MHA MEDIHEALTH ACADEMY

Surgery on Children

Original Article

doi:10.51271/SOC-0087

Iodine nutrition, bamboo shoot consumption, thiocyanate exposure, thyroid function, weight and height, and associations among them in the tribal children of Tripura, Northeast India

Indrajit Ray*[1], Amar Kumar Chandra[2], Saru Kumar Debbarma[3], Sekhar Kumar Mookerjee[4], Ajoy Datta[1], Laishram Hemchandra Singh[5]

[1]*Department of Human Physiology, Ramkrishna Mahavidyalaya, Kailashahar, Tripura, India*
[2]*Department of Physiology, University of Calcutta, Kolkata, West Bengal, India*
[3]*Department of Medicine, Agartala Government Medical College & G.B. Hospital, Agartala, Tripura, India*
[4]*Department of Medicine, Medical College & Hospital, Kolkata, West Bengal, India*
[5]*Department of Zoology, D.M. College of Science, Imphal West, Manipur, India*

Received: 11/09/2026 ◆ **Accepted**: 11/10/2026 ◆ **Published**: 20/10/2026

Cite this article: Ray I, Chandra AK, Debbarma SK, Mookerjee SK, Datta A, Singh LH. Iodine nutrition, bamboo shoot consumption, thiocyanate exposure, thyroid function, weight and height, and associations among them in the tribal children of Tripura, Northeast India. *Surg Child*. 2026;3(4):139-148. doi:10.51271/SOC-0087

***Corresponding Author:** Indrajit Ray, rayindrajit0@gmail.com

ABSTRACT

Aims: To evaluate the status of iodine consumption (IC) and bamboo shoot consumption (BSC) and their impacts on Tripura's iodized salt-consuming tribal population, this study aimed at assessing iodine nutrition, BSC, thiocyanate exposure, thyroid function, weight and height, and associations among them in Tripura's tribal children.

Methods: This cross-sectional study included 127 children aged 6-12 years from Deorachhara, Unakoti and Naithangchhara. The study assessed thyroid volume (TV), free thyroxine (FT4), free triiodothyronine (FT3), thyrotropin, thyroglobulin antibody (Tg-Ab), thyroid peroxidase antibody (TPO-Ab), urinary iodine (UI), urinary thiocyanate (USCN), salt iodine, water iodine, weight, height and BSC.

Results: The medians of BSC (grams/person/day), WI (µg/L), UI (µg/L), FT4 (pmol/L) and FT3 (pmol/L) were 83.3, 1.1, 103, 22.1 and 5.01 in Deorachhara; 119.0, 5.0, 100.0, 17.0 and 4.22 in Naithangchhara; and 166.7, 4.5, 143.0, 19.7 and 5.87 in Unakoti, respectively. Unakoti showed significantly higher thyrotropin and FT3 levels, and significantly lower FT4 level, weight, and height compared to Deorachhara. There were significant positive correlations between Tg-Ab and TPO-Ab in Unakoti and Naithangchhara, and USCN and TPO-Ab in boys. Deorachhara showed a significant negative correlation between TV and Tg-Ab. Naithangchhara showed significantly lower thyrotropin, FT4, and FT3 levels, and a significantly higher Tg-Ab level compared to Unakoti. Unakoti showed the highest underweight and thinness prevalence, whereas Naithangchhara showed the highest stunting prevalence.

Conclusion: Children with lower normal median free thyroid hormone levels showed a higher undernutrition prevalence and risks of autoimmune thyroid diseases, probably due to higher BSC and lower adequate IC.

Keywords: Thyroid gland, thyroxine, triiodothyronine, thyrotropin, autoantibodies, nutritional status

INTRODUCTION

Iodine, an essential trace element, is required by mammals for the production of thyroid hormones (TH)–thyroxine (T_4) and triiodothyronine (T_3).[1,2] Thyroid gland produces 100% of T_4 and 20% of T_3 in men, and remaining 80% of T_3 is produced by extrathyroidal deiodination of T_4 in liver, kidney, brain, pituitary and brown fat.[1] Less than 1% of T_4 and T_3 remains as free F_4 (FT_4) and free F_3 (FT_3).[1] Free TH, being accessible to peripheral tissues, regulate various biological activities.[3]

To produce sufficient TH, daily iodine consumption (IC) should be at least enough to ensure a median urinary iodine (UI) level of 100 µg/L indicating adequate iodine consumption (AIC).[4] Foodstuffs deficient in iodine and/or rich in goitrogens may cause iodine deficiency (ID)[1,2,5] which decreases TH.[1] In low TH (hypothyroidism), hypothalamic thyrotropin releasing hormone (TRH) stimulates pituitary gland to produce thyroid stimulating hormone (TSH)/ thyrotropin which, in turn, stimulates thyroid gland to

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.

release TH (predominantly FT_4). Besides, hyperthyroidism i.e., high TH (predominantly FT_4) decrease TSH inhibiting pituitary gland and hypothalamus.[6] Prolonged TSH action produces goiter (enlargement of thyroid gland) by stimulating hypertrophy and hyperplasia.[1] Beside hypothyroidism and goiter, ID may also (a) increase the incidences of stillbirth, spontaneous abortion, congenital anomalies, low birth weight, young one's mortality, deaf-mutism, squint, spastic diplegia, cretinism,[5] short stature,[4] delayed bone maturation, retarded sexual maturation,[1] (b) damage brain in young ones,[5] and (c) lower intelligence quotient up to 13.5 points.[4] All these disorders are known as iodine deficiency disorders (IDD). Besides, both ID[7] and excess IC[4,7] may cause autoimmune thyroid diseases (AITD) by increasing thyroglobulin antibody (Tg-Ab) and thyroid peroxidase antibody (TPO-Ab). Excess IC may convert the higher Tg-Ab or TPO-Ab state to overt hypothyroidism.[8] To control IDD, major strategies are sustainably eliminating ID by supplementing exogenous iodine through universal salt iodization (USI) program and monitoring IC periodically.[4]

In the context of thyroid function, Tripura's tribal population holds special relevance, because they traditionally consume bamboo shoot (BS) which contains antithyroid constituents like thiocyanate.[9] Besides, the State of Tripura is iodine deficient[10] and found goiter endemic,[11,12] where effectiveness of the prophylactic USI program introduced in 1988[11] was not satisfactory.[12] But the information regarding the status of IC and bamboo shoot consumption (BSC) and their impacts on the thyroid gland and overall health of Tripura's iodized salt-consuming tribal population was scarce. Therefore, this study aimed at assessing thyroid pathophysiology, thyroid volume (TV), FT_4, FT_3, TSH, Tg-Ab, TPO-Ab, UI, urinary thiocyanate (USCN), salt iodine (SI), water iodine (WI), weight, height and BSC, and associations among them in the tribal children of Tripura.

METHODS

Ethics

This study was approved by the Institutional Human Ethical Committee, Department of Physiology, University of Calcutta, Kolkata, India (Date: 03.10.2013, Decision No:IHEC/PHY/CU/H-P 34/13) under the research study entitled "Studies on Anti-thyroidal Biomolecules in Bamboo-shoots of North-East and evaluation of their Molecular and Physiological actions in Thyroid disruptions". All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and the Helsinki Declaration.

Study Population

Three hilly villages-Deorachhara, Unakoti, and Naithangchhara-were randomly selected for the study from the Tripura Tribal Autonomous District Council, Northeast India. Deorachhara and Unakoti are in Unakoti district, and Naithangchhara is in Dhalai district. These villages were sparsely populated and under USI program, besides all were similar in climate, economy, culture, education, dietary habits and available health facilities. As school-aged children have ability to reflect current status of iodine nutrition[5] and urine samples collected at random from 40 subjects of an area represent current status of iodine nutrition in that area,[13] the willing tribal children aged 6-12 years receiving no medical treatment were selected randomly ensuring at least 40 subjects from each village. Thus, a total of 127 children (boys-59 and girls-68) were selected from these three villages. The study was conducted during the BSC period of 2015-2018.

