

The influence of far-infrared drying parameters on the sensory properties of Georgian black tea

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Summary

The study investigates the physicochemical and organoleptic properties of black tea dried at different temperatures using advanced technologies to obtain high-quality aromatic tea. Tea quality and health benefits are associated with essential oils, alkaloids, and phenolic compounds. Tea leaves harvested in May and September were divided into two groups: one dried by conventional hot-air drying and the other by infrared emitters operating mainly in the far-infrared range (8–20 μm). Drying was conducted at temperatures from 75 °C to 95 °C (with 5 °C intervals) until a residual moisture content of 5–7 % was achieved. Under optimal regimes, key physicochemical indicators determining tea quality (taste, aroma, colour, and storage stability) and sensory properties were evaluated. The results showed that for both Martvili and Tkibuli teas, infrared drying at 85–90 °C for ~15 min yielded higher sensory aroma scores and overall sensory quality compared with hot air drying. Tea produced using infrared drying demonstrated superior physicochemical and sensory characteristics compared to conventionally dried tea. Among the samples, infrared-dried Tkibuli tea (extractive substances 370.0 $\text{mg}\cdot\text{kg}^{-1}$, total phenolic compounds 170.5 $\text{mg}\cdot\text{kg}^{-1}$, sensory score 5.15) outperformed Martvili tea (extractive substances 356.8 $\text{mg}\cdot\text{kg}^{-1}$, total phenolic compounds 167.4 $\text{mg}\cdot\text{kg}^{-1}$, sensory score 4.95).

Keywords

infrared radiation; technological parameters; tea quality; extractive substances; total phenolic compounds; sensory score

Tea production has been known to human-kind since ancient times. Tea effectively quenches thirst, relieves fatigue and headaches, and restores human energy and working capacity. All these properties of tea products are determined by the presence of caffeine alkaloids, essential oils, phenolic compounds, and other substances [1, 2]. The production of high-quality tea is equally dependent on the correct implementation of technological processes and on the quality of the raw material to be processed, which is influenced by biological (cultivar), soil-climatic, and agrotechnical factors (fertiliser application and pruning) [3, 4].

Black tea is produced through the following technological processes: withering, rolling, fermentation, drying, and dry sorting.

To impart appropriate technological and consumer qualities to tea, special importance is attributed to the fermentation and drying stages of tea leaf processing. During fermentation, the aroma, colour, and taste of tea are formed, whereas improper drying conditions and temperatures may lead to a reduction in the content of aroma- and flavour-determining compounds, as well as deterioration of the quality of the finished tea. Therefore, the correct selection of the thermal treatment

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method during tea drying is of decisive importance in shaping the final quality of tea [5, 6]. The sensory properties of tea are formed as a result of interactions among various compounds present in the leaf, among which phenolic and aromatic substances play a leading role.

According to the works of OBANDA et al. [7] and QU et al. [8], despite numerous studies devoted to fermentation and drying, only a limited number of investigations have specifically addressed the drying process. Drying is a crucial stage in black tea processing, as it reduces moisture content and prolongs shelf life, while simultaneously contributing to the formation of aroma, taste, and colour [8]. Hot-air drying, a traditional drying method, is characterised by simple operation and certain advantages; however, its drawbacks include prolonged drying time and excessive losses of nutrients [8].

The aromatic characteristics of tea are formed through interactions among various compounds present in the tea leaf, among which phenolic and aromatic substances play a leading role [9]. During the fermentation process, compounds responsible for the specific bitterness, astringency, pleasant taste, and aroma of tea undergo transformation [7, 10, 11].

In the study by JIANG et al. [12], the aromatic characteristics during processing were comprehensively investigated using sensory evaluation, gas chromatography-mass spectrometry (GC-MS), and odour activity value (*OAV*) analysis. In total, 764 volatile compounds were identified and classified into 16 categories. Notably, terpenoids, heterocyclic compounds, and esters accounted for 19.4 %, 16.3 %, and 16.1 % of the total volatile compounds formed during processing, respectively. Furthermore, the second stages of fermentation and drying exhibited the most pronounced variations, during which 99 and 123 volatile compounds, respectively, changed significantly. In addition, *OAV* analysis led to the identification of 17 volatile compounds as key differential aroma-active components.

