Food Chemistry 72 (2001) 319–327

Food Chemistry

www.elsevier.com/locate/foodchem

Comparative responses in plain black tea quality parameters of different tea clones to fermentation temperature and duration

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Received 29 February 2000; received in revised form 26 July 2000; accepted 26 July 2000

Abstract

The amounts of black tea theaflavins, brightness, and sensory evaluations varied with clones in the order clone 6/8 > SC12/28 > S15/10, while thearubigins and total colour changed in the reverse order. The rates of change of these plain tea quality parameters varied in all clones causing significant ($P \leqslant 0.05$) fermentation duration and clone interactions. Thus, the total amount and rate of development of each quality parameter is unique to a clone and a change in fermentation duration for optimal quality parameter achievement in one clone cannot be extrapolated to another clone. Although processing of black tea at low fermentation temperatures improved black tea quality, there was no significant difference between fermenting at 15 and 20°C. Long fermentation duration and high temperature favoured production of more intense coloured black teas with high thearubigin levels, which were less bright and had lower theaflavin levels. There were significant ($P \leqslant 0.05$) interactions between fermentation duration and temperature in all the plain black tea parameters development indicating that their rates of formation and amounts formed varied with time at different temperatures. Clones 6/8 and SC12/28 plain tea quality parameters were more sensitive to temperature and duration changes than clone S15/10. Thus there are clones, which can withstand high temperature and long fermentation duration without drastic impairment of their plain black tea quality parameters.

Keywords: *Camellia sinensis*; Plain black tea quality; Clones; Fermentation temperature and duration

1. Introduction

In processing young tender shoots of *Camellia sinensis* into plain black tea, control of fermentation conditions is necessary for production of superior quality beverages. The parameters whose controls are normally considered during fermentation are temperature (Cloughley, 1980; Obanda & Owuor, 1993; Owuor & Obanda, 1993), time (duration); (Cloughley, 1979; Owuor & Reeves, 1986), and supply of adequate oxygen (Takino, Imagawa, Harikawa & Tamaka, 1964; Nakagawa & Torii, 1965). It was recently demonstrated that the amount of oxygen supplied by blowing air through the "dhool" (macerated tea leaf) is adequate to produce high quality plain black teas under Kenya black tea processing conditions, provided fermentation is of sufficient duration and there is control of temperature (Owuor & Obanda, 1998a,b).

For the processing of high quality plain black teas, it is critical to determine and use the correct fermentation time. Consequently, different methods have been evaluated to assess optimal fermentation time. These efforts have concentrated on monitoring the formation of some plain black tea quality parameters. Bhatia (1960) assessed changes in epigallocatechin gallate (EGCG). Roberts and Chandradasa (1982) measured colour development, Takeo (1974) evaluated formation of theaflavins (TF) and thearubigin polymers, while Cloughley (1979) developed an in-line TF measurement method to optimise fermentation time and Owuor and Reeves (1986) compared the in-line TF analysis method with TF in made tea and sensory evaluation.

Despite these efforts, no reliable method has been developed and adopted for routine use in factories (Owuor, Orchard & McDowell, 1994). Consequently factory personnel continue to use visual assessment of "dhool" and sensory evaluation of made black teas after fermentation trials to assess and determine the optimum fermentation time. Indeed, in attempting to adopt the use of in-line TF analysis (Cloughley, 1979)

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PII: S0308-8146(00)00232-6

for Kenyan black teas, it was observed that even in the same clones there were variations in the optimal fermentation time determined by experiments done on different days (Owuor & Reeves, 1986). Earlier, using one clone (Owuor & Obanda, 1993), it was demonstrated that the rate of formation of TFs in black tea varied with temperature. Whereas it is not known how the formation of thearubigins, total colour and brightness of black tea vary due to fermentation temperatures, part of the previously observed variation in optimal fermentation time for the same clone processed on different days could be due to variations in the ambient temperatures.

Although changes in optimal fermentation duration have been recorded due to variations in temperatures (Cloughley, 1980; Owuor & Obanda, 1993), it is always assumed that all clones behave in the same way. Thus, a regularly observed procedure is that when there is rise in ambient temperature, factory personnel arbitrarily shorten the duration and vice versa. Thus, with a change in ambient temperature of 3°C, some factories vary the fermentation duration by as much as 30 min while others change the duration by only 10 min. This arbitrary change in fermentation duration by factory personnel is due to the belief that all clones behave in the same way and if at one time changes of ambient temperature, by e.g. 3°C, necessitated a 20 min variation in fermentation duration, this would hold for all clones. The arbitrary change in fermentation duration may adversely affect the quality of resultant black teas. This study was done to assess whether there are interactions between fermentation duration and temperature, and whether different clonal teas react in a similar way to variations in fermentation duration and temperature.

