Original article

Iodine nutrition in ewes : effects of low to high iodine intake on iodine content of biological fluids in pregnant and lactating ewes

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Summary — In a first experiment, 2 groups of 46 and 47 multiparous ewes received diets which provided an iodine intake of 0.36 and 0.26 mg/kg dry matter (group C) and, 2.01 and 1.94 mg/kg (group D), respectively, for pregnancy and lactation. In a second experiment, 3 groups of 10 nulliparous ewes received diets which provided an I intake of 0.13 and 0.12 mg/kg dry matter (group A), 0.22 and 0.20 mg/kg dry matter (group B), and 10.77 and 8.88 mg/kg dry matter (group E), respectively, for pregnancy and lactation. Observations and sampling were carried out on the ewes from the first third of pregnancy to the 2nd and the 6th week of lactation.

The diets provided adequate nutrition for pregnant and lactating ewes. Dietary I content had no effect on the dry matter intake, the size or the weight of the litter and the length of pregnancy.

Plasma inorganic iodine (PII) was less affected by the I intake during lactation than during pregnancy. The excretion of I in milk induced a decrease in PII between pregnancy and lactation. The I in urine expressed as µg I/g creatinine was largely affected by the I intake. Colostrum I was 6.7, 4.0, 1.2, 1.3 and 1.5 times higher in groups A, B, C, D and E than the I in milk collected 1 week *postpartum*. Milk iodine (MI) content and the ratio MI/PII were markedly dependent on the I intake.

During pregnancy, plasma T4 concentration decreased for each group. Plasma T4 concentration remained low during lactation in the low I intake group, whereas it increased at the same time in the other groups. The plasma T3 concentration decreased at the 6th week of lactation in the highest I intake group.

Experimental values showed that 0.12 mg I/kg dry matter induced depletion in the I stocks of pregnant and lactating ewes, whereas an I intake above 10 mg I/mg dry matter disturbed the metabolism of thyroid hormones.

dietary iodine — ewes — plasma inorganic iodine — milk iodine — thyroxine

Résumé — Nutrition en iode des brebis : effets de différents niveaux d'ingestion d'iode, de la carence à la toxicité, sur les teneurs en iode des liquides biologiques. *Deux expériences sur des brebis ont permis de préciser les effets de 5 régimes dont les teneurs en iode étaient égales, respectivement en gestation et en lactation, à 0,13 et 0,12 mg/kg MS (lot A), 0,22 et 0,20 mg/kg MS (lot B), 0,36 et 0,26 mg/kg MS (lot C), 2,01 et 1,94 mg/kg MS (lot D), 10,77 et 8,88 mg/kg MS (lot E). Les observations et les prélévements ont été effectués sur les brebis du premier tiers de la gestation à la 2e ou 6e semaine de lactation.*

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Aucun effet de la concentration en iode du régime sur la quantité de MS ingérée, la taille et le poids de la portée, et la durée de gestation n'a pu être enregistré.

L'excrétion d'iode par le lait a induit une diminution du taux des iodures plasmatiques (PII) durant la lactation. L'excrétion d'iode par l'urine a été fortement perturbée par la teneur en iode du régime. La teneur en iode du colostrum était, respectivement pour les lots A, B, C, D et E : 6,7, 4,0, 1,2, 1,3 et 1,5 fois supérieure à celle du lait récolté une semaine après le part. Le rapport iode du lait sur iodure plasmatique était largement affectée par la teneur en iode du régime.

Les thyroxinémies des brebis ont diminué durant la gestation. Le régime A à faible teneur en iode a inhibé l'augmentation de la thyroxinémie des brebis durant la lactation. Le régime E à très forte teneur en iode a induit une diminution de la triiodothyroninémie des brebis à la 6e semaine de lactation.

