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# Influence of iodine on nutritional, metabolic and immunological response of goats fed *Leucaena leucocephala* leaf meal diet

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SUMMARY

Fifteen indigenous nondescript kids (8·2 kg; 8 months initial age), randomly allotted into three equal groups, were used to study the effects of supplementation of extra iodine on their performance when fed a leucaena (*Leucaena leucocephala*) leaf meal containing diet. Group I (CON) was fed a control concentrate supplement consisting of a conventional protein source whereas the other two groups (LL and LLI) were fed a concentrate containing leucaena leaf meal so as to supply 0·5 of the net crude protein (CP) requirements. Additionally, animals in group LLI were given supplemental iodine (as potassium iodide solution) at 0·25 mg/head/day. Wheat straw was provided *ad libitum* as the sole source of roughage during the 120 days of the experimental period. A metabolism trial, conducted at the end of the feeding trial, revealed no variation in the dry matter intake (DMI) among the groups. A significant ($P<0{\cdot}01$) decline was evident in digestibility of CP in both the leucaena-fed groups (0·463 and 0·482 versus 0·586) whilst that of the other organic components remained unaffected. Animals on the LL diet exhibited lower ($P<0{\cdot}01$) nitrogen retention and average daily gain (ADG) in live weight (LW). Blood collected periodically was analysed for the thyroid hormones triiodothyronine ($T_3$) and thyroxine ($T_4$) as well as other biochemical parameters. At the end of the experimental feeding, the cell-mediated immune (CMI) response of the goats was assessed by intra-dermal inoculation of phytohaemagglutinin-P and measuring the change in skin thickness at various post-inoculation hours. The results revealed that the serum concentration of glucose was significantly ($P<0{\cdot}05$) higher in the LLI group of animals fed leucaena with iodine. The concentration of cholesterol in serum of LL animals increased significantly ($P<0{\cdot}05$) compared to the CON and LLI groups. No variation due to dietary interventions was evident in other indices of metabolic profile. While the concentration of circulating $T_3$ remained unaffected due to dietary intervention, that of $T_4$ reduced significantly ($P<0{\cdot}05$) in the LL group. Moreover, the $T_4$ concentration in the LLI group remained similar to that of control indicative of positive impact of iodine supplementation. The immune response revealed that the skin thickness of animals in the LL group was lower ($P<0{\cdot}05$) as compared to the control, indicating a compromise of CMI response due to feeding of leucaena leaf meal. Supplementation of iodine appeared to be partially effective in potentiating the response. In conclusion, iodine supplementation could be adopted as a strategic management strategy to ameliorate the negative impacts of feeding leucaena leaf meal in growing kids.

## INTRODUCTION

Leucaena (*Leucaena leucocephala*) is a protein-rich browse legume having a pan-tropical distribution. It has potential as a supplement in the primarily crop residue-based small ruminants feeding systems common to most of the tropics. Considering its easy accessibility and good forage quality with an average crude protein (CP) content ranging from 140 to 300 g/kg (Akbar & Gupta 1985; Gupta & Atreja 1998; Pattanaik *et al*. 2000), leucaena is very suitable, both on an economic and nutritional basis, as a protein supplement to cereal straw-based feeding regimens by

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the resource-poor farmers of developing countries. However, the presence of mimosine impedes the effective and optimal exploitation of this protein-rich forage. Mimosine, a non-protein toxic amino acid, is an antimitotic and depilatory agent (Hegarty *et al.* 1964; Reis *et al.* 1975), and its rumen metabolite 3-hydroxy-4-(1H)-pyridone (DHP) is a potent goitrogen (Hegarty *et al.* 1976, 1979). Hence feeding of leucaena could lead to a hypothyroid condition (Jones & Hegarty 1984) with typical signs of alopecia, anorexia, reduced weight gain, enlarged thyroid and low circulating concentrations of thyroid hormones (Jones 1985). The expression of toxicity, however, is related to the proportions of leucaena in the diet, mimosine intake, duration of feeding, and diet composition (Jones & Hegarty 1984; Elliot *et al.* 1985). At lower rates of feeding, signs of leucaena toxicity may be absent but live weight (LW) gain may still be depressed (Jones & Winter 1982).

To overcome the negative impacts of leucaena feeding, animal nutritionists have tried a number of approaches including heat treatment (Tangendjaja *et al.* 1984, 1990), ensiling (Hongo *et al.* 1986), wilting and leaching (Padmavathy & Shobha 1987), pelleting (Srivastava & Sharma 1998) and feeding of DHP-degrading microbes (Jones & Megarrity 1983; Akingbade *et al.* 2002) with various degrees of success and applicability. Although inoculation with rumen bacteria capable of degrading DHP constitutes one of the most effective approaches to deal with the problems of leucaena toxicosis, its applicability by the smallholder farmers of developing countries is doubtful for a number of reasons inherent to their livestock production system.

