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Comprehensive characterization in different types of tartary buckwheat tea based on intelligent sensory technology

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Abstract

As an alternative type of tea product, tartary buckwheat tea (TBT) has become popular in the current market because of its rich taste, natural healthiness and convenience of use. Because sensory evaluation is easily affected by the individual differences and external factors that affect human assessors, the present study used intelligent sensory systems (electronic nose, electronic tongue and electronic eye) to analyze different types of TBT to establish a scientific basis for its quality characteristics. Results showed that obvious differences in color, aroma and taste were found among the different types of teas. The taste differences in the TBT were mainly acquired by the CTS sensor (saltiness) and ANS sensor (sweetness), with the greatest number of volatile substance was detected in the whole plant tea. Overall, intelligent sensory technology could accurately evaluate TBT thus providing the capability to meet the needs of different types of consumers and of different occasions.

Keywords: tartary buckwheat tea; electronic nose; electronic tongue; electronic eye.

Practical Application: This study uses intelligent sensory technology to evaluate the color, taste and flavor of different types of tartary buckwheat tea, thus providing a scientific basis for upgrading these tea products and for satisfying the different requirements of consumers who drink TBT.

1 Introduction

Buckwheat is an annual or perennial dicotyledonous herb of the Polygonaceae family. Its rapid growth, short growth cycle and wide adaptability has given it a special role as a cover crop and for its gluten-free grain composition (Huda et al., 2021). Buckwheat has been cultivated for more than 2000 years, with the main cultivated species, common buckwheat (*Fagopyrum esculentum* Moench.) and tartary buckwheat (*Fagopyrum tataricum* Gaertn.), being widely distributed in countries such as Russia, China, Ukraine, France and Poland (Zhang et al., 2021). Buckwheat contains not only nutritive components (such as starch, protein, dietary fiber, minerals) but also many active substances (such as rutin and quercetin) (Bai et al., 2015; Huda et al., 2021). Its high contents of nutritional and active ingredients means that buckwheat is considered a naturally healthy crop resource that integrates nutrition with good health (Giménez-Bastida & Zieliński, 2015; Zhu, 2016). Modern medical research has revealed that buckwheat and its products can scavenge free radicals, delay aging, and enhance human immunity, with certain adjuvant treatment effects on diabetes, hyperlipidemia and coronary heart disease (Peng et al., 2019; Yao et al., 2020b). Compared with common buckwheat, tartary buckwheat contains more active compounds, such as flavonoids, which has attracted widespread attention as a raw material to include in a healthy diet (Guo et al., 2017; Li & Zhang, 2001).

Tartary buckwheat is still one of the staple foods in many ethnic minority areas with the mountainous alpine areas of China. As society's concepts of health and understanding of the nutritional and health value of tartary buckwheat have increased, the nutrition and health benefits of tartary buckwheat and its processed products have made it increasingly popular. As modern food processing technology and equipment, including tartary buckwheat processing technology, has developed, the number of tartary buckwheat products has increased and its range has diversified (Giménez-Bastida & Zieliński, 2015). As well as various traditional handmade snacks, tartary buckwheat foods mainly consist of rice noodle products, snack foods, drinks, vegetables and other types of products. In recent years, interest in tartary buckwheat tea (TBT) has also increased because of its health benefits and convenience. Unlike traditional tea products (green teas and black teas), TBT is strictly a grain tea, a substitute tea made from tartary buckwheat seeds and other raw materials (Qin et al., 2013; Tang et al., 2019; Zhou et al., 2022). Total flavonoid content in the tea infusion of TBT, which is rich in flavonoids, can be used as a source of rutin in the human diet (Xu et al., 2019b). Previous studies have reported that the long-term consumption of TBT can induce the activity of a hepatic drug-metabolizing enzyme (Zou et al., 2016). TBT can be divided into rice grain tea (so called because the grains look similar to those of rice) and granulated tea. The types of rice grain tea are whole grain

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tea (WGT) and whole embryo tea (WET). WGT uses tartary buckwheat seeds as the raw material, which are boiled and baked to maintain a complete grain shape whereas WET is processed from the embryo of tartary buckwheat. For granulated tea, the raw materials are strongly squeezed through a screen or perforated plate with the required size of aperture for granulation. Depending on the different raw materials, TBT can be divided into whole bran tea (WBT) and whole plant tea (WPT) (Guo et al., 2017). As a typical product of tartary buckwheat, TBT is increasingly popular with consumers who appreciate its unique sensory properties and potential health benefits.

