Antioxidant, antimicrobial and synergistic activities of tea polyphenols

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ABSTRACT

Microbial resistance to conventional antibiotics has become an increasing global problem and there is a need to find out novel, potent antimicrobial agents with alternative modes of action as accessories to antibiotic therapy. This study investigated the antioxidant, antimicrobial and synergistic properties of tea polyphenols. The tea germplasm from Kenya, China and Japan that are grown in Kenya were characterised for their biochemical profiles. The total phenolic content, theaflavins and thearubigins content of different tea products used in this study were determined spectrophotometrically according to Folin-Ciocalteus and flavognost methods respectively. The individual catechin contents were characterised by high performance liquid chromatography (HPLC) and identified according to their HPLC retention times, elution order and comparison with authentic standards. The antioxidant activity of tea polyphenols was determined using UV-Vis spectrophotometer on its ability to scavenge 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical. The Agar Disc Diffusion method was used to screen for antimicrobial and synergistic activities of the tea liquors. Black, green, purple coloured leaf and white (silvery tips) tea products characterised for their biochemical profiles differed significantly in the levels of total polyphenols, total catechins, catechins fractions, theaflavins and thearubigins ($P \leq 0.05$). Green, purple coloured leaf (aerated) and black tea from terminal buds and white tea products analysed in this study exhibited slightly higher antioxidant activity compared to black tea. The different types of tea products assayed in this study exhibited significant influence on the inhibition zone diameters against bacteria and fungi exposed to the tea extracts. Methicillin and penicillinase resistant *S. aureus* ATCC 25923, *C. albicans* ATCC 90028 and a clinical isolate of *C. neoformans* were more susceptible to all tea extracts than *E. coli* and *S. typhi*. There was synergism between most tea extracts and penicillin G against methicillin and penicillinase resistant *S. aureus* ATTC 25923.

Key words: Black tea, Catechins, Methicillin, Penicillinase, Theaflavins.

INTRODUCTION

Tea (*Camellia sinensis*) is the second most common beverage after water consumed by humans (Mckay and Blumberg, 2002). Although this beverage has nutritional value per se, tea is refreshing, mildly stimulating and produces a feeling of wellbeing (Hamilton-Miller, 1995). Extensive studies indicate that tea has some beneficial health effects besides being refreshing. There is growing evidence that the catechins components of green tea have antibacterial activity

(Yam *et al.*, 1997). Apart from its antimicrobial properties, green tea has been established to exhibit synergistic activity with some antibiotics against some enteric pathogens (Tiwari *et al.*, 2005). Tea polyphenols have particularly proven to synergistically enhance the antimicrobial activity of antimicrobial agents used against methicillin resistant *Staphylococcus aureus* (Hu *et al.,* 2002).

Despite the valuable data generated so far from green tea, little data information has been generated from black tea. Black tea, a major source of theaflavins and thearubigins, has been shown to have antibacterial properties both *in vivo* and *in vitro* (Bandyopadhyayet *et al.,* 2005). Theaflavin-3, 3'-digillate has been reported to have antifungal activity against *Candida albicans* and *Cryptococcus neoformans* in a dose and contact time-dependent manner (Okubo *et al.*, 1991). The objective of this study was to investigate the relationship between biochemical profiles of different types of tea products processed from different tea germplasm grown in Kenya and antioxidant, antimicrobial and synergistic properties on resistance of bacteria and fungi.

MATERIALS AND METHODS

Test microorganisms and tea samples

The test bacteria of American Type Culture Collection (ATCC) were sourced from the Kenya Medical Research Institute Centre for Respiratory Research (KEMRI-CRDR) Nairobi and included methicillin and penicillinase resistant *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, *Candida albicans* ATCC 90028 and clinical isolates of *Salmonella typhi* and *Cryptococcus neoformans.*

The tea samples were sourced from Tea Research Institute (TRI), Timbilil Estate, Kericho (Latitude 0° 22'S, Longitude 35° 21'E, Altitude 2180 m amsl) and processed at the TRI miniature factory as described by Karori *et al.* (2007).

