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Estimation of daily fluoride consumption and risk assessment of fluoride intake through Camellia sinensis infusion

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Abstract
This study investigated the fluoride content in infusions of black, green, oolong, and white tea, commonly consumed in India. Fluoride concentrations were determined using a fluoride ion-selective electrode method. The fluoride intake levels for both teens and adults are calculated and found well below the lower threshold for increased risk of dental fluorosis. Specifically, the highest observed chronic daily intake for teens (approximately 0.0115 mg/kg/day) is roughly 5 to 6 times lower than the WHO guideline's lower limit for dental fluorosis risk. Similarly, the highest observed chronic daily intake for adults (approximately 0.005 mg/kg/day) is roughly 10 to 14 times lower than this limit. Therefore, based on the chronic daily intake values the fluoride exposure for both teens and adults appears to be well within the permissible limits set by the WHO to prevent adverse health effects such as dental fluorosis.

Key Words: Brewing, fluoride, infusion, Chronic Daily Intake

1. Introduction

Black tea is consumed primarily in western countries and in south Asian countries such as India and Sri Lanka, whereas green and oolong teas are consumed mainly in East Asian countries such as China, Japan, and Taiwan. Teas of C. sinensis undergo different manufacturing processes; green tea is produced by steaming (Japan) or panning (China) to prevent catechin oxidation by polyphenol oxidase (Graham, 1999).. With no fermentation, green tea leaves retain their green colour and almost all of their original polyphenol content. The different processes of manufacturing give the various teas their characteristic colors and flavors. Oolong tea has an excellent characteristic combining the freshness of green tea and the fragrance of black tea. White tea is non-oxidized tea produced from young shoots of Camellia sinensis (Alcazar et al., 2007). Globally tea is growing in over 35 countries and India holds second position in the tea production (Das and Zirmire, 2018).

Fluoride is an essential micronutrient, and an appropriate amount of intake of this mineral, daily, can prevent the development of dental caries. However, numerous studies have indicated that excessive fluoride ingestion over a long period can lead to potentially severe dental and skeleton fluorosis, hypertension, damage to the neurological system, and a lower intelligence quotient (Lung et al., 2008; Valdez-Jiménez et al., 2011; Mohammadi et al., 2017; Razdan et al., 2017; Yuan et al., 2020).Tea

(Camellia sinensis) is a plant exhibiting high tendency for accumulation of fluorides. Up to 98 % of fluorides are accumulated in the leaves used for the preparation of widely consumed tea infusions. Fluorides from tea leaves are released into infusions, which make the second after drinking waters important source of fluorine for humans. A narrow margin between acceptable fluoride concentration and health risk requires a reliable examination of a large variety of tea products for fluoride contents. The present work is an attempt to determine fluoride content in infusions of different types of tea leaves. The objectives were to understand the effect of brewing conditions on fluoride release.

2. Material and Methods

Chemicals and Glassware: All reagents used were of Merck Company and glassware was acid washed with 10% (w/v) nitric acid and triple rinsed with de-ionized water. De-ionized water was prepared by Lab-Q Water Purification System. Chemicals used were Sodium nitrate ($NaNO_3$), Sodium fluoride (NaF), Sodium acetate (CH_3COONa), Sodium hydroxide (NaOH), Acetic acid (CH_3COOH). NaF was dried at 110°C for two hours and after cooling was used as standard solutions needed for construction of calibration curve. Instruments used in the investigation are Industrial Oven, Heating Plate, Weighing Balance, PH meter and Fluoride ion selective electrode.

Sample Collection and preparation: All samples of the tea were purchased at supermarkets and local marketplaces. Approximately 200 g of each tea was collected and individually stored in airtight plastic bags (referred to as uncrushed tea samples). Approximately 100 g of each type of tea was crushed using an electrical grinder and individually packed into plastic bags. The concentrations of fluoride ions in 15 different samples of black, green, white and oolong tea were analyzed. Tea infusions were prepared on a customary way of tea preparation. For all measurement de-ionized water was used so that we can be sure that measured fluorides are from tea. From each tea were randomly selected five samples and dried at 80°C for five hours and analyzed on fluoride content. The infusion was prepared using 2.0 g of tea leaves boil with 200 ml de-ionized water for 2 min.

Stock and standard solution preparation: 0.221gm NaF was dissolved in a liter of de-ionized water and stored in polyethylene bottle (for 100 ppm). Before weighing, NaF was dried for an hour at 110°C. Serial concentrations of sodium fluoride solution were prepared, and 25 ml of each concentration was added to equal volume of TISAB solution (Colina et al, 1990).

Analysis of Fluoride: The amount of fluoride in tea infusion was analyzed by potentiometric methods using previously described model. Samples were prepared for analysis by 25 ml of TISAB solution to 25 ml of the unknown solution to keep ionic strength and pH constant. During the measurement solutions were constantly mixing, and temperature was kept at 25°C. All measurement was made for five samples of each tea and the results presented here were average. Fluoride ion selective electrode was immersed in the solutions and readings on the ion analyzer were recorded.