Since thyroid problems constitute major problems associated with leucaena feeding, it would be reasonable to hypothesize that provision of extra iodine would help overcome the toxicity. There have been suggestions that treatment with iodine or thyroxine ($T_4$) may alleviate signs of leucaena toxicity (Hammond 1995). However, early studies by Jones *et al.* (1978), Holmes (1980), Jones & Hegarty (1984) and Pratchett *et al.* (1991) have failed to elicit a clear-cut advantage based on treatment and/or supplementation with iodine or $T_4$. However, in most of these studies, the experimental animals had access to very high contents of dietary leucaena extending up to total (sole) leucaena feeding. On the contrary, it is generally believed that leucaena can constitute up to 0·3 of the diet of ruminants without overt signs of toxicity (Hammond 1995), but sub-clinical effects, mainly in terms of reduced weight gain and feed intake, may still be apparent. In previous studies involving adult goats, improved nutrient utilization and nitrogen retention when leucaena-containing diets were fortified with iodine has been observed (Pattanaik *et al.* 2000; Rajendran *et al.* 2001*a*, *b*). The present study, therefore, was undertaken to ascertain the effects of iodine supplementation in growing kids with a moderate content of leucaena leaf meal fed a wheat straw-based diet.

## MATERIALS AND METHODS

### *Animals, feeds and feeding*

The study was conducted at the Animal Nutrition Research facility of Indian Veterinary Research Institute, Izatnagar in India. The animal experimentation of the study was ethically approved by the Staff Research Council of the institute. Fifteen indigenous kids (8·2 kg; initial age 8 months) were obtained from the Sheep & Goat Farm of the institute and used for the experiment. The kids were randomly allotted into three equal groups in a completely randomized block design.

Leucaena twigs were collected from the institute farm in a single batch and were allowed to dry under the sun. Following manual separation, the dried leaves were ground and stored in gunny bags, and incorporated into concentrate mixtures as and when required. The mimosine content of the leucaena was determined on this stored leaf meal.

All the kids were reared on a common nutritional regime before the initiation of the experiment. The animals in the first group (control; CON) were fed a concentrate supplement consisting of a conventional protein source whereas those in the other two groups were fed a concentrate containing leucaena leaf meal (LL), the latter replacing 0·50 of the net CP. Additionally, animals in the third group (LLI) were given supplemental iodine (as potassium iodide solution) of 0·25 mg/head/day. The required quantity of iodine was supplied through 5·0 ml of potassium iodide solution, which was added (by thorough mixing) to the concentrate mixture allowance of individual goats. Wheat straw was provided *ad libitum* as the sole source of roughage for all the three groups during the 120 days of the experimental period.

### *Management and experimental procedure*

The animals were housed in a well-ventilated cement-floored barn having provision for individual feeding and watering. Each goat was housed in an individual pen. The goats were tagged for identification using numbered plastic tags tied to their necks. For exercise, the animals were let loose into an adjacent paddock for one hour daily in the morning. All the kids were dewormed using anthelmintic Albomar (albendazole, 5 mg/kg body weight; Smith Kline Pharmaceuticals Limited, India) and dipped for ectoparasites using 50 ppm Butox® solution (deltamethrin 12·5 mg/ml; Intervet India Pvt Ltd) besides being vaccinated for prevalent common infectious diseases before the onset of the experiment. The animals were weighed at the beginning and thereafter at fortnightly intervals to record the change in LW.

Individual animals were offered a weighed quantity of the respective concentrate supplement at 08.00 h after recording the residues, if any. Following complete consumption of the supplement, wheat straw was offered at 10.00 h so as to ensure *ad libitum* consumption. The animals were watered twice daily.

A metabolism trial of 7 days' duration involving quantification of intake and excretion was conducted at the end of 120 days of the feeding trial, after allowing for proper adaptation in the metabolism cages. During the collection period, records were kept of daily feed intake, and faecal and urinary outputs during the preceding 24 h. The daily urinary output of individual goats was collected quantitatively in plastic bottles; suitable aliquots were preserved in glass bottles containing dilute (200 ml/l) $H_2SO_4$ for nitrogen estimation. An appropriate aliquot of the wet faeces was weighed, mixed well with 5 ml of dilute (200 ml/l) $H_2SO_4$ and pooled into previously weighed wide-mouth plastic bottles. At the end of the collection period, the pooled aliquots of the wet faeces for each animal were weighed, mixed well and analysed for nitrogen concentration. Another aliquot of the faecal output was dried in a forced-draft oven for dry matter (DM) estimation. Samples of feeds, refusals and faeces were pooled for each animal over the 7 days of collection and stored in airtight (zipped) polyethylene bags for further processing.