Estimation of total polyphenols and biochemical profiling of the tea extracts

The Folin-Ciocalteu phenol reagent method was used to determine total polyphenols in the tea extracts according to ISO (BS ISO 14502-1: 2005(E)). A modified high performance liquid chromatography method was used to assay for the tea catechins (Zuo *et al.*, 2002).

Analysis of total theaflavins content and total thearubigins

Black, green, purple and white Tea were also assayed for total theaflavins (TFs) using the Flavognost Method of Hilton and Palmer-Jones (1973). Total thearubigins (TRs) were determined in the tea samples using the Roberts and Smith method (Roberts and Smith, 1961).

Antioxidant activity of tea and freeze drying of tea liquors

The stable 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) was used for determination of free radical scavenging of tea extracts using a modified method of Brand-Williams *et al.* (1995). Tea liquors derived from the processed tea samples were freeze dried according to the method described by Turkmen *et al.* (2009).

Antimicrobial assays

The Agar Disc Diffusion method was used to screen for antimicrobial activities of the tea liquors according to the National Committee of Clinical and Laboratory Standards (NCLSIs, 2012).

Statistical analysis

Data was subjected to analysis of variance by using SAS software version 9.1. The least significant difference (LSD) values were used to separate differences among the treatment means.

RESULTS

Total tea polyphenols

The results revealed that black, green and white tea products processed from the test germplasm differed significantly ($P \leq 0.05$) in the levels of total polyphenols (Table 1). Green tea processed from Kenyan germplasm were higher in total polyphenols with their levels ranging from 20.2 to 24.4% compared to green tea processed from the Chinese and the Japanese germplasm, which ranged from 16.7 to 18.5%, respectively. Cultivar TRFK 6/8, a high black tea quality Kenyan clone, exhibited the highest total polyphenol content of 24.4 and 19.3% in green and black processed tea, respectively. The purple leaf coloured cultivars, TRFK 306/3, TRFK 73/1 and TRFK K-purple, produced non-aerated kinds of tea that were not significantly different (P 0.05) in total polyphenol content with green tea processed from cultivars with green coloured leaf. Black Tea, processed only from the terminal leaf bud, were significantly (P 0.05) higher in total polyphenol content than black tea processed from the youngest two leaves and a bud. White tea processed from plucked shoots of the two cultivars AHP S15/10 and TRFK 301/5 were not significantly (P 0.05) different in total polyphenol content from conventional green tea.

Total catechin content

The total catechin data of green, black, white tea products processed from 11 tea cultivars assayed in this study are presented in Table 1. The data reveal that the tea cultivars that produced the different tea products significantly differed (P. 0.05) in total catechin content. There were significant differences (P. 0.05) in total catechin contents between the processed black tea, green tea, white and purple leaf coloured tea. Non-aerated (green) tea contained significantly (P. 0.05) higher amounts of total catechins than aerated (black) tea. Green (un-aerated) tea from Kenyan cultivars were significantly higher in total catechin content than those from Chinese and Japanese cultivars. White tea processed from the Kenyan cultivars TRFK 301/5 and AHP S15/10 had the highest levels of total catechins at 22.8% and 22.3% respectively. Among the Kenyan purple coloured leaf tea cultivars, the highest catechin content was recorded in non-aerated tea products from clones TRFK 73/1 with 16.1% and TRFK 306/3 with 11.9%.

Total theaflavins and total thearubigins levels

There was no significant difference ($P < 0.05$) in the total TRs levels for Kenyan, Chinese and Japanese green tea. This was also exhibited by Kenyan black tea and black tea buds. Black tea had the highest levels of total TFs and total TRs which ranged from 1.1 to 1.7% and 14.6 to 17.2%, respectively (Table 1). Black tea from the popular high black tea quality clone TRFK 6/8 had the highest total TFs and the lowest content of TRs among the black tea products. White tea had the lowest total TFs as compared to green, black and aerated and unaerated tea from the purple coloured leaf clones. TRs were particularly low in white tea processed from cultivars AHP S15/10 and TRFK 301/5.