Color, aroma and taste are the key factors affecting the quality of tea drinks (Cheng et al., 2020; Mao et al., 2018; Zhu et al., 2020). For a comprehensive analysis of tea, assessors use their normal senses of vision, smell, and taste to evaluate the color, aroma and taste of tea products (Caroline et al., 2020). Sensory evaluation is affected by the subjective influence of the assessor's physical and psychological conditions (Xu et al., 2019a). In contrast, intelligent sensory systems (electronic nose, electronic tongue and electronic eyes) are equipped with gas, liquid and color sensors, which can simulate the human smell, taste and visual systems, and provide an overall analysis of the product's aroma, taste and color (Chen et al., 2011; Guohua et al., 2013; Wojnowski et al., 2017). This type of analysis does not require the complicated processing of samples, its detection speed is fast, and is not affected by the subjectivity of the assessor, and has been widely used for food applications (Qiu et al., 2015; Wang & Wei, 2015). Unlike traditional tea drinks, TBT has the special odour and taste, with differences in components from the different types. The present study aims to use an electronic nose, electronic tongue and electronic eye to comprehensively analyze different types of TBT thus providing a theoretical basis for the subsequent upgrading of the quality of tea products, and a scientific basis for satisfying the needs of consumers who drink TBT.

2 Materials and methods

2.1 Materials

WET, WBT, WPT and WGT were obtained from the Key Laboratory of Coarse Cereal Processing, Chengdu University, China. The samples were prepared by putting 5 g of the grain tea into 200 mL of boiling water for 15 min. After filtering, the first tea soup was labeled T1. The above steps were repeated to obtain the second tea soup (T2), the third tea soup (T3), the fourth tea soup (T4), fifth tea soup (T5) and sixth tea soup (T6).

2.2 Electronic tongue analysis

An 80 mL sample of each tea was placed in a special test cup then the Astree electronic tongue (Alpha MOS, Toulouse, France) was used for detection. The analysis time was 120 s and the number of data acquisitions was 120. The signals from seven sensors were monitored: PKS (universal), CPS (universal), AHS (sourness), CTS (saltiness), NMS (umami), ANS (sweetness) and SCS (bitterness) for taste detection and Ag/AgCl as a reference.

2.3 Electronic nose analysis

The Heracles NEO electronic nose (Alpha MOS, Toulouse, France) was used for detection with two chromatography columns (MXT-5 and MXT-1701). The conditions were as follows: an injection volume of 5000 μL; an injection rate of 125 μL/s; an injection port temperature of 200 °C; a pressure of 10 kPa,; a flow rate of 30 mL/min; and an injection time of 45 s. A normal alkane standard solution (C6-C16) was used for calibration. The retention times were converted into retention indices then the compounds were qualitatively analyzed using the AroChem Base database, with the peak areas indicating the relative contents of the odor components.

2.4 Electronic eye analysis

A 24 color correction board was used for color adjustment using the IRIS VA400 electronic eye (Alpha MOS, Toulouse, France). A 5 mm aperture was used to turn on the upper and lower backlight at the same time to eliminate the background. A white background plate was photographed by the calibrated electronic eye then the sample was placed in a paper cup. The images of the samples were collected one by one, and repeated 3 times for each sample.

2.5 Scanning electron microscopy analysis

For the scanning electron microscopy analysis, cross-sections of the grain teas were prepared manually then mounted on the sample table using double-sided adhesive tape. After gold plating, the grain tea cross-sections were examined and photographed using a Phenom desktop SEM instrument.

2.6 Statistical analysis

AlphaSoft V14.2 software (Alpha MOS) was used for principal component analysis (PCA) and Discriminant Factor Analysis (DFA), and SIMCA 14.0 software for partial least squares discriminant analysis (PLS-DA). WPS office 2019 was used to produce the charts.

