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Clonal plain black tea quality parameters responses of hard physical withered leaf to rehydration and fermentation durations

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Abstract: Hard physical withers in tea processing result in reduced plain black tea quality parameters, but improve flavoury black tea quality. Chemical withers with minimal moisture loss improve plain black tea quality parameters. But chemical withered leaf is normally bulky and not flaccid thus reducing maceration rates. Hard physical withers reduce polyphenol oxidase activity, thereby impairing ability of the leaf to produce high amounts of plain black tea quality parameters, especially theaflavins and thearubigins. This study examined if rehydrating hard physical withered leaf could improve its fermentability and influence fermentation duration, and if such changes are cultivar dependent. Rehydrating hard physical withered leaf increased ($p \leq 0.05$) total theaflavins, thearubigins, brightness, total colour and sensory evaluation of resultant black teas. The patterns of the responses did not vary with cultivars or fermentation duration. The theaflavins and brightness declined ($p \leq 0.05$) while thearubigins and total colour increased ($p \leq 0.05$) with long fermentation durations irrespective of withering regime. Results demonstrate that problems of plain black tea quality reduction due to hard physical withers can be partially reversed by rehydration to chemical wither standard, but the withering regime does not influence when maximum plain black tea quality parameters are produced.

Keywords: Physical wither, rehydration, fermentation duration, black tea quality.

Running title: Rehydration and fermentation durations effects on quality of hard withered tea leafIntroduction.

Introduction

Detachment of leaf from tea (*Camellia sinensis* L. O. Kuntze) plant initiates both biochemical and physiological transformations associated with senescence (1) and moisture losses that results in the leaf being soft, pliable, flaccid and easy to macerate (2-4). These changes are referred to as chemical and physical withers (3-5), respectively. Both are necessary in black tea processing (5, 6). Achievement of both chemical and physical withers improve quality of flavoury (aromatic) black teas (5). However, achieving chemical wither alone improves plain black tea quality (3-5).

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In some tea producing countries, e.g. Kenya and Malawi, tea production has risen faster than expansion in the factory processing capacities. Production of tea varies greatly with seasons (7, 8). During peak crop production seasons when growth rate is fast (9-11), many processors are unable to cope with all harvested leaf (12-15). The black tea processing stage most adversely affected by this problem is the withering stage. Withering takes large factory space, energy and labour. Consequently, there is delay in accepting leaf into the factories due to limited withering space and plucked leaf can take up to three days before delivery into a factory (14). With the high crop achievement of optimal wither is problematic as some leaf arrive after excessive moisture removal (hard physical wither), leading to production of low quality plain black teas (6, 16-19). Again, during the peak crop production, quantity of leaf delivered in the factory can be large, such that the factory takes long durations before completing processing of the delivered leaf. To control leaf from generating high respiratory temperature that leads to cell wall destruction and initiation of uncontrolled fermentation, the generated temperature is dissipated by blowing air through the leaf (20). This process is accompanied by moisture loss leading to hard physical wither (14, 15). The hard physically withered leaf produces black teas with low theaflavins and thearubigins levels (12, 15, 18, 19, 21). Theaflavins and thearubigins are the plain black tea quality parameters and significant relationship has been demonstrated between theaflavins levels and plain black tea quality as assessed by sensory (22-25) and/or price (7, 26, 27) evaluation. The thearubigins are responsible for the black tea colour, body and thickness (28). The excessive moisture removal therefore reduces plain black tea quality (12, 18, 19, 21). This reduction is associated with decline in activities of the oxidative enzymes (29, 30). However, the reduction of activity of the oxidative enzymes, e.g. lipoxygenase, due to moisture removal during withering can be reversed by rehydration (29). It is not documented if such reversal with rehydration cano lead to improvement in plain black tea quality.

In a previous study in which hard physically withered leaf was blended with freshly plucked leaf, the oxidative potential of the leaf increased thereby improving plain black tea quality, provided the quantity of the hard physically withered did not exceed 30% (31). It is therefore possible that rehydration of hard physically withered leaf could improve the fermentability of the leaf leading to production of plain black tea with high theaflavins and thearubigins levels.

