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DEVELOPMENT AND QUALITY EVALUATION OF MULBERRY-GREEN TEA THROUGH MIXED PROCESSING BASED ON ORGANOLEPTIC AND BIOCHEMICAL ATTRIBUTES

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ABSTRACT

Tea (*Camellia sinensis* (L.) Kuntze) is an important plantation crop and widely consumed beverage. Mulberry (Morus spp.), mainly grown for sericulture, is also a good source of phytochemicals and antioxidant compounds. The present study was conducted to develop a mixed processed mulberry-green tea product and standardise it by evaluating different processing methods and blending ratios. The experiment was carried out with young and tender shoots of mulberry variety BC259 and freshly plucked two leaves and a bud tea shoot of variety S3A3. Mulberry and green tea leaves were mixed at three ratios, 75:25, 80:20 and 60:40 and subjected to five processing methods, steaming, dipping in boiling water, roasting, rolling and CTC processing. The processed products were evaluated organoleptically on a 10-point scale for dry leaf, infused leaf, liquor colour, brightness, briskness, mellowness, flavour and overall quality. The biochemical traits (moisture, ash, ascorbic acid, caffeine, total phenolic content and antioxidant activity) were also determined by standard analytical methods. The processing method and the blending ratio had significant effect on most of the organoleptic attributes. The dipping–cooling–CTC–drying method in boiling water obtained the highest overall organoleptic scores. The 75:25 blending ratio was found to be the best among the ratios tested. Moisture, ascorbic acid, caffeine and antioxidant activity were significantly affected by processing method, blending ratio and their interaction, whereas ash content was only significantly affected by processing method. Processing method significantly impacted total phenolic content, but blending ratio and their interaction did not. The highest antioxidant activity and ascorbic acid were obtained by dipping in boiling water–cooling–CTC–drying method and the highest total phenolic content was observed by steaming–cooling–CTC–drying. The combined organoleptic and biochemical evaluation revealed the best combination to be dipping in boiling water–cooling–CTC–drying with 75:25 mulberry tea ratio. A standardised protocol has been described for value addition of mulberry leaves by incorporating them in a green tea-based beverage.

Key words : Mulberry, Green tea, Mixed processing, Organoleptic evaluation, Antioxidant activity.

Introduction

Tea (*Camellia sinensis* (L.) Kuntze) is one of the most consumed beverages in the world and an important plantation crop in Assam and other parts of Northeast India. In addition to the regular tea products, there has been a growing focus on creating value-added and speciality beverages from local plant resources. Such diversification can provide opportunities for product innovation and increase the utilisation and economic value of agricultural resources, especially for small-scale producers (Zohora and Arefin, 2022).

Mulberry (*Morus* spp.) is an important perennial crop that is mainly used in sericulture, as leaves are the main food for silkworm. But mulberry leaves are not only used

in sericulture, they are known to contain different phytochemicals like phenolic compounds and have been reported to have antioxidant potential (Polumackanycz *et al*., 2021; Sanchez-Salcedo *et al*., 2015). These properties have aroused interest in the use of mulberry leaves as raw material for the development of value-added food and beverage products. Therefore, the use of mulberry leaves in the preparation of a tea-like beverage may be an additional means of their utilisation and could create opportunities for income diversification from mulberry cultivation.

The green tea is appreciated for its typical sensory properties and the content of biologically active compounds, in particular polyphenolic compounds. The antioxidant properties of tea have greatly contributed to the importance of tea as a functional beverage (Tongsai *et al*., 2022; Musial *et al*., 2020). The combination of mulberry leaf and green tea can thus represent an interesting approach for developing a novel beverage by merging the characteristic qualities of both plant materials. The incorporation of mulberry into tea can also provide an alternative use of mulberry leaves and contribute to the diversification of tea products (Wu *et al*., 2026).

However, the proper processing conditions are required for the development of a satisfactory mulberry–green tea beverage. Processing influences the physical characteristics, appearance, liquor quality and biochemical composition of tea products. Differences in processing operations may therefore influence the acceptability and quality of a blended product. The relative proportions of mulberry and green tea are also an important consideration, because excessive incorporation of either component may change the sensory characteristics and biochemical composition of the final beverage (Jeon and Choi, 2019; Yang *et al*., 2025). Hence, an appropriate processing protocol has to be established by means of a systematic evaluation of the processing method and blending ratio.