3 Results and discussion

3.1 Appearance and morphology

From observing the differences in the raw materials and processes, WGT and WET were the types of grain tea exhibiting rice grain-like appearance whereas the granulated teas, WBT and WPT, were cylindrical and nodular (Figure 1A). There were significant differences between the total flavonoid content of the two types of tea, with that of the granulated tea being higher than that of the rice grain teas. Early research suggested that tartary buckwheat seeds contained rutin and quercetin as healthy sources of flavonoids for human consumption (Fabjan et al., 2003). Bran powder is added in WBT, and the branches, leaves and flowers as the raw materials in WPT. Studies also have shown that the total flavonoid content of buckwheat may greatly depend on the cultivar, genetic variations, and tissues/organ (Li et al., 2019; Uddin et al., 2013; Xu & Chang, 2012). Because of these differences in the processing methods, WGT and WET produced floating tea residues after soaking, whereas WGT and WPT did not (Figure 1B). Therefore, TBT

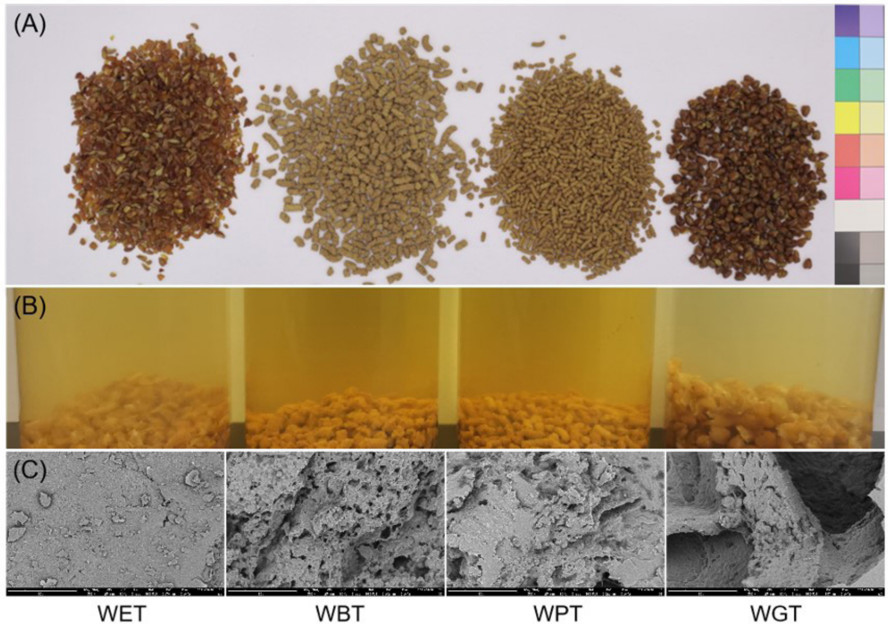

Figure 1. Sample images of tartary buckwheat tea (A) and after infusion (B). Scanning electron microscopy (C).

can be brewed in a teabag to avoid the adverse effects of residue when being drunk. The observations of the cross-sections of the different types of TBT using a scanning electron microscope showed that the surface of WET were relatively regular with no obvious pores (Figure 1C). The internal structure of WGT had larger pores, with a loose interior. The surface of the granulated tea had many pore-like structures of different sizes and of uneven distribution, with different levels of folds and cracks and also a few irregular flaky particles. This may have been caused by the granules being more compacted after extrusion; while the WGT became puffed up during processing so that the grains were looser. Although the total amount of rutin and quercetin in granulated TBT was higher than that of rice type, the total dissolution rate was significantly lower (Yao et al., 2020a). The seeds of the most common tartary buckwheat cultivars are hard to shell, and seeds are treated with steaming and drying before used or processed in foods, which make the seeds turn dark (Li et al., 2020). Future work should focus on the effects of adding other raw materials to meet the needs of different types of consumer and on establishing buckwheat cultivars (e.g. easily dehulled) suitable for processing into tea, and strengthen the comprehensive utilization capacity of whole plant (Kaewkod et al., 2022).