Blood was collected from all the animals by jugular venipuncture at the beginning and thereafter at 40-day intervals, and serum, that was separated by centrifugation, was stored at −20 °C until analysis.

### *Immune response*

At the end of the experimental feeding, the cell-mediated immune (CMI) response of the goats was assessed by delayed-type hypersensitivity (DTH) reaction to intra-dermal inoculation of phytohaemagglutinin-P (PHA-P) as described by Sevi *et al.* (2001). The skin of the area to be tested (both sides of the neck region) was shaved 24 h in advance so as to facilitate subsiding of any inflammation due to abrasion. An area of about 1 $cm^2$ was encircled with a marker pen. The thickness of the skin was measured with the help of a vernier caliper, which was represented as the basal (0 h) value. Subsequently, a calculated volume of the PHA-P solution in phosphate buffer saline was inoculated intradermally to the marked site so as to deliver about 15 μg of PHA-P per site, and the change in thickness of the skin was monitored at 24 h intervals up to 96 h post-inoculation.

### *Analyses and statistics*

Samples of feeds, residues and faeces, after grinding to pass through a 2 mm sieve, were analysed for proximate components as per AOAC (1995). The metabolizable energy (ME) value of the compound diet was evaluated as per MAFF (1984). Mimosine concentration in the leucaena leaf meal was assayed as per Megarrity (1978). Analysis of various serum biochemical parameters (glucose, total protein, albumin, globulin, urea and cholesterol) were undertaken as described elsewhere (Pattanaik *et al.* 1999). Serum concentration of thyroid hormones triiodothyronine ($T_3$) and $T_4$ was assayed using radioimmuno assay (RIA) kits obtained from Bhabha Atomic Research Centre, Mumbai, India, with the minimum detectable limits of 0·01 and 0·05 ng/ml, respectively. The intra- and inter-assay variations were 0·12 and 0·08, respectively.

The statistical analysis of the data was undertaken by analysis of variance as described by Snedecor & Cochran (1989). Means were compared using Duncan's multiple range test. Significance was declared at $P<0{\cdot}05$ unless otherwise stated. Data from one animal in the control group were deleted as the animal sustained a fracture of the fore leg not related to diet.

## RESULTS

The composition of the feeds and fodder are listed in Table 1. Based on the estimated consumption of leucaena leaf meal, that contained 22·4 g mimosine/kg DM, the mean mimosine intake was calculated to be $0{\cdot}19 \pm 0{\cdot}015$ and $0{\cdot}20 \pm 0{\cdot}018$ g/kg LW for groups LL and LLI, respectively.

### *Nutrient utilization, nitrogen balance and growth*

The mean digestibility of dietary components is given in Table 2. The mean digestibility of DM and organic matter (OM) tended ($P<0{\cdot}10$) to be lower in LL group animals in comparison to CON or LLI. The CP digestibility, on the other hand, reduced significantly ($P<0{\cdot}01$) in both the leucaena-fed groups, irrespective of iodine supplementation. There was no effect of dietary treatment on the digestibility of ether extract and total carbohydrate. The plane of nutrition during the metabolism trial revealed no influence of the treatments on the mean daily intake of DM or CP; however, the ME intake as well as the digestible organic matter in dry matter (DOMD) were significantly ($P<0{\cdot}05$) reduced in the LL group compared to the control.

The mean daily nitrogen intake values were similar ($P>0{\cdot}05$) across the treatment groups (Table 3). Excretion of nitrogen through faeces was significantly higher ($P<0{\cdot}05$) in both the leucaena-fed groups

Table 1. *Ingredient and chemical composition of the experimental feeds*

| Attributes | Concentrate supplement* | | Wheat straw |
|---|---|---|---|
| | CON | LL/LLI | |
| *Ingredient composition* (*g/kg*) | | | |
| Maize | 200 | 200 | – |
| Groundnut meal | 300 | 130 | – |
| Wheat bran | 470 | 220 | – |
| LLM† | – | 420 | – |
| Mineral mixture‡ | 20 | 20 | – |
| Common salt | 10 | 10 | – |
| *Chemical composition* (*g/kg DM*) | | | |
| DM | 935·4 | 928·2 | 929·3 |
| OM | 916·5 | 886·8 | 924·0 |
| CP | 228·5 | 221·8 | 39·2 |
| Ether extract | 26·4 | 32·0 | 8·7 |
| Total carbohydrate | 661·6 | 633·0 | 876·1 |
| Ash | 83·5 | 113·2 | 76·0 |