Various drying methods are currently employed, including convective, conductive, radiant, sublimation, microwave, and others. During the drying process, tea leaves lose their reddish copper colour and, as a result of profound physicochemical transformations, acquire the final colour, taste, and aroma characteristic of black tea. The convective drying method, which is predominantly used in the tea industry, does not allow for the immediate termination of its action or rapid dehydration of the material. Prolonged drying leads to a reduction in valuable extractive substances present in

tea leaves, primarily phenolic compounds, which not only continue to undergo oxidation but also partially convert into insoluble forms.

During drying, the temperature of the tea mass increases by 24–26 °C and reaches 50–55 °C after 20–25 min, at which point enzyme inactivation begins. Simultaneously, under the influence of elevated temperatures, simple sugars react with quinones to form aldehydes, thereby enhancing the aromatic properties of tea. Therefore, it is necessary to employ a drying method capable of rapidly penetrating the leaf tissue. The use of infrared (IR) radiation drying enables rapid heating of tea leaves and prompt termination of fermentation, making it possible to obtain tea with high extractability and pronounced aroma [13].

Despite the advancement of knowledge in tea chemistry, up to the present stage, the comprehensive investigation and identification of the full composition of flavour- and aroma-determining compounds in commercial tea has remained a major challenge. This is primarily due to the lack of analytical equipment capable of examining the complete complex of substances influencing tea quality, particularly those responsible for taste and aroma, and of identifying the compounds that either enhance or deteriorate the aroma of commercial tea.

Consequently, the insufficient comprehensive understanding of flavour- and aroma-determining compounds makes it impossible to accurately assess the true quality of commercial tea or to develop effective recommendations aimed at improving its quality. In view of the above, the comprehensive investigation of the complete complex of flavour- and aroma-determining compounds in commercial tea, as well as the identification of aroma-active compounds that enhance taste and aroma and their optimisation through the selection of new technological processing parameters, is of high relevance and importance [11].

The determination of optimal parameters for the tea drying process using modern thermal treatment methods, including IR radiation, is of considerable relevance. During IR drying, rapid heating of the entire volume of tea leaves occurs as a result of radiation, leading to uniform temperature distribution both on the surface and within the leaf structure. As a result, the fermentation process is rapidly terminated, while aroma- and flavour-determining compounds are formed more quickly, with some of them volatilising. At the same time, temperature regulation is easily controlled, which directly influences the volatilisation behaviour of compounds responsible for the taste and aroma of tea.

Therefore, the identification of aromatic compounds, determination of their volatilisation temperatures, and optimisation of these parameters represent an important and highly relevant task in improving tea quality [13].

Based on the analysis of existing literature, it was determined that the complete complex of compounds responsible for the aroma and taste of tea, as well as their volatilisation temperatures, has not been sufficiently investigated. Consequently, the development of a methodology for determining the complete complex of tea aromatic compounds, the establishment of the temperature ranges of their volatilisation, and the optimisation of aroma- and flavour-forming compounds constitute the scientific novelty of the present study.

The aim of this research was to determine the optimal parameters of far-infrared (FIR) drying for the production of Georgian black aromatic tea, to investigate thermodynamic parameters in order to identify the optimal temperature range and drying duration, and, on this basis, to develop recommendations for quality improvement, with the prospect of obtaining enhanced chemical and sensory characteristics of tea.

Scientific hypothesis

Based on preliminary analysis, the use of the unique properties of IR radiation operating in the FIR range (8–20 μm) will enable the improvement of black tea quality through the application of newly selected temperature parameters, by increasing the content of compounds responsible for its taste and aroma.

MATERIALS AND METHODS

Samples

The research was conducted at the Didi Chkoni Tea Factory in the Martvili region (Georgia) and the Bueti Tea Factory in the Tkibuli region (Georgia). Experimental, fermented, and finished tea samples were prepared directly at the respective tea factories.

The technical characteristics of the raw material used for the study are presented in Tab. 1.

Equipment

Tea leaf drying was carried out using laboratory-scale equipment equipped with carbon fibre IR emitters, which primarily operate in the FIR region 8–20 μm (Yancheng Hongtai Alloy Electric Apparatus, Yancheng, Jiangsu, China). The distance between the radiation tubes was 22.0 mm, and the dimensions of the emitting panel were 247 mm \times 42 mm, with an output power of 0.7 kW over an area of 0.0104 m². The distance between the tea layer and the emitter was maintained at 100 mm.

The initial moisture content of the tea leaves was determined using a Japanese tea moisture analyzer, Kawasaki Kiko Tea Analyzer GTN-B (Kawasaki Kiko, Shizuoka, Japan), which recorded an average moisture content of 43.4 %.

