Monitoring the Fermentation Process and Detection of Optimum Fermentation Time of Black Tea Using an Electronic Tongue

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***Abstract*—This paper presents a new methodology to monitor the fermentation process and detect the optimum fermentation time of crush tear curl black tea with a voltammetric electronic tongue. An electronic tongue with an array of five noble metal working electrodes has been developed for this purpose. A suitable large amplitude pulse voltammetric waveform has been employed for probing the chemical changes in tea samples under fermentation. Good correlation between the electronic tongue responses and the biochemical changes has been obtained by principal component analysis (PCA) during various stages of fermentation. The electronic tongue fermentation profile has been derived from PCA analysis and it is observed that such a profile enables detection of optimum fermentation times. Finally, a model based on partial least squares regression technique has been developed for real-time indication of fermentation level. The optimum fermentation times observed from the electronic tongue fermentation profiles derived from PCA and partial least squares regression correlate by a factor of 0.97 and 0.96, respectively, with the reference values obtained from an ultraviolet-visible spectrophotometer-based instrumental analysis.**

***Index Terms*—Black tea, voltammetric electronic tongue, principal component analysis, partial least squares regression.**

I. Introduction

THE production of finished black tea from freshly plucked green leaves involves several crucial time dependent stages such as withering, rolling, crush-tear-curl (CTC), fermentation, drying and sorting. Out of these stages, fermentation is one of the most important stages of tea processing; the duration of which significantly affects the quality of finished tea [1]. The fermentation of black tea is an endogenous phenomenon of enzyme-mediated oxidation of polyphenolic substances present in tea leaves [2]. The chemical changes pertaining to fermentation commences as soon as the leaf is macerated during rolling/rotor-vane stages and proceed rapidly during the exhaustive leaf maceration brought about by the CTC process. The precursors for quality attributes, i.e. the polyphenolic substances, are contained within the vacuoles of the intact cells of the tea shoots, while the important oxidative enzymes - polyphenol oxidase (PPO) and peroxidase (PO) remain associated with the chloroplast. The rupture of fragile vacuolar membranes caused by rolling and CTC results the diffusion of polyphenols into the cytoplasm for subsequent oxidation aided by the enzyme PPO. The process of enzymatic oxidation is initiated with the primary oxidation of phenolic substances to quinones. The quinones being subsequently converted to a number of new phenolic compounds result in considerable qualitative and quantitative changes in the biochemical constituents of the processed tea leaves. Polyphenolic substances especially Catechins, undergo significant chemical transformations of condensation and polymerization, lead to the formation of pigmenting compounds, the theaflavins (TF) and thearubigins (TR) [3]. These compounds are responsible for the desirable taste and colour of the black tea liquor. The extent of fermentation thus bears a profound impact on the quality of finished tea. In fact, it is established that under-fermented tea produces harsh and raw liquor while an over fermented tea is mostly dull with very little briskness [4]. Hence it is essential that the tea fermentation process be monitored and that the termination of tea fermentation process occurs at an optimum level for maximizing the taste of tea liquor.

Tea industries rely on the human perceptions of vision and olfaction to monitor the fermentation process of tea. In this approach, evolution of colour and aroma of tea samples are repeatedly monitored by experts to assess the degree of fermentation. It is observed that the colour of tea leaves changes distinctively from green to coppery brown as the fermentation proceeds, while the aroma changes from grassy to sweet floral. However, such distinctness of colour and aroma decreases while the fermentation approaches optimum point, making organoleptic evaluations more difficult. Hence, the human sensory approach has obvious limitations in terms of accuracy and reproducibility. Moreover, the organoleptic

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