2. Materials and methods

2.1. Leaf and manufacture

The leaf used in the study was plucked from the Tea Research Foundation of Kenya Clonal Tea Museum planted in 1983 at Timbilil Estate (altitude 2180 m above mean sea level, longitude 35°21″ east and latitude 0°22″ south). The clones used were 6/8, SC12/28, and S15/10. The clones were selected because of their different fermenting abilities. Generally, clone 6/8 is classified as a good quality tea and fast fermenter (Owuor et al., 1994), while clone S15/10, although yielding, up to 11,950 kg made tea per hectare under commercial estate production (Oyamo, 1992), is a slow and poor fermenter (Owuor et al.; Obanda & Owuor, 1993). Clone SC12/28 was selected from open pollinated progenies of clone S15/10. Thus, it is a half-sib clone with clone S15/10 as the mother. It is reasonably high yielding, a faster fermenter, and of medium quality. The plants were receiving 150 kg N per hectare per year in a single dose as NPKS 25:5:5:5. Plucking standards conformed to the normal recommended commercial practice of mostly two leaves and a bud, plus minor amounts of three leaves and a bud (Othieno, 1988). From each clone, 9 kg green leaf was plucked per replicate. The experiment was replicated four times.

Immediately the leaf was delivered to the miniature factory, the three clones were put in separate environmentally controlled withering units (TeaCraft, UK) with maximum temperature set at 22°C and minimum temperature set at 20°C. After 14 h, the leaf, which had achieved both chemical wither and 70% physical wither (Owuor & Orchard, 1989, 1990), was divided into seven equal portions for each clone. Each was then miniature "Crush, Tear and Curl" macerated (Owuor & Reeves, 1986). The macerated leaf (dhool) was fermented for 0, 30, 60, 90, 120, 150 and 180 min at 15, 20, 25 and 30°C. Fermentation was done in environmentally controlled units (TeaCraft) and was terminated by firing (drying) in a miniature fluid-bed dryer (TeaCraft). The fired black teas were subjected to chemical analysis and sensory evaluation without sorting.

2.2. Chemical analysis, sensory evaluations and statistical analyses

The TF levels were determined by the Flavognost method as outlined by Hilton (1973), while thearubigins, total colour and brightness were analysed by the method of Roberts and Smith (1963). Tea tasting (sensory evaluation) was done by two professional tasters at tea-brokerage firms in Mombasa, Kenya. The tasting scores were based on briskness, brightness, infusion, colour, thickness, flavour and overall quality, each on a scale of 0–10 for Taster A and 0–20 for Taster B. The results were analysed using analysis of variance as split-split plot with clones as main treatments and split for fermentation temperature sub-split for fermentation duration.

3. Results and discussion

The quality and value of black tea are assessed using three senses: sight, taste and smell. The smell is due to volatile flavour compounds and is mainly important for flavoury black teas (Howard, 1978; Robinson & Owuor, 1992). Most Kenyan black teas are classified as plain to medium flavoury in the international tea market. Such black teas are normally sold for their taste and appearance. The chemicals responsible for the taste and appearance of black tea are the TFs and thearubigins. TFs are responsible for the astringency, brightness, colour and briskness of the black tea, while thearubigins contribute to the mouth feel (thickness) and colour of the tea (Biswas, Sarkar & Biswas, 1973). The plain black tea quality parameters are therefore TFs, thearubigins, total colour, and brightness.

The variations in the plain black tea quality parameters and sensory evaluation of different clones due to fermentation duration are presented in Table 1 and Figs. 1–3. Except for sensory evaluation by Taster A and brightness (Tables 1 and 3), the clones had significantly ($P \leqslant 0.05$) different quality parameters. The order of magnitude of quality as assessed by all the parameters recorded was clone 6/8 > SC12/28 > S15/10 (Table 1 and Figs. 1–3). Thus, as had been observed in other studies (Owuor, Horita, Tshshida & Murai, 1987), tea clones exhibit different quality potential.