Anthropometric Measurements

Weight and height have been widely and successfully used with reference to one another or age to assess health and nutritional risk, especially in children.[14] So, weight and height were measured using a digital weighing scale and an anthropometric rod, and recorded to nearest 100 grams and centimeters, respectively. Body-mass index (BMI) was calculated using the formula: "BMI (in kilograms/square meters)=(weight in kilograms)/(height in meters)^2".[15] Body surface area (BSA) was calculated using Dubois and Dubois formula: "BSA (in square meters)=(weight in kilograms)$^{0.425}$×(height in centimeters)$^{0.725}$×71.84×10^{-4}".[4] Weight, height and BMI of each child were compared with those of CDC (Centers for Disease Control and Prevention of the United States) reference z-scores for the child's gender and age.[16] A child with <-2SD (SD, standard deviation) weight-for-age, <-2SD height-for-age, <-2SD BMI-for-age, >1SD BMI-for-age or >2SD BMI-for-age was considered as underweight, stunted, thin, overweight or obese, respectively.[15]

Thyroid Ultrasonography

Echogenicity of thyroid gland was studied for detecting nodules and measuring TV following WHO (World Health Organization) ultrasonographic guidelines,[4] using a portable compact color doppler ultrasound scanner system with a 7.5 MHz linear array transducer (GE LOGIQ E BT 12 Console with 12 L RS Linear Probe, Wipro GE Healthcare Pvt. Ltd) by a radiologist. Each thyroid lobe's volume was calculated by the formula: "Each thyroid lobe's volume (in milliliters)=0.479×(length in centimeters)×(width in centimeters)×(depth in centimeters)".[4] TV was calculated by adding the volumes of right and left lobes. TV of each child was compared with the 97th percentile reference TV of iodine-sufficient children for the child's sex and age[4] to diagnose as goitrous or normal.

Serum Levels of FT_4, FT_3, TSH, Tg-Ab and TPO-Ab

Serum was separated within 2 hours of fasting venous blood collection from each child and stored at -20°C until analysis. Serum levels of FT_4, FT_3, TSH, Tg-Ab and TPO-Ab were measured by ELISA microwell methods using the kits of FT_4 (Product Code: 1225-300, Accu-Bind ELISA Microwells, Monobind Inc., Lake Forest, CA 92630, USA), FT_3 (Calbiotech Inc., 10461 Austin Dr. Spring Valley, CA, 91978), TSH (Product Code: 325-300, Accu-Bind ELISA Microwells, Monobind Inc., Lake Forest, CA 92630, USA), anti-Tg-Ab (EUROIMMUN, Medizinische, Labordiagnostika, AG) and anti-TPO-Ab (EUROIMMUN, Medizinische, Labordiagnostika, AG), respectively.

Diagnostic tests to evaluate thyroid function: (a) Diagnostic criteria and values (both according to assay manuals): AITD: Tg-Ab (negative: <100 IU/ml, positive: ≥100 IU/ml); TPO-Ab (negative: <50 IU/ml, positive: ≥50 IU/ml). (b) Diagnostic criteria (according to published literature)[17] and values

(according to assay manuals): Euthyroid: normal TSH (0.39-6.16 µIU/ml [0.39-6.16 mIU/L]) and normal FT_4 (0.8-2.0 ng/dl [10.3-25.7 pmol/L]); Euthyroid hypothyroxinemia: normal TSH and low FT_4 (<0.8 ng/dl [<10.3 pmol/L]); Euthyroid hyperthyroxinemia: normal TSH, high FT_4 (>2.0 ng/dl [>25.7 pmol/L]) and low FT_3 (<1.4 pg/ml [<2.15 pmol/L]); Primary/Overt hypothyroidism: high TSH (>6.16 µIU/ml [>6.16 mIU/L]) and low FT_4 [Hashimoto's thyroiditis: Primary hypothyroidism with positive Tg-Ab and positive TPO-Ab]; Secondary/central hypothyroidism: low TSH (<0.39 µIU/ml [<0.39 mIU/L]) and low FT_4; Subclinical hypothyroidism: high TSH and normal FT_4; Primary hyperthyroidism: low TSH and high FT_4 [Graves disease: Primary hyperthyroidism with positive Tg-Ab, positive TPO-Ab and positive TRAb (thyrotropin receptor antibody)]; Secondary/TSH-mediated/central hyperthyroidism: high TSH and high FT_4; Subclinical hyperthyroidism: low TSH, normal FT_4 and high FT_3 (>4.2 pg/ml [>6.45 pmol/L]).

Urinary Iodine Level

Urine samples were collected from the selected children and stored at 4°C until analysis. Urine samples were collected ensuring at least 40 samples from each village.[13] Urine samples' iodine contents were assayed following Karmarkar et al.[18] method.

Urinary Thiocyanate Level

The dietary consumption of thiocyanate in a population is determined from the USCN.[19] So, urine samples' thiocyanate contents were estimated following Aldridge modified method of Michajlovskij and Langer.[20]

Salt Iodine Level

Iodized salt samples were collected from the families of selected children, ensuring at least 35 salt samples from each village, as 35 salt samples collected randomly from an area reflect USI program status in that area.[21] Salt samples' iodine contents were estimated following iodometric titration method.[4]

Water Iodine Level

Samples of water used for drinking and house-hold works were collected from the families of selected children and stored at 4°C until analysis. Water samples' iodine contents were assayed following Karmarkar et al.[18] method.

Bamboo Shoot Consumption

To determine per capita daily BSC in the selected villages, 61 randomly selected tribal families consisting of 270 members were interviewed regarding their consumed BS's types and forms, duration of BS availability in a year, consumption frequency per week, consumption amount per day, number of family members, and the information thus obtained was recorded.

Statistical Analysis

Means (SDs) and medians of age, TV, FT_4, FT_3, TSH, Tg-Ab, TPO-Ab, UI, USCN, WI, SI, weight, height and BSC were calculated using Microsoft Excel Office 2019. Two tail z-test (for n [children number] ≥30) and t-test (for n<30) of Microsoft Excel Analysis Tool Pak were used to calculate mean differences' significance levels (p-values). First order partial correlation coefficients (r) were calculated using the formula: "$r_{12.3}=(r_{12}-r_{13}xr_{23})/\sqrt{\{(1-r_{13}^2)(1-r_{23}^2)\}}$....$r_{23.1}=(r_{23}-r_{12}xr_{13})/\sqrt{\{(1-r_{12}^2)(1-r_{13}^2)\}}$" [where 1=UI, 2=SI and 3=WI], and 9th order partial 'r' using the formula: "$r_{12.3456789XY}=(r_{12.3456789X}-r_{1Y.3456789X}xr_{2Y.3456789X})/\sqrt{\{(1-r_{1Y.3456789X}^2)(1-r_{2Y.3456789X}^2)\}}$,...., $r_{XY.123456789}=(r_{XY.12345678}-r_{9X.12345678}xr_{9Y.12345678})/\sqrt{\{(1-r_{9X.12345678}^2)(1-r_{9Y.12345678}^2)\}}$" [where 1=age, 2=TV, 3=FT4, 4=FT3, 5=TSH, 6=Tg-Ab, 7=TPO-Ab, 8=USCN, 9=UI, X=weight, and Y=height], and their p-values were obtained when t-values were calculated using the formula: "t=r/√{(1-r²)/(n-number of variables)}", and consulted with the critical t value table of two-tail test.[22] The statistical charts were prepared using Microsoft Excel Office 2019.

RESULTS

Table 1 details children's demographic characteristics, variable means (SDs) and medians by village and total, and the significance levels (p-values) of mean differences across villages. Dietary survey on BS showed an overall median BSC of 119 grams/person/day for about 6 months from May to October. The studied families mainly consumed muli (*Melocanna baccifera*), mritinga (*Bambusa tulda*), rupai (*Dendrocalamus longispathus*), dalu (*Schizostachyum dullooa*), barak (*Bambusa balcooa*) and jai or bari (*Bambusa vulgaris* var. *vulgaris*) types of BS in cooked forms as curry, fry, prickle and boiled BS. Unakoti having significantly higher BSC showed significantly higher levels of TSH and FT_3, and significantly lower levels of FT_4, weight, height, BMI and BSA compared to Deorachhara. Besides, Naithangchhara having significantly lower UI showed significantly lower levels of FT_4, FT_3 and TSH, and significantly higher levels of Tg-Ab and BMI compared to Unakoti.