The temperature was controlled within the range of 75 °C to 95 °C by adjusting the voltage using a transformer of type ACMC 100-1 (Yueqing Tianze, Venzhou, Zhejiang, China). To maintain a stable temperature at each set point, an XH-W3001 thermostat (Chenyuan Technology, Shenzhen, Guangdong, China) was used. Additionally, the temperature of the tea leaves was determined using an AR360A+ IR laser thermometer (Simzo, Long, China).

Mass loss during drying was monitored using an analytical digital balance, model SF-400C (Toms, Qilin, China), with a measurement accuracy of 0.01 g.

The IR drying setup consisted of a quartz IR radiation panel mounted on a stand, positioned above the analytical balance. A container with the tea sample to be dried was placed on the balance directly beneath the IR emitter.

The control tea samples were dried in an operating industrial drying cabinet YX-6CHZ-H8 (Anxi Yongxing Tea Machinery, Quanzhou, China), 13 kW at 100 \pm 0.5 °C.

The diagram of the test bench for the heat treatment by the panel of IR rays is shown in Fig. 1.

Tab. 1. Technical characteristics of tea leaves used in the study.

Tea leaf sample	Initial moisture [%]	Raw material fraction	Leaf size [mm]		Single leaf mass [g]	Destroyed cells in twisted leaves [%]
			Length	Width		
Martvili tea	43.0 \pm 0.3	Delicate 2-leaf buds – 96 %	45 \pm 2	25 \pm 1	1.1 \pm 0.2	87 \pm 3
	42.0 \pm 0.3	Coarse 3-leaf buds – 4 %	48 \pm 2	29 \pm 1	1.4 \pm 0.2	89 \pm 3
Tkibuli tea	44.0 \pm 0.3	Delicate 2-leaf buds – 96 %	47 \pm 1	26 \pm 1	1.2 \pm 0.1	72 \pm 3
	43.0 \pm 0.3	Coarse 3-leaf buds – 4 %	49 \pm 1	29 \pm 1	1.4 \pm 0.1	75 \pm 3

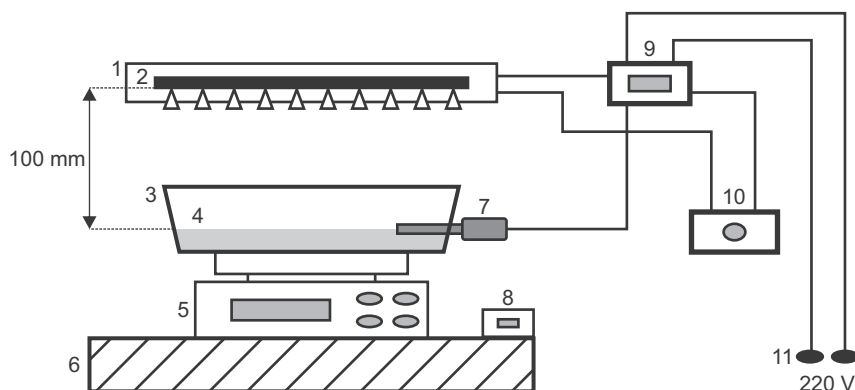


Fig. 1. Schematic diagram of the tea drying setup for determining changes in aromatic compounds.

1 – infrared radiation panel, 2 – quartz emitter, 3 – aluminium drying container, 4 – tea layer in the container, 5 – analytical digital balance, 6 – table, 7 – temperature-sensing bulb, 8 – digital timer, 9 – thermostat, 10 – voltage-regulating transformer, 11 – power supply.

Laboratory methods

The percentage of disrupted cells in rolled tea leaves was determined by immersing ten rolled leaves in a potassium ferricyanide (red prussiate of potash) solution (potassium ferricyanide, $K_3[Fe(CN)_6]$, Kharkiv, Ukraine, $\geq 99.0\%$) for 30 min. During this period, the disrupted cells turned black, based on which the average percentage of disrupted cells was calculated for the ten leaves. The obtained values are presented in Tab. 1.

Prior to the initiation of drying, a temperature-sensitive thermostat bulb was fixed inside the container body. The total mass of the container and the thermostat bulb was determined using an analytical balance. Subsequently, a tea sample weighing 60 ± 3 g was placed into the container, ensuring that the thickness of the tea layer did not exceed 30 mm. The combined mass of the empty container, the experimental tea sample, and the thermostat bulb was then measured using an analytical balance.