* The compounded mixtures were fortified with a vitamin premix containing 50 000 IU vitamin A and 5000 IU vitamin $D_3$ per gram.
† Leucaena leaf meal.
‡ Minimum assay (g/kg): Ca 280; P 120; Fe 0·50; I 0·26; Cu 0·77; Co 0·13.

while that through urine varied significantly ($P<0·05$) among the three groups, being 3·1, 2·4 and 1·8 g/d for the control, LL and LLI groups, respectively. Retention of nitrogen (either as g/day or as proportion of intake) reduced significantly ($P<0·01$) in LL compared to LLI group. When compared as proportion of absorbed nitrogen, the retention was significantly ($P<0·01$) improved in LLI compared to the other two groups.

Animals belonging to all the three groups exhibited positive growth response (Table 3). The average daily gain (ADG), however, was significantly ($P<0·01$) reduced in LL group as compared to the control as well as LLI groups.

### *Metabolic profile and immune response*

The results of blood biochemical parameters are given in Table 4. Serum concentration of glucose was significantly ($P<0·05$) higher in LLI animals fed leucaena with iodine compared to LL. No variation due to dietary interventions was evident with respect to serum concentrations of total protein, albumin, globulin, albumin:globulin ratio and urea. The serum concentration of cholesterol, on the other hand, increased significantly ($P<0·05$) in LL group as compared to control or LLI groups. The periodic alterations in serum $T_3$ and $T_4$ are depicted in Figs 1 and 2, respectively. The concentration of circulating thyroid hormones revealed that, while the concentration of $T_3$ remained unaffected due to dietary intervention, that of $T_4$ reduced significantly in the leucaena-fed group LL.

The CMI response (Fig. 3), as assessed through DTH reaction to PHA-P, revealed that the skin thickness of animals in the LL group were significantly lower ($P<0·05$) as compared to control, but that of the animals in the LLI group was comparable to both.

## DISCUSSION

The mimosine content of the leucaena leaf meal was apparently towards the lower end of the reported range of 20–140 g/kg (Akbar & Gupta 1985; Garcia *et al*. 1996), but it is known to show significant variability attributable to plant strain variation, stage of growth and methods of drying among other factors (Garcia *et al*. 1996).

Both the leucaena-fed groups of goats exhibited a reduction in CP digestibility. Richards *et al*. (1994*a*) also reported a reduction in CP digestibility in lactating goats when leucaena was incorporated in the diet replacing part of a concentrate supplement. Furthermore, and similar to the present observations, Srivastava & Sharma (1998) also observed negative effects of leucaena on the digestibility of the organic components DM and CP when fed at 200 g/kg. This could be attributed to the presence of variable amounts of tannins and other polyphenolics in leucaena. Protein degradability has been known to be negatively correlated with polyphenolics and

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Table 2. *Influence of iodine supplementation of leucaena diet on intake and digestibility coefficients*

| | Treatments | | | | |
|---|---|---|---|---|---|
| | CON ($n=4$) | LL ($n=5$) | LLI ($n=5$) | S.E. (D.F. = 11) | *P* |
| *Intake* | | | | | |
| DMI | | | | | |
| Concentrate (g/day) | 180 | 183 | 183 | 2·2 | 0·820 |
| Wheat straw (g/day) | 171 | 120 | 134 | 10·5 | 0·191 |
| Total (g/day) | 351 | 303 | 317 | 11·8 | 0·299 |
| ($g/W^{0·75}$) | 56·7 | 57·7 | 60·4 | 0·23 | 0·429 |
| (g/kg LW) | 31 | 33 | 35 | 1·0 | 0·334 |
| CP intake | | | | | |
| g/day | 47·8 | 45·4 | 45·9 | 0·79 | 0·461 |
| $g/W^{0·75}$ | 7·9 | 8·7 | 8·8 | 0·25 | 0·339 |
| DCP intake | | | | | |
| g/day | 28·0 | 20·5 | 22·2 | 0·59 | 0·001 |
| $g/W^{0·75}$ | 4·6 | 3·9 | 4·3 | 0·23 | 0·429 |
| DOM intake | | | | | |
| g/day | 196 | 144 | 166 | 6·9 | 0·047 |
| $g/W^{0·75}$ | 33 | 28 | 32 | 1·2 | 0·300 |
| ME intake | | | | | |
| MJ/day | 2·9 | 2·2 | 2·5 | 0·10 | 0·037 |
| $kJ/W^{0·75}$ | 487 | 415 | 474 | 49·3 | 0·139 |
| DOMD | 56 | 48 | 52 | 1·1 | 0·036 |
| *Digestibility coefficients* | | | | | |
| DM | 0·570 | 0·499 | 0·542 | 0·0115 | 0·086 |
| OM | 0·609 | 0·531 | 0·576 | 0·0139 | 0·066 |
| CP | 0·586 | 0·463 | 0·482 | 0·0104 | 0·002 |
| EE | 0·615 | 0·602 | 0·633 | 0·0107 | 0·486 |
| Total carbohydrates | 0·610 | 0·544 | 0·597 | 0·0129 | 0·132 |