3.2 Color identification and analysis

The color of a tea infusion is one of the most important factors indicating the quality of tea. The tea infusion of TBT was brownish-yellow and clear. From the electronic eye analysis, the main color (with a color ratio greater than or equal to 5%) was selected for statistical analysis. The electronic eye images of WET, WGT, WBT and WPT were shown in Figure 2A. The main colors of WET were 3779, 3778, 3796, 3795, 3780 and 3777, with the largest proportion being 3779. The main colors of WGT were 4053 and 4054 and for granulated tea, the unique color number of WPT was 3760. PCA is an unsupervised multivariate statistical analysis method based on data dimensionality reduction, which can objectively reflect the information of the original variables and perform linear classification. The contribution rate of PC1 was 52.72%, and the cumulative contribution of PC1 and PC2 was 99.247%, thereby reflecting most of the information (Figure 2B). The recognition index reached 95, indicating that the electronic eye could completely distinguish between the different types of tea grain based on their significant differences in color. The higher total flavonoid content in WPT might be attributed to the higher concentration of flavonoid contained in buckwheat flowers and leaves (Bai et al., 2015; Christa & Soral-Śmietana, 2018). Moreover, the flavonoid content of WGT is decreased during the dehulling process due to the partial loss of buckwheat bran, which contains a high content of flavonoid (Sedej et al., 2012; Wang et al., 2013).

As the number of infusions increased, the color value from the electronic eye changed gradually (Figure 2D and 2E). For WET, the dominant color was 3778 and 3799 in T1, 3792 and 3793 in T2, 4048 and 4049 in T3, 4066 and 4067 in T4, 4086 and 4087 in T5 and 4087 and 4088 in T6. For WGT, 4050 was dominant in T2, T3 and T4. The color changes for WBT were similar to those of WPT 4032 and 4048 in T3, 4049 and 4050 in T4 and 4070 in T5. Color change is the most intuitive way to judge the quality of tea infusion, has become a commonly used method for the sensory evaluation of foods such as beverages and tea products (Chaturvedula & Prakash, 2011). As the number of infusions increased, the color value from the electronic eye changed gradually. Overall, infusing 2 or 3 times could be considered the most suitable choice for TBT soup because it can provide the greatest concentration of colored dissolved substances. Even after being brewed more than 6 times, yellow substances were still being dissolved from the TBT. Compared with semi-fermented tea (oolong tea) and fermented tea (black tea), tea soup of all types of TBT is lightly colored and not durably brewing (Zhang et al.,