The container containing the thermostat bulb and tea sample was positioned beneath the IR emitter, and the IR emitter was switched on. The voltage was regulated using a transformer, while a digital stopwatch was simultaneously activated. Mass losses of the tea sample were recorded at 3 min intervals. The experiment was continued until a constant mass of tea was achieved. Based on the obtained data, the mass loss of the tea leaves was calculated, which was assumed to represent the combined mass of evaporated moisture and volatilised aromatic compounds.

The experiments were conducted at temperatures of 75 °C, 85 °C, 90 °C and 95 °C.

The moisture content (W) after the heat treatment was calculated based on the initial moisture content (W_0 , in percent) and mass loss (Δm , in grams) according to the formula based on the standards GOST 13586.5-2015 [14], and ISO 1446:2001 [15].

$$W = 100 \frac{\left(\frac{W_0}{100} - \frac{\Delta m}{m_0}\right)}{\left(1 - \frac{\Delta m}{m_0}\right)} \quad (1)$$

where m_0 is initial sample weight (in grams).

The total content of extractive substances and phenolic compounds in tea was determined using standard methods. The water extract content of tea was determined according to ISO 9768:1994 [16]. The principle of the method is as follows: a defined amount of tea was extracted with boiling water under standardised conditions, the extract was filtered, the filtrate was evaporated, and the dry residue was weighed. The mass fraction of water-soluble extractives was expressed as milligrams per kilogram.

The total phenolic content was determined using the Folin–Ciocalteu spectrophotometric method in accordance with ISO 14502-1:2005 [17]. The principle of this method involves the reaction of the tea extract with the Folin–Ciocalteu reagent, followed by measurement of colour intensity using a spectrophotometer at approximately 760 nm. Calibration was performed using gallic acid as the standard. Total phenolic content was expressed as milligrams of gallic acid equivalents per kilogram.

For the tea drying experiments, we selected a temperature range of 75–95 °C, since at higher temperatures of 100–120 °C, intensive losses of

aromatic compounds occur, which is contrary to the objectives of our study. For Indian teas, a drying temperature range of 105–120 °C is considered appropriate; however, Georgian tea raw material contains fewer aromatic compounds compared to Indian tea, and drying at 120 °C would substantially reduce their content in the final product, leading to quality deterioration.

A temperature of 75–80 °C is sufficient for the inactivation of oxidative enzymes [18]. Acidic oxidative enzymes in tea, which function as oxidoreductases, are inactivated at 75–80 °C, orthodiphenol oxidase is inactivated at 70–75 °C, while peroxidase is relatively heat-stable and is inactivated at approximately 80 °C.

Black tea samples, dried by IR radiation at 75, 85, 90, and 95 °C, were subjected to sensory evaluation using a five-point scale. The aim was to determine the effect of IR drying on the sensory properties of black tea and to identify the temperature regime (75, 85, 90, or 95 °C) that provides the best aroma, balanced taste, and highest overall sensory score.

Samples were prepared under standardised conditions: the same raw material (single batch), uniform leaf size, and identical fermentation level. Drying was conducted at 75, 85, 90, and 95 °C until the final moisture content reached 5–7 %, after which the samples were conditioned for 24 h in airtight containers.

Tea preparation for sensory evaluation followed the ISO 1520:2006 [19] cupping method: 2.0 g tea, 100 ml water, water temperature 100 °C; infusion time 5 min, white porcelain cup. Samples were coded so that evaluators were blind to the drying temperature.

The tasting panel consisted of nine trained

assessors, and each sample was evaluated individually in a calm, neutral environment. Sensory attributes were rated on a five-point scale: 5 – very good, 4 – good, 3 – average, 2 – weak, 1 – poor. Based on the panel's evaluations, the sample dried at 85 ± 0.5 °C exhibited the best overall sensory characteristics.

No instrumental volatile analysis GC-MS and gas chromatography-olfactometry (GC-O) was conducted in this study.

Statistical analysis

Statistical analysis of the experimental data was performed by calculating the arithmetic mean and standard deviation. Each experiment was carried out at least three times, and the results are expressed as mean \pm standard deviation.

Differences among the control sample (hot-air drying) and IR-dried samples at 85 °C and 90 °C were evaluated using one-way analysis of variance (ANOVA). When statistically significant differences were observed, post-hoc comparisons were conducted using Tukey's honestly significant difference (HSD) test to identify differences between individual groups.

Differences were considered statistically significant at $p < 0.05$, corresponding to a confidence level of at least 95 %.

