be restarted by sending new tea from the curling unit to this fermentation band.

- If the quality is medium, the duration of fermentation will be considered. Fermentation will continue if 1 h and 45 min has not been exceeded, in order to potentially increase the quality level. If 1 h and 45 min has been exceeded, the total fermentation time of 2 h and 15 min will not be expected against the possibility of decreasing the quality, and medium quality tea will be sent to the medium quality oven. At the same time, a new fermentation cycle starts by sending tea to the fermentation band from the curling unit.
- If the quality is low, the fermentation time is checked again. Fermentation will continue if the period has not exceeded 2 h and 15 min. Fermentation will continue due to the potential of increasing the quality, because the quality is already at the lowest level. If the time has exceeded 2 h and 15 min, the tea is not fermented after that, and it is not allowed to spoil because of over fermentation. The tea will be sent to the low-quality oven, and new tea will be sent from the curling unit to the empty band.

A flow chart of the proposed system is given in Figure 9.

In the simulation study, a new sniffing process was not performed by the e-nose on the fermentation band. The data of 64 samples were used. This information is entered during the fermentation separately for each band from the bottom-right corner of the screen. The numbers 06, 24, and 22 were used for data entries of low-, medium-, and high-quality teas, respectively.

System operations for low-, medium-, and high-quality teas are shown in Figure 10(a–c), respectively.

In the simulation system which is shown in Figure 10(a), the information for 06-numbered low-quality tea was entered for the 1st, 2nd, and 3rd fermentation bands, and the information for 24-numbered medium quality tea was entered for the 4th and 5th fermentation bands. The tea in the 1st fermentation band has been fermented for 10 min, and it is of low quality. The quality of tea may increase, and the fermentation process is in progress. The tea in the 2nd fermentation band was evaluated as low-quality tea, after 2 h and 17 min of fermenting with control of the e-nose in every 5 min. When tea quality was determined again as low just after the limit of the longest fermentation, the tea has been sent to the low-quality oven. The tea in the 3rd fermentation band has been fermented for 21 min and is of low quality, so the fermentation process is ongoing. The tea in 4th fermentation band has been fermented for 32 min and is of medium quality. It's fermentation process is continuing in order to potentially increase quality. The tea in the 5th fermentation band has been fermented for 23 min and is of medium quality. The fermentation process is ongoing.

In Figure 10(b), the tea in 4th fermentation band was evaluated as medium quality. The tea in this band has been fermented for 1 h and 52 min. Quality was expected to increase up until the last half hour (1 h and 45 min) of the traditional fermentation time, but when the last half hour was reached, the resultant medium quality was not risked, and the tea has been sent to the medium quality oven.

The fermentation temperature of the 2nd fermentation band was measured as 31°C, and the cooling process has been started. The humidity of the 3rd fermentation band was measured as 98%, and the output which reduces the band humidity has been activated.