Antioxidant activity

There was no significant difference ($P > 0.05$) in the antioxidant activity among the different types of tea products (Table 1). However, antioxidant activity was marginally higher among the green tea processed from Kenyan germplasm, as well as the white tea from Kenyan clones. There was no significant difference ($P > 0.05$) in the antioxidant capacity between Kenyan black tea and green tea processed from cultivars Hanlu and Yabukita from China and Japan respectively. Purple coloured leaf (unaerated) manufactured from clone TRFK 306/3, which is rich in anthocyanins and clone TRFK 6/8 processed as green tea had a high DPPH radical scavenging activity with a mean value of 74.5% and 74.2%, respectively; followed by white tea from clones AHP S15/10 and TRFK 301/5 (74.3% and 74.1%), respectively.

Table 1: Percent total polyphenols, total theaflavins, total thearubigins and antioxidant activity of processed tea products from different germplasm grown in same environment in Kenya.

Tea Samples	TP%	TC%	TFs%	TRs%	AA%
Black tea products from Kenyan germplasm Green leaf coloured cultivars					
AHP S15/10	18.8	5.22	1.1	15.5	72.7
BBK 35	17.5	4.95	1.3	16.2	73.4
TRFK 303/577	17.4	5.41	1.5	15.4	72.4
TRFK 6/8	19.3	6.36	1.7	14.6	73.3
Purple leaf coloured cultivars					
TRFK K-Purple	16.2	3.22	1.3	17.2	72.3
TRFK 306/3	18.7	6.18	1.3	15.7	73.7
TRFK 73/1	16.3	5.22	1.5	15.6	73.3
Mean	17.7	5.22	1.4	17.9	73.0
Black tea products from buds of Kenyan germplasm					
AHP S15/10	17.2	9.06	1.4	13.1	73.8
TRFK 301/5	19.0	10.84	1.1	10.4	73.7
Mean	18.1	9.95	1.4	11.7	73.8
Green tea products from Kenyan germplasm Green leaf coloured cultivars					
AHP S15/10	20.2	17.46	0.4	7.7	73.5
BBK 35	20.9	19.65	0.4	6.8	73.3
TRFK 303/577	22.8	19.96	0.4	8.7	74.0
TRFK 6/8	24.4	17.63	0.5	9.3	74.2
Purple leaf coloured cultivars					
TRFK K-Purple	19.7	12.34	0.6	10.2	74.1
TRFK 306/3	22.2	11.92	0.4	11.2	74.5
TRFK 73/1	21.5	16.10	0.4	8.8	73.9
Mean	21.7	16.44	0.5	8.9	73.9
Green tea products from germplasm of other sources					
Hanlu st. 830 (China)	18.5	13.98	0.3	9.6	73.3
Yabukita st. 536 (Japan)	16.7	10.68	0.2	9.8	72.8
Mean	17.6	12.33	0.3	9.7	73.0
White tea products from Kenyan germplasm					
AHP S15/10	22.0	22.29	0.1	0.8	74.1
TRFK 301/5	25.2	22.79	0.1	0.9	74.1
Mean	23.6	22.79	0.1	0.9	74.1
CV%	3.8	16.16	17.6	6.6	0.9
LSD ($P \leq 0.05$)	0.7	0.76	0.5	0.8	0.5

1. TPs-total polyphenols;
2. TCs-total catechins;
3. TFs-total theaflavins;
4. TRs-total thearubigins

Antimicrobial activity

Data obtained from this study, indicated that methicillin and penicillinase resistant *S. aureus* ATCC 25923 was susceptible to the tea extracts (Table 2). Black tea from clones TRFK 6/8, AHP S15/10 and BBK 35 had no significant difference in their inhibitory activity with the green tea processed from leaf of Kenyan cultivars. There was also no significant difference in the inhibitory activity between the Kenyan black tea products with tea processed as black tea products from the terminal buds and some of the Kenyan, Chinese and Japanese green tea studied.

Escherichia coli ATCC 25922 was inhibited weakly by black tea and black tea from the buds (Table 2). There was no significant difference ($P > 0.05$) in the inhibitory effects of black tea and black tea buds. This was also exhibited by green, purple tea extracts processed from Kenyan tea cultivars, Chinese and Japanese green tea extracts. White tea extracts processed from clone TRFK 301/5 exhibited the highest inhibitory effect with a zone of inhibition.