Ces résultats montrent que des régimes à teneurs en iode inférieures à 0,12 mg/kg MS induisent des déplétions des stocks d'iode des brebis gestantes et en lactation. A l'inverse, des régimes à teneur en iode supérieure à 10 mg/kg MS perturbent le métabolisme des hormones thyroïdiennes.

iode alimentaire — brebis — iodure plasmatique — iode du lait — thyroxine

Introduction

Inadequate dietary iodine (I) could induce breeding disorders leading to economic loss (Underwood, 1977). The dietary I allowances for domestic animals are based entirely on clinical investigations. The discrepancies between the different analytical methods of determining I in feedstuffs are considerable. Thus, requirements must be established by quantitative nutritional studies where I intake is controlled. The sheep has been used as an animal model for studying the maternal/fœtal relationships of thyroid hormone metabolism, because of the close resemblance of thyroid physiology in fœtal lamb to that of the human fœtus (Erenberg & Fisher, 1973; Hollingsworth *et al.*, 1975). Thyroidectomy of the fœtus and of the ewe has been performed to reproduce the effect of a lack of thyroid hormones on brain development (Hua *et al.*, 1980; Bhakthavathsalan *et al.*, 1981; McIntosh *et al.*, 1982, 1983). Therefore, nutritional experiments with an ovine model could be a reliable way of studying the disturbance in thyroid status induced by an I deficiency. The purpose of this study was to de-

scribe the effect of 5 iodine diets, ranging from a subdeficient to a subtoxic level, on pregnant and lactating ewes. In a first experiment, dietary iodine was given to 2 large groups of ewes *via* the mineral supplement, allowing 0.3 and 2.0 mg I/kg dry matter (DM). This design made it possible to describe variables that have never been studied extensively before in ovines, such as the I content of urine and milk, plasma inorganic iodine (PII) and plasma thyroid hormones. In a second experiment, experimental diets were distributed to 3 groups of ewes. These provided an I content of 0.1, 0.2 and 10 mg/kg DM for the whole diet. In the present paper, the findings relating to ewes are reported, whereas results pertaining to lambs will be reported in a second paper (Aumont *et al.*, 1989).

Materials and methods

Animals

Experiment 1. Multiparous Ile-de-France ewes with a dated pregnancy of 20—30 days were randomly assigned to 2 groups (C and D) made up of 46 and 47 animals each. Mean body

weight (± SD) at mating was 77.5 ± 6.9 for group C and 74.3 ± 6.9 for group D. The experimental animals received the experimental diets from the 7th week of gestation to the second week of lactation.

Experiment 2. Thirty nulliparous Romanov x Ile-de-France ewes with a dated pregnancy of 20—30 days were assigned to 3 equal groups (A, B, E). The group assignment was made in an attempt to equalize the body weight (kg, mean ± SD) : A: 43.9 ± 4.8; B: 45 ± 2.2; E: 45.3 ± 2.8 and plasma T4 concentration (nmol/l) : A: 74.2 ± 8.6; B: 73.5 ± 6.9; E: 73.6 ± 10.7. The animals received the experimental diets from the 7th week of gestation to the 6th week of lactation.

Diets

Experiment 1. The diets were composed of first- and second-cut hay, maize grain preserved with propionic acid and mineral supplements adequate for mineral, trace element and vitamin requirements (INRA, 1978). Calcium iodate was incorporated into the trace element premix in order to obtain a mineral supplement I content of 5 mg/kg for group C and 92 mg/kg for group D. The daily intakes of the mineral supplement were 30 g/day in pregnancy and 40 g/day in lactation. During lactation, 700 g concentrate/day, containing 0.05 mg I/kg/DM composed of soya bean meal and maize, was distributed to group C ewes. Group D animals received the same diet, except that potassium iodide was incorporated into the concentrate in order to get an I content of 0.80 mg/kg DM. Samples of each component in the diet were collected and analysed for their I contents.

Experiment 2. Three foods — crude forage, a pregnancy concentrate and a lactation concentrate — were made up for each group with wheat straw, hard wheat, soya bean cake and caramel. All the components were screened for the lowest I content. Caramel was produced according to Lamand *et al.* (1983). The fibrous food was prepared by mixing 50—100 mm long hatched straw (0.05 mg I/kg DM) with caramel that had been incorporated with urea and sublimed sulphur (Table I). The concentrates were prepared by mixing hard wheat meal and soya bean meal, trace elements, minerals, vitamins and caramel (Table I). The potassium iodide solution (10 mg/l) was incorporated into the caramel at a rate required for a pregnancy concentrate, *i.e.* U: 2 mg/kg DM (group B) and 13.0 mg/kg DM (group E) and for a lactation

concentrate, *i.e.* 0.3 mg/kg DM (group B) and 14 mg/kg DM (group E) (Table I). The proposed amounts of DM of straw ranged between 500—800 g DM/day in pregnancy, and 1 000 g DM/day in lactation. The proposed amounts of DM of concentrate varied between 500—600 g DM/day in pregnancy and between 800—1 200 g DM/day in lactation. The daily refusals of each food were weighed for each group. The amounts of the different foods were distributed so as to equalize the daily intake of each food between all groups. In order to avoid rumen acidosis, the concentrates were given in such a way that fibrous DM intake would account for more than 45% of the total DM intake.