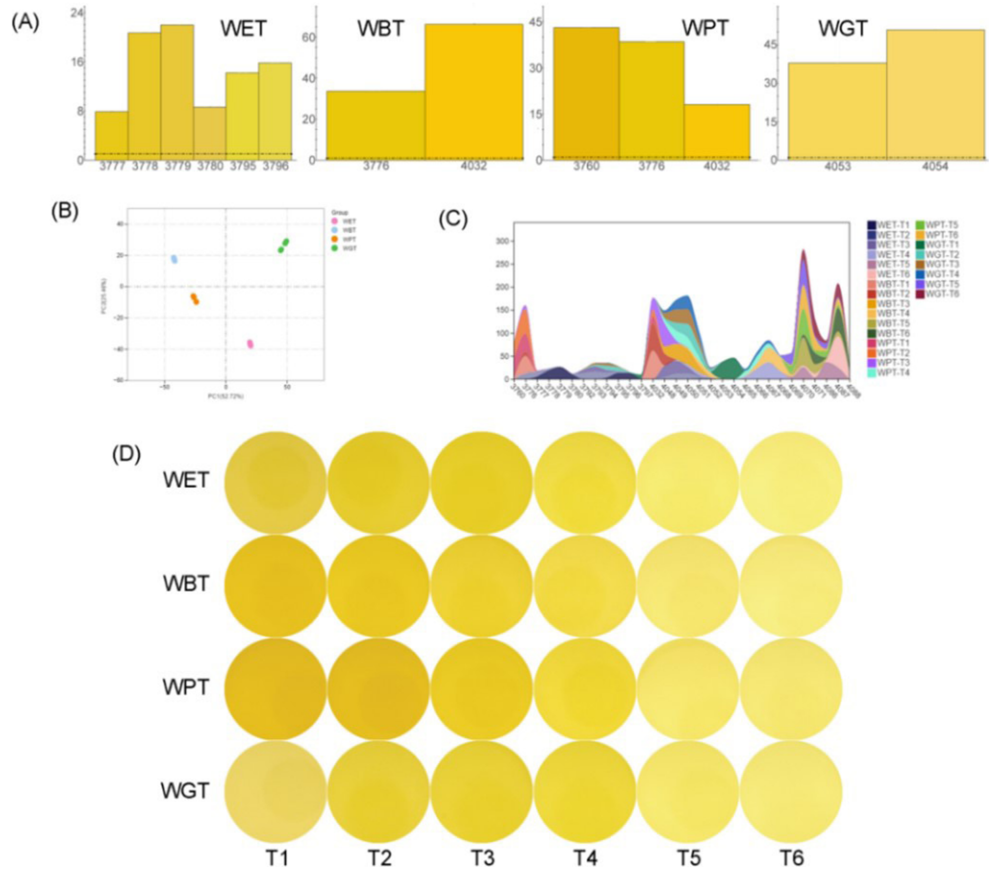

Figure 2. Color parameters of different TBT (A); Principal component analysis plots for the color of TBT (B); Change in color with different infusion times (C and D).

2020). Subsequently, fermentation technology can be applied to the production process of TBT to increase soup color and durable.

3.3 Taste characteristics and analysis

Electronic tongues consist of a series of non-specific sensors with cross-sensitivity that respond to a wide variety of compounds (Rodríguez-Méndez et al., 2016). The differences in the response of the electronic tongue were used to quickly and intuitively analyze the taste characteristics of TBT. Firstly, PCA was used to provide an overview of the electronic tongue data, with Figure 3A showing that PC1 was 67.79% and PC2, 31.18% thus explaining 98.97% of the information from the sample and indicating that the PCA model could comprehensively reflect the electronic tongue dat. The four types of TBT with different flavors could clearly be distinguished on the PCA chart. Compared with PCA, PLS-DA is a multivariable statistical analysis method with supervised pattern recognition. To determine if the electronic tongue could be used to distinguish between the taste of the different types of TBT, the value of Q2 was greater than 0.5, indicating that the model had a good predictive ability. The reliability of the PLS-DA model was further verified by a permutation test. The variables of the Y matrix, defined when the model was established, were randomly arranged 200 times, and the values of RY2 and Q2 of the permuted model were found to be smaller than those of the original model, and the Q2 regression line had a negative intercept (Figure 3B). This indicated that the PLS-DA model was stable and reliable with no overfitting. To further exploring the contribution of the response values from the electronic tongue sensors to the taste grouping, the key sensors affecting taste recognition were screened out then the PLS-DA model was used for load analysis. The variable important for the projection (VIP) was further used to filter the key difference variables. The results showed that the variables with a VIP value greater than 1.0 came from the CTS and ANS sensors, indicating that these two sensors were the key factors for identifying taste. Interestingly, differences in taste among TBT may depend primarily on saltiness and sweetness not no the bitterness. Free amino acids not only quality components, but can also contribute to a different oral taste of tea, such as sweetness, salty and umami of tea (Zhao et al., 2016; Tong et al., 2019). Previous research showed that the protein content of granulated TBT was higher than that of rice grain tea (Zhao, 2018). Whether amino acids invoke differential responses on sweetness and salty remains to be ascertained and worthy of further study. The SCS sensor showed a stable response with the highest response value from all types of tea and for the number of infusions (Figure 3C). The astringent and bitter taste was characteristic for teas due to the polyphenols and free amino acids present in them (Chen et al., 2020). Not only the tea soup but also the tea dregs should be consumed to obtain the beneficial health effects of drinking TBT.