The results obtained showed that the clinical isolate of *S. typhi* was inhibited by the majority of tea extracts (Table 2). The black tea extracts did not differ significantly ($P > 0.05$) in the inhibitory effects with green tea extracts. Processed Kenyan black tea buds had no inhibitory effects while white tea extracts processed from clones AHP S15/10 and TRFK 301/5 had the highest inhibitory effects as compared to all the tea studied.

There was no significant difference ($P > 0.05$) in the antifungal activity of Kenyan black tea and purple coloured leaf (aerated) tea extracts with the Chinese and Japanese green tea extracts against *C. albicans* ATCC 90028 (Figure 1). Unaerated tea from purple leaf coloured and white tea extracts did not differ significantly in the antifungal activity with black tea extracts against *C. albicans* ATCC 90028. Generally, different tea extracts had antifungal activity against *C. albicans* ATCC 90028 and a clinical isolate of *C. neoformans.*

A clinical isolate of *C. neoformans* was inhibited by all the different types of tea extracts used (Figure 1). White tea extracts from the Kenyan tea cultivars exhibited the highest antifungal activity against the clinical isolate of *C. neoformans* compared with black tea, black tea buds, green tea and aerated and unaerated tea extracts from the purple leaf coloured clone. Black tea extracts gave the lowest inhibitory activity.

Table 2: Antibacterial, synergistic, antagonistic and additive effects of tea liquors and antibiotics against methicillin and penicillinase resistant *S. aureus* ATCC 25923, *E. coli* ATCC 25922 and a clinical isolate *S. typhi* determined by zones of inhibition (mm).

Tea Sample	Tea alone ($1\ mg\ ml^{-1}$)	Gentamicin + Tea	Tetracycline + Tea	Penicillin G + Tea	Ampicillin +Tea
Black tea products from Kenyan germplasm					
Green leaf coloured cultivars					
AHP S15/10	16.0[6.0](8.0)	12.3[6.0](7.0)	12.0[6.0](7.0)	18.7[6.0](11.3)	12.0[6.0](8.3)
BBK 35	16.0[6.0](7.0)	12.7[6.0](6.0)	13.0[6.0](7.7)	19.3[6.0](7.0)	12.7[6.0](7.0)
TRFK 303/577	14.0[6.0](9.3)	8.0[6.0](8.3)	8.0[7.0](6.3)	12.3[7.3](8.3)	12.0[7.3](8.3)