Improvement of the oxidative potential of leaf changes black tea quality (30, 32). Varying degree of physical wither was associated with changes in oxidative potential of leaf. Soft withered leaf fermented faster (18). Thus possible restoration of the polyphenol oxidase activity could change the fermentation ability and rate. Different cultivars have varying fermentation potentials (32). It is not documented how different clones may respond to rehydration of hard physically withered leaf. This study evaluated the influence of rehydrating hard physically withered leaf on the quality parameters of plain black tea and if rehydration could influence fermentation rates in different clones.

Materials and Methods

Leaves and tea processing

Leaves were obtained from clones TRFK 6/8 and TRFK 31/11 planted at the Tea Research Institute (TRI), (Formerly Tea Foundation of Kenya (TRFK)), Museum of Clonal Tea Plants (altitude 2,180 m above mean sea level, latitude 00 22'S, longitude 35° 21'E). The two clones are among the widely cultivated tea plants in Kenya (33) and were receiving recommended agronomic inputs (34). From each cultivar was harvested 12 kgs of green leaf consisting of two leaves and a bud. The total plucking duration was 2 hours. The leaf was divided into three equal portions. One portion was subjected to chemical wither only over a period of 16 hours (5, 16) and the final wither was 75%. The other two portions were subjected to combined slow physical and chemical wither by passing a steam of ambient temperature air to a final wither of 64% over a period of 16 hours (5, 16). One portion was processed at this degree of physical wither and was classified as hard physically withered leaf. The third portion was rehydrated with surface moisture to attain moisture content equivalent to a physical wither of 75%. The portion was classified as rehydrated hard physical withered leaf. Each portion of the withered leaf was further divided into four sub-samples before maceration. The samples were miniature CTC-macerated (5, 6) then subjected different fermentation durations, set at 60, 90, 120 and 150 minutes. Fermentation was terminated using a bench top fluid bed dryer (Tea craft, UK). The unsorted black teas were subjected to chemical analyses and sensory evaluation as explained below. Processing was done on three separate occasions and each occasion was used as a replicate.

Chemical analysis and sensory evaluation

Total theaflavins were determined by the Flavognost method (35) while thearubigins, liquor colour and brightness were determined as described by Roberts and Smith (36). Experienced professional tea tasters, at two tea broking firms in Mombasa, evaluated the black teas. The sensory evaluation was based on brightness, strength, colour, body and infusion, in a scale of 0-20 and 0-10 for each attribute by taster A and B, respectively. The Mombasa Tea Auction Centre is the second largest in the world after Colombo. The tasters have expert knowledge of black teas, especially of Kenyan teas, which they auction regularly. The results were subjected to analysis of variance using the MSTAT statistical package as a factorial three trial in a randomised complete block design. Clones were the main treatments, withering technique the sub-treatment and withering duration the sub-sub-treatment.

Results and Discussion

The changes in plain black tea quality parameters and sensory evaluations due to cultivars, rehydration of hard physical withered leaf and fermentation duration are presented in Tables 1-3. There were no significant clonal variations in theaflavins, thearubigins, total colour and sensory evaluations by Taster B. However, clonal black tea brightness and sensory evaluation by Taster A were different ($p \leq 0.05$). Despite the lack of significant differences in total theaflavins levels with clones, in previous studies (24, 37-39), clone TRFK 31/11 had been demonstrated to have higher levels of gallated theaflavins than clone TRFK 6/8. The gallated theaflavins are more astringent than non-gallated theaflavins (40) leading to more astringency even when the total theaflavins levels are equivalent (24, 39, 41). Indeed, although several studies had demonstrated relationship between total theaflavins levels and plain black tea quality as assessed by sensory (22, 23, 25) and/or price (7, 26, 27) evaluation, a better relationship was obtained when the contributions of the individual theaflavins had been normalized (24, 37-39). In this study the individual theaflavins were not analysed, but the superior evaluation of black tea from clone TRFK 31/11 over TRFK 6/8 by taster A can be attributed to this earlier observation. However, in terms of brightness, TRFK 6/8 was superior to TRFK 31/11, explaining the use of TRFK 6/8 as a standard in clonal field evaluations (42, 43). Overall, the results confirm that the two cultivars have high quality potentials.