RESULTS AND DISCUSSION

Prior to the initiation of the drying process, the main characteristics of the tea batch were determined using standard laboratory methods. These included tea type, technical specifications, initial mass of the experimental tea samples, fermenta-

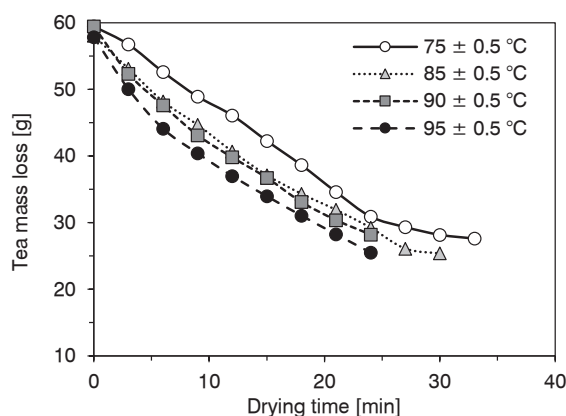


Fig. 2. Mass loss of Martvili black tea during far infrared drying at different temperatures.

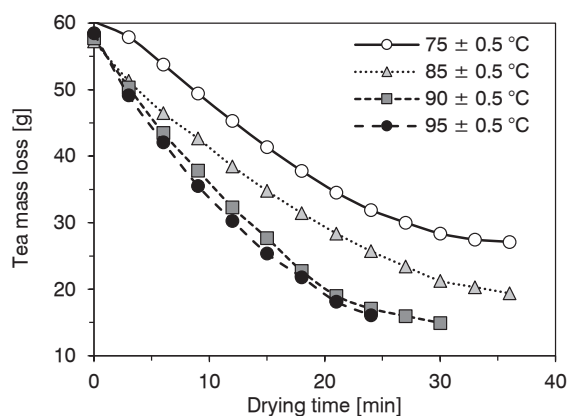


Fig. 3. Mass loss of Tkibuli black tea during far infrared drying at different temperatures.

tion duration, average proportion of disrupted cells in rolled leaves, and other relevant parameters (Tab. 1).

To investigate moisture loss kinetics during Georgian tea production, changes in tea sample mass were monitored at specific drying temperatures under laboratory conditions simulating industrial processing. Mass loss was recorded continuously throughout the drying period. The results obtained at different drying temperatures are presented in Fig. 2 and Fig. 3.

During tea drying, the observed mass loss reflects drying kinetics, i.e., moisture loss over time. This study did not directly quantify the volatilisation of aroma-related compounds. Consequently, any statements about aroma in this work are derived exclusively from sensory evaluation, not from gravimetric measurements. In future studies, the volatilised fraction will be subjected to detailed analysis using GC-O and GC-MS to identify key aroma-active compounds and further optimise drying conditions.

Previous studies have reported that during black tea production, the concentration of aromatic compounds in the final product increases, as volatile oils and aroma precursors present in fresh tea leaves undergo thermally induced biochemical transformations [9, 10].

As shown by the drying curves of Martvili tea (Fig. 2), at all investigated temperatures, mass loss was most pronounced during the initial 3 min of drying. Subsequently, the rate of moisture loss gradually decreased and reached a quasi-stationary phase characterised by a relatively low mass reduction rate. At 85 °C, a noticeable decline in mass loss intensity occurred within the 15–18 min interval, suggesting partial inhibition of aroma-related compound volatilisation due to incomplete drying of the raw material. At 90 °C, this effect was observed after approximately 15 min, while at 95 °C it appeared after about 12 min.

A similar drying pattern was observed for Tkibuli tea samples (Fig. 3). At 75 °C, mass loss remained relatively high during the first 3 min, whereas after approximately 21 min a marked reduction in the drying rate was detected.

Overall, Fig. 2 and Fig. 3 indicate that moisture loss occurs predominantly in the initial stage of drying. These findings are consistent with previous reports [13], which showed that the reduction in evaporated moisture becomes apparent, on average, after the first 5 min of drying.

The physicochemical and organoleptic characteristics of Martvili and Tkibuli black

Tab. 2. Physical, chemical, and organoleptic characteristics of Martvili and Tkibuli black teas.