As observed previously (Cloughley, 1979, 1980; Owuor & Reeves, 1986), the TF levels increased up to a maximum then declined as fermentation duration increased (Table 1 and Fig. 1). However, there were variations in the maximum TFs formed in different clones and these were reached after different times. This demonstrates that there are clones with better potential to make higher levels of TFs than others. In earlier studies, TFs had been demonstrated to be black tea quality indicators (Davies, 1983; Ellis & Cloughley, 1981) and a good relationship was noted between the high TF levels

Table 1
The mean effect of fermentation at 15 to 30°C on plain black tea quality parameters due to variations in clones and fermentation time

Item	Clone	Duration (min)							Mean
		0	30	60	90	120	150	180	
Theaflavins (μmol/g)	6/8	5.61	14.33	21.58	27.07	25.79	24.20	23.70	20.33
	S15/10	4.64	10.60	13.29	14.11	14.30	14.67	14.92	12.36
	SC12/28	3.80	8.39	14.59	18.19	19.95	19.35	18.37	14.66
	Mean	4.68	11.11	16.49	19.79	20.02	19.41	18.99	
	C.V. (%)			12.4					
	LSD ($P \leqslant 0.05$)			0.77					2.99
	Interactions			1.34					
Thearubigins (%)	6/8	11.63	12.79	14.33	15.83	17.50	17.47	18.47	15.43
	S15/10	9.23	10.99	12.10	13.36	14.19	14.22	14.54	12.68
	SC12/28	10.60	11.51	13.53	14.64	15.60	16.51	17.28	14.20
	Mean	10.48	11.76	13.32	14.61	15.76	16.00	16.76	
	C.V. (%)			7.95					
	LSD ($P \leqslant 0.05$)			0.45					1.72
	Interactions			0.78					
Total colour (%)	6/8	1.75	2.67	3.89	4.68	4.71	5.05	4.92	3.97
	S15/10	1.31	2.25	3.15	3.48	3.69	3.84	3.95	3.10
	SC12/28	1.25	1.82	2.66	3.39	3.91	4.33	4.75	3.16
	Mean	1.44	2.25	3.24	3.85	4.10	4.37	4.63	
	C.V. (%)			12.03					
	LSD ($P \leqslant 0.05$)			0.15					0.54
	Interactions			0.27					
Brightness (%)	6/8	19.64	30.02	32.22	31.21	28.59	26.20	24.47	27.48
	S15/10	22.48	28.22	28.20	25.08	24.62	22.41	21.96	24.71
	SC12/28	18.46	26.44	27.49	28.52	26.58	23.99	22.70	24.88
	Mean	20.19	28.23	29.30	28.27	26.60	24.20	23.04	
	C.V. (%)			9.69					
	LSD ($P \leqslant 0.05$)			1.00					NS
	Interactions			1.73					
Taster A	6/8	14	19	21	24	25	25	24	22
	S15/10	14	16	18	19	21	22	23	19
	SC12/28	13	16	19	22	23	23	23	20
	Mean	14	17	20	22	23	23	23	
	C.V. (%)			10.38					
	LSD ($P \leqslant 0.05$)			1					NS
	Interactions			1					
Taster B	6/8	33	59	75	88	87	89	80	73
	S15/10	26	33	40	47	50	62	64	46
	SC12/28	34	53	65	77	81	81	74	66
	Mean	31	48	60	71	73	77	73	
	C.V. (%)			13.34					
	LSD ($P \leqslant 0.05$)			3					11
	Interactions			6					