Table 2 shows the prevalence of underweight, stunting and thinness. Unakoti showed highest prevalence of underweight, and thinness, whereas Naithangchhara showed highest stunting prevalence.

Table 3 highlights the distribution pattern of FT_4, FT_3, TSH, Tg-Ab, TPO-Ab, UI, WI and SI. Normal levels of FT_4, FT_3 and TSH were observed in 92.9%, 81.1% and 93.7% children, respectively. Iodine level was ≥15 parts per million (ppm) in 80.3% salt samples.

Table 4 presents 9th order partial 'r' between different variable pairs along with p-values. There were significant positive correlations between TV and height in Unakoti, between Tg-Ab and TPO-Ab in Unakoti, Naithangchhara and total children, between TV and weight in Deorachhara and total children, between TPO-Ab and FT_3 in Deorachhara, between FT_4 and TSH in girls, between FT_4 and weight in total children, between age and Tg-Ab in total children, between UI and height in Naithangchhara and total children, between USCN and FT_4 in Naithangchhara and total children, between UI and TPO-Ab and between USCN and TPO-Ab in boys. Besides, there were significant negative corrections between TPO-Ab and TSH in Unakoti, between TV and Tg-Ab in Deorachhara, between Tg-Ab and FT_3 in boys, between TSH and weight in total children, between Tg-Ab and weight in boys, between age and UI in Naithangchhara and boys, and between UI and weight in total children.

Table 1. Demographic characteristics, and levels of TV, FT_4, FT_3, TSH, Tg-Ab, TPO-Ab, UI, USCN, WI, SI and BSC by village and total, and significance levels of mean differences across villages among the studied tribal children in Tripura

Variable	Deorachhara (DC) (n=45) (M/F=0.80)	Unakoti (UK) (n=41) (M/F=0.78)	Naithangchhara (NC) (n=41) (M/F=1.05)	Total (n=127) (M/F=0.87)	Mean differences' significance level*		
	Mean (SD)/median	Mean (SD)/median	Mean (SD)/median	Mean (SD)/median	DC vs. UK	UK vs. NC	DC vs. NC
Age (y)	9.02 (2.02)/9.56	8.37 (1.45)/8.24	8.68 (1.49)/8.75	8.70 (1.69)/8.77	0.084 (NS)	0.341 (NS)	0.371 (NS)
Weight (kg)	24.2 (6.6)/24.0	20.0 (3.6)/19.7	21.5 (3.7)/20.2	22.0 (5.2)/20.9	0.000 (S)	0.077 (NS)	0.016 (S)
Height (cm)	124.5 (12.3)/ 125.4	118.7 (7.7)/119.3	119.1 (9.2)/118.9	120.9 (10.3)/120.4	0.009 (S)	0.868 (NS)	0.020 (S)
BMI	15.3 (1.7)/14.9	14.1 (1.1)/14.1	15.0 (0.9)/15.1	14.8 (1.4)/14.6	0.000 (S)	0.000 (S)	0.370 (NS)
BSA (m^2)	0.92 (0.17)/0.93	0.82 (0.10)/0.82	0.84 (0.11)/0.82	0.86 (0.14)/0.84	0.001 (S)	0.311 (NS)	0.028 (S)
TV (ml)	0.85 (0.34)/0.86	0.83 (0.23)/0.85	0.79 (0.20)/0.76	0.82 (0.27)/0.82	0.650 (NS)	0.392 (NS)	0.250 (NS)
FT_4 (pmol/L)	22.8 (6.1)/22.1	19.2 (4.8)/19.7	16.3 (3.5)/17.0	19.5 (5.6)/20.1	0.002 (S)	0.001 (S)	0.000 (S)
FT_3 (pmol/L)	4.91 (1.44)/5.01	6.02 (1.57)/5.87	4.37 (0.84)/4.22	5.09 (1.48)/5.04	0.001 (S)	0.000 (S)	0.033 (S)
TSH (mIU/L)	2.66 (1.23)/2.13	3.25 (1.34)/3.02	1.40 (0.90)/1.31	2.44 (1.39)/2.23	0.034 (S)	0.000 (S)	0.000 (S)
Tg-Ab (IU/ml)	12.2 (2.5)/11.5	13.1 (5.2)/12.0	20.6 (15.4)/14.7	15.2 (10.0)/12.5	0.335 (NS)	0.003 (S)	0.001 (S)
TPO-Ab (IU/ml)	4.39 (1.59)/4.05	4.61 (2.04)/4.15	7.86 (21.40)/1.40	5.58 (12.25)/3.89	0.583 (NS)	0.333 (NS)	0.301 (NS)
UI (µg/L)	117.8 (69.3)/103	130.7 (49.9)/143	103.4 (51.0)/100	117.3 (58.4)/108	0.321 (NS)	0.014 (S)	0.269 (NS)
USCN (mg/dl)	1.08 (0.67)/0.9	0.95 (0.36)/0.9	0.92 (0.88)/0.5	0.99 (0.67)/0.8	0.228 (NS)	0.844 (NS)	0.324 (NS)
WI (µg/L)	2.18 (2.91)/1.1	6.32 (5.54)/4.5	5.83 (3.79)/5.0	4.69 (4.56)/3.0	0.000 (S)	0.642 (NS)	0.000 (S)
SI (ppm)	22.2 (11.0)/26.6	20.5 (12.3)/20.0	21.0 (7.4)/21.0	21.2 (10.4)/20.7	0.511 (NS)	0.840 (NS)	0.549 (NS)
BS (g/person/day)	125.6 (78.4)/83.3 (FN=15)	194.4 (118.0)/166.7 (FN=23)	131.7 (86.0)/119.0 (FN=23)	153.8 (101.4)/119.0 (FN=61)	0.037@ (S)	0.046@ (S)	0.826# (NS)

BMI: Body-mass index, BSA: Body surface area, TV: Thyroid volume, FT_4: Free thyroxine, FT_3: Free triiodothyronine, TSH: Thyroid stimulating hormone, Tg-Ab: Thyroglobulin antibody, TPO-Ab: Thyroid peroxidase antibody, UI: Urinary iodine, USCN: Urinary thiocyanate, WI: Water iodine, SI: Salt iodine, BSC: Bamboo shoot, n: Children number, M/F: Male/female ratio, FN: Families' number, S: Significant, NS: Not significant, SD: Standard deviation
*: Two-tail t-test (@: Assuming Unequal Variances, #: Assuming Equal Variances) and z-test at α=0.05 were performed to find out mean differences' significance level

Table 2. Prevalence of underweight, stunting and thinness by village, gender and total among studied tribal children in Tripura

Type of malnutrition	Prevalence					
	Deorachhara	Unakoti	Naithangchhara	Boys	Girls	Total
Underweight (<-2SD weight-for-age)	11 (24.4%)	21 (51.2%)	18 (43.9%)	25 (42.4%)	25 (36.8%)	50 (39.4%)
Stunting (<-2SD height-for-age)	12 (26.7%)	18 (43.9%)	21 (51.2%)	27 (45.8%)	24 (35.3%)	51 (40.2%)
Thinness (<-2SD BMI-for-age)	4 (8.9%)	10 (24.4%)	2 (4.9%)	4 (6.8%)	12 (17.6%)	16 (12.6%)

Malnutrition data presented in n (%), where n is children number. SD: Standard deviation, BMI: Body-mass index

Ninth order partial 'r' involving BMI and BSA replacing weight and height, respectively were also calculated (not shown in table). There were significant positive correlations between TV and BSA in Unakoti, Deorachhara and total children, between FT_4 and BSA in total children, and between UI and BSA in Unakoti and boys. There were significant negative correlations between UI and BMI in Deorachhara and total children, and between Tg-Ab and BMI in boys. There were no significant differences between the means of boys and girls for the study variables (not shown in table).

First order partial correlation among UI, WI and SI showed a significant positive correlation between UI and WI (not shown in table).

Figure 1 graphically represents the levels of BSC, FT_4, weight, height, and BMI, alongside the prevalence of undernutrition (underweight, stunting, and thinness) in Unakoti (which has a higher BSC and a lower FT_4) and Deorachhara (which has a lower BSC and a higher FT_4).