Mixed processing of mulberry leaves with green tea is of particular importance in Assam where tea is a major plantation crop and mulberry is an established sericultural crop and provides an opportunity to explore the value addition and diversified utilisation of locally available agricultural resources (Directorate of Sericulture, Government of Assam, 5 Sep 2026). The project report identified need for standardised methods for preparation of mulberry leaves for blending with green tea and for determination of suitable quality attributes for such value-added products. Mulberry and green tea have been acknowledged for their individual beverage potential but systematic evaluation of different mixed-processing methods and mulberry to green tea ratios is needed for developing a consistent and acceptable product.

In this study, mulberry and green tea leaves were treated with five different mixing processing methods at three ratios of mulberry to green tea, 75:25, 80:20 and 60:40. The effect of processing method and blending ratio on the quality of product was evaluated by organoleptic and biochemical parameters of the products obtained. In this study, a suitable processing method and blending ratio was identified for the development and standardisation of an acceptable mulberry-green tea beverage. The experimental evaluation is a basis for creating a standardised processing protocol for value addition of mulberry by incorporating it with green tea.

Materials and Methods

Planting material

Mulberry raw material for mixed processing with green tea was chosen to be young and tender shoots of mulberry variety BC 259, which have relatively tender leaves with low pubescence. For green tea, fresh shoots (two leaves and a bud; 2L+B) of the variety S_3A_3 were plucked. The shoots were young and tender and were deemed suitable for green tea processing.

Standardisation of Mixed Processing of Mulberry and Green Tea leaves

Mulberry leaves and green tea leaves were mixed and processed together to produce a mulberry-green tea mixed product. Leaves were processed at three different ratios of mulberry leaf: green tea leaf *viz.*; 75:25, 80:20 and 60:40 by five different processing methods.

Processing techniques

Five processing methods were applied for the preparation of mulberry-green tea by mixed processing (Fig. 1). Differences between methods were mainly in the initial heat-treatment and the subsequent size-reduction operations. Drying conditions were uniform.

1. *Steaming–Cooling–Rolling–Drying:* The mixed mulberry leaves and green tea leaves were steamed at 100°C for 3 min and then cooled for 2 hrs. The cooled leaves were then rolled for 30 min. The leaves were dried at an inlet temperature of 60-65°C and a temperature at the outlet of 50-55°C.
2. *Dipping in boiling water–cooling–rolling–drying*: The mixed leaves were dipped in boiling water (100°C) for 2 min and then cooled for 2 hrs 20 min. The leaves were cooled, rolled for 30 min and then dried at an inlet temperature of 60-65°C and outlet temperature of 50-55°C.

3. *Roasting–Cooling–Rolling–Drying:* Mixed leaves were roasted at 85°C for 30 min, then cooled for 1 hr 30 min. The cooled material was rolled for 30 min and then dried at an inlet temperature of 60-65°C and an outlet temperature of 50-55°C.
4. *Steaming–Cooling–CTC–Drying:* The mixed leaves were steamed at 100°C for 3 min and cooled for 2hrs. The cooled leaves were rolled for 30 min and processed through three-cut crush-tear curl (CTC). The CTC processed material was further rolled for 30 min and then dried at an inlet temperature of 60-65°C and an outlet temperature of 50-55°C.
5. *Dipping in boiling water–cooling–CTC–Drying:* The mixed leaves were dipped in boiling water at 100°C for 2 min and cooled for 2 hrs 20 min. The cooled leaves were rolled for 30 min and CTC processing was done for three cuts and rolled for another 30 min. Finally, it was dried at an inlet temperature of 60-65°C and an outlet temperature of 50-55°C.

Organoleptic evaluation

The mixed processed products were sent for organoleptic assessment to three tea broker houses *viz*, Paramount Tea Marketing Pvt. Ltd., Associated Brokers Pvt. Ltd. and Eastern Tea Brokers. Pvt. Ltd. Organoleptic evaluation was done on a scale of 1-10. The parameters assessed are dry leaf, infused leaf, colour, briskness, brightness, mellowness, flavour and quality (Liu *et al*., 2026).

Biochemical evaluation

Moisture content was determined by the hot-air oven method (AOAC, 1970). The moisture content was determined as % of fresh weight basis by drying 10 g of sample at 100 ± 2°C for 16 h.