Similar to previous studies (3-6, 16), chemical withered leaf had higher ($p \leq 0.05$) theaflavins, thearubigins, brightness, total colour and sensory evaluation scores in plain black tea than hard physically withered leaf (Tables 1-3). Hard physical withered leaf produced plain black teas with low theaflavins as had been observed in previous studies (16-18, 44). The low plain black tea quality parameters produced by hard physically withered tea leaves were due to reduction/deactivation of oxidative enzymes activities (29, 30). Results presented herein demonstrated such decline occurred in similar patterns in both cultivars. However, the effect of the hard physical wither was reversed by rehydration to equivalent of the chemical withered leaf. The produced plain black teas from the rehydrated hard physical withered leaf had plain black tea quality parameters that were slightly lower than the chemically withered leaf, though the differences were not significantly different. Thus rehydration of hard physically withered leaf is a suitable method of reversing low quality of plain black tea arising from hard physical withered leaf.

High moisture content in tea leaf leads to better fermentation ability, resulting in black teas with higher plain black tea quality parameters (16-18, 44). Such favourable fermentation could be due faster rates of oxidation. However, usually tea processors have fixed fermentation durations which only vary due to changes in ambient temperatures (12, 14, 17, 45, 46). It is therefore possible that increasing/varying fermentation durations could reverse the low quality produced from hard physically withered leaf. The influence of varying fermentation durations in the chemical and physical withered leaf are presented in Tables 1-3. There were variations in black tea quality parameters as had been observed in previous studies (47, 48). The theaflavins (Table 1) and sensory evaluation (Table 3) reached maximum levels after 90 minutes of fermentation, similar to previous observations (17). Fermentation of “dhool” from rehydrated leaf reached maximum at the same time as leaf from chemical and/or hard physical withered leaf. Indeed, there were no significant interactions effects between withering parameters and fermentation durations. The results demonstrate that low plain black tea quality caused by hard physical wither cannot be corrected by varying fermentation duration.

The results reported herein demonstrate that rehydration of hard physically withered leaf improved the plain black tea quality, but withering schedule/regime had no influence on optimal fermentation duration.

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Table 1: Changes in plain black tea theaflavins and thearubigins due to rehydration of hard withered tea leaf and fermentation duration

Item	Clone	Wither	Fermentation duration (Minutes)				Mean wither	Mean clone
			60	90	120	150		
Theaflavins (µmol/g)	31/11	Chemical	24.60	25.99	24.42	24.28	24.82	
		Slow hard physical	22.33	21.18	21.12	20.33	21.24	
		Rehydrate hard physical	24.27	23.34	22.67	21.77	23.02	23.03
		Mean fermentation	23.74	23.5	22.74	22.13		
		CV (%)			8.96			
		LSD (P<0.05)			1.57		3.62	
	6/8	Chemical	25.55	28.15	26.00	25.06	26.19	
		Slow hard physical	22.82	22.95	20.11	19.68	21.39	
		Rehydrate hard physical	25.49	26.18	23.81	21.69	24.29	23.96
		Mean fermentation	24.62	25.76	23.31	22.14		
		CV (%)			5.37			
		LSD (P<0.05)			1.93		2.26	
	All clones	Chemical	25.08	27.07	25.12	24.67	25.51	
		Slow hard physical	22.58	22.07	20.61	20.01	21.32	
		Rehydrate hard physical	24.88	24.76	23.20	21.73	23.66	
		Fermentation time	24.18	24.63	23.02	22.14		
		CV (%)			7.30			
		LSD, (P<0.05)			1.58		1.57	
Thearubigins (%)	31/11	Chemical	18.00	19.33	21.64	23.26	20.56	
		Slow hard physical	15.96	17.86	18.75	21.5	18.52	
		Rehydrate hard physical	19.30	21.90	22.32	24.99	22.13	20.4
		Mean fermentation	17.76	19.70	20.91	23.25		
		CV (%)			12.27			
		LSD (P<0.05)			3.75		4.40	
	6/8	Chemical	17.33	20.63	20.59	21.71	20.07	
		Slow hard physical	17.29	19.37	19.87	21.08	19.40	
		Rehydrate hard physical	18.83	20.62	21.62	21.73	20.70	20.06
		Mean fermentation	17.82	20.20	20.69	21.51		
		CV (%)			3.83			
		LSD (P<0.05)			1.15		1.12	
	All clones	Chemical	17.67	19.98	21.12	22.49	20.31	
		Slow hard physical	16.63	18.61	19.31	21.29	18.96	
		Rehydrate hard physical	19.07	21.26	21.97	23.36	21.41	
		Fermentation time	17.78	19.95	20.80	22.38		
		CV (%)			14.85			
		LSD, (P<0.05)			2.78		2.76	NS