Figure 2 shows the scatter plots of FT_4 against weight, height, and BMI in Unakoti (which has a higher BSC and a lower FT_4) and Deorachhara (which has a lower BSC and a higher FT_4).

DISCUSSION

This study revealed the status of iodine nutrition, BSC, thiocyanate exposure, thyroid function, physical health, and associations among them in Tripura's studied children.

For optimal TH production, thyroid gland requires varying amounts of iodine based on age (years): 90 µg/day for children under 6, 120 µg/day for children aged 6-12, and 150 µg/day for adolescents and adults. Consistently meeting these requirements typically results in a median UI level of 100 µg/L, indicating AIC across all age groups.[4] Median UI levels of 100-199 µg/L representing a range of AIC indicate adequate iodine nutrition.[4] Besides, median UI levels (µg/L) of <20, 20-49, 50-99, 200-299 and ≥300 indicate severe ID, moderate ID, mild ID, more than AIC and excess IC, respectively.[4] As per these criteria, the studied children had AIC.

Bioavailability of iodine in an area is generally reflected in its WI. An area is considered as severe, moderate, relative iodine deficient or iodine sufficient depending on whether WI level (µg/L) is <4, 4-10,>10-20 or >20, respectively.[23] As per these criteria, the studied villages were severe to moderate iodine deficient, overall being severe iodine deficient which

Table 3. Distribution pattern of FT_4, FT_3, TSH, Tg-Ab, TPO-Ab, UI, WI and SI among studied tribal children in Tripura

Variable	Range				
FT_4 (pmol/L)					
<10.30 (low level)*	10.30–25.74 (normal level)*		>25.74 (high level)*		Total
3 (2.4%)	118 (92.9%)		6 (4.7%)		127 (100%)
FT_3 (pmol/L)					
<2.15 (low level)*	2.15–6.45 (normal level)*		>6.45 (high level)*		Total
2 (1.6%)	103 (81.1%)		22 (17.3%)		127 (100%)
TSH (mIU/L)					
<0.39 (low level)*	0.39–6.16 (normal level)*		>6.16 (high level)*		Total
6 (4.7%	119 (93.7%		2 (1.6%)		127 (100%)
Tg-Ab (IU/ml)					
≥100 (i.e. positive)*			<100 (i.e. negative)*		Total
0 (0.0%)			127 (100%)		127 (100%)
TPO-Ab (IU/ml)					
≥50 (i.e. positive)*			<50 (i.e. negative)*		Total
1 (0.8%)			126 (99.2%)		127 (100%)
UI (µg/L)					
<20 (severe ID)	20-49 (moderate ID)	50–99 (mild ID)	100–199 (adequate)	200–299 (>adequate)	Total
6 (4.7%)	16 (12.6%)	36 (28.4%)	63 (49.6%)	6 (4.7%)	127 (100%)
WI (µg/L)					
<4 (severe ID)	4-10 (moderate ID)	>10–20 (relative ID)		>20 (adequate)	Total
73 (57.5%)	42 (33.1%)	12 (9.4%)		0 (0.0%)	127 (100%)
SI (ppm)					
<15 (below adequate)		≥15 (adequate)		≥30 (above adequate)	Total
25 (19.7%)		74 (58.3%)		28 (22.0%)	127 (100%)

Data presented in n (%), where n is children number. Note FT_4: Free thyroxine, FT_3: Free triiodothyronine, TSH: Thyroid stimulating hormone, Tg-Ab: Thyroglobulin antibody, TPO-Ab: Thyroid peroxidase antibody, UI: Urinary iodine, WI: Water iodine, SI: Salt iodine, ID: Iodine deficiency, *Values as per assay manuals

confirmed our previous report.[10] However, this study showed a positive correlation between UI and WI ($p<0.05$) as was observed by Lv et al.[24] All these suggested that though these villages were iodine deficient, water available in these villages was a significant source of the consumed iodine.

Generally, achieving ≥15 ppm iodine in ≥90% salt samples indicate USI program's satisfactory effectiveness.[4] As per this criterion, effectiveness of the ongoing USI program under this study was not satisfactory. However, USI program under this study was better in effectiveness than that of 1996-98.[12] Besides, SI had no correlation with UI. All these suggested that the ongoing USI program was not a significant source of consumed iodine.

Usually, Total Goiter Rates (TGR) of 0.0-4.9%, 5.0-19.9%, 20.0-29.9% and ≥ 30% indicate 'no', 'mild', 'moderate' and 'severe' IDD, respectively.[4] Besides, thyroid nodule prevalence in children normally varies within 1.0-1.5%.[25] This study showing all children with normal TV and 0.8% children with thyroid nodules suggested that IDD were not major problems in these villages. This study's TV was lower than that of excess IC area.[26]

This study's village-wise and overall means/medians of FT_4, FT_3 and TSH were in normal ranges. This study's overall means of FT_4 and FT_3 were higher and lower, respectively than that of excess IC area,[26] and higher in both cases than that of AIC area.[27] This study's overall median TSH was lower than that of excess IC[26] and AIC areas.[27] Overall, 86.1% studied children were euthyroid. This study also showed high FT_3 in 17.3% children, being highest (34.1% children) in Unakoti having highest mean and median levels of BSC, TSH and FT_3. All these suggested that BS might have increased FT_3, probably by elevating TSH. This study's thyroid dysfunction prevalence (1.6% subclinical hypothyroidism and 2.4% euthyroid hypothyroxinemia) was lower than that of AIC area.[27]

This study's overall median Tg-Ab was lower than that of AIC area,[27] and the prevalence of positive Tg-Ab (0%) and positive TPO-Ab (0.8%) were lower than that of excess IC area.[26] Generally, AITD prevalence in children varies within 0.5-3% in areas having no ID.[28] Thus, it appeared that positive thyroid auto-antibodies were not major problems in these villages.

This study's median BSC (grams/person/day) during BS-growing seasons varied from 83.3 in Deorachhara, 119 in Naithangchhara to 166.7 in Unakoti, overall being 119 which were higher than that of Australia and New Zealand (where BSC varied within 31–70 grams/person/day).[29] This study showing higher BSC ($p=0.037$) associated with higher levels of TSH ($p=0.034$) and FT_3 ($p=0.001$), and lower levels of FT_4 ($p=0.002$), height ($p=0.009$), weight ($p<0.001$), BMI ($p<0.001$) and BSA ($p=0.001$) in Unakoti than in Deorachhara-suggested that higher BSC might have lowered FT_4, subsequently impacting height, weight, BMI, and BSA, with a concurrent

Table 4. Ninth order partial correlation coefficients (r) and significance levels (p-values) for some variable pairs involving age, TV, FT_4, FT_3, TSH, Tg-Ab, TPO-Ab, UI, USCN, weight and height by village, gender and total among studied tribal children in Tripura