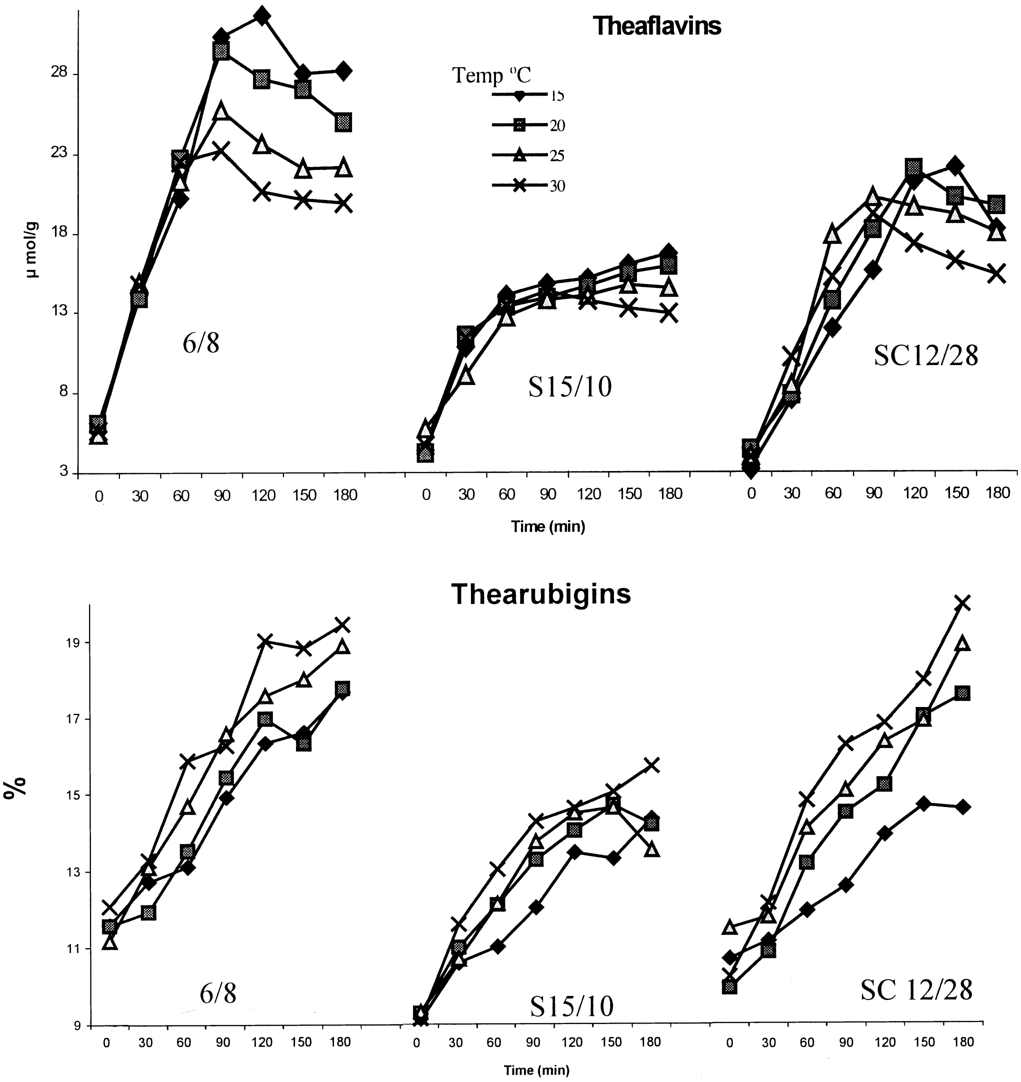

Fig. 1. Effect of fermentation duration (minutes) at temperatures (°C) on the production of theaflavins and thearubigins in different clones.

and prices or valuation of some plain black teas (Cloughley, 1983; Hilton & Ellis, 1972; Hilton & Palmer-Jones, 1975). The variations in the TF levels observed here in different clones and with different fermentation durations seemed to have closely followed those of sensory evaluation. These results demonstrate that clones with low potential to make high TF levels are likely to be of poor quality and such low levels of TF cannot be corrected by varying fermentation time. Again, each clone developed maximum TF after different times. Generally in factories, fermentation trials are done to determine the optimal fermentation duration. Once that time has been determined, all the leaf available is subjected to the same fermentation duration. However, the data presented here demonstrate that, in the manufacture of clonal tea, each clone needs to have its own optimum fermentation duration determined to get the best quality out of the leaf. This is more clearly demonstrated by the significant ($P \leqslant 0.05$) interactions in the TF levels between clones and fermentation durations. The significant interactions imply that different clones develop TFs at different rates and in different patterns.