Ash content

Ash content was estimated by muffle furnace method (AOAC, 1970). Five grams of moisture free powdered sample was incinerated at 600°C for 6 h and ash content expressed as g/100 g sample on dry weight basis.

Ascorbic acid Ascorbic acid was determined by dye-titration method (AOAC, 1970) using 4% oxalic acid for extraction. Results were expressed as mg ascorbic acid/ 100 g sample.

Total phenolic content Total phenols were determined by the Folin–Ciocalteu method (Bray and Thorpe, 1954) using 80% ethanol as extraction solvent. Absorbance was read at 650 nm using catechol as standard.

Caffeine: The caffeine content was determined by UV-Visible spectrophotometric method of Wanyika *et al*. (2010). The aqueous extract was treated with HCl and lead acetate and the absorbance was measured at 274 nm. Caffeine concentration was calculated from a standard curve made from pure caffeine.

Antioxidant activity: Free-radical scavenging activity was assessed using the DPPH assay (Molyneux, 2004). The samples were treated with methanol and then reacted with 1 mM DPPH and incubated in the dark at room temperature for 30 min. The absorbance was measured at 517 nm and the percentage of DPPH inhibition was used to express the radical scavenging activity.

Results and Discussion

Organoleptic evaluation of Mixed-processed Mulberry-green tea

Dry and Infused leaf

Table 1 indicated that the dry leaf characteristics of mixed-processed mulberry-green tea were significantly affected by processing method and blending ratio. Among the processing methods, the highest organoleptic score was obtained for P5 (boiling water dipping–cooling–CTC–drying) and the lowest for P3 (roasting–cooling–rolling–drying). In the blending ratios, the highest score was given to R1 (75:25), followed by R2 (80:20) and R3 (60:40). But the interaction between processing method and blending ratio was not significant.

Table 2 shows that the processing method and blending ratio had a considerable effect on the appearance of infused leaf of the mixed processed mulberry-green tea. Of the processing methods, P5 (boiling water dipping–cooling–CTC–drying) had the highest score which showed a better appearance of infused leaves. The highest score was recorded at R1 (75:25) of the blending ratios. However, interaction effects between processing method and blending ratio were not significant. The higher proportion of mulberry leaves may have changed the visual characteristics of the blended tea due to an increase in contribution of mulberry leaf pigments and other soluble constituents. Processing conditions affect the colour and appearance quality of mulberry leaf tea (Jeon and Choi, 2019; Yan *et al*., 2025).

Colour and Brightness of liquor

The data presented in Table 3 showed that liquor colour of the mixed-processed mulberry–green tea was significantly affected by both processing method and blending ratio. The highest liquor colour scores were

Table 1 : Dry leaf of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	7.500	7.167	6.833	7.167
P2	7.500	7.333	6.833	7.222
P3	7.167	6.500	6.333	6.667
P4	7.833	7.500	7.167	7.500
P5	8.167	8.000	7.833	8.000
Mean R	7.633	7.300	7.000	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.421	0.204	0.144	S
Factor (R)	0.326	0.158	0.112	S
Factor (P X R)	N/A	0.354	0.250	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Table 2 : Infused leaf of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	7.333	6.667	6.333	6.778
P2	7.500	7.000	6.833	7.111
P3	7.167	6.333	6.167	6.556
P4	7.833	7.333	7.333	7.500
P5	8.167	7.833	7.667	7.889
Mean R	7.600	7.033	6.867	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.465	0.226	0.160	S
Factor (R)	0.360	0.175	0.124	S
Factor (P X R)	N/A	0.391	0.277	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

observed in P5 (boiling water dipping–cooling–CTC–drying) and R1 (75:25 mulberry: tea). However, non-significant interaction was observed between processing method and blending ratio.