Table 2: Changes in plain black tea total colour and brightness due to rehydration of hard withered tea leaf and fermentation duration

Item	Clone	Wither	Fermentation duration (Minutes)				Mean wither	Mean clone
			60	90	120	150		
Total colour (%)	31/11	Chemical	4.62	5.43	5.76	6.09	5.48	
		Slow hard physical	4.51	5.04	5.43	5.67	5.16	
		Rehydrate hard physical	5.19	5.83	5.86	6.29	5.79	5.48
		Mean fermentation	4.77	5.43	5.68	6.02		
		CV (%)			6.71			
		LSD (P<0.05)			0.55		0.64	
	6/8	Chemical	5.15	5.66	5.9	6.32	5.76	
		Slow hard physical	4.69	5.1	5.45	5.83	5.27	
		Rehydrate hard physical	5.13	5.88	5.76	6.27	5.76	5.59
		Mean fermentation	4.99	5.55	5.7	6.14		
		CV (%)			7.29			
		LSD (P<0.05)			0.61		0.49	
	All clones	Chemical	4.89	5.55	5.83	6.21	5.62	
		Slow hard physical	4.60	5.07	5.44	5.75	5.22	
		Rehydrate hard physical	5.16	5.86	5.81	6.28	5.78	
		Fermentation time	4.88	5.49	5.69	6.08		
		CV (%)			7.68			
		LSD, (P<0.05)			0.39		0.39	NS
Brightness (%)	31/11	Chemical	31.37	26.71	24.11	22.81	26.25	
		Slow hard physical	24.57	22.9	19.42	17.41	21.08	
		Rehydrate hard physical	27.44	25.39	21.88	19.42	23.53	23.61
		Mean fermentation	27.79	25	21.8	19.88		
		CV (%)			7.36			
		LSD (P<0.05)			2.61		3.05	
	6/8	Chemical	34.82	29.6	26.77	23.24	28.36	
		Slow hard physical	31.08	28.45	21.37	19.56	25.11	
		Rehydrate hard physical	32.59	31.14	25.87	22.18	27.95	27.14
		Mean fermentation	32.83	29.73	24.67	21.33		
		CV (%)			7.55			
		LSD (P<0.05)			3.01		3.19	
	All clones	Chemical	33.1	28.16	25.44	22.52	27.3	
		Slow hard physical	27.82	25.68	20.4	18.49	23.1	
		Rehydrate hard physical	30.02	28.27	23.88	20.8	25.74	
		Fermentation time	30.31	27.37	23.24	20.6		
		CV (%)			7.39			
		LSD, (P<0.05)			1.74		1.72	1.92
		Interactions	Clone*wither =2.44			Clone*fermentation =1.45		

Table 3: Changes in plain black tea total sensory evaluation due to rehydration of hard withered tea leaf and fermentation duration