Sampling

Experiment 1. Blood samples of ewe plasma were taken between 8 and 9 h in tubes with lithium heparin by venipuncture of the left jugular vein 11, 8, 5, 3 and 1 weeks *prepartum* and 16 h, 1 and 2 weeks *postpartum*. Urine samples from ewes were taken at the same time in polypropylene tubes. Samples were frozen at −18°C until analysis.

Experiment 2. Samples of blood, urine and milk from lactating ewes were collected 15, 13, 11, 9, 7, 5, 3, 2 and 1 week *prepartum* and 16 h, 1, 2, 4 and 6 weeks *postpartum* as in experiment 1.

Analysis

Iodine was determined by the Sandell and Kolthoff reaction after alkaline ashing. All the components were analysed for their I contents (Bellanger *et al.,* 1979). PII was determined in each plasma sample by the method of Aumont & Tressol (1987). Total milk iodine content was determined for each sample by the method of Aumont (1982). The urine iodine (UI) was determined by the method of Aumont & Tressol (1986) and expressed as µg/g creatinine to overcome the variation due to the amounts of water excreted. The creatinine in urine was determined by the method of Jaffe (Bartels *e t al.,* 1972). The thyroxine concentration was determined in each plasma sample whereas triiodothyronine (T3) was measured in plasma samples collected during lactation. T4 and T3 in plasma were assayed by radioimmunoassay as described by Cabello & Levieux (1980) with a commercial kit purchased from the Commis-

Table I. Composition of the made-up feeds (exp. 2) proposed to 3 groups of pregnant and lactating ewes for control of the iodine intake.

Fibrous food		Concentrates	Pregnancy	Lactation
Wheat straw (g/kg)	940	Hard wheat (g/kg)	946	742
Molasses (g/kg)	50	Soya bean cake (g/kg)	—	200
Urea (g/kg)	8.5	Molasses (g/kg)	20	20
Sulphur+ (g/kg)	1.5	$CaCO_3$ (g/kg)	25	20
Net energy* (MJ/kg DM)	2.68	$CaHPO_4$ (g/kg)	4.5	13
Mean protein** (g/kg DM)	43	MgO (g/kg)	1	1
		NaCl (g/kg)	1.6	1.6
		Sulphur+ (g/kg)	1.5	1.5
		$ZnSO_4\ 7H_2O$ (mg/kg)	200	200
		$CuSO_4\ 5H_2O$ (mg/kg)	19	19
		$MnSO_4\ H_2O$ (mg/kg)	142	142
		$CoSO_4\ 7H_2O$ (mg/kg)	0.62	0.62
		$Na_2\ SeO_3$ (mg/kg)	0.20	0.20
		Vit. A (UI/kg)	10 000	10 000
		Vit. D (UI/kg)	180	180
		Vit. E (UI/kg)	50	50
		Net energy* (MJ/kg DM)	7.67	7.67
		Mean protein** (g/kg DM)	92	142
		I content $ (mg/kg/DM) for each group		
Group A	0.059	Group A	0.17	0.07
Group B	0.059	Group B	0.35	0.31
Group E	0.059	Group E	14.00	13.00

* Net energy for lactation as defined by INRA (1978).
** Available protein : digestable protein in the intestine, as defined by INRA (1978).
+ Sublimed sulphur.
$ Iodine determination : Bellanger *et al.* (1979).

sariat à l'Energie Atomique (T4K and T3K; CEA, Saclay, France).