The results in Table 4 showed that the brightness of the liquor was significantly affected by both the processing method and the blending ratio, but the interaction was non-significant. The highest brightness score was obtained by P5 (boiling water dipping-cooling-CTC-drying),

Table 3 : Colour of liquor of mixed processed mulberry and tea leaves

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	6.000	5.833	5.667	5.833
P2	6.500	6.333	6.167	6.333
P3	5.833	5.667	5.333	5.611
P4	6.667	6.500	6.167	6.444
P5	7.000	6.833	6.500	6.778
Mean R	6.400	6.233	5.967	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.354	0.172	0.122	S
Factor (R)	0.275	0.133	0.094	S
Factor (P X R)	N/A	0.298	0.211	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Table 4 : Brightness of liquor of mixed processed mulberry and tea leaves

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	6.833	6.667	6.333	6.611
P2	7.167	7.000	7.167	7.111
P3	6.167	6.000	5.667	5.944
P4	7.667	7.333	7.167	7.389
P5	7.833	7.667	7.500	7.667
Mean R	7.133	6.933	6.767	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.339	0.165	0.117	S
Factor (R)	0.263	0.128	0.090	S
Factor (P X R)	N/A	0.285	0.202	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

followed by P4, P2, P1 and P3, respectively. Among the blending ratios, R1 (75:25) got the highest score, followed by R2 (80:20) and R3 (60:40).

The increased liquor colour and brightness of P5 could be due to the synergistic effects of boiling-water treatment and CTC processing that led to rapid enzyme inactivation and greater destruction of leaf tissues, thereby promoting the extraction of colour contributing compounds. The

higher scores at R1 (75:25) indicate that this ratio offered better balance of mulberry and green tea. Increasing the ratio of mulberry leaves altered the visual quality of liquor (Jeon and Choi, 2019; Deka *et al*., 2020).

Briskness and Mellowness

The interaction between processing method and blending ratio was not significant, but the processing method and blending ratio had a significant effect on the briskness of the liquor (Table 5). The highest briskness score was found in P5 (boiling water dipping-cooling-CTC-drying). R1 (75:25) showed the highest score among the blending ratios, followed by R2 (80:20) and R3 (60:40). The increased briskness of P5 may be due to increased cell disruption during the CTC processing, which can improve the extraction of soluble tea constituents that contribute to the liquor character. The higher score at R1 (75:25) suggests that this blending proportion gave a desirable balance of mulberry and green tea while lowering the mulberry proportion decreases briskness (Deka *et al*., 2020).

The analysis of the data in Table 6 indicated that the processing method had a significant effect on the quality attribute of the mixed-processed mulberry–green tea, while the blending ratio and the interaction between the processing method and ratio were non-significant. Among the processing methods, P5 (boiling water dipping–cooling–CTC–drying) had the highest score and was more excellent than the other four treatments.

Flavour and quality

The data shown in Table 7 indicated that the flavour of mixed-processed mulberry–green tea liquor was significantly affected by both processing method and blending ratio, and the interaction between the two was non-significant. The highest scores of flavour among the respective treatments were recorded in P5 (boiling water dipping–cooling–CTC–drying) and R1 (75:25).

The results in Table 8 showed that processing method and blending ratio had significant effect on overall liquor quality of the mixed-processed mulberry-green tea and interaction effect was non-significant. Among the processing methods, the highest quality score was obtained with P5 (boiling water immersion-cooling-CTC-drying). The most suitable blending ratio was R1 (75:25).

The combined effects of boiling-water treatment and CTC processing can improve the extraction of soluble compounds, which may explain the better flavour and overall quality of P5, and can influence the sensory properties of the infusion. Similar processing method effects on flavour and overall acceptability have been reported in mulberry leaf tea and green tea (Jeon and Choi, 2019; Deka *et al*., 2020).

Table 5 : Briskness of liquor of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	6.667	6.667	6.333	6.556
P2	7.333	6.833	6.667	6.944
P3	6.333	6.500	6.167	6.333
P4	7.500	7.000	6.833	7.111
P5	7.667	7.167	7.000	7.278
Mean R	7.100	6.833	6.600	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.561	0.272	0.193	S
Factor (R)	N/A	0.211	0.149	NS
Factor (P X R)	N/A	0.472	0.334	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Table 6 : Mellowness of liquor of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	6.500	6.500	6.333	6.444
P2	6.833	6.833	6.833	6.833
P3	6.000	5.667	5.833	5.833
P4	7.167	7.000	7.000	7.056
P5	7.500	7.333	7.000	7.278
Mean R	6.800	6.667	6.600	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.250	0.121	0.086	S
Factor (R)	N/A	0.094	0.066	NS
Factor (P X R)	N/A	0.210	0.149	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Biochemical Evaluation of Mixed-Processed Mulberry-Green Tea

Moisture content (%, fresh weight basis)

The results in Table 9 showed that the processing method, mixing ratio and their interaction had a significant effect on the moisture content of the mixed-processed