Like TFs, the other plain black tea parameters, except brightness and sensory evaluation by Taster A, varied significantly ($P \leqslant 0.05$) with clone and fermentation duration. The variations in sensory evaluations, TFs and brightness were in the order 6/8 > SC12/28 > S15/10 while thearubigins and total colour varied in the reverse order. Although significant variations were not recorded in clones in the brightness and Taster A evaluation, the order was 6/8 > SC12/28 > S15/10, i.e. similar to that observed in the TFs, thearubigins, total colour, and taster B's evaluation. The amounts and rates of development of the different parameters with time varied in the clones studied, causing the time and clone interactions to be significant. Although the thearubigins and total colour increased with the fermentation duration in all clones, the rate of increase tended to be faster in the

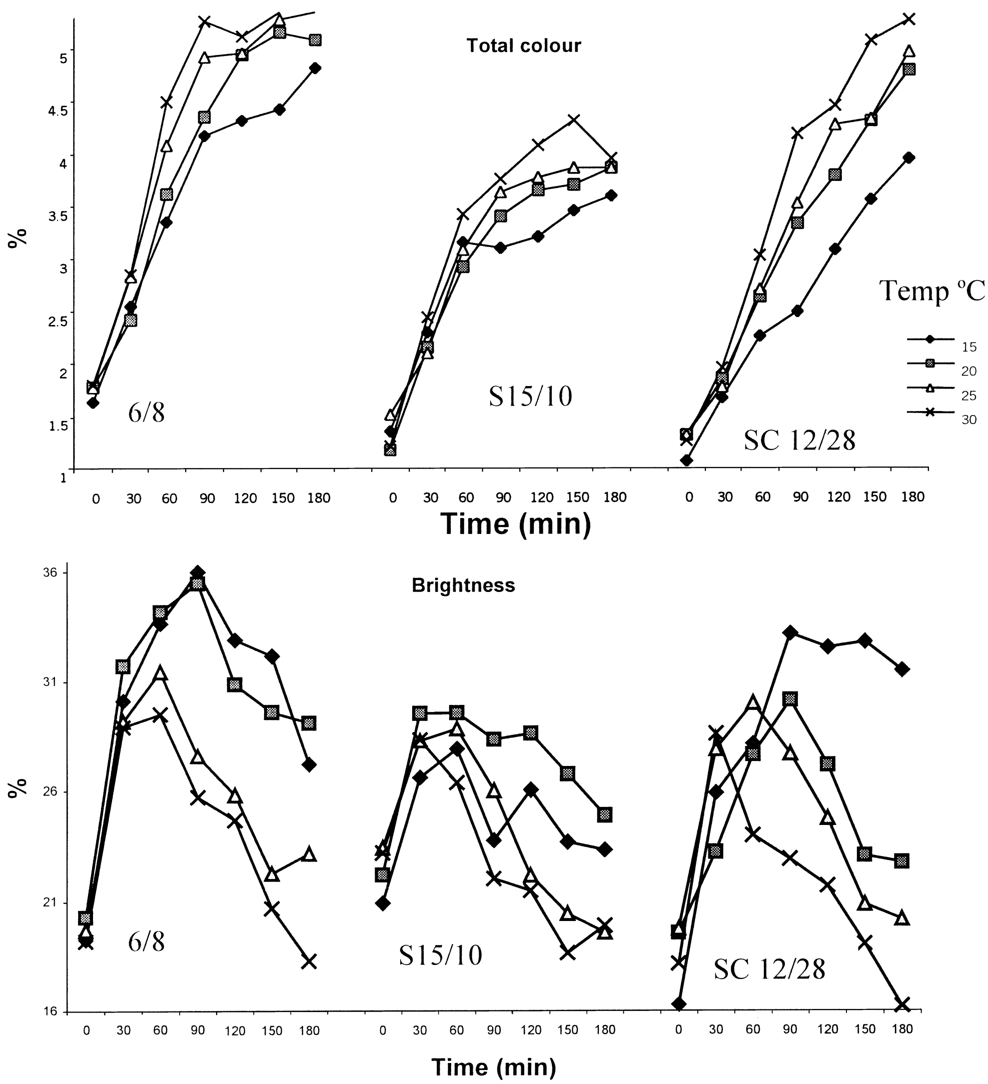

Fig. 2. The effects of fermentation duration (minutes) at temperatures (°C) on the development of total colour and brightness in black teas from different clones.

early part of fermentation than in the later stages (Table 1 and Figs. 1 and 2). The sensory evaluation and brightness, on the other hand responded in a similar pattern to TFs. There was a rise to up a maximum level, followed by a decline (Table 1 and Figs. 1–3). However, the maximum brightness formed ahead of maximum TFs. This observation confirms the earlier observation that spectroscopic brightness may not only be related to the total theaflavins in black tea (Obanda & Owuor, 1997). Generally, clone S15/10 is classified as a poor fermenter (Obanda & Owuor, 1993). This was more clearly demonstrated by individual plain black tea parameters (Figs. 1 and 2) and by sensory evaluation (Fig. 3). Compared to clones 6/8 and SC12/28, amounts and rates of development of the individual parameters were slower and the maximum individual parameters were lower.