Item	Clone	Wither	Fermentation duration (Minutes)				Mean wither	Mean clone
			60	90	120	150		
Taster A	31/11	Chemical	83	102	86	63	84	
		Slow hard physical	57	78	65	53	63	
		Rehydrate hard physical	81	97	73	58	77	76
		Mean fermentation	73	92	75	58		
		CV (%)			17.79			
		LSD (P<0.05)			31		12	
	6/8	Chemical	91	91	74	59	79	
		Slow hard physical	49	57	40	30	44	
		Rehydrate hard physical	86	99	64	41	73	65
		Mean fermentation	76	82	60	43		
		CV (%)			25.56			
		LSD (P<0.05)			25		25	
	All clones	Chemical	87	92	75	58	81	
		Slow hard physical	53	67	53	42	53	
		Rehydrate hard physical	84	98	69	50	75	
		Fermentation time	75	87	67	50		
		CV (%)			30.59			
		LSD, (P<0.05)			18		17	11
Taster B	31/11	Chemical	20	21	19	21	20	
		Slow hard physical	20	22	20	19	20	
		Rehydrate hard physical	20	19	20	90	19	20
		Mean fermentation	20	21	20	20		
		CV (%)			6.05			
		LSD (P<0.05)			1		1	
	6/8	Chemical	19	21	20	20	20	
		Slow hard physical	22	22	21	20	21	
		Rehydrate hard physical	20	20	20	19	20	20
		Mean fermentation	20	21	20	20		
		CV (%)			6.39			
		LSD (P<0.05)			1		1	
	All clones	Chemical	20	21	20	20	20	
		Slow hard physical	21	22	20	20	21	
		Rehydrate hard physical	20	19	20	19	19	
		Fermentation time	20	21	20	20		
		CV (%)			7.51			
		LSD, (P<0.05)			1		1	NS

References

1. Ullah, M.R., Bordoloi, A.K., and Gogoi, N. 1986. Hastening of leaf senescence in the processing of green tea leaf to black tea. *Journal of the Science of Food and Agriculture* 37:1042–1044.
2. Jabeen, S., Alam, S., Saleem, M., Ahmad, W., Bibi, R., Hamid, F., and Shah, H.U. 2015. Withering timings affect the total free amino acids and mineral contents of tea leaves during black tea manufacturing. *Arabian Journal of Chemistry*:(In press).
3. Ullah, M.R. 1984. A reappraisal of withering process in black tea manufacture. II. Chemical wither in current practices of artificial withering and its effects on tea liquors. *Two and A Bud* 31:24-27.
4. Ullah, M.R. 1984. A reappraisal of withering process in black tea manufacture. I. Physical and chemical withers and their effects on tea liquors. *Two and A Bud* 31:20-24.
5. Owuor, P.O., Tsushida, T., Horita, H., and Murai, T. 1987. Effects of artificial withering on chemical composition and quality of black tea. *Tropical Science* 27:159-166.
6. Owuor, P.O., Wanyiera, J.O., Njeru, K.E., Munavu, R.M., and Bhatt, B.M. 1989. Comparison of the chemical composition and quality changes due to different withering methods in black tea manufacture. *Tropical Science* 29:207-213.
7. Cloughley, J.B. 1983. Effect of harvesting policy and nitrogen application rates on the production of tea in Central Africa. II. Quality and total value of the crop *Experimental Agriculture* 19:47-54.
8. Cloughley, J.B., Grice, W.J., and Ellis, R.T. 1983. Effects of harvesting policy and nitrogen application rates on the productions of tea in Central Africa I. Yield and crop distribution. *Experimental Agriculture* 19:33-46.
9. Kowalsick, A., Kfoury, N., Robbat, A., Ahmed, S., Orians, C., Griffin, T., Sean, B.C., and Stepp, J.R. 2014. Metabolite profiling of Camellia sinensis by automated sequential, multidimensional gas chromatography/mass spectrometry reveals strong monsoon effects on tea constituents. *Journal of Chromatography A* 1370:230-239.
10. Odhiambo, H.O., Nyabundi, J.O., and Chweya, J. 1993. Effects of soil moisture and vapour pressure deficits on shoot growth and the yield of tea in the Kenya highlands. *Experimebntal Agriculture* 29:341-350.
11. Ng'etich, W.K., Stephens, W., and Othieno, C.O. 2001. Responses of tea to environment in Kenya. 3. Yield and yield distribution. *Experimental Agriculture* 37:361-372.
12. Owuor, P.O., and Obanda, M. 1997. Advances in withering technologies and future strategies to cope with high tea production in Kenya. *Tea* 18:184-193.
13. Owuor, P.O., and Orchard, J.E. 1991. Variations in black tea quality due to changing withering techniques in smallholder factories. *Tea* 12:32-40.
14. Owuor, P.O., Orchard, J.E., Robinson, J.M., and Taylor, S.J. 1990. Variations in the chemical composition of clonal black tea due to delayed withering. *Journal of the Science of Food and Agriculture* 52:55-61.
15. Tomlins, K.I., and Mashingaidze, A. 1997. Influence of withering, including leaf handling, on the manufacturing and quality of black teas - a review. *Food Chemistry* 60:573-580.
16. Owuor, P.O., and Orchard, J.E. 1989. The effects of degree of physical wither on the chemical composition of black tea. *Tea* 10:47-52.
17. Owuor, P.O., and Orchard, J.E. 1990. Changes in the quality and chemical composition of black tea due to degree of physical wither, condition and duration of fermentation. *Tea* 11:109-117.
18. Ullah, M.R., Gogoi, N., and Baruah, D. 1984. The effect of withering on fermentation of tea leaf and development of liquor characters of black teas. *Journal of the Science of Food and Agriculture* 35:1142–1147.
19. Obanda, M., Owuor, P.O., and Bore, J.K. 1997. Effects of moisture loss and temperature of leaf during withering on black tea quality parameters. *Tea* 18:45-50.
20. Melican, J.T., and Mallows, R. 1991. Occurrence and causes of "red leaf" in plucked tea before withering. In *Proceedings of International Symposium on Tea Science* Shizuoka, Japan. 581-585.