Variable pair	Deorachhara (n=45)	Unakoti (n=41)	Naithangchhara (n=41)	Boys (n=59)	Girls (n=68)	Total (n=127)
TV & weight	r=0.5351, p<0.001) (S)	r=-0.0014, p>0.05 (NS)	r=0.0823, p>0.05 (NS)	r=0.2048, p>0.05 (NS)	r=0.3213, p<0.02 (S)	r=0.2625, p<0.01 (S)
TV & height	r=- 0.0844, p>0.05 (NS)	r=0.4432, p<0.02) (S)	r=0.0610, p>0.05 (NS)	r=0.0235, p>0.05 (NS)	r=0.1428, p>0.05 (NS)	r=0.0967, p>0.05 (NS)
FT_4 & TSH	r=- 0.1582, p>0.05 (NS)	r=0.2472, p>0.05 (NS)	r=- 0.0623, p>0.05 (NS)	r=0.1102, p>0.05 (NS)	r=0.2676, p<0.05 (S)	r=0.1589, p>0.05 (NS)
FT_4 & weight	r=0.1623, p>0.05 (NS)	r=- 0.2080, p>0.05 (NS)	r=0.0853, p>0.05 (NS)	r=0.2408, p>0.05 (NS)	r=0.0801, p>0.05 (NS)	r=0.2005, p<0.05 (S)
Tg-Ab & TV	r=- 0.3743, p<0.05) (S)	r=0.0788, p>0.05 (NS)	r=0.0725, p>0.05 (NS)	r=0.0323, p>0.05 (NS)	r=0.1646, p>0.05 (NS)	r=0.0710, p>0.05 (NS)
TPO-Ab & TSH	r=0.2909, p>0.05 (NS)	r=- 0.3578, p<0.05) (S)	r=- 0.2597, p>0.05 (NS)	r=- 0.0313, p>0.05 (NS)	r=- 0.0941, p>0.05 (NS)	r=- 0.0719, p>0.05 (NS)
Tg-Ab & TPO-Ab	r=0.1073, p>0.05 (NS)	r=0.6258, p<0.001) (S)	r=0.3773, p<0.05) (S)	r=0.7366, p<0.001 (S)	r=0.3220, p<0.02 (S)	r=0.3822, p<0.001 (S)
Age & Tg-Ab	r=0.2373, p>0.05 (NS)	r=0.0506, p>0.05 (NS)	r=0.2498, p>0.05 (NS)	r=0.1031, p>0.05 (NS)	r=0.2749, p<0.05 (S)	r=0.2025, p<0.05 (S)
Tg-Ab & FT_3	r=- 0.0574, p>0.05 (NS)	r=0.00184, p>0.05 (NS)	r=- 0.1067, p>0.05 (NS)	r=- 0.2770, p<0.05 (S)	r=- 0.0676, p>0.05 (NS)	r=- 0.0974, p>0.05 (NS)
UI & TPO-Ab	r=0.1311, p>0.05 (NS)	r=0.0606, p>0.05 (NS)	r=0.1083, p>0.05 (NS)	r=0.3658, p<0.01 (S)	r=0.0234, p>0.05 (NS)	r=0.0731, p>0.05 (NS)
UI & weight	r=-0.3232, p>0.05 (NS)	r=0.1021, p>0.05 (NS)	r=- 0.2893, p>0.05 (NS)	r=- 0.2899, p<0.05 (S)	r=- 0.1904, p>0.05 (NS)	r=- 0.1878, p<0.05 (S)
UI & height	r=0.2758, p>0.05 (NS)	r=0.2534, p>0.05 (NS)	r=0.3733, p<0.05 (S)	r=0.3958, p<0.01 (S)	r=0.1520, p>0.05 (NS)	r=0.2425, p<0.01 (S)
Age & UI	r=-0.0765, p>0.05 (NS)	r=-0.2124, p>0.05 (NS)	r=-0.3865, p<0.05 (S)	r=-0.3208, p<0.05 (S)	r=0.0170, p>0.05 (NS)	r=- 0.1580, p>0.05 (NS)
USCN & TPO-Ab	r=-0.0780, p>0.05 (NS)	r=0.0955, p>0.05 (NS)	r=- 0.1556, p>0.05 (NS)	r=0.3196, p<0.05 (S)	r=- 0.1170, p>0.05 (NS)	r=- 0.0280, p>0.05 (NS)
USCN & FT_4	r=0.0091, p>0.05 (NS)	r=0.0396, p>0.05 (NS)	r=0.5613, p<0.001) (S)	r=0.1520, p>0.05 (NS)	r=0.2068, p>0.05 (NS)	r=0.1969, p<0.05 (S)
TPO-Ab & FT_3	r=0.4543, p<0.01 (S)	r=- 0.1762, p>0.05 (NS)	r=- 0.2117, p>0.05 (NS)	r=0.2278, p>0.05 (NS)	r=- 0.0092, p>0.05 (NS)	r=0.0060, p>0.05 (NS)
TSH & weight	r=- 0.0775, p>0.05 (NS)	r=0.0647, p>0.05 (NS)	r=0.2352, p>0.05 (NS)	r=- 0.2553, p>0.05 (NS)	r=- 0.2616, p<0.05 (S)	r=- 0.2423, p<0.01 (S)
Tg-Ab & height	r=- 0.1852, p>0.05 (NS)	r=- 0.0158, p>0.05 (NS)	r=0.0376, p>0.05 (NS)	r=0.2952, p<0.05 (S)	r=- 0.1465, p>0.05 (NS)	r=- 0.0089, p>0.05 (NS)
Tg-Ab & weight	r=0.2731, p>0.05 (NS)	r=- 0.1613, p>0.05 (NS)	r=- 0.2382, p>0.05 (NS)	r=- 0.3274, p<0.05 (S)	r=- 0.0859, p>0.05 (NS)	r=- 0.1257, p>0.05 (NS)
TPO-Ab & weight	r=0.0628, p>0.05 (NS)	r=0.1632, p>0.05 (NS)	r=0.1679, p>0.05 (NS)	r=0.3196, p<0.05 (S)	r=0.0945, p>0.05 (NS)	r=0.0597, p>0.05 (NS)

TV: Thyroid volume, FT_4: Free thyroxine, FT_3: Free triiodothyronine, TSH: Thyroid stimulating hormone, Tg-Ab: Thyroglobulin antibody, TPO-Ab: Thyroid peroxidase antibody, UI: Urinary iodine, USCN: Urinary thiocyanate, n: Children number; S: Significant, NS: Not significant

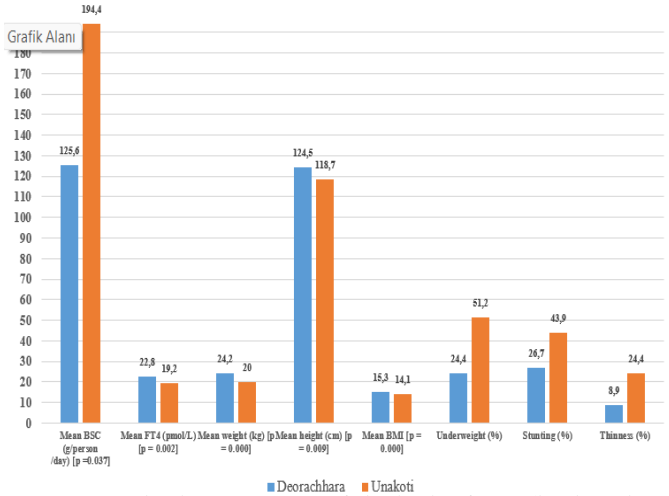


Figure 1. Graphical representation of the levels of BSC (bamboo shoot consumption), FT_4 (free thyroxine), weight, height, and BMI, alongside the prevalence of malnutrition (under-weight, stunting, and thinness) in Unakoti (which has a higher BSC and a lower FT_4) and Deorachhara (which has a lower BSC and a higher FT_4)

BSC: Bamboo shoot consumption, FT4: Free thyroxine, BMI: Body-mass index

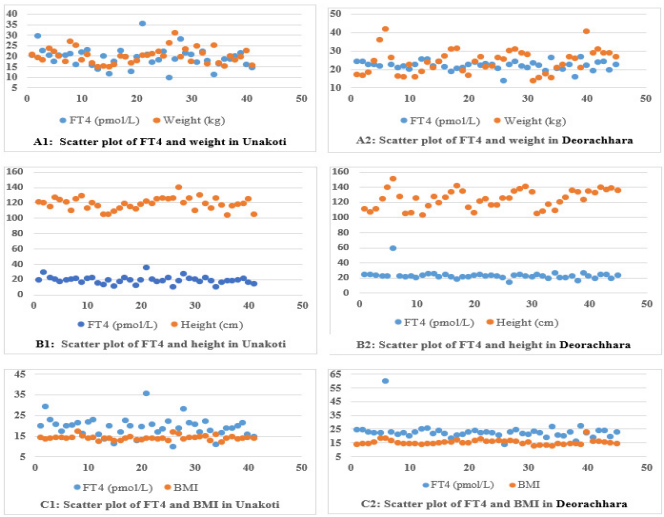


Figure 2. Scatter plots of FT_4 (free thyroxine) against weight, height, and BMI (body-mass index) in Unakoti (which has a higher BSC [bamboo shoot consumption] and a lower FT_4) [panels A1, B1, and C1] and Deorachhara (which has a lower BSC and a higher FT_4) [panels A2, B2, and C2], respectively