Table 7 : Flavour of liquor of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	7.500	7.333	6.833	7.222
P2	7.500	7.500	7.000	7.333
P3	7.167	6.833	6.667	6.889
P4	7.833	7.667	7.333	7.611
P5	8.000	7.833	7.500	7.778
Mean R	7.600	7.433	7.067	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.365	0.177	0.125	S
Factor (R)	0.283	0.137	0.097	S
Factor (P X R)	N/A	0.307	0.217	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Table 8 : Quality of liquor of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	7.500	7.500	7.000	7.333
P2	7.833	7.667	7.333	7.611
P3	7.500	7.333	6.833	7.222
P4	8.000	7.833	7.500	7.778
P5	8.333	8.000	7.667	8.000
Mean R	7.833	7.667	7.267	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.333	0.162	0.114	S
Factor (R)	0.258	0.125	0.088	S
Factor (P X R)	N/A	0.280	0.198	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

mulberry–green tea. The highest moisture content was obtained for P3 (roasting-cooling-rolling-drying) among the processing methods. Among the blending ratios, highest moisture content was observed in R3 (60:40) followed by R2 (80:20) and R1 (75:25). The higher moisture content in P3 could be due to roasting treatment that may have led to relatively lesser efficient moisture removal as compared to the other processing methods. The increased moisture content in R3 (60:40) could be attributed to the greater level of green tea in the blend, as processing and leaf composition can affect moisture retention and drying behaviour (Donlao and Ogawa, 2019; Sanaeifar *et al.*, 2020).

Table 9 : Moisture content (%, fresh weight basis) of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	3.183	3.350	3.667	3.400
P2	2.977	3.067	3.457	3.167
P3	3.360	3.663	3.983	3.669
P4	2.633	2.763	2.877	2.758
P5	2.203	2.407	2.537	2.382
Mean R	2.871	3.050	3.304	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.012	0.006	0.004	S
Factor (R)	0.009	0.004	0.003	S
Factor (P X R)	0.020	0.010	0.007	S

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Table 10 : Ash content (%, dry weight basis) of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	4.977	5.237	5.437	5.217
P2	4.650	4.677	4.807	4.711
P3	5.213	5.53	5.537	5.401
P4	4.137	4.217	4.430	4.261
P5	3.867	3.903	2.700	3.490
Mean R	4.569	4.697	4.582	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.583	0.283	0.200	S
Factor (R)	N/A	0.219	0.155	NS
Factor (P X R)	N/A	0.490	0.347	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Ash content (%, dry weight basis)

The processing method had a significant effect on the ash content of the mixed-processed mulberry–green tea as shown in Table 10, whereas the blending ratio and

Table 11 : Ascorbic acid content (mg/100g, dry weight basis) of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	125.403	125.033	50.163	100.200
P2	126.853	126.597	125.60	126.303
P3	123.060	122.750	122.117	122.642
P4	127.257	126.827	126.033	126.706
P5	129.853	129.213	128.320	129.129
Mean R	126.485	126.084	110.419	
Factors	**C.D.**	**SE(d)**	**SE(m)**	**Significance**
Factor (P)	125.403	125.033	50.163	S
Factor (R)	126.853	126.597	125.60	S
Factor (P X R)	123.060	122.750	122.117	S

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Table 12 : Total Phenol content (mg GAE/g, dry weight basis), GAE: Gallic acid equivalent, of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	35.927	35.540	35.023	35.497
P2	36.240	35.807	35.037	35.694
P3	35.407	34.277	23.680	31.121
P4	38.213	38.203	37.657	38.024
P5	38.737	37.580	36.210	37.509
Mean R	36.905	36.281	33.521	
Factors	**C.D.**	**SE(d)**	**SE(m)**	**Significance**
Factor (P)	4.495	2.183	1.544	S
Factor (R)	N/A	1.691	1.196	NS
Factor (P X R)	N/A	3.781	2.674	NS

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

its interaction with the processing method were non-significant. Processing methods such as P3 (roasting–cooling–rolling–drying) had the highest ash content and P5 (boiling water dipping–cooling–CTC–drying) had the lowest. The higher ash content observed in P3 might be due to differences in the effect of roasting and subsequent drying on the concentration of mineral constituents of the processed leaves. The mineral components in mulberry leaves can be affected by processing and drying conditions (Zhao *et al*., 2025).