Statistical analysis

The gaussian distribution of variables was assessed by skewness and kurtosis tests (Snedecor & Cochran, 1957). Then the unrelated variables were analysed using one-, two-, or three-way analysis of variance with or without logarithm transformation. The effects of time and factor "iodine intake" on related variables, *i.e.* variables determined at each time of sampling, were assessed by analysis of variance with repeated measurements (Winer, 1971). The analysis of variance—covariance was used to describe length of pregnancy and plasma T4 at 16 h *postpartum* (Seebeck, 1973). Values from group E samples were not analysed for studying the effects of dietary I on the I content of biological fluids because the values were always 20—50 times higher than those of the other groups. Differences between blocks were identified by the Student test for independent samples and by the Newman—Keuls test for related samples (Steel and Torrie, 1980). Non-parametric tests were used to describe the MI/PII value (Siegels, 1956). Means of the data are given in the text with their standard deviation. When logarithm transformation was needed, the mean and SD are given after exponential reconversion.

Results

Feed intake, body weight and zootechnical performance

Experiment 1. All the proposed mineral supplement was ingested. The average daily DM intake was 1.875 kg/day in pregnancy and 2.597 kg/day during lactation. Thus, the I content of the whole diet (mg/kg DM) was estimated in pregnancy to be 0.36 (group C) and 2.01 (group D) and in lactation 0.26 (group C) and 1.94 (group D). The body weight (kg) at 1 week *prepartum* was 98.4 ± 6.8 for group C and 89.5 ± 7.4 for group D. There was no significant difference between the 2 groups in the number of lambs per ewe, litter weight or the length of pregnancy (litter weight as a covariable; Table II).

Table II. Effects of iodine intake during pregnancy on the size and weight of the litter and length of pregnancy.

Experiment	Experiment 1		Experiment 2				
Experimental groups	group C	group D	group A		group B		group E
Iodine in diet (mg/kg DM)	0.36	2.01	0.13		0.22		10.77
Size of the litter	**Number $ of ewes**						
1	9	4	2		1		1
2	20	22	5		5		6
3	15	19	3		4		2
4	2	2	0		0		1
Mean * and SE of the weight of the litter (kg)							
1	4.94a 0.87	4.89a 0.55	4.65+ 0.78		4.80+ —		3.70+ —
2	8.04b 1.21	8.66b 1.06	5.31a 0.54		4.61a 0.27		5.20a 0.28
3	10.89c 1.27	10.48c 1.44	6.78b 0.48		5.87b 0.52		5.10a 0.19
4	13.55+ 2.90	12.40+ 5.50	— —		— —		6.50+ —
Mean* and SE of the length of pregnancy (d)							
1	148.0b 1.7	146.8a 2.2					
2	146.9a 1.7	148.4b 1.5	146.6 3.0		145.8 1.9		145.0 2.9
3	147.2a 1.5	148.1ab 1.1					
4	147.0+ 2.8	146.5+ 0.7					

$ Chi-square test not significant between groups within experiments.
* Means within groups with unlike superscript were significantly different (*t* test, 1% risk).

+ Samples not involved in the analysis of variance.
** Analysis of variance—covariance involving weight of the litter as a covariable.

Experiment 2. There was no difference in DM intake, net energy intake or body weight evolution between the 3 groups (Figure 1a, b, c). The total iodine daily intake (µg/day) ranged between 100—151 for group A, from pregnancy to lactation, 185 and 428 for group B and 9 800 to 15 800 for Group E (Fig. 1d). Thus the I contents of the whole diets (mg/kg DM) were, respectively, 0.13 and 0.12 for group A, 0.22 and 0.20 for group B, and 10.77 and 8.88 for group E in pregnancy and in lactation. No significant effect of the intake was recorded in the number of lambs per ewe, the weight of the litter or the length of pregnancy.

Plasma inorganic iodine

Experiment 1. A logarithmic transformation was required to normalize the distribution of PII variables. The PII of ewes from group D was higher ($P < 0.01$) than that of group C : up to 2.6—3.7 times during pregnancy and up to 1.4—1.9 times during lactation. There was a decrease ($P < 0.01$) in the PII of ewes between pregnancy and lactation. This decrease was 1.8 times lower in group C and 3.8 times lower in group D (Fig. 2).

Experiment 2. The PII of group E ewes was 10—50 times higher than the PII of the other groups (Fig. 3). The PII of group B ewes was