The changes in the plain black tea parameters due to fermentation temperature and duration are presented in Table 2 and Figs. 1–3. The TFs, brightness and sensory evaluation levels (Taster B) decreased while the thearubigins and total colour levels increased with increase in fermentation temperature. There was a significant difference in total colour and sensory evaluation (Taster B) between fermentations at 15 and 20°C, with differences in the same direction for other parameters, except for sensory evaluation of Taster A. Thus, although cold fermentation temperatures are recommended (Cloughley, 1980; Owuor & Obanda, 1993) for the achievement of high quality black teas, the costs involved in reducing fermentation temperatures below 20°C may be too high for the quality improvement achieved. Thus, while cold fermentation temperatures are recommended, processing below 20°C requires excessively long duration for

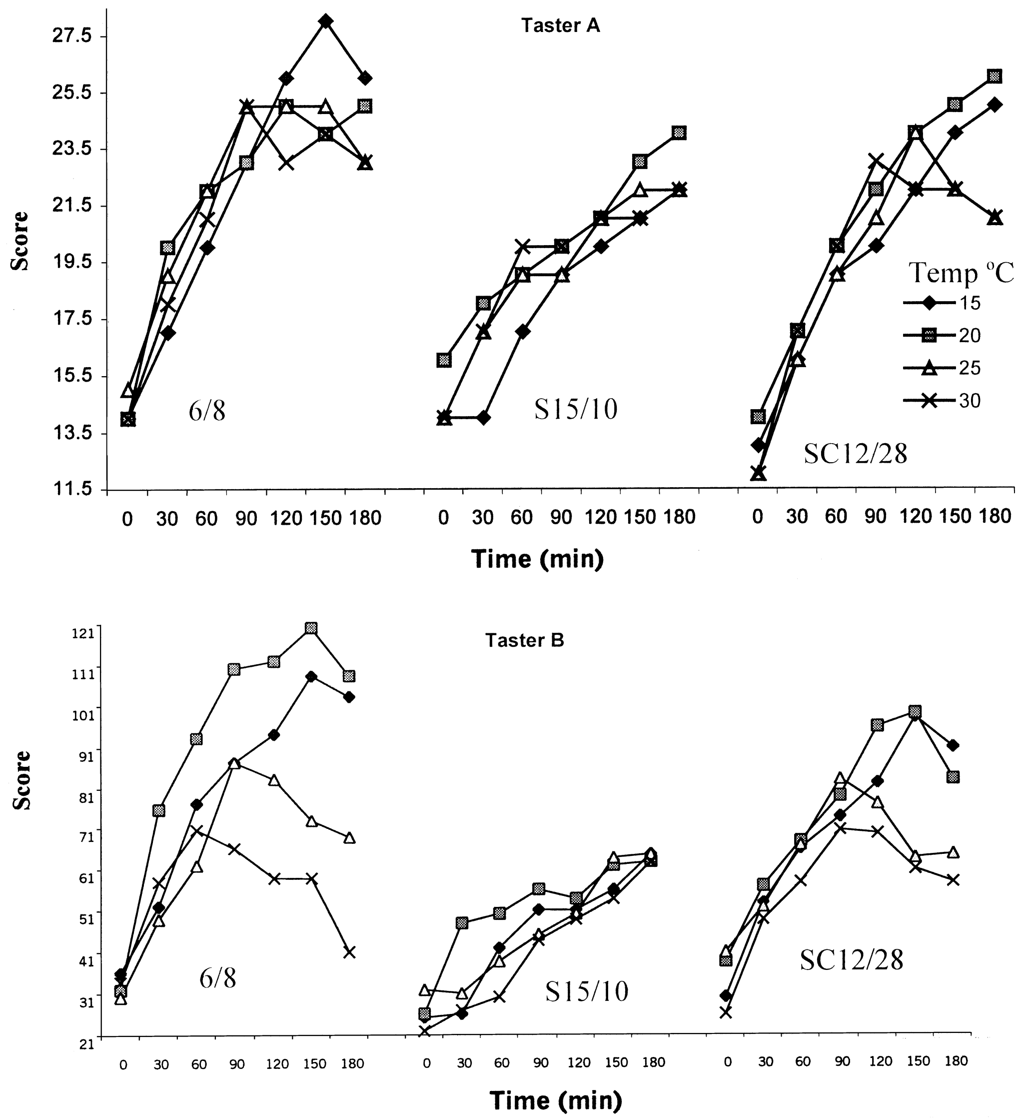

Fig. 3. Variation of sensory evaluations in different clones due to fermentation durations (minutes) and temperatures (°C).