DOM: digestible organic matter; DCP: digestible crude protein; EE: ether extract.

Table 3. *Influence of iodine supplementation of leucaena diet on LW change and nitrogen balance*

| | Treatments | | | | |
|---|---|---|---|---|---|
| | CON ($n=4$) | LL ($n=5$) | LLI ($n=5$) | S.E. (D.F. = 11) | *P* |
| *LW change* | | | | | |
| Initial (kg) | 8·5 | 8·3 | 8·0 | 0·26 | 0·780 |
| Final (kg) | 11·0 | 9·7 | 10·3 | 0·31 | 0·305 |
| Net gain (kg) | 2·5 | 1·5 | 2·3 | 0·10 | 0·003 |
| ADG (g) | 21 | 12 | 19 | 0·8 | 0·003 |
| *Nitrogen retention* | | | | | |
| Intake (g/day) | 7·7 | 7·3 | 7·4 | 0·13 | 0·453 |
| Excretion (g/day) | | | | | |
| Faecal | 3·2 | 3·9 | 3·8 | 0·11 | 0·039 |
| Urinary | 3·1 | 2·4 | 1·8 | 0·10 | 0·002 |
| Retention (g/day) | 1·4 | 0·9 | 1·7 | 0·09 | 0·009 |
| Proportion of NI | 0·18 | 0·13 | 0·23 | 0·013 | 0·006 |
| Proportion of NA | 0·31 | 0·27 | 0·48 | 0·022 | 0·004 |

NI: nitrogen intake; NA: nitrogen absorbed.

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Table 4. *Effects of iodine supplementation to leucaena diet on serum biochemistry and thyroid hormones**

| | Treatments | | | | |
|---|---|---|---|---|---|
| | CON ($n=4$) | LL ($n=5$) | LLI ($n=5$) | S.E. (D.F.$=44$) | *P* |
| Glucose (mg/dl) | 47 | 45 | 50 | 1·4 | 0·014 |
| Total protein (g/dl) | 6·7 | 6. 7 | 6·5 | 0·16 | 0·398 |
| Albumin (g/dl) | 3·3 | 3·2 | 3·1 | 0·14 | 0·538 |
| Globulin (g/dl) | 3·4 | 3·5 | 3·4 | 0·18 | 0·719 |
| A:G ratio | 1·0 | 0·9 | 1·0 | 0·08 | 0·894 |
| Urea (mg/dl) | 34 | 33 | 33 | 1·5 | 0·794 |
| Cholesterol (mg/dl) | 99 | 114 | 93 | 4·4 | 0·001 |
| $T_3$ (ng/ml) | 1·7 | 1·4 | 1·3 | 0·17 | 0·222 |
| $T_4$ (ng/ml) | 27 | 22 | 26 | 1·2 | 0·015 |

* Means of four collections.

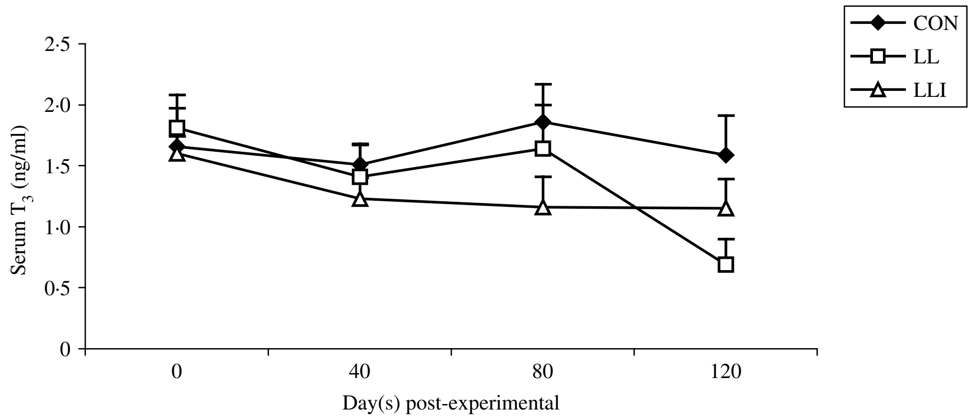


Fig. 1. Periodic alterations in the serum $T_3$ concentrations in goats fed control diet (◆) or diets containing leucaena leaf meal with (△) and without (□) iodine.