Sample	Moisture [g·kg ⁻¹]	Extractive substances [mg·kg ⁻¹]	TPC [mg·kg ⁻¹]	Organoleptic characteristics (score points)				Brewed leaf
				Appearance	Infusion colour	Infusion taste	Infusion aroma	
Martvili tea								
1 Experimental	67.0 ± 0.2 ^a	356.8 ± 0.5 ^b	167.4 ± 0.3 ^a	4.00 ± 0.10 ^a Dark brown, uniform	5.25 ± 0.10 ^a Medium-high	5.25 ± 0.10 ^a Slightly tart and mild	5.25 ± 0.10 ^a Good, aromatic	5.00 ± 0.10 ^a Uniform, brown
2 Control	65.5 ± 0.2 ^b	355.2 ± 0.5 ^b	166.0 ± 0.3 ^b	4.00 ± 0.10 ^a Dark brown, uniform	5.00 ± 0.10 ^b Medium-high	5.00 ± 0.10 ^b Slightly tart and mild	5.00 ± 0.10 ^b Floral	5.00 ± 0.10 ^a Uniform, brown
Tkibuli tea								
3 Experimental	66.0 ± 0.2 ^a	370.0 ± 0.5 ^a	170.5 ± 0.3 ^a	4.25 ± 0.10 ^a Black, uniform	5.50 ± 0.10 ^a Strong	5.50 ± 0.10 ^a Tart, pleasant	5.50 ± 0.10 ^a Strongly aromatic	5.00 ± 0.10 ^a Uniform, brown
4 Control	63.0 ± 0.2 ^c	346.0 ± 0.5 ^c	167.6 ± 0.3 ^b	4.25 ± 0.10 ^a Black, uniform	5.25 ± 0.10 ^b Medium-high	5.25 ± 0.10 ^b Slightly tart and mild	5.25 ± 0.10 ^b Floral	5.00 ± 0.10 ^a Uniform, brown

Teas were dried in a drying unit using infrared radiation at 85 ± 0.5 °C (experimental) and in an operating industrial dryer at 100 ± 0.5 °C (control). TPC – total phenolic compounds (expressed as milligrams of gallic acid equivalents).

Values are expressed as mean ± standard deviation (*n* = 3). Values marked with different letters within the same column are significantly different (*p* < 0.05).

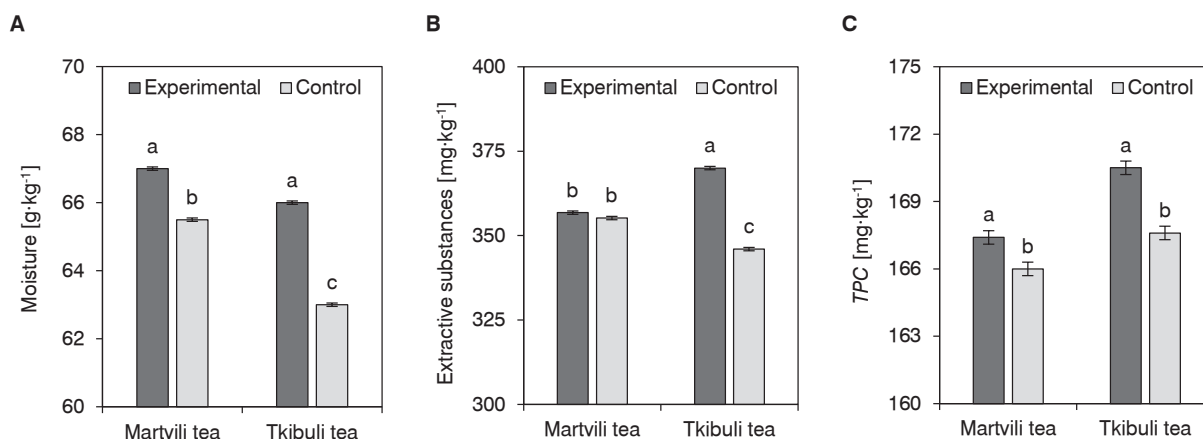


Fig. 4. Parameters of Martvili and Tkibuli black tea after drying with far-infrared rays.

A – moisture content, B – extractive substances, C – total phenolic compounds.

Teas were dried in a drying unit using infrared radiation at 85 ± 0.5 °C (experimental) and in an operating industrial dryer at 100 ± 0.5 °C (control).

Different letters above columns indicate statistically significant difference at the 5% significance level ($n = 3$).

TPC – total phenolic compounds (expressed as milligrams of gallic acid equivalents).