TRFK 6/8	16.3[6.0](7.7)	14.3[6.0](7.7)	16.0[6.0](8.3)	18.0[6.0](9.0)	8.7[6.0](8.0)
Purple leaf coloured cultivars					
TRFK K-Purple	13.7[6.0](6.0)	7.3[6.0](6.0)	8.0[6.0](6.0)	17.3[6.0](6.0)	9.0[6.0](6.0)
TRFK 306/3	14.0[6.0](6.0)	14.0[6.0](6.0)	14.7[6.0](6.0)	16.3[6.0](6.0)	11.3[6.0](6.0)
TRFK 73/1	14.3[7.0](6.0)	11.0[6.0](6.0)	10.0[6.0](6.0)	18.0[6.0](6.0)	8.0[6.0](6.0)
Mean	14.9[6.2](7.1)	11.4[6.0](6.7)	11.7[6.1](6.8)	17.2[6.2](7.7)	10.5[6.2](7.1)
Black tea products from buds of Kenyan germplasm					
AHP S15/10	13.7[6.0](6.0)	12.7[6.0](7.0)	12.3[6.0](6.0)	18.0[6.0](6.0)	11.3[6.0](6.0)
TRFK 301/5	14.3[7.3](6.0)	11.3[6.0](6.0)	14.0[7.0](6.0)	18.7[10.0](6.0)	9.7[8.3](6.0)
Mean	14.0[6.7](6.0)	12.0[6.0](6.5)	13.2[6.5](6.0)	18.3[8.0](6.0)	10.5[7.2](6.0)
Green tea products from Kenyan germplasm					
Green leaf coloured cultivars					
AHP S15/10	16.7[7.0](6.0)	9.3[7.0](6.0)	14.0[7.0](6.0)	18.0[8.3](6.0)	11.0[6.0](6.0)
BBK 35	22.0[8.7](8.0)	11.7[7.3](6.0)	14.0[7.0](7.0)	16.7[8.3](11.3)	9.3[7.0](7.0)
TRFK 303/577	19.0[8.0](7.0)	10.3[7.0](6.0)	12.0[8.0](7.0)	18.7[7.3](10.0)	7.7[7.3](9.0)
TRFK 6/8	21.0[8.0](7.3)	8.0[6.0](6.0)	6.0[7.0](7.0)	21.0[6.0](11.0)	8.0[8.3](10.3)
Purple leaf coloured cultivars					
TRFK K-Purple	18.0[7.7](6.0)	12.7[6.0](6.0)	8.0[6.0](6.0)	23.0[7.3](6.0)	11.0[6.0](6.0)
TRFK 306/3	17.0[7.0](7.7)	13.3[7.0](6.0)	12.0[7.0](7.0)	17.0[7.3](8.3)	11.0[7.3](7.3)
TRFK 73/1	13.3[7.0](7.0)	13.0[6.0](7.0)	13.7[7.0](7.7)	18.0[7.7](10.3)	11.7[7.0](12.3)
Mean	18.1[7.6](7.0)	11.2[6.6](6.1)	11.4[7.0](6.8)	18.9[7.5](9.0)	9.9[7.0](8.3)
Green tea products from germplasm of other sources					
Hanlu st. 831 (China)	14.7[7.0](7.3)	16.0[6.0](8.3)	17.0[7.0](6.0)	22.0[7.0](7.3)	13.0[7.7](7.3)
Yabukita st. 536 (Japan)	16.0[7.0](8.0)	13.0[7.0](7.0)	12.7[7.0](7.0)	19.0[7.3](8.3)	12.0[7.7](7.0)
Mean	15.3[7.0](7.7)	14.5[6.5](7.7)	14.8[7.0](6.5)	20.5[7.2](7.8)	12.5[7.7](7.2)
White tea products from Kenyan germplasm					
AHP S15/10	18.0[7.0](25.0)	10.7[6.0](6.0)	15.0[7.3](7.3)	20.3[8.0](19.0)	9.3[7.0](8.3)
TRFK 301/5	22.0[11.0](12.3)	11.3[6.3](7.0)	13.7[7.0](7.0)	17.0[7.0](16.0)	9.0[7.0](8.0)