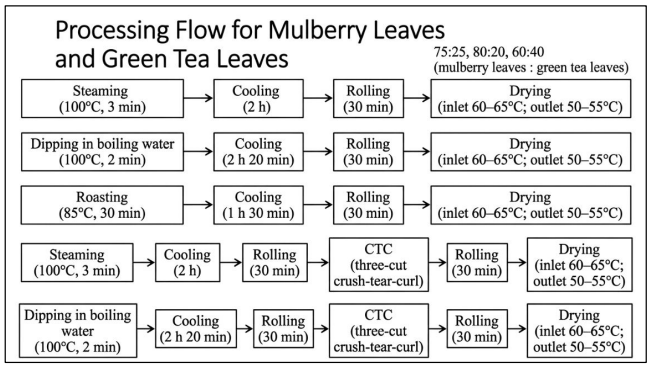


Fig. 1 : Mixed processing techniques for mulberry and green tea leaves.

Ascorbic acid content (mg/100g, dry weight basis)

The results of Table 11 indicated that the ascorbic acid content of the mixed-processed mulberry–green tea was significantly affected by processing method, blending ratio and their interaction. Among the processing methods, the highest content of ascorbic acid was found in P5 (boiling water dipping-cooling-CTC-drying). Among the blending ratios, R1 (75:25 mulberry tea) showed the highest ascorbic acid content. The higher ascorbic acid content in P5 could be due to the boiling-water treatment followed by CTC processing and drying which could have led to a higher retention of ascorbic acid than the other processing methods. It has been reported that boiled and dried green tea has similar higher levels of ascorbic acid compared to steamed and roasted tea (Neog *et al*., 2020).

Total phenol content (mg GAE/g, dry weight basis)

From the data of Table 12, total phenol content of mixed-processed mulberry–green tea was significantly affected by the processing method, whereas the blending ratio and its interaction with processing method were non-significant. Among the processing methods, P4 (steaming–cooling–CTC–drying) obtained the highest total phenol content, while P3 (roasting–cooling–rolling–drying) obtained the lowest. The higher total phenol content observed in P4 may be attributed to steaming, which can favour the retention or release of phenolic compounds, while the lower content in P3 may reflect greater thermal alteration during roasting. Heat-processing conditions have been reported to markedly influence the phenolic composition of mulberry leaves, with steaming affecting polyphenol levels (Lee and Choi, 2012).

Caffeine content (%, dry weight basis)

The results in Table 13 showed that the processing method, mixing ratio and their interaction significantly affected caffeine content of the mixed-processed

Table 13 : Caffeine content (%, dry weight basis) of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	0.077	0.103	0.113	0.098
P2	0.060	0.077	0.083	0.073
P3	0.120	0.137	0.130	0.129
P4	0.047	0.063	0.080	0.063
P5	0.030	0.043	0.057	0.043
Mean R	0.067	0.085	0.093	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.006	0.003	0.002	S
Factor (R)	0.005	0.002	0.002	S
Factor (P X R)	0.011	0.005	0.004	S

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

Table 14 : Antioxidant activity (%, dry weight basis) of mixed processed mulberry and tea leaves.

Process	Ratio (Mulberry: Tea)			Mean P
	R1	R2	R3	
P1	71.210	71.013	70.613	70.946
P2	71.647	71.370	70.940	71.319
P3	70.830	70.413	70.260	70.501
P4	72.337	71.860	71.293	71.830
P5	72.867	72.417	72.077	72.453
Mean R	71.778	71.415	71.037	
Factors	C.D.	SE(d)	SE(m)	Significance
Factor (P)	0.062	0.030	0.021	S
Factor (R)	0.048	0.023	0.016	S
Factor (P X R)	0.107	0.052	0.037	S

***** P1= Steaming-cooling-rolling-drying, P2= Dipping in boiling water- cooling-rolling-drying, P3= Roasting-cooling-rolling-drying, P4= Steaming-cooling-CTC-drying, P5= Dipping in boiling water- cooling-CTC-drying; R1= 75:25, R2= 80:20, R3= 60:40; Significant at 5% probability level, S=Significant, NS=non-significant.

mulberry–green tea. For the processing methods, the highest caffeine content was observed in P3 (roasting–cooling–rolling–drying) and for the blending ratios, the highest caffeine level was observed in R3 (60:40 mulberry tea). The higher caffeine content of P3 might be attributed to the higher caffeine retention during roasting and subsequent drying as caffeine is quite stable during tea processing conditions. The highest caffeine content was found in R3, which corresponds to the blend having a higher proportion of green tea. Green tea is the main source of caffeine in the mixed product (Donlao and Ogawa, 2019).