proanthocyanidins (Rittner & Reed 1992). In addition, Dzowela *et al.* (1995) have reported depressing effects of the presence of tannins in leguminous forages on DM degradation. Leguminous forages like *Accacia*, *Calliandra* and *Leucaena* contained varied amounts of soluble polyphenolics and fibre-bound proanthocyanidins that had a negative relationship with OM degradability (Norton 1994; Maasdorp *et al.* 1999).

The mean daily ME (MJ/day) intake was significantly ($P<0·05$) reduced in the LL animals as compared to the control, which could be attributable to a reduction in energy content of the leucaena diets in comparison to the control diet. The animals in both the leucaena-fed groups, however, showed a reduction in wheat straw consumption by a margin of about 30 and 22%, respectively, for the LL and LLI groups. This observation is in line with the earlier findings of Mtenga & Shoo (1990) that leucaena supplementation reduced voluntary feed intake of hay in goats. In contrast, Dana *et al.* (2000) observed an improvement in total DMI without depressing the intake of the basal feed in sheep fed leucaena leaf hay. However, studies by Tomkins *et al.* (1991) also indicated that supplementation with leucaena dry leaves at about 300 g/kg reduced the intake of pangola grass basal diet by about 8%. The possible explanation for this could be related to a lowering of circulatory thyroid hormones generally associated with leucaena feeding. Earlier studies by Fox *et al.* (1974) and Bermudez *et al.* (1983) found a relationship between voluntary food intake and exogenous administration of thyroid hormones. Forbes (1988) in fact suggested that, although there is no evidence of a direct involvement of thyroid hormones in the control of intake in mammals, they could play a role, possibly

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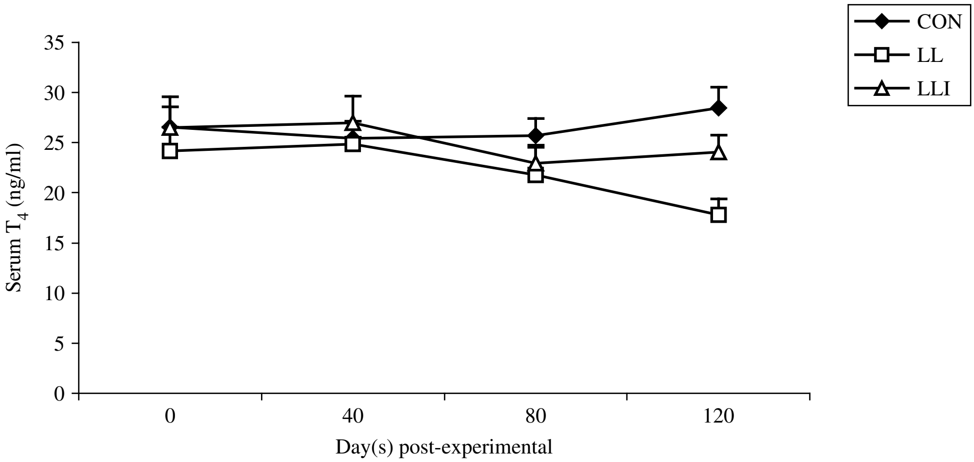


Fig. 2. Periodic alterations in the serum $T_4$ concentrations in goats fed control diet (◆) or diets containing leucaena leaf meal with (△) and without (□) iodine.