21. Sabhapondit, S., Bhattacharyya, P., Bhuyan, L.P., Hazarika, M., and Goswami, B.C. 2014. Optimisation of withered leaf moisture during the manufacture of black tea based upon theaflavins fractions. *International Journal of Food Science and Technology* 49:205–209.

22. Hilton, P.J., Palmer-Jones, R., and Ellis, R.T. 1973. Effects of season and nitrogen fertilizers upon flavonol composition on tea making quality of fresh shoots of tea (*Camellia sinensis* L.) in Central Africa. *Journal of the Science of Food and Agriculture* 24:819-826.

23. Hilton, P.J., and Palmer-Jones, R.W. 1973. Relationship between flavonol composition of fresh tea and theaflavins content of manufactured tea. *Journal of the Science of Food and Agriculture* 24:813-818.

24. Owuor, P.O., Obanda, M., Nyirenda, H.E., Mphangwe, N.I.K., Wright, L.P., and Apostolides, A. 2006. The relationship between some chemical parameters and sensory evaluations for plain black tea (*Camellia sinensis*) produced in Kenya and comparison with similar teas from Malawi and South Africa. *Food Chemistry* 97:644-653.

25. Wright, L.P., Mphangwe, N.I.K., Nyirenda, H.E., and Apostolides, Z. 2002. Analysis of the theaflavin composition in black tea (*Camellia sinensis*) for predicting the quality of tea produced in Central and Southern Africa. *Journal of the Science of Food and Agriculture* 82:517-525.

26. Hilton, P.J., and Ellis, R.T. 1972. Estimation of market value of Central African tea by theaflavins analysis. *Journal of the Science of Food and Agriculture* 23:227-233.

27. Hilton, P.J., and Palmer-Jones, R.W. 1975. Chemical assessment of the quality of tea and its relation to market value over an extended period. *Journal of the Science of Food and Agriculture* 26:1681-1682.

28. Biswas, A.K., Biswas, A.K., and Sarkar, A.R. 1973. Biological and chemical factors affecting the valuation of North East India plain teas. III. Statistical evaluation of the biochemical constituents and their effects on colour, brightness and strength of black teas. *Journal of the Scienc of Food and Agriculture* 24:1457-1477.

29. Takeo, T., and Tsushida, T. 1980. Changes in lipoxygenase activity in relation to lipid degradation in plucked tea shoots. *Phytochemistry* 19:2521-2522.