Antioxidant activity (%, dry weight basis)

The results in Table 14 showed that the processing method, the mixing ratio and their interaction had a significant effect on the antioxidant activity of the mixed-processed mulberry–green tea. Among the processing methods, the highest antioxidant activity was observed in P5 (boiling water dipping–cooling–CTC–drying). The blending ratio of R1 (75:25 mulberry tea) exhibited the highest antioxidant activity. The increased antioxidant activity in P5 might be related to processing-induced modifications that increase the availability or extractability of antioxidant compounds in mulberry–green tea. The increase of activity in R1 can be attributed to the higher proportion of mulberry leaves, which are rich in the phenolic and flavonoid compounds with antioxidant activity (Katsube *et al*., 2009; Bai *et al*., 2023).

Conclusion

The results obtained from the organoleptic and biochemical properties of mixed processed mulberry and tea leaves concluded that the best process for producing a mixed product is dipping in boiling water- cooling-CTC-drying.

The order for suitability of the process is Dipping in boiling water- cooling-CTC-drying > Steaming-cooling-CTC-drying > Dipping in boiling water- cooling-rolling > Steaming-cooling-rolling-drying > Roasting-cooling-rolling-drying.

Similarly, the desired ratio of mixing mulberry and tea leaves was obtained from perusal of data from analyzing organoleptic and biochemical properties of mixed processed products. Mixing of mulberry leaves and tea leaves was done in three ratios 75:25, 80:20 and 60:40. The order for suitability of the ratios is 75:25 > 80:20 > 60:40.

The standard of the process dipping in boiling water-cooling-CTC-drying in the ratio 75:25 is as follows:

For processing 10 kg of fresh leaves, 7.5 kg of mulberry leaves are mixed with 2.5 kg of tea leaves before processing. The mixed fresh leaves are dipping in boiling water (100°C) for 2 minutes. The boiled leaves are then evenly spread on a cooling trough for 2 hours 20 minutes to reduce the surface moisture followed by pre conditioning of the tea leaves in a table roller for 30 minutes. The pre conditioned leaves are macerated in a CTC machine to evenness in appearance of the mixed product. Immediate drying after CTC is done to prevent

oxidation of the tea leaves at an inlet temperature of 60-65°C and an outlet temperature of 50-55°C.

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References

AOAC International (1970). *Official methods of analysis of the Association of Official Analytical Chemists*. Association of official analytical chemists.

Bai, H., Jiang W., Yan R., Wang F., Jiao L., Duan L. and Wang S. (2023). Comparing the effects of three processing methods on the efficacy of mulberry leaf tea: Analysis of bioactive compounds, bioavailability and bioactivity. *Food Chem.*, **405**, 134900.

Bray, H.G. and Thorpe W. (1954). Analysis of phenolic compounds of interest in metabolism. *Methods of Biochemical Analysis*, 27-52.

Deka, H., Barman T., Sarmah P. P., Devi A., Tamuly P., Paul R.K. and Karak T. (2020). Quality characteristics of infusion and health consequences: a comparative study between orthodox and CTC green teas. *RSC Adv.*, **10(54)**, 32833-32842.

Directorate of Sericulture, Government of Assam (5 Sep 2026). *Mulberry cultivation and management*. Government of Assam. https://sericulture.assam.gov.in/portlet-innerpage/mulberry-cultivation-and-management

Donlao, N. and Ogawa Y. (2019). The influence of processing conditions on catechin, caffeine and chlorophyll contents of green tea (*Camelia sinensis*) leaves and infusions. *LWT*, **116**, 108567.

Jeon, Y.H. and Choi S.W. (2019). Evaluation of phytochemical constituents and organoleptic properties of mulberry leaf tea obtained by different processing methods. *Food Sci. Preser.*, **26(1)**, 59-67.

Katsube, T., Tsurunaga Y., Sugiyama M., Furuno T. and Yamasaki Y. (2009). Effect of air-drying temperature on antioxidant capacity and stability of polyphenolic compounds in mulberry (*Morus alba L.*) leaves. *Food Chem.*, **113(4)**, 964-969.