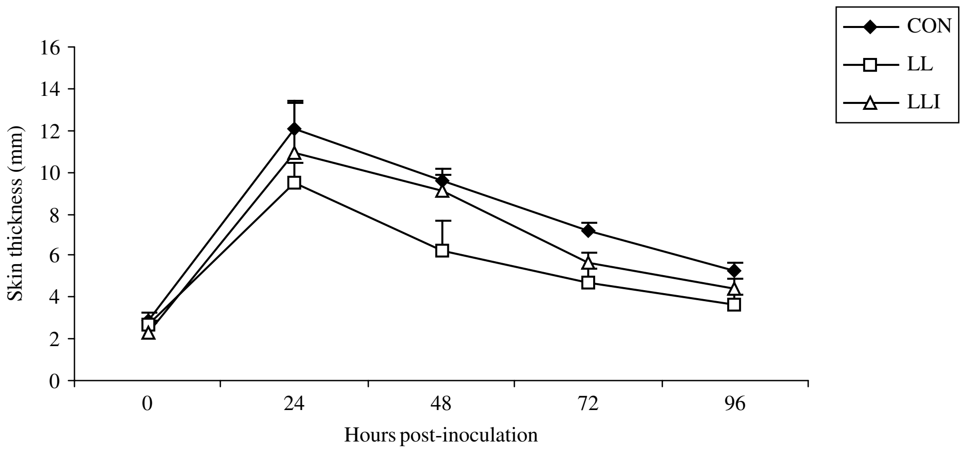


Fig. 3. DTH response to intra-dermal inoculation of phytohaemagglutinin-P by goats fed control diet (◆) or diets containing leucaena leaf meal with (△) and without (□) iodine.

by inducing greater energy requirement and therefore feed intake, to support the increased metabolic rate. The observed partial improvement in wheat straw intake in LLI group compared to LL animals could possibly therefore be explained on the basis of higher $T_4$ concentration (Table 4).

In spite of a similar ($P>0{\cdot}05$) nitrogen intake, the faecal excretion was higher ($P<0{\cdot}05$) in both LL and LLI animals as compared to the control, similar to the observations of Richards *et al.* (1994*a*). Moreover, the urinary N excretion also showed significant variation ($P<0{\cdot}01$), being lower in both the leucaena-fed groups. This could be attributable to the presence of tanniniferous compounds in the leucaena; tannins and related polyphenols may have shifted the excretion of metabolized nitrogen from urine to faeces as has been suggested by Reed *et al.* (1990). Although not estimated in the present study, the tannin content of leucaena is known to range from 12 to 44 g/kg (D'Mello & Fraser 1981; Akbar & Gupta 1985). The negative effects of tannins and related polyphenolic compounds present in leguminous forages on the intake, digestibility and nitrogen utilization are well known (Reed *et al.* 1990). The present findings are similar to the observations of Egan & Ulyatt (1980) who suggested that condensed tannins (in sainfoin) increased the amount of metabolized nitrogen recycled to the digestive tract, thereby increasing its excretion through faeces with a concomitant decrease in its excretion in the urine. A further reduction ($P < 0.01$) in urinary nitrogen excretion in the LLI group in comparison to LL resulted in better ($P < 0.01$) nitrogen retention in the former, similar to the control. Provision of added iodine, as in the case of LLI, appeared to promote better nitrogen utilization efficiency as could be ascertained from the lower excretion of nitrogen in urine and this was aptly reflected as higher coefficient of retention of absorbed nitrogen in LLI (0·481) in comparison to LL (0·269) and control (0·313). A positive response of iodine supply in terms of protein utilization has been reported earlier (Regius-Mocseny *et al.* 1992). A similar trend of better nitrogen utilization was also recorded earlier when diets for goats containing leucaena and mustard cake were supplemented with extra iodine (Pattanaik *et al.* 2000, 2001).