the formation of better quality teas, and may be very expensive to attain, since this will need extra refrigeration in areas where temperatures are above 20°C, while at the same time improving only marginally, the quality and valuation of the resultant black teas. The lower Tfs with higher fermentation temperatures could be due to changes in the multiple forms of polyphenol oxidase or the transformation of TF to thearubigins. This aspect requires further investigation.

There were variations in the duration to achieve maximum levels of each of the different plain black tea parameters. Higher amounts of thearubigins and total colour were developed with increase in fermentation duration at all the fermentation temperatures monitored. Thus, long duration and high temperatures of fermentation favour production of thicker and more coloury black teas. Maximum sensory evaluation scores, TFs and brightness levels at different fermentation temperatures were attained at different fermentation durations. At low fermentation temperatures, maximum sensory evaluation scores and levels of TFs and brightness were attained after longer fermentation duration. Thus production of high quality black teas at lower fermentation temperatures requires longer fermentation duration. Indeed, these maxima for TFs and brightness levels, achieved at low fermentation temperatures, were higher than the maxima attained by fermenting at higher temperatures. Thus, maintenance of low fermentation temperatures, though requiring longer fermentation duration, ensures that the resultant black teas are better quality (Cloughley, 1980; Owuor & Obanda, 1993; Obanda & Owuor, 1993). There were significant ($P \leqslant 0.05$) interactions between fermentation durations and temperatures in all plain black tea parameters, indicating that the rate and patterns of their development varied with

Table 2
The mean effect on plain black tea quality parameters of three clones due to variations in fermentation temperature and duration

Item	Temp (°C)	Duration (min)							Mean
		0	30	60	90	120	150	180	
Theaflavins (μmol/g)	15	4.31	10.72	15.32	20.14	22.57	21.96	21.78	16.68
	20	4.81	11.00	16.50	20.41	21.35	20.83	20.10	16.43
	25	4.96	10.70	17.19	19.81	19.01	18.55	18.13	15.48
	30	4.66	12.02	16.96	18.81	17.14	16.31	15.96	14.56
	Mean	4.68	11.11	16.49	19.79	20.02	19.41	18.99	
	C.V. (%)				12.24				
	LSD ($P \leqslant 0.05$)				0.77				1.17
	Interactions				1.55				
Thearubigins (%)	15	10.48	11.51	12.05	13.20	14.60	14.90	15.32	13.15
	20	10.28	11.29	12.96	14.44	15.43	15.44	16.21	13.73
	25	10.68	11.89	13.67	15.17	16.17	16.33	17.46	14.48
	30	10.50	12.36	14.60	15.64	16.85	17.31	18.06	15.05
	Mean	10.48	11.76	13.32	14.61	15.76	16.00	16.76	
	C.V. (%)				7.95				
	Interactions				0.45				0.72
					0.90				
Total colour (%)	15	1.36	2.18	2.92	3.26	3.54	3.82	4.12	3.03
	20	1.42	2.14	3.07	3.70	3.97	4.23	4.58	3.30
	25	1.53	2.24	3.29	4.03	4.34	4.50	4.73	3.53
	30	1.43	2.42	3.65	4.41	4.56	4.92	4.92	3.78
	Mean	1.44	2.25	3.24	3.85	4.10	4.37	4.63	
	C.V. (%)				12.03				
	LSD ($P \leqslant 0.05$)				0.15				0.22
	Interactions				0.31				
Brightness (%)	15	18.85	27.57	29.93	31.02	30.52	29.58	27.38	27.84
	20	20.72	28.20	30.50	31.36	28.92	26.51	25.63	27.41
	25	20.99	28.48	30.13	27.13	24.29	21.22	21.02	24.75
	30	20.21	28.65	26.66	23.59	22.66	19.49	18.15	22.77
	Mean	20.19	28.23	29.30	28.27	26.60	24.20	23.04	
	C.V. (%)				9.69				
	LSD ($P \leqslant 0.05$)				1.00				1.64
	Interactions				1.20				
Taster A	15	14	16	18	20	23	24	24	20
	20	15	18	20	22	23	24	25	21
	25	14	17	20	22	23	23	22	20
	30	13	17	20	23	22	22	22	20
	Mean	14	17	20	22	23	23	23	
	C.V. (%)				10.38				
	LSD ($P \leqslant 0.05$)				1				NS
	Interactions				2				
Taster B	15	30	44	62	71	76	87	86	65
	20	33	60	70	81	87	94	85	73
	25	34	44	56	72	70	67	67	58
	30	27	45	53	59	57	61	54	50
	Mean	31	48	60	71	73	77	73	
	C.V. (%)				13.34				
	LSD ($P \leqslant 0.05$)				3				7
	Interactions				7				