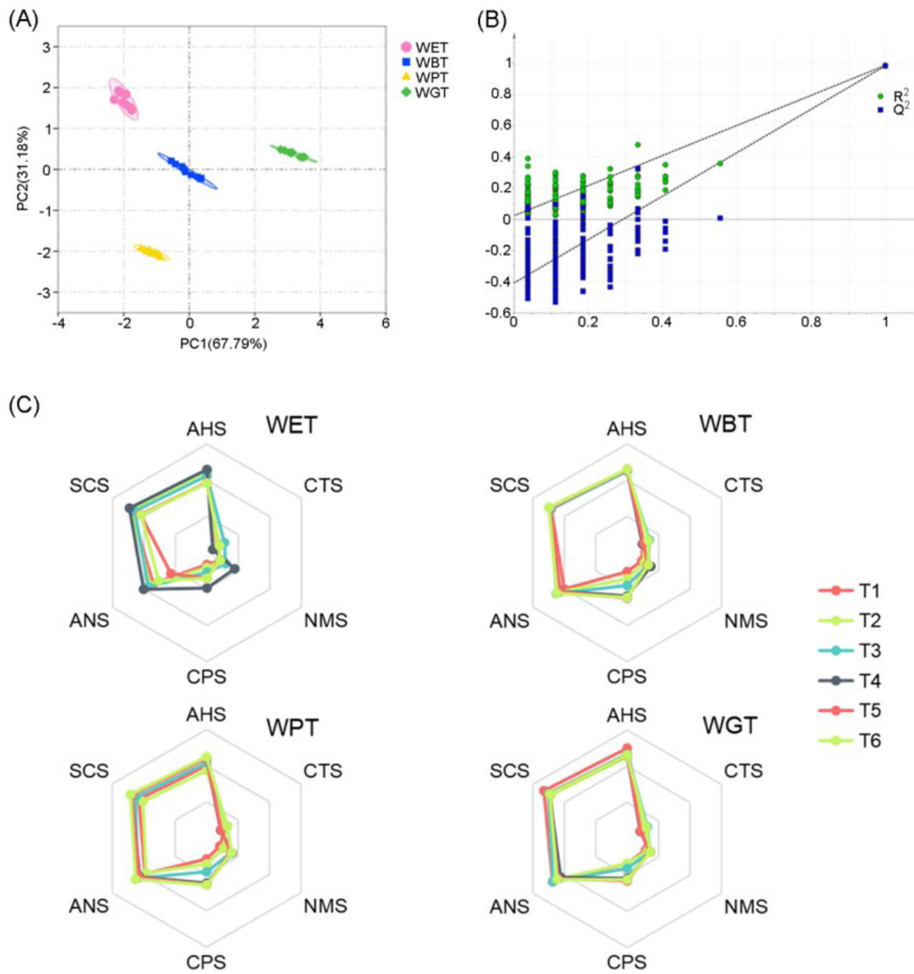

Figure 3. Principal component analysis plot (A) and OPLS-DA for the taste of TBT (B). Radar charts of electronic tongue sensors response intensity with different infusion times (C).

3.4 Electronic nose odor analysis

The electronic nose is sensitive for obtaining odor information from samples, and slight changes in volatile compounds may cause a difference in the response of the sensors (Yang et al., 2016). The Heracles Neo ultra-fast gas phase electronic nose was used to qualitatively analyze the volatile compounds and for the statistical analysis of the odor of the different types of TBT. The electronic nose PCA result on the different types of TBT was shown in Figure 4A, and the plot showed overlap among samples. Here, PCA was not able to distinguish the four types of TBT, indicating that the Heracles Neo electronic nose could not be distinguish between the four types of TBT through PCA discrimination model.

The electronic nose DFA result on the different types of TBT was shown in Figure 4B. The contribution rates of DF1 and DF2 were 52.92% and 44.29%, respectively, a total of 97.21%, thus reflecting most of the information from the measured sample. The figure also shows that the distances between the TBT in the horizontal and vertical coordinates were different with no overlap, indicating that the Heracles Neo electronic nose could be completely and quickly distinguish between the four types of TBT through their significant differences in odor. Electronic nose technology could thus be used for identifying flavor components and the pattern recognition DFA methods could effectively discriminate. In this experiment, the discrimination between samples by PCA was unsatisfactory, whereas that by DFA was much better. Moreover, Linear Discriminant Analysis (LDA) technology could reduce the drift effect observed in the response of the electronic nose, thus improving the classification accuracy (Xu et al., 2019b).