The indigenous goats of the region used for the study are medium-sized animals with various coat colours ranging between brown, black and white, and reared mainly for meat. The mean ADG in the control animals was similar to the range reported for the indigenous kids in earlier studies (Bedi *et al.* 2000; Anbarasu *et al.* 2004; Hembade & Patel 2004). Contrary to the present observations, Yami *et al.* (2000) reported that diets containing moderate to high rates of leucaena, at least up to 450 g/kg, can be fed to goats without significant adverse effects on LW gain. However, the lack of negative effects in their study could be explained on the basis of a lower mimosine concentration of the leucaena leaf meal used. The present results indicate that at the current rate of inclusion (0·25 of DMI), leucaena leaf meal is detrimental to growth performance of kids. This is in confirmation of the findings of Jones & Winter (1982) that, at lower rates of feeding, signs of leucaena toxicity may be absent, but LW gain may still be depressed. In the present study, with an average intake of 0·2 g mimosine/kg LW, no overt clinical signs of toxicity were recorded during the 120 days of the experiment, although Hegarty *et al.* (1964) have suggested that daily intake of mimosine in the range of *c.* 0·2–0·3 g/kg LW is sufficient to induce hair shedding. Although it is generally believed that leucaena can constitute up to 300 g/kg diet of ruminants without signs of toxicosis (Hammond 1995), the present results revealed that sub-clinical effects mainly in terms of reduced weight gain are apparent even at 250 g/kg. In experiments where legumes have replaced a concentrate feed, superior animal performance with concentrate supplementation has been attributed to greater energy intake due to a better energy concentration of the concentrate supplement than the legume-based supplement (Richards *et al.* 1994*b*). A similar trend was also evident in the present study, with the comparable but greater growth performance of control and LLI animals in comparison to LL correlating well with the variation in ME intake (Table 2). The comparable performance of the LLI animals with those fed the control suggests that iodine supplementation was effective in overcoming the growth-retarding effects of leucaena feeding. Megarrity & Jones (1983) have reported no effects of $T_4$ injections in goats fed only leucaena. Similarly, Pratchett *et al.* (1991) observed no effects of intramuscular iodine injection on LW gain of heifers grazing on leucaena–pangola grass pasture and showing clinical signs of leucaena toxicosis. Jones *et al.* (1978) also failed to notice an effect of iodine injections on LW gain or a clinical sign of toxicosis in steers given *ad libitum* access to leucaena. In all these and other related studies, the experimental animals had access to much higher rates of leucaena feeding extending frequently up to sole leucaena feeding and also showing clinical signs of toxicity in some cases. On the other hand, in the present study the rate of inclusion of leucaena was restricted to below 300 g/kg of the total DMI, a level generally believed to be reasonably safe. Thus a lower rate of incorporation resulting, consequently, in a virtual absence of clinical toxicosis other than sub-clinical growth retardation possibly explains the positive response of iodine supplementation obtained in the present study. Furthermore, the present findings are in line with earlier findings of better growth performance in goats following iodine supplementation when fed on conventional as well as goitrogenic diets (Bedi *et al.* 2000; Pattanaik *et al.* 2001).

The hypoglycaemic effect of leucaena observed in the present study, as was also reported by Kailas (1991), appeared to have been overcome by iodine supplementation. Similar observations of increased glucose concentration with iodine supplementation have been observed (Rajendran *et al.* 2001*b*). Contrary to the present observations, Yami *et al.* (2000) observed that plasma urea concentration showed an increase with higher dietary concentrations of leucaena. Serum protein synthesis is known to be influenced by dietary protein (Khattab *et al.* 1998) while blood albumin concentration has been used to assess protein intake (Shetaewi & Ross 1991). Hence the comparable values of serum proteins observed in different groups in the present study could be explainable in light of the observed similar dietary protein intake. Concentration of cholesterol in serum of LL group animals increased significantly ($P < 0.05$) compared to the control and LLI, indicating a probable thyroid insufficiency (Kaneko 1989) due to leucaena feeding that responded positively to iodine supplementation. Serum cholesterol is often used as an index of thyroid function because hypothyroidism is generally associated with an elevation in serum cholesterol.

During early stages of iodine deficiency, there is a tendency for preferential production of the less-iodinated thyroid hormone $T_3$ at the expense of the more-iodinated $T_4$ (Stanbury & Pinchera 1994). The present finding of similar $T_3$ concentrations accompanying a lower $T_4$ in leucaena-alone-fed group (LL) could be attributable to such a physiological compensatory mechanism. The similar concentration of $T_4$ in LLI group compared to that of the control indicated the positive influence of iodine supplementation.

A lower DTH response in the LL group of animals suggests a compromised CMI response compared to the control. In contrast, an improved skin thickness in the LLI group in relation to LL animals indicates that supplementation of iodine appeared to be partially effective in potentiating the CMI response. Although there are apparently no reports where the effects of leucaena feeding on the immune response were studied, Schone *et al*. (1987) observed a depression of immune response in pigs fed rapeseed meal, another goitrogenic feedstuff, which responded positively to extra iodine feeding, indicative of a role of hypothyroidism in depression of immune responses. They explained the depression in immune response and the concomitant reduction in growth in the hypothyroid animals to impaired protein synthesis or unfavourable synthesis-catabolism. Ramakrishna *et al*. (1991) also reported a non-significant depression of CMI in goats with induced hypothyroidism. Similarly, Williamson *et al*. (1990) reported in domestic fowl that stress-induced changes in thyroid hormones could modulate CMI responses. In light of these reports it would be reasonable to conclude that feeding of leucaena may result in depressed CMI response mediated possibly through its effects on thyroid hormones. This could be further confirmed by the observations of Marsh (1995) that growth hormones and thyroid hormones play a role in eliciting the production of factors such as thymulin and interleukin-2, which affect the immune system.

Considering the underlying positive results from the present study, it can be concluded that iodine supplementation could be adopted as a nutritional strategy to ameliorate the negative impacts of low rates of leucaena leaf meal feeding in growing kids. However, this needs to be further confirmed with a long-duration study.

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