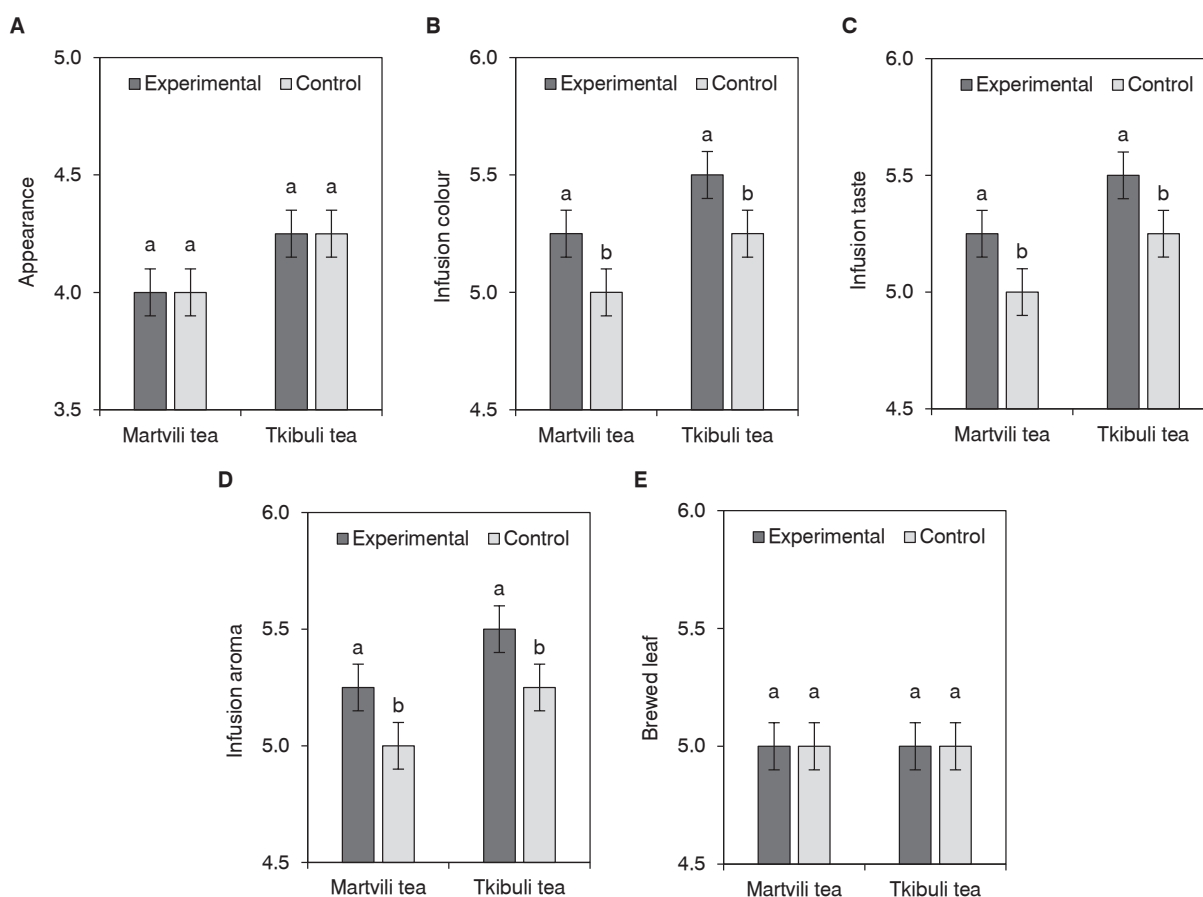


Fig. 5. Organoleptic characteristic of Martvili and Tkibuli black tea after far-infrared drying.

A – appearance, B – infusion colour, C – infusion taste, D – infusion aroma, E – brewed leaf.

Teas were dried in a drying unit using infrared radiation at 85 ± 0.5 °C (experimental) and in an operating industrial dryer at 100 ± 0.5 °C (control).

Different letters above columns indicate statistically significant difference at the 5% significance level ($n = 3$).

tea samples dried by IR radiation at 85 ± 0.5 °C (experimental) and by hot air at 100 ± 0.5 °C (control) are summarised in Tab. 2.

The drying method significantly influenced the physicochemical and sensory properties of the black tea samples. One-way ANOVA revealed significant differences in moisture content, extractive substances, and total phenolic compounds between experimental and control samples ($p < 0.05$). IR-dried teas exhibited comparable moisture content and higher levels of extractive substances compared to conventionally dried control samples.