Lee, W.J. and Choi S.W. (2012). Quantitative changes of polyphenolic compounds in mulberry (*Morus alba* L.) leaves in relation to varieties, harvest period and heat processing. *Preventive Nutr. Food Sci.*, **17(4)**, 280.

Liu, C., Wang C., Wei M., Ning M., Xu Z., Chen S. and Tang Q. (2026). Influence of leaf tenderness on the aroma and taste characteristics of green tea from *Camellia sinensis* cv. *Chuancha* No. 2: Integrated sensory and chemical profiling. *Food Chem.: X*, 103754.

Molyneux, P. (2004). The use of the stable free radical diphenylpicrylhydrazyl (DPPH) for estimating antioxidant activity. *Songklanakarin J. Sci. Technol.*, **26(2)**, 211-219.

Musial, C., Siedlecka-Kroplewska K., Kmiec Z. and Gorska-Ponikowska M. (2021). Modulation of autophagy in cancer cells by dietary polyphenols. *Antioxidants*, **10(1)**, 123.

Neog, M., Das P. and Saikia G.K. (2020). Changes in phytochemicals during processing of green tea. *Int. J. Curr. Microbiol. Appl. Sci.*, **9(1)**, 414-421.

Polumackanycz, M., Wesolowski M. and Viapiana A. (2021). *Morus alba* L. and *Morus nigra* L. leaves as a promising food source of phenolic compounds with antioxidant activity. *Plant Foods Hum. Nutr.*, **76(4)**, 458-465.

Sanaeifar, A., Huang X., Chen M., Zhao Z., Ji Y., Li X. and Yu X. (2020). Nondestructive monitoring of polyphenols and caffeine during green tea processing using Vis NIR spectroscopy. *Food Sci. Nutr.*, **8(11)**, 5860-5874.

Sánchez-Salcedo, E.M., Mena P., García-Viguera C., Martínez J.J. and Hernández F. (2015). Phytochemical evaluation of white (*Morus alba L.*) and black (*Morus nigra* L.) mulberry fruits, a starting point for the assessment of their beneficial properties. *J. Functional Foods*, **12**, 399-408.

Tongsai, S., Jangchud K., Jangchud A., Tepsongkroh B., Boonbumrung S. and Prinyawiwatkul W. (2022). Relationship between sensory and chemical properties of Assam green teas under different pan-firing and rolling time conditions. *Int. J. Food Sci. Technol.*, **57(5)**, 3116-3127.

Wanyika, H.N., Gatebe E.G., Gitu L.M., Ngumba E.K. and Maritim C.W. (2010). Determination of caffeine content of tea and instant coffee brands found in the Kenyan market. *Afr. J. Food Sci.*, **4(6)**, 353-358.

Wu, J., Yang Q., Xia W., Wang X., Pan H., Yin H. and Liu F. (2026). Changes in antioxidant, non volatile and volatile contents of mulberry leaf green tea prepared using different fixation methods. *J. Sci. Food Agricult.*, **106(7)**, 4178-4189.

Xiang, R., Cheng J., Zhu M. and Liu X. (2019). Effect of mulberry (*Morus alba*) polyphenols as antioxidant on physiochemical properties, oxidation and bio-safety in Cantonese sausages. *LWT*, **116**, 108504.

Yan, Z., Zhang Y., Wang L., Zhou J., Cheng Q. and Li W. (2025). Revealing the effects of withering methods and withering time on the active components of mulberry leaf tea using HS-SPME/GC-MS. *J. Chromatography A*, 466267.

Yang, C., Li X., Niu W., Jia Y., Peng Y., Huang C. and Luo A. (2025). Effects of electron beam irradiation pretreatment on the physicochemical components, sensory properties, and aroma compounds of mulberry leaf tea fermented with *Eurotium cristatum*. *Food Chem.*, 145768.

Zhao, C., Li T., Zhang C., Li H., Wang Y., Li C. and Zhao W. (2025). Drying methods affect nutritional value, amino acids, bioactive compounds, and in vitro function of extract in mulberry leaves. *Food Chem.*, **481**, 144018.

Zohora, K.F.T. and Arefin M.R. (2022). Tea and tea product diversification: A review. *Turkish J. Agricult.-Food Sci. Technol.*, **10(12)**, 2334-2353.