3. Result and Discussion

The results showed the general rank with respect to the fluoride concentration in an infusion: Black Tea Infusion (BTI)> Green Tea Infusion (GTI)> Oolong Tea Infusion (OTI)> White Tea Infusion (WTI)

Since 1% tea to water ratio was the ratio used for makings of commercial tea drinks and used in other reports (Duckworth and Duckworth, 1978; Fung et al., 1999), tea infusions were prepared in 1% tea to boiling water ratio for this study. Fluoride contents of tea infusions for 15 brands of four different tea types were determined and the results are shown in figure 1.

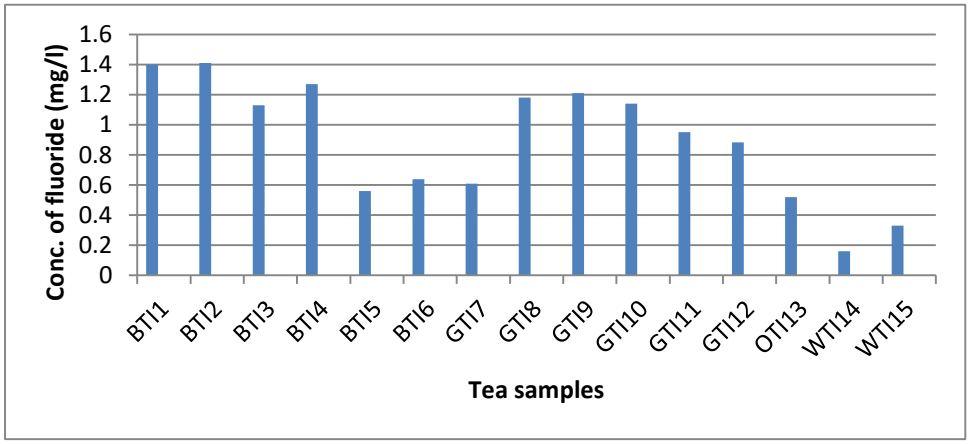

Figure 1: Concentration of fluoride in tea infusions (mg/l) after 2 min of brewing

Estimated daily fluoride intake (DFI), chronic daily intake (CDI) and fluoride intake risk due to the consumption of preference beverages were calculated from the following formulas and according to the method of USEPA (USEPA, 1992).

Table 1: Equations used to estimate the Human Exposure and Health Risk (Pattaravisitsate et al., 2021).

Equations	**Description**
Chronic Daily Intake (CDI) = $\frac{C \times DI \times EF \times ED}{BW \times AT}$	C is the fluoride concentration in tea infusion (mg/l). DI is the average daily intake rate of tea (l/day). EF is the exposure frequency (day(s)/year). ED is the exposure duration (year). BW is body weight (kg). AT is the averaging time (days). CDI is the chronic daily intake (mg/kg/day). RfD is the reference dose (mg/kg/day).
Hazard Quotient (HQ) = CDI/RfD **An HQ of < 1 indicates an insignificant risk level, whereas an HQ of > 1 implies a potential noncancer-causing health impact.**	

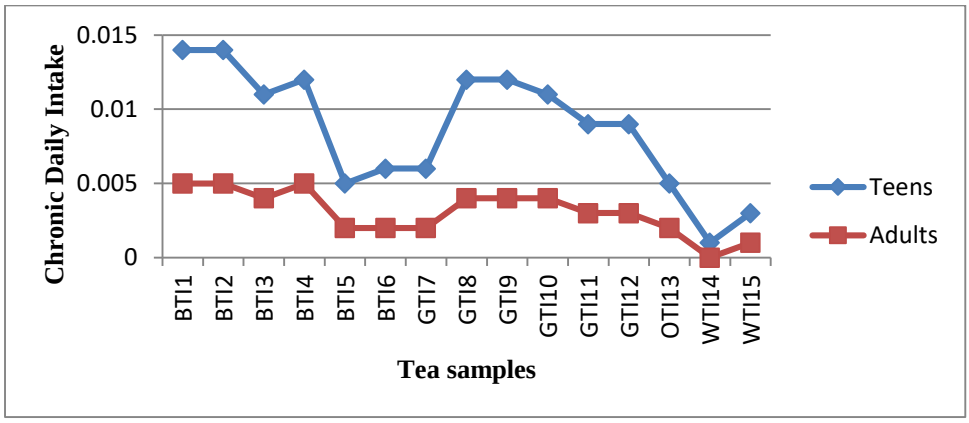

Figure 2: Chronic Daily Intake (CDI) of fluoride following a 2-minute infusion (mg/kg/day)

The chronic daily intake (CDI) was calculated to estimate the non adverse health effect of fluoride exposure from tea. The concentrations of infusible fluoride obtained after 2 min brewing times for each type of tea were utilized and the different exposure parameters, such as daily intake (DI) of tea, exposure frequency (EF), exposure duration (ED), body weight (BW), average time and RfD, were selected from previous studies, and their probability distributions among age groups are displayed in Table 2. It is noteworthy that the estimation of health risk for ingestion of fluoride in drinking tea was calculated based on the input parameters shown in Table 2.

Table 2: Exposure parameters of the probabilistic risk model (Pattaravisitsate et al., 2021)

Input parameter	**Unit**	**Distribution**	**Reference**
Daily intake (DI)	l/day	Teens; 0.5 Adults; 1	Miri et al., (2018)
Exposure Frequency (EF)	Day/year	345	Smith, (1994)
Exposure Duration (ED)	Year	6	Huang et al., (2017)
Body weight (BW)	Kg	Teens; 46.25 Adults; 57.03	Wu et al., (2011)
Average Time (AT)	Day	Teens; 2190 Adults; 9125	Huang et al., (2017)
Oral Reference Dose (RfD)	Mg/kg/day	0.06	Fallahadeh et al., (2018)

Reference dose (RfD) is an estimate of daily exposure that is not expected to be a significant risk of adverse effects throughout life. The RfD of fluoride is 0.06 mg/kg/day, which includes both 0.05 mg/kg/day due to fluoride intake via beverage and 0.01 mg/kg/day due to fluoride intake via meals. When the HQ is greater than 1, the estimated potential fluoride exposure exceeds the RfD and a risk of fluorosis may be posed.

The fluoride intake levels for both teens and adults, as presented in the table (Table 3), are well below the lower threshold for increased risk of dental fluorosis. Specifically, the highest observed CDI for teens (approximately 0.0115 mg/kg/day) is roughly 5 to 6 times lower than the WHO guideline's lower limit for dental fluorosis risk. Similarly, the highest observed CDI for adults (approximately 0.005 mg/kg/day) is roughly 10 to 14 times lower than this limit. Therefore, based on the chronic daily intake

values presented in the table (Table 3), the fluoride exposure for both teens and adults appears to be well within the permissible limits set by the WHO to prevent adverse health effects such as dental fluorosis.

Table 3: Hazard Quotient (HQ) for Teens and Adults form 2 – minute infusion

Code Name	Hazard Quotient (HQ)	
	Teens	Adults
BTI*1	0.00084	0.0003
BTI2	0.00084	0.0003
BTI3	0.00066	0.0002
BTI4	0.00072	0.0003
BTI5	0.00030	0.00012
BTI6	0.00036	0.00012
GTI*7	0.00036	0.00012
GTI8	0.00072	0.00024
GTI9	0.00072	0.00024
GTI10	0.00066	0.00024
GTI11	0.00054	0.00018
GTI12	0.00054	0.00018
OTI*13	0.00030	0.00012
WTI*14	0.00006	0.00000
WTI15	0.00018	0.00006

*BTI- Black Tea Infusion, *GTI- Green Tea Infusion, *OTI- Olong Tea Infusion, *WTI- White Tea Infusion

Since all the Hazard Quotient (HQ) values (as shown in table 3) for the tested Tea brands (BTI1 to WTI15) for both teens and adults are substantially less than the established limit of 1, it can be concluded that the exposure to these tea brands, under the conditions of a 2-minute infusion, is unlikely to pose a significant health risk to either teens or adults. The HQ values indicate a very low potential for adverse health effects.

According to WHO, the optimum fluoride intake for humans should range from 2 to 4 mg/day (WHO, 2011). The level recommended by USEPA is similar, from 2.5 to 4 mg F^-/day for children and adults, respectively (USEPA-US Environmental Protection Agency; 2017). This amount of fluoride can be covered by about 2 – 3 cups (ca. 400 – 600 ml) daily of a popular black tea with F^- concentration about 6 mg/l, even after 15-minute brewing, but without taking into account other sources of fluoride (e.g. toothpaste etc.).

4. Conclusion

Crucially, the study performed a health risk assessment by calculating the Chronic Daily Intake (CDI) and Hazard Quotient (HQ) of fluoride from tea consumption for both teens and adults, based on standard exposure parameters. The highest observed CDI for teens and adults for a 2 - minute infusion was found to be well below established health guidelines. For context, the generally accepted optimal fluoride

intake for caries prevention is around 0.05 - 0.07 mg F/kg body weight/day, with a risk of dental fluorosis increasing above this level, particularly at intakes exceeding 0.1 mg/kg body weight/day for children. The calculated HQ values for all tested tea brands and both age groups were substantially less than 1 (ranging from approximately 0 to 0.00084), indicating an insignificant risk of adverse health effects, including fluorosis, under the typical consumption scenarios.

Author Profiles

Ms. Suwanshi Chandrakar carried out her dissertation work in the year 2025 at the Chhattisgarh Council of Science and Technology, Raipur, under the supervision of Dr. Beena Sharma.

Dr. Beena Sharma is currently serving as Scientist 'C' at the Chhattisgarh Council of Science and Technology, Raipur (C.G.).

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