Tea Sample	Tea alone (1 mg ml^{-1})	Gentamicin + Tea	Tetracycline + Tea	Penicillin G + Tea	Ampicillin +Tea
Mean	20.0[9.0](18.7)	11.0[6.2](6.5)	14.3[7.2](7.2)	18.7[7.5](17.5)	9.2[7.0](8.2)
Distilled water	6.0[6.0](6.0)	6.0[6.0](6.0)	6.0[6.0](6.0)	6.0[6.0](6.0)	6.0[6.0](6.0)
Chloramphenicol (0.60µg/ml)	32.0[20](23)				
Antibiotics alone (µg ml^{-1})					
Gentamicin 1.96		18.0[8.0](8.0)			
Tetracycline 1.96			19.0[9.0](9.0)		
Penicillin G 1.96 [250] (125)				14.0[8.0](10.0)	
Ampicillin 1.96 [62.5] (15.64)					18.0[8.0](7.0)

CV% = 2.24 [3.27] (3.72); LSD ($P \leq 0.05$) = 0.24 [0.16] (0.22); Parentheses [x] = *E .coli*; brackets (x) = *S .typhi*

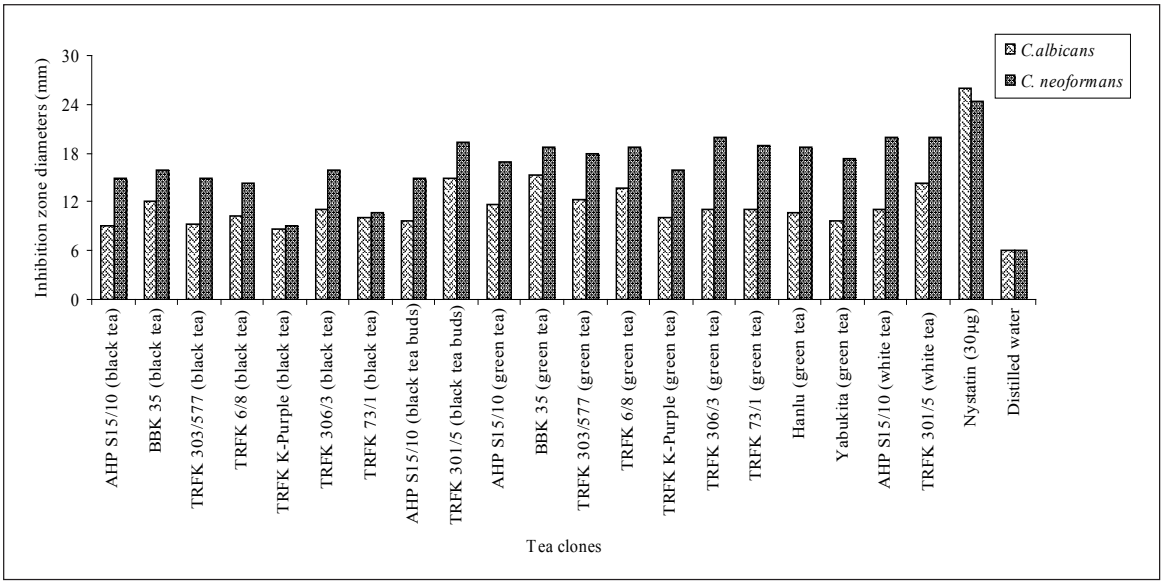

Figure 1: Variation in antifungal activity among different types of Kenya tea extracts.

Synergistic effects of tea liquors and antibiotics

Methicillin and penicillinase resistant Staphylococcus aureus ATCC 25923

There was a marked increase in the inhibition zone diameters in tea extracts combined with penicillin G against methicillin and penicillinase resistant *S. aureus* ATCC 25923 except for black tea processed from clones TRFK 303/577 and TRFK 306/3 (Table 2). This clearly indicates that tea extracts synergize with penicillin G against methicillin and penicillinase resistant *S. aureus* ATCC 25923.

Escherichia coli ATCC 25922

A combination of black, green (Kenyan, Chinese and Japanese) tea extracts with gentamicin and tetracycline did not significantly differed ($P > 0.05$) with tea extracts, gentamicin or tetracycline alone. Synergism was only observed in black tea processed from the buds of clone TRFK 301/5 with penicillin G. Similarly, there was no significant difference in combination of tea extracts with penicillin G and ampicillin.

Clinical Isolate of S. typhi

There was a significant difference in the means ($P \leq 0.05$) of the inhibitory effects of black tea extracts combined with gentamicin as compared to black tea extracts alone (Table 2). Thus, black tea extracts did not synergize with gentamicin. This was also exhibited by black tea buds and green tea from the Kenyan, Chinese and Japanese cultivars except white tea. Black tea processed from terminal buds had no inhibitory effects even in combination with tetracycline, penicillin G and ampicillin. Green tea also did not differ significantly ($P > 0.05$) when the tea extracts were combined with tetracycline compared to tea extracts alone.

DISCUSSION

The results of the study reveal Kenyan tea to be as high in the levels of their total polyphenols as in tea processed from Chinese and Japanese germplasm; which is in agreement with results from previously reported studies (Wachira and Kamunya, 2005; Karori *et al.,* 2007). The general trend among the samples assayed showed that non-aerated tea had higher total polyphenol content than aerated tea from the same sample. The variation in the polyphenolic composition of the different tea products is ascribed to the different process methods applied particularly the leaf maceration and auto-oxidation steps during manufacturing. During black tea manufacture, the gallocatechins are first oxidized and dimerized to theaflavins and thearubigins because of their high oxidation potential and high concentration in leaves (Mahanta and Hemanta, 1992). Several other factors have been discovered to influence the polyphenol content of a tea product. These include genotype, geographical origin, soil composition, harvesting time, post-harvest treatment and physical structure of the leaves (Lin *et al.,* 2003). As a result, the bioactive molecules against microbes and different types of tea products processed from different cultivars grown in different environments are likely to give different bioefficacy levels against target microbes. To minimize these variations, the tea germplasm from Kenya, China and Japan were grown in the same environment and processed into different types of tea products.