30. Ullah, M.R., and Roy, P.C. 1982. Effect of withering on the polyphenol oxidase level in the tea leaf. *Journal of the Science of Food and Agriculture* 33:492–495.

31. Owuor, P.O., and Obanda, M. 1997. Impact of improper leaf handling on plain black tea quality parameters. *Tea* 18:51-55.

32. Obanda, M., Owuor, P.O., and Wekesa, H. 2002. The influence of clone and plucking standards on the formation of black tea chemical and sensory parameters. *Tea* 23:81-90.

33. Wachira, F.N. 2002. Detection of genetic diversity and characterization of Kenyan tea germplasm. A Tea Genetic Diversity (TGD) Project. TGD Final Project Document. Kericho, Kenya: Tea Research Foundation of Kenya.

34. Othieno, C.O. 1988. Summary of recommendation and observations from Tea Research Foundation of Kenya. *Tea* 9:50-65.

35. Hilton, P.J. 1973. Tea. In *Encyclopaedia of industrial chemical analysis*. F.D. Snell, and L.S. Ettre, editors. New York: John Wiley and Sons Inc. 455–518.

36. Roberts, E.A.H., and Smith, R.F. 1963. Phenolic substances of manufactured tea. II. Spectrophotometric evaluation of tea liquors. *Journal of the Science of Food and Agriculture* 14:689–700.

37. Owuor, P.O., and Obanda, M. 1997. The effects of some agronomic and processing practices and clones on the relative composition of the individual theaflavins in black tea. *Food Science and Technology, International, Tokyo* 3:344-347.

38. Owuor, P.O., and Obanda, M. 2007. The use of green tea (*Camellia sinensis* (L) leaf flavan-3-ols composition in predicting plain black tea quality potential. *Food Chemistry* 100:873-884.

39. Owuor, P.O., and Obanda, M. 1995. Clonal variation in the individual theaflavin and their

impact on astringency and sensory evaluation. *Food Chemistry* 54:273-277.

40. Sanderson, G.W., Ranadive, A.S., Eisenberg, L.S., Farrel, F.J., Simon, R., Manley, C.H., and Coggon, P. 1976. Contributions of polyphenolic compounds to the taste of tea. In *American Chemical Society Symposium Series no 26, Phenolic, Sulphur and Nitrogen Compounds in Food Flavours*: American Chemical Society. 14-46.

41. Thanaraj, S.N., and Seshadri, R. 1990. Influence of polyphenol oxidase activity and polyphenol content of tea shoot on quality of black tea. *Journal of the Science of Food and Agriculture* 51:57-69.

42. Cherotich, L., Kamunya, S.M., Alakonya, A., Msomba, S.W., Uwimana, M.A., Wanyoko, J.K., and Owuor, P.O. 2013. Variation in catechin composition of popularly cultivated tea clones in East Africa (Kenya). *American Journal of Plant Science* 4:628-640.

43. Kamunya, S.M., Wachira, F.N., and Muoki, R.C. 2004. Evaluation of newly developed clones of tea (*Camellia sinensis* (L.) O. Kuntze) for yields, drought tolerance and quality: Preliminary indications. *Tea* 25:12-19.

44. Owuor, P.O., and Orchard, J.E. 1992. Effects of storage time in a two-stage withering process on the quality of made seedling tea. *Food Chemistry* 45:45-49.

45. Emdadi, L., Nasemajad, B., Shukrgozar, S.T., Mehranian, M., and Vahabzadeh, F. 2009. Optimization of withering time and fermentation conditions during black tea manufacture using response surface methodology. *Chemistry and Chemical Engineering* 16:61-68.

46. Owuor, P.O., and Obanda, M.A. 1996. The impact of withering temperature on black tea quality. *Journal of the Science of Food and Agriculture* 70:288-292.

47. Cloughley, J.B. 1979. The determination of optimum fermentation in the factory. In-line TF analysis during fermentation. *Tea Research Foundation of Central Africa, Quarterly Newsletter* No.55:16-18.

48. Takeo, T. 1983. Photometric evaluation and statistical analysis of tea infusion. *Japan Agricultural Research Quarterly* 8:154-164.