BSC: Bamboo shoot consumption, FT4: Free thyroxine, BMI: Body-mass index

compensatory increase in TSH and FT_3. This scenario aligned with the known effects of primary hypothyroidism. Besides, this study showing the trends of positive correlation between Tg-Ab and TPO-Ab proportionate to BSC in three villages, being significant in Unakoti ($p<0.001$), Naithangchhara ($p<0.05$) and total children ($p<0.001$) suggested a positive association between Tg-Ab and TPO-Ab, and this was possibly because of increased BSC. This study also showed the trends of positive to negative correlations (i) between TV and height, being significantly positive in Unakoti having highest BSC ($p<0.02$), and (ii) between TPO-Ab and TSH, being significantly negative in Unakoti having highest BSC ($p<0.05$). These correlations suggested (i) a positive association between TV and height, a finding that has been previously reported,[30] and (ii) a negative association between TPO-Ab and TSH, a finding that contradicted previously reported positive correlation between these two,[31] and these were possibly because of higher BSC. Furthermore, this study showed the trends of positive to negative correlations (i) between TV and Tg-Ab, being significantly negative in Deorachhara having lowest BSC ($p<0.05$), and (ii) between FT_4 and weight, being positive in the village having lower BSC and significantly positive in total children ($p<0.05$). These correlations suggested (i) a negative association between TV and Tg-Ab, a finding that has been previously reported,[32] and (ii) a positive association between FT_4 and weight in total children, and these were possibly because of lower BSC. But this study was unable to ascertain cause-effect relationship among the variables of these correlations. This study also showed the trends of positive to negative correlations between TV and weight, being significantly positive in Deorachhara having lowest BSC ($p<0.001$) and total children ($p<0.01$). These correlations suggesting a positive association between TV and weight, a finding that has been previously reported,[30] indicated that higher weight enhanced TV, a finding that has also been previously reported,[33] and these were probably because of lower BSC. Besides, this study showed the trends of positive to negative correlations between TSH and FT_4, being positive in the village having higher BSC and significantly positive in girls ($p<0.05$). This positive correlation suggested that elevated TSH enhanced FT_4 in girls, potentially increasing the risk of TSH-mediated hyperthyroidism, and this effect was possibly because of higher BSC. Literature has already reported BS's association with reduced T_4 and increased TV in rats.[34] Besides, there have been some reports on BS's antithyroid action. BS has been reported to contain thiocyanate[12] which decreases thyroidal iodine uptake,[29] and 2,4-dihydroxy benzoic acid[35] which inhibits thyroid peroxidase (TPO) activity.[36] BS has also been reported to reduce TH synthesis decreasing the activities of sodium-potassium adenosine triphosphatase (Na+-K+-ATPase) and deiodinase.[37] However, it has already been reported that iodine can partially mitigate BS's antithyroid action.[34,38]

This study's median UI (µg/L) were 103 in Deorachhara, 143 in Unakoti, and 100 in Naithangchhara. This study showing lower UI ($p=0.014$) associated with lower levels of FT_4 ($p=0.001$), FT_3 ($p<0.001$) and TSH ($p<0.001$), and higher levels of Tg-Ab ($p=0.003$) and BMI ($p<0.001$) in Naithangchhara than in Unakoti-suggested that lower AIC might have (i) decreased FT_4 and FT_3, which remained associated with decreased TSH, and (ii) increased BMI and Tg-Ab. This scenario reflected a potential risk of secondary/central hypothyroidism. These findings appeared reflecting the findings of a previous study[27] that reported Tg-Ab's strong associations with lower levels of UI, FT_4 and FT_3 in an area having median UI of 150 µg/L. Besides, this study showed the trends of positive correlation between TV and BSA proportionate to UI in three villages, being significant in Unakoti ($p<0.01$), Deorachhara ($p<0.01$) and total children ($p<0.001$). These correlations suggested a positive association between TV and BSA, a finding that has been previously reported,[30] and this was possibly because of higher AIC. This study showing the trends of negative to positive correlations between FT_4 and BSA, being positive in the village having lower UI and significantly positive in total children ($p<0.01$) suggested a positive association between FT_4 and BSA, and this was possibly because of lower AIC. However, this study was unable to decide cause-effect relationship among the variables of these correlations. Furthermore, this study showed the trends of negative to positive correlations (i) between age and Tg-Ab, being positive in the village having lower UI and significantly positive in total children ($p<0.05$), and (ii) between Tg-Ab and FT_3, being negative in the village having lower UI and significantly negative in boys ($p<0.05$). These correlations suggested (i) an increase in Tg-Ab with the advancement of age in total children, a finding that has been previously reported in females,[39] and (ii) a negative association between Tg-Ab and FT_3 in boys, a finding that has been previously reported in school children,[27] and these were probably because of lower AIC.

This study showing a positive correlation between USCN and TPO-Ab ($p<0.05$) in boys suggested that thiocyanate increased TPO-Ab in boys, a finding that supported the reported hypothesis that excess thiocyanate may promote thyroid autoantibodies.[40] This study showing a positive correlation between UI and TPO-Ab ($p<0.01$) being associated with the positive correlation between USCN and TPO-Ab in boys suggested that both increased iodine excretion and increased thiocyanate elevated TPO-Ab, potentially indicating ID in boys. Because increased UI, while sometimes linked to increased IC, can also reflect increased iodine excretion, especially when influenced by thiocyanate.[41] This study showing a negative correlation between age and UI ($p<0.05$) being associated with the positive correlation between UI and TPO-Ab in boys suggested that problem of increased TPO-Ab probably got reduced with the advancement of age in boys. This study showing a positive correlation between TPO-Ab and FT_3 in Deorachhara having highest mean USCN ($p<0.01$) suggested a positive association between TPO-Ab and FT_3, a finding that contradicted the previously reported negative correlation,[31] implying a probable link between elevated levels of TPO-Ab and FT_3 with ID which was potentially mediated by thiocyanate in Deorachhara. Because an increase in T_3 by ID has already been reported[4] and an increase in TPO-Ab by ID has already been suggested in this study.

Furthermore, this study showing positive correlations between USCN and FT_4 in Naithangchhara having lowest UI ($p<0.001$) and total children ($p<0.05$) suggested that increased thiocyanate raised FT_4 in children, and lower AIC might have favored this. However, thiocyanate has already been reported to increase FT_4.[42] The mechanism through which thiocyanate

increases FT_4 is still unclear, as thiocyanate decreases TH synthesis inhibiting iodide transport and incorporation of iodide to thyroglobulin.[42] However, thiocyanate has been reported to decrease protein-bound T_4 levels and thereby to increase FT_4 in rats.[42]

Unakoti having highest BSC showed highest prevalence of underweight (51.2%) and thinness (24.4%), whereas Deorachhara having lowest BSC showed lowest prevalence of underweight (24.4%) and stunting (26.7%). Besides, Naithangchhara having lowest UI showed highest stunting prevalence (51.2%) and lowest thinness prevalence (4.9%). All these suggested that BS might have increased underweight and thinness, whereas lower AIC might have increased stunting and thereby lowered thinness. By gender, boys had highest prevalence of underweight (42.4%) and stunting (45.8%), whereas girls had highest thinness prevalence (17.6%). All these suggested that boys were more susceptible to underweight and stunting, and girls to thinness.