Sensory evaluation demonstrated that IR drying at 85 ± 0.5 °C resulted in significantly higher scores for infusion colour, taste, and aroma, particularly for Tkibuli black tea samples ($p < 0.05$). No statistically significant differences were observed in brewed leaf appearance among the samples ($p > 0.05$).

According to Tab. 2, experimental black tea samples from both Martvili and Tkibuli exceeded the control samples by 0.25 ± 0.1 points in overall sensory evaluation. Similarly, IR-treated teas scored 0.25 ± 0.1 points higher than teas dried using conventional hot-air dryers at 100 ± 0.5 °C. Based on combined physicochemical and organoleptic assessments, Tkibuli tea outperformed Martvili tea by 0.25 ± 0.1 points, resulting in an improvement of the factory-grade tea classification by one level. These results suggest that IR drying at 85–90 °C may contribute to improved retention of aroma-related characteristics, as indirectly supported by the taster values presented in Tab. 2.

Fig. 4 compares the physicochemical parameters of black tea samples from Martvili and Tkibuli dried either by IR radiation at 85 ± 0.5 °C (experimental) or by hot air at 100 ± 0.5 °C (control). The moisture content of control samples dried at 100 ± 0.5 °C was $1.5 \text{ g}\cdot\text{kg}^{-1}$ lower for Martvili tea and $3.0 \text{ g}\cdot\text{kg}^{-1}$ lower for Tkibuli tea compared to the experimental samples.

The content of extractives in the control samples was $1.6 \text{ mg}\cdot\text{kg}^{-1}$ lower for Martvili tea and $24.0 \text{ mg}\cdot\text{kg}^{-1}$ lower for Tkibuli tea than the content in the experimental samples ($p < 0.05$). Total phenolic compounds were $1.4 \text{ mg}\cdot\text{kg}^{-1}$ lower for Martvili tea and $2.9 \text{ mg}\cdot\text{kg}^{-1}$ lower for Tkibuli tea compared to the experimental samples ($p < 0.05$). These results indicate that higher drying temperatures may adversely affect the retention of quality-related compounds.

Fig. 5 presents the comparative organoleptic profiles of black tea samples from Martvili and Tkibuli dried either by IR radiation at

85 ± 0.5 °C (experimental) or by hot air at 100 ± 0.5 °C (control). IR-dried experimental samples achieved, on average, 0.25 ± 0.10 points higher scores across all sensory attributes compared to the control samples. This trend was consistent for both tea origins. Furthermore, Tkibuli tea demonstrated superior performance relative to Martvili tea in both physicochemical and sensory evaluations, indicating a higher overall quality and improved potential for factory-grade black tea production. These findings confirm that IR drying at 85 ± 0.5 °C enhances the sensory quality of black tea while maintaining or improving its physicochemical properties.

Interpretations concerning aroma should be considered qualitative and sensory-based; without GC-MS and GC-O, no quantitative conclusions about volatile compounds can be drawn.

CONCLUSION

This study demonstrated that black tea produced using IR drying technology exhibited improved physicochemical and organoleptic characteristics compared to tea obtained by conventional hot-air drying. Among the investigated samples, IR-dried Tkibuli tea showed higher values of extractive substances ($370 \pm 0.5 \text{ mg}\cdot\text{kg}^{-1}$), total phenolic compounds ($170.5 \pm 0.3 \text{ mg}\cdot\text{kg}^{-1}$), and weighted average sensory score (5.15 ± 0.1) than IR-dried Martvili tea ($356.8 \pm 0.5 \text{ mg}\cdot\text{kg}^{-1}$, $167.4 \pm 0.3 \text{ mg}\cdot\text{kg}^{-1}$, and 4.95 ± 0.1 , respectively).

Sensory evaluation indicated that IR-dried tea samples achieved, on average, 0.25 points higher scores than conventionally dried samples. This improvement may be associated with more favourable retention of improved sensory aroma scores and overall perceived aroma quality, resulting in an enhancement of factory-grade tea quality by one level.

The results further suggest that during FIR drying of both Martvili and Tkibuli teas, the rate of mass loss decreases after approximately 15 min within the temperature range of 85–90 °C. This behaviour indicates a decrease in the rate of moisture evaporation under the conditions studied, in which case direct measurements of volatile aromatic compounds were not performed.

Future research will focus on the identification and characterization of aroma-active compounds in tea samples based on the determined thermodynamic parameters using GC-O and GC-MS. Further optimization of IR drying parameters and evaluation of their applicability under industrial production conditions are also planned.

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