time at different temperatures. Thus it is not easy to extrapolate optimal fermentation duration when there is a change in temperatures. It is therefore important that, at different temperatures, optimal fermentation duration needs to be established for every clone, for production of high quality black teas.

Although all clones made good quality black teas at 20°C or lower, the qualities of black teas from clones 6/8 and SC12/28 were more sensitive to temperature variations than clone S15/10 (Table 3 and Figs. 1–3). While high fermentation temperatures encouraged production of black teas with higher thearubigins and total colour,

Table 3
The mean effects of fermentation durations of 0 to 180 minutes on plain black tea quality parameters due to variations in clone and fermentation temperature

Item	Clone	Temperature (°C)				Mean
		15	20	25	30	
Theaflavins (μmol/g)	6/8	22.48	21.59	19.21	18.02	20.33
	S15/10	13.04	12.63	11.99	11.81	12.36
	SC12/28	14.53	15.06	15.24	13.82	14.66
	Mean	16.68	16.43	15.48	14.55	
	C.V. (%)			12.24		
	LSD ($P \leqslant 0.05$)			1.17		2.98
	Interactions			NS		
Thearubigins (%)	6/8	14.74	14.82	15.75	16.43	15.43
	S15/10	11.90	12.58	12.82	13.37	12.69
	SC12/28	12.81	13.78	14.88	15.34	14.24
	Mean	13.15	13.73	14.48	15.05	
	C.V. (%)			7.95		
	LSD ($P \leqslant 0.05$)			0.72		1.72
	Interactions			NS		
Total colour (%)	6/8	3.61	3.77	4.18	4.34	3.97
	S15/10	2.89	2.99	3.12	3.39	3.10
	SC12/28	2.59	3.16	3.28	3.62	3.16
	Mean	3.03	3.36	3.53	3.78	
	C.V. (%)			12.03		
	LSD ($P \leqslant 0.05$)			0.22		0.54
	Interactions			NS		
Brightness (%)	6/8	30.21	30.20	25.62	23.88	27.48
	S15/10	24.64	27.17	24.14	22.88	24.71
	SC12/28	28.65	24.85	24.48	21.55	24.88
	Mean	27.84	27.41	24.75	22.77	
	C.V. (%)			9.69		
	LSD ($P \leqslant 0.05$)			1.64		NS
	Interactions			2.83		
Taster A	6/8	22	22	22	22	21
	S15/10	18	20	19	19	19
	SC12/28	20	21	19	20	20
	Mean	20	21	20	20	
	C.V. (%)			10.38		
	LSD ($P \leqslant 0.05$)			NS		NS
	Interactions			NS		
Taster B	6/8	80	93	65	55	73
	S15/10	45	51	47	41	46
	SC12/28	71	74	64	56	66
	Mean	65	73	58	50	
	C.V. (%)			13.34		
	LSD ($P \leqslant 0.05$)			7		11
	Interactions			12		

they had lower TFs, brightness and sensory evaluation. The response to temperature variations was less critical in clone S15/10 than clones 6/8 and SC12/28 (Table 3 and Figs. 1–3). Thus, although fermentation at low temperatures is recommended, there are clones that can withstand higher temperatures, up to 30°C without much quality loss (Obanda and Owuor, 1993). Thus clone S15/10 could be processed at higher temperatures with less quality losses than the other clones.

Acknowledgements

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