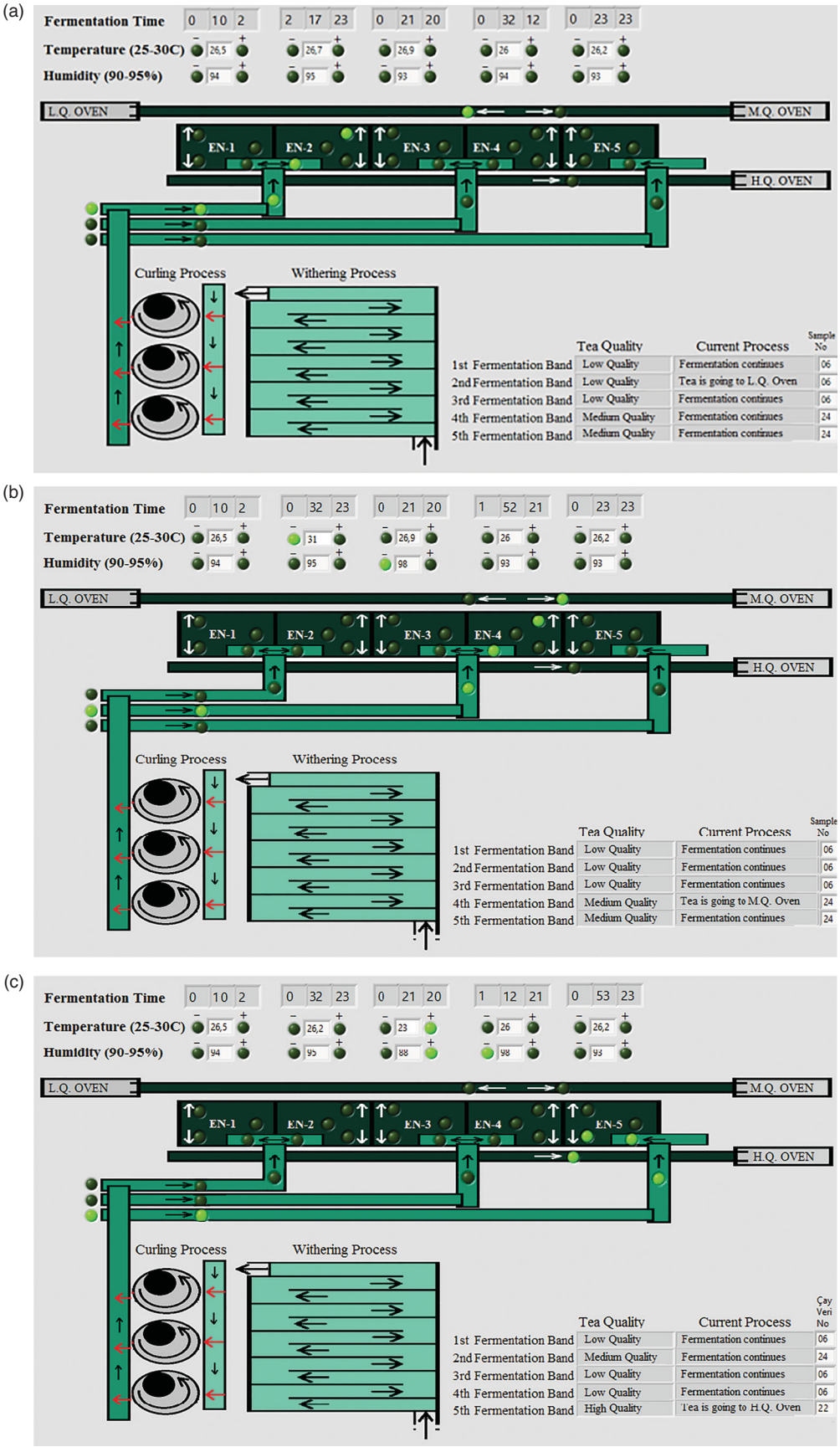

Figure 10. (a) Processing of low-quality tea. (b) Processing of medium quality tea. (c) Processing of high-quality tea.

In Figure 10(c), the information for 06-numbered low-quality tea was entered for the 1st, 3rd, and 4th fermentation bands, the information for 24-numbered medium quality tea was entered for the 2nd fermentation band, and the information for 22-numbered high quality tea was entered for the 5th fermentation band. The tea in the 5th fermentation band was evaluated as high quality at the 53rd minute

of fermentation and has been sent to the high quality oven irrespective of the time. The fermentation temperature of the 3rd fermentation band was measured as 23°C, and the heating process has been started. Also the humidity was measured as 88%, and the input which increases the band humidity has been activated. The humidity of the 4th band was measured as 98%, and the reduction process has been started.

5. Results and discussion

In the current black tea production system, after the withering process, the green tea leaf is curled for 45 min. Then, the curled tea is fermented with hot vapour for 2 h and 15 min, and finally, the fermented wet tea is dried. Black tea is manufactured without any idea about quality. The quality of the finished tea is determined by tea tasters' tasting or the chemical analysis method, and these teas are packed after the necessary blending process according to their qualities.

The quality evaluation of tea fermentation for 3 h after 45 min of the curling process is shown in Figure 5. In the current method, when the results of the chemical analysis are taken into account, tea has to be sent to the oven as a medium quality tea with a TF/TR ratio of 0.04 at the end of 135 min. In the proposed system, it will be sent to the oven as a high-quality tea with 0.05 TF/TR ratio at the 120th minute.

By the recommended method:

- The manufacturing process is controlled to increase the quality. Tea is not manufactured at which quality that it reaches at the end of the 2 h and 15 min. It is manufactured at medium quality, if it can't reach to high quality. It is manufactured at the low quality in the worst case scenario. More amount of high-quality black tea will be manufactured with the same amount of green tea entry.
- Instead of waiting 2 h and 15 min for the whole fermentation process in the fermentation band, the tea will sometimes leave the band earlier. By this means, new tea fermentation will be started on that band and the factory will be able to produce a greater amount of black tea in the same period.
- At the end of the fermentation process, the quality of the tea will not be an enigma, the tea will come out of production with the best possible and identified quality level via e-nose and so the work load of the factory will be reduced.

By controlling the temperature and humidity of each fermentation band separately, ideal fermentation conditions will be provided, and better quality tea will be produced. In addition, when new tea doesn't come from the curling unit, the steam of the fermentation band will not escape. Thus, wastefulness will be prevented, and the quality of other teas on the band will not be affected.

6. Conclusion

In the present system, the quality level of manufactured black tea is not known. The same fermentation process is carried out on all teas for 2 h and 15 min. The tea is then dried, and the quality of the tea is determined by the tea taster.