The total catechins content in white and green tea products were significantly higher than those of aerated tea products from the same clones. The findings of this study corroborated with those of Karori *et al.* (2007), who found that green tea had significantly higher catechin content than black tea. The enzymatic oxidation of catechins located in the vacuole is as a result of polymerisation of flavan-3-ol monomers to form TFs and TRs which are compounds that have an influence on the quality of black tea (Owuor and Obanda, 2001). In this study, aerated tea products had lower amounts of individual catechins due to the formation of TFs and TRs.

There was high radical scavenging activity on the DPPH radical by both the black and green tea. The antioxidant activity of the ordinary green tea is mainly attributed to the presence of high levels of bioactive catechins that have the ability to donate hydrogen ions to stabilise the free radicals (Leung *et al.*, 2001). The high antioxidative effect of polyphenols in both white and green Kenyan tea is due to the presence of phenolic hydroxyl groups in their structures that make them potent free radical scavengers (Amie *et al.*, 2003). This explains why radical scavenging is high in the gallocatechins, including epigallocatechins gallate and epigallocatechin (Zhu *et al.,* 2001).

The results on the antibacterial and antifungal activity also indicated that the green tea products, as well as production from the purple leaf coloured (unaerated) tea and white tea products processed from Kenyan tea cultivars exerted the highest antimicrobial activities; while black tea and black tea processed from terminal tea buds, had lower inhibitory activity. This may indicate that the presence of the hydroxyl moieties at 3', 4', and 5' on the B ring in the catechin and epicatechin molecules is a major contributing factor that contributed to inhibitory activity of both green, unaerated tea from the purple leaf coloured clone and white tea. This is in agreement

with a study reported by Nance *et al.* (2006), who concluded that antimicrobial activity of catechins is predominantly as a result of the gallic moiety and hydroxyl group member. The highest antimicrobial activity also corresponded to the highest total polyphenols content and to antioxidant activity.

The findings of this study also indicated that the antimicrobial effects of assayed tea extracts differed depending on the concentration and type of the extract; from black, green, purple leaf coloured and white tea and also the type of test organism; bacteria or fungi. The conclusion by Taguri *et al.* (2006) that the antimicrobial potency of polyphenols is dependent upon bacterial species, is consistent with the findings of this study, which showed that, while the tea extract was active against the Gram-positive bacteria, methicillin and penicillinase resistant *S. aureus* ATCC 25923, it did not affect the activity of *E. coli* ATCC 25922 and the clinical isolate of *S. typhi*.

The antibacterial results of this study showed a marked increase in the inhibition zone diameters on combination of tea extract with penicillin G. This is in agreement with results of earlier researchers (Zhao *et al.*, 2001; Hu *et al.*, 2002) who reported enhanced effect of Japanese tea on inhibitory activities with β-lactams antibiotics against methicillin resistant *S. aureus* ATCC 25923. Synergistic inhibition by tea extracts and the antibiotics could be attributed to the presence of dual binding sites on the bacterial surface for antibiotic and tea extract (Tiwari *et al.*, 2005). The tea extracts and penicillin G synergistically inhibited the growth of methicillin and penicillinase resistant *S. aureus* ATCC 25923 possibly because they directly or indirectly attack the same site which is the peptidoglycan on the cell wall (Zhao *et al.*, 2001). The tea extracts-induced damage of the bacterial cell wall and the possible interference with its biosynthesis through direct binding with peptidoglycan may be the major reasons for the synergism against methicillin resistant *S. aureus* ATCC 25923.

CONCLUSION

Green and white tea products are rich in catechins while black tea products are rich in TFs and TRs. Despite the above differences, the black tea products are potent in their *in vitro* antioxidant properties. Therefore, it is concluded that tea is a great source of antioxidants. Tea extracts can be used in management of bacterial and fungal infections caused by methicillin and penicillinase resistant *S. aureus* ATCC 25923, *C. albicans* and *C. noeformans*, respectively. The concomitant administration of tea extracts and antibiotics may not impair the antibacterial activity of these penicillin G.

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