This study's overall means of age, weight, height, BMI and BSA were lower than that of the children drinking water containing higher iodine and having higher obesity prevalence.[43] This study showing positive correlations between UI and height in total children ($p<0.01$), and between UI and BSA in boys ($p<0.02$), and negative correlations between UI and weight ($p<0.05$), and between UI and BMI in total children ($p<0.02$) suggested that higher IC increased height sometimes increasing BSA, decreased weight and thereby lowered BMI, whereas lower IC increased weight and thereby enhanced BMI. The increase in height by increased IC was possibly because of boosting of bone development and growth by increased TH, specially FT_3, resulted from increased IC. Because FT_3 has been reported to stimulate bone development and growth.[44] Besides, the decreases in weight and thereby decreases in BMI by increased IC might be linked to body fat reduction resulted from enhanced calorigenesis by increased TH, particularly FT_3, resulted from increased IC. Because FT_3 has also been reported to elevate calorigenesis, increasing basal metabolic rate, thermogenesis and lipolysis.[44] Furthermore, this study showing positive correlations between FT_4 and weight ($p<0.05$), and between FT_4 and BSA ($p<0.01$) in total children suggested that increased FT_4 associated with increased weight was reflecting a trend of weight gain (associated with increased BSA). Because a study observed that individuals with higher baseline FT_4 showed preference for a high fat and a high protein diet and, therefore, hypothesized that individuals with higher baseline FT_4 would gain more weight.[45] Besides, TSH exhibiting negative correlation with weight in total children ($p<0.01$) in this study suggested that TSH reduced weight which was likely to be associated with body fat burning. Because literature reported that (i) the presence of TSH receptors in liver and adipocytes (in addition to thyroid) suggests TSH's role in influencing thermogenesis, adipogenesis, lipolysis/lipogenesis, and (ii) increased TSH in obese one is a compensatory mechanism to counter weight gain.[45] This study showing a positive correlation between Tg-Ab and height ($p<0.05$) in boys suggested that an increase in height might have produced relative ID by increasing iodine requirement against lower AIC, and this ID was probably linked to raised Tg-Ab in boys. This study showing negative correlations between Tg-Ab and weight ($p<0.05$), and between Tg-Ab and BMI ($p<0.05$) suggested that Tg-Ab remained associated with lower weight, and consequently with lower BMI. However, this study couldn't settle cause-effect relationship between higher Tg-Ab and lower weight.

However, this study's Tg-Ab and TPO-Ab showing no positive associations with TSH suggested that they were not risk factors for differentiated thyroid cancer (DTC). Because the combination of Tg-Ab, TPO-Ab and high TSH was identified as a risk factor for DTC.[46]

The strengths of this study were (1) conducting the research in three different villages, and (2) investigating the same fourteen variables in each village. This research design allowed for a more robust and nuanced understanding of the phenomena being studied by capturing diverse perspectives and analyzing the interplay of multiple variables across three villages with varied quantitative profiles.

Limitations

This study had several limitations. The study (1) being cross-sectional, was not always able to determine cause-effect relationship among the variable pairs, and (2) did not consider (a) intakes of (i) dietary nitrates, fluorides, calcium, magnesium and isothiocyanate which reduce absorption and incorporation of dietary iodine, and (ii) vegetables of Cruciferae family, cassava, maize, peanuts, walnuts, lima beans, sweet potatoes, millets, soya bean containing glucosinolates and goitrins which block iodine incorporation in TH and suppress T_4 secretion, and (b) status of iron, zinc, copper, selenium, vitamin A and vanadium-deficiency of which may cause hypothyroidism.[1]

CONCLUSION

This study concludes that Tripura's studied tribal children with lower normal median FT_4 levels showed a higher prevalence of underweight and thinness, and were at risk of developing TSH-mediated hyperthyroidism and AITD (increased TPO-Ab and Tg-Ab levels), possibly due to elevated levels of thiocyanate and other antithyroid substances derived from higher BSC. Additionally, studied tribal children with lower normal median FT_4 and FT_3 levels showed a higher stunting prevalence, and were at risk of weight gain and increased Tg-Ab levels, possibly due to lower AIC. However, further studies are needed to confirm these findings and to elucidate the underlying mechanisms.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the Institutional Human Ethical Committee, Department of Physiology, University of Calcutta, Kolkata, India (Date: 03.10.2013, Decision No:IHEC/PHY/CU/H-P 34/13).

Informed Consent

Informed consent was obtained from a parent or legal guardian. Where appropriate, age-adjusted assent was also obtained from the child. The inclusion of vulnerable populations in this study adhered to national and

international ethical guidelines. Extra care was taken to ensure voluntary participation, understanding, and protection of participant dignity and autonomy.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

This study was funded by the Department of Biotechnology (DBT), Ministry of Science Technology, Government of India, New Delhi under North Eastern Region (NER) Twinning Project MAP-240/2013 (Sanction Number BT/471/NE/TBP/2013, dated 26th December, 2014). Author Ajoy Datta received fellowship from DBT, Government of India.

Author Contributions

Concept: AKC; Design: IR, AKC; Control: AKC; Resources: IR; Materials: IR, AD; Data Collection and/or Processing: IR, AD; Analysis and/or Interpretation: IR, AKC, SKD, SKM; Literature Review: IR, AKC, SKD, SKM; Writing the Article: IR; Critical Review: AKC; Final Approval: IR, AKC, SKD, SKM, AD, LHS; Accountability: IR, AKC, SKD, SKM, AD, LHS.