The qualitative analysis of volatile compounds in tea grains using the AroChem Base database led to 55 volatile compounds being detected, mainly alcohols, aldehydes, alkanes and esters (Figure 4C). Of these four types of volatile substance, WPT produced the largest number, followed by WET. The composition of volatile compounds varied in the different types of TBT because it was composed of a wider range of raw materials and production process. Previous work indicated that the major aroma compounds of steam technology were alkanes and alkenes, while roasted technology contained aldehydes and alkanes as major aroma compounds, which caused different flavor in different types of TBT (Cao et al., 2014; Sui et al., 2012). The aroma of baked goods is a composition of various volatile compounds that may come from raw materials or may arise

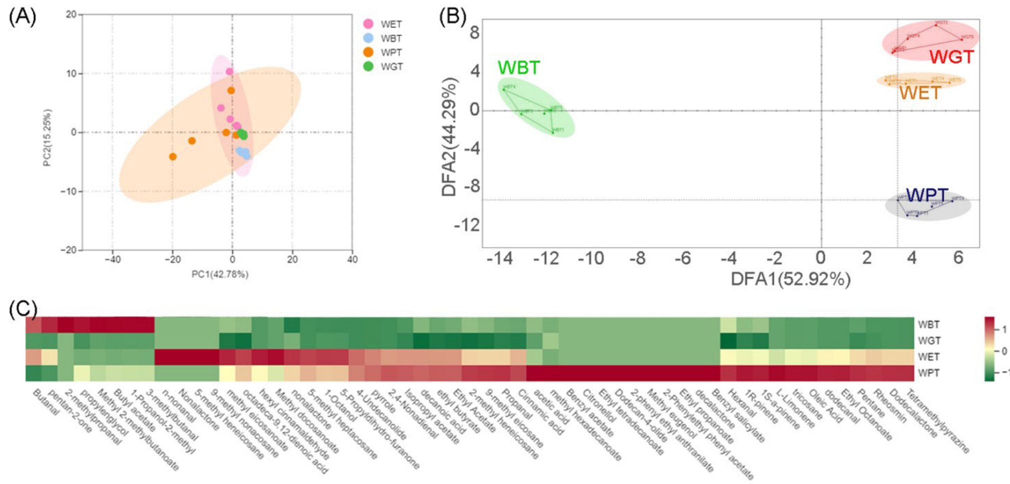

Figure 4. Plot of Principal component analysis (A) and Discriminant Factor Analysis (B) of electronic nose. The thermogram of volatile compounds in TBT (C).

during thermal processing, in this case, via baking (Maillard reaction compounds) (Starowicz & Zieliński, 2019). During processes such as roasting, caramelization and Maillard reactions occur, producing a variety of volatile compounds, to give their special flavor, which caused better flavor in TBT. Therefore, optimization of roasting parameters and processing standard will be key contributors to enhance flavor quality of TBT.

4 Conclusions

This research has focused on the different types of TBT and provided an objective evaluation of the characteristics of TBT based on the use of intelligent sensory systems. The results of analysis by electronic nose, electronic tongue and electronic eye have shown that the data on the sensory characteristics from the different types of TBT were quite different. Principal component analysis, discriminant factor analysis and soft independent modeling could distinguish between the different types of TBT, thus providing an objective and effective method of discriminating between the color and fragrance of TBT. Different processing methods and materials caused different effects on the appearance and internal morphology of TBT, leading to differences in its color, flavor and taste. This study has provided a rapid and accurate method for evaluating the characteristics of TBT based on using the electronic tongue, electronic nose and electronic eye. This approach could be used as an aid or supplement to human sensory evaluation, and also for the objective and intelligent evaluation of TBT. Comprehensive evaluation through the use of intelligent sensory systems will be the future direction for developing electronic instruments to replace the present methods for the quality control and identification of TBT.

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