In the proposed system, the e-nose will detect the quality during manufacturing and will operate the system accordingly, keeping the tea quality at the highest level possible. In this way, higher quality tea will be manufactured and the manufacturing capacity will increase.

In addition, since teas having different qualities are dried in different ovens, tea sorting work will be made much easier in the future.

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Disclosure statement

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References

[1] Weerawatanakorn M, Hung W-L, Pan M-H, et al. Chemistry and health beneficial effects of oolong tea and theasinensins. Food Sci Hum Wellness. 2015 Dec;4(4):133–146.
[2] Vuong QV, Roach PD. Caffeine in green tea: its removal and isolation. Sep Purif Rev. 2014 Apr;43(2):155–174.
[3] Łuczaj W, Skrzydlewska E. Antioxidative properties of black tea. Prev Med. 2005 Jun;40(6):910–918.
[4] Hazarika M, Chakravarty SK, Mahanta PK. Studies on thearubigin pigments in black tea manufacturing systems. J Sci Food Agric. 1984 Nov;35(11):1208–1218.
[5] Liang Y, Lu J, Zhang L, et al. Estimation of black tea quality by analysis of chemical composition and colour difference of tea infusions. Food Chem. 2003 Feb;80(2):283–290.
[6] Palit M, Tudu B, Dutta PK, et al. Classification of black tea taste and correlation with tea taster's mark using voltammetric electronic tongue. IEEE Trans Instrum Meas. 2010 Aug;59(8):2230–2239.
[7] Akuli A, Pal A, Ghosh A, et al. Estimation of theaflavins (TF) and thearubigins (TR) ratio in black tea liquor using electronic vision system. AIP Conf Proc. 2011;1362:253–254.

[8] Rajamäki T, Alakomi H-L, Ritvanen T, et al. Application of an electronic nose for quality assessment of modified atmosphere packaged poultry meat. Food Control. 2006 Jan;17(1):5–13.
[9] Di Natale C, Macagnano A, Martinelli E, et al. The evaluation of quality of post-harvest oranges and apples by means of an electronic nose. Sens Actuators B Chem. 2001 Aug;78(1–3):26–31.
[10] Ghasemi-Varnamkhasti M, Mohtasebi SS, Siadat M, et al. Meat quality assessment by electronic nose (machine olfaction technology). Sensors. 2009 Jul;9(8): 6058–6083.
[11] Di Natale C, Davide FAM, D'Amico A, et al. An electronic nose for the recognition of the vineyard of a red wine. Sens Actuators B Chem. 1996 Jul;33(1):83–88.
[12] García M, Aleixandre M, Gutiérrez J, et al. Electronic nose for wine discrimination. Sens Actuators B Chem. 2006 Feb;113(2):911–916.
[13] Bhattacharyya N, Seth S, Tudu B, et al. Detection of optimum fermentation time for black tea manufacturing using electronic nose. Sens Actuators B Chem. 2007 Mar;122(2): 627–634.
[14] Bhattacharyya N, Seth S, Tudu B, et al. Monitoring of black tea fermentation process using electronic nose. J Food Eng. 2007 Jun;80(4):1146–1156.
[15] Bhattacharyya N, Bandyopadhyay R, Bhuyan M, et al. Electronic nose for black tea classification and correlation of measurements with 'tea taster' marks. IEEE Trans Instrum Meas. 2008 Jul;57(7):1313–1321.
[16] Tozlu B, Okumus HI, Simsek C. Online quality classifying with electronic nose for black tea production. Int J Acad Res. 2014 Jul;6(4):158–163.
[17] Tozlu B, Okumus HI, Şimşek C, et al. On-line monitoring of theaflavins and thearubigins ratio in Turkish black tea using electronic nose. Int J Eng Appl Sci. 2015 Dec;7(5):40–49.
[18] D Costa WAJM, Mohotti AJ, Wijeratne MA. Ecophysiology of tea. Braz J Plant Physiol. 2007 Dec;19(4): 299–332.
[19] Emdadi L, Nasernajad B, Shokrgozar ST, et al. Optimization of withering time and fermentation conditions during the manufacture of black tea using a response surface methodology. Trans C Chem Chem Eng. 2009 Jun;16(1):61–68.
[20] Higdon JV, Frei B. Tea catechins and polyphenols: health effects, metabolism, and antioxidant functions. Crit Rev Food Sci Nutr. 2010 Jun;43(1):89–143.
[21] Venkatesan S, Senthurpandian VK, Murugesan S, et al. Quality standards of CTC black teas as influenced by sources of potassium fertiliser. J Sci Food Agric. 2006 Apr;86(5):799–803.
[22] Tüfekci M, Güner S. The determination of optimum fermentation time in Turkish black tea manufacture. Food Chem. 1997 Sep;60(1):53–56.