REFERENCES

1. Scientific Committee on Food (SCF). Opinion of the Scientific Committee on Food on the Tolerable Upper Iodine Level of Iodine. SCF/CS/NUT/UPPLEV/26 Final. European Commission (EC), Brussels–Belgium; 2002. Available from: https://ec.europa.eu/food/fs/sc/scf/out146_en.pdf [Last accessed on May 17, 2025]
2. National Coordinating Committee on Food and Nutrition (NCCFN) of Ministry of Health Malaysia (MHM). Iodine (Chapter 19). In: Recommended Nutrient Intakes for Malaysia; 2017:342-355. Available from: https://hq.moh.gov.my/nutrition/wp-content/uploads/2023/12/FA-Buku-RNI.pdf [Last accessed on May 28, 2025]
3. Welsh KJ, Soldin SJ. Diagnosis of endocrine disease: how reliable are free thyroid and total T_3 hormone assays? *Eur J Endocrinol.* 2016;175:R255-R263. doi:10.1530/EJE-16-0193
4. World Health Organization (WHO). Assessment of iodine deficiency disorders and monitoring their elimination: a guide for programme managers.–3rd edn., Geneva; 2007. Available from: https://www.who.int/publications/i/item/9789241595827 [Last accessed on May 28, 2025]
5. World Health Organization (WHO). Global Prevalence of Iodine Deficiency Disorders. MDIS (Micronutrient Deficiency Information System) Working Paper #1, Geneva; 1993. Available from: https://iris.who.int/handle/10665/37149 [Last accessed on May 28, 2025]
6. Fitzgerald SP, Bean NG. Thyroid stimulating hormone (TSH) autoregulation reduces variation in the TSH response to thyroid hormones. *Temperature.* 2018;5(4):380-389. doi:10.1080/23328940.2018.1513110
7. Wan S, Qu M, Wu H, et al. Autoimmune thyroid diseases after 25 years of universal salt iodisation: an epidemiological study of Chinese adults in areas with different water iodine levels. *Br J Nutr.* 2020;124:853-864. doi:10.1017/S0007114520001786
8. Teng W, Shan Z, Teng X, et al. Effect of iodine intake on thyroid diseases in China. *N Eng J Med.* 2006;354:2783-2793. doi:10.1056/NEJMoa054022
9. Chandra AK, Mukhopadhyay S, Lahiri D, Tripathy S. Goitrogenic content of Indian cyanogenic plant foods & their in vitro anti-thyroidal activity. *Indian J Med Res.* 2004;119(5):180-185.
10. Chandra AK, Ray I, Ray P. Iodine content in water of Tripura in North Eastern India. *J Food Sci Technol.* 1999;36(6):558-560.
11. Chandra AK, Ray I. Dietary supplies of iodine and thiocyanate on the etiology of endemic goiter in Tripura. *Indian J Pediatr.* 2001;68(5):399-404. doi:10.1007/BF02723011
12. Chandra AK, Ray I. Evaluation of the effectiveness of salt iodization status in Tripura, north-east India. *Indian J Med Res.* 2002;115:22-27.
13. Dunn JT, van der Haar F. A practical guide to the correction of iodine deficiency. Technical Manual no. 3, ICCIDD/UNICEF/WHO Publication, The Netherlands; 1990.
14. World Health Organization (WHO). Physical Status: The Use and Interpretation of Anthropometry. Report of a WHO Expert Committee (WHO Technical Report Series: 854), Geneva; 1995. Available from: https://www.who.int/publications/i/item/9241208546 [Last accessed on May 28, 2025]
15. Cashin K, Oot L. Guide to Anthropometry: A Practical Tool for Program Planners, Managers, and Implementers. Food and Nutrition Technical Assistance III Project (FANTA)/ FHI 360, Washington DC; 2018. Available from: https://www.fantaproject.org/tools/anthropometry-guide [Last accessed on May 28, 2025]
16. Centers for Disease Control and Prevention (CDC). Z-score Data Files–Growth Charts. National Center for Health Statistics, USA; 2009. Available from: http://medbox.iiab.me/modules/en-cdc/www.cdc.gov/growthcharts/zscore.htm [Last accessed on May 28, 2025]
17. Aw TC, Yap CYF. Thyroid function tests. *Proceedings of Singapore Healthcare.* 2011;20(2):132-137. doi:10.1177/201010581102000212
18. Karmarkar MG, Pandav CS, Krishnamachari KAVR. Principle and procedure for iodine estimation. A laboratory manual. Indian Council of Medical Research (ICMR), New Delhi; 1986.
19. Querido A, Delange F, Dunn T, et al. Definitions of endemic goiter and cretinism, classification of goiter size and severity of endemias and survey techniques. In: Dunn JT, Medeiros-Neto GA (eds) Endemic Goiter and Cretinism: Continuing Threats to World Health, Pan American Health Organization (PAHO), Scientific Publication No. 292, Washington DC; 1974:262-272.
20. Michajlovskij N, Langer P. Studies on relations between thiocyanate formation and goitrogenic properties of foods. I. Preformed thiocyanate content of some foods [in German]. *Hoppe Seylers Z Physiol Chem.* 1958;312:26-30.
21. World Health Organization (WHO). Indicators for assessing iodine deficiency disorders and their control through salt iodization. Micronutrient Series, WHO/NUT/94.6, Geneva; 1994. Available from: https://iris.who.int/handle/10665/70715 [Last accessed on May 28, 2025]
22. Das D, Das A. Statistics in Biology and Psychology, Sixth edn. Academic Publishers, Kolkata; 2015.
23. Zeltser ME, Aidarkhanov BA, Berezhnaya IM, et al. Iodine deficiency and its clinical manifestations in Kazakhstan. International Council for Control of Iodine Deficiency Disorders (ICCIDD). *IDD Newsletter.* 1992;8(1):5-6.
24. Lv S, Wang Y, Xu D, et al. Drinking water contributes to excessive iodine intake among children in Hebei, China. *Eur J Clin Nutr.* 2013;67:961-965. doi:10.1038/ejcn.2013.127
25. Richman DM, Benson CB, Doubilet PM, et al. Thyroid nodules in pediatric patients: sonographic characteristics and likelihood of cancer. *Radiol.* 2018;288(2):591-599. doi:10.1148/radiol.2018171170
26. Chen W, Ho Y, Wang W, et al. Adverse effects on thyroid of Chinese children exposed to long-term iodine excess: optimal and safe Tolerance Upper Intake Levels of iodine for 7- to 14-y-old children. *Am J Clin Nutr.* 2018;107:780-788. doi:10.1093/ajcn/ nqy011
27. Tamang B, Khatiwada S, Gelal B, et al. Association of antithyroglobulin antibody with iodine nutrition and thyroid dysfunction in Nepalese children. *Thyroid Res.* 2019;12:1-8. doi:10.1186_s13044-019-0067-z
28. Zimmermann MB, Aeberli I, Andersson M, et al. Thyroglobulin is a sensitive measure of both deficient and excess iodine intakes in children and indicates no adverse effects on thyroid function in the UIC range of 100-299 µg/L: a UNICEF/ICCIDD Study Group Report. *J Clin Endocrinol Metab.* 2013;98(3):1271-1280. doi:10.1210/jc.2012-3952
29. Food Standards Australia New Zealand (FSANZ). Cyanogenic glycosides in cassava and bamboo shoots: a human health risk assessment. Technical Report Series No. 28; 2004:1-24. Available from: https://www.foodstandards.gov.au/publications/documents/28_Cyanogenic_glycosides.pdf [Last accessed on April 19, 2021]
30. Aydıner O, Aydıner EK, Akpınar I, Turan S, Bereket A. Normative data of thyroid volume-ultrasonographic evaluation of 422 subjects aged 0-55 years. *J Clin Res Pediatr Endocrinol.* 2015;7(2):98-101. doi:10.4274/jcrpe.1818
31. Gautam B, Poudel S, Pokhrel S. Significance of thyroid peroxidase antibodies (anti-TPO antibodies) in patients undergoing thyroid function tests. *J Gandaki Med College-Nepal.* 2024;17(2):111-116. doi:10.3126/jgmc-n.v17i2.71641

32. Lin Z, Lu C, Teng D, et al. Influencing factors and new reference intervals of adult thyroid volume in iodine-sufficient areas of China. *Biological Trace Element Res.* 2023;201:5652-5661. doi:10.1007/s12011-023-03635-x
33. Liu L, Liu L, Li M, et al. Study on association between height, weight, iodine supplementation and thyroid volume. *Br J Nutr.* 2022;127:1358-1366. doi:10.1017/S0007114521002622
34. Chandra AK, Ghosh D, Mukhopadhyay S, Tripathy S. Effect of bamboo shoot, *Bambusa arundinacea* (Retz.) Wild. on thyroid status under conditions of varying iodine intake in rats. *Indian J Exp Biol.* 2004;42:781-786.
35. Dey SK, Brahma BK, Goyal AK. GC-MS profiling of phytocomponents from hydromethanolic fraction of *Bambusa tulda* leaf: a potential candidate for anti-diabetic activity. *Int J Life Sci Res.* 2018;6(3):382-388.
36. Khadem S, Marles RJ. Monocyclic phenolic acids; hydroxy- and polyhydroxybenzoic acids: occurrence and recent bioactivity studies. *Molecules.* 2010;15(11):7985-8005. doi:10.3390/molecules15117985
37. Sarkar D, Chandra AK, Chakraborty A, et al. Effects of bamboo shoots (*Bambusa balcooa*) on thyroid hormone synthesizing regulatory elements at cellular and molecular levels in thyrocytes. *J Ethnopharmacol.* 2020;250:112463. doi:10.1016/j.jep.2019.112463
38. Sarkar D, Chandra AK, Chattopadhyay S, et al. Possible mechanism of bamboo shoots (*Bambusa balcooa*) induced thyroid disruption–an in vitro study. *Hum Exp Toxicol.* 2020;10:960327120958037. doi:10.1177/0960327120958037
39. Ma C, Li D, Yin Y, et al. Establishing thresholds and effects of gender, age, and season for thyroglobulin and thyroid peroxidase antibodies by mining real-world big data. *Clin Biochem.* 2019;74:36-41. doi:10.1016/j.clinbiochem.2019.08.011
40. Singh LH, Chandra AK, Yumnam SD, et al. Thiocyanate in excess develops goiter followed by autoimmune thyroid diseases even after effective salt iodization in a rural community of north east India. *Ecotox Environ Safe.* 2021;208:111711. doi:10.1016/j.ecoenv.2020.111711
41. Miller JK, Moss BR, Swanson EW, Lyke WA. Effect of thyroid status and thiocyanate on absorption and excretion of iodine by cattle. *J Dairy Sci.* 1975;58(4):526-531.
42. Leko MB, Gunjaca I, Pleic N, Zemunik T. Environmental factors affecting thyroid-stimulating hormone and thyroid hormone levels. *Int J Mol Sci.* 2021;22:6521. doi:10.3390/ijms22126521
43. Chen W, Li X, Wu Y, et al. Associations between iodine intake, thyroid volume, and goiter rate in school-aged Chinese children from areas with high iodine drinking water concentrations. *Am J Clin Nutr.* 2017;105:228-233. doi:10.3945/ajcn.116.139725
44. Leung AM, Brent GA. The Influence of Thyroid Hormone on Growth Hormone Secretion and Action (Chapter 4). In: Cohen LE (ed) Growth Hormone Deficiency: Physiology and Clinical Management, Springer; 2016. doi:10.1007/978-3-319-28038-7
45. Stanikova D, Krajcovicova L, Lobotkova D, et al. Thyroid hormone levels and BMI-SDS changes in adolescents with obesity. *Front Endocrinol.* 2023;14:1304970. doi:10.3389/fendo.2023.1304970
46. Frohlich E, Wahl R. Thyroid autoimmunity: role of anti-thyroid antibodies in thyroid and extra-thyroidal diseases. *Front Immunol.* 2017;8:521. doi:10.3389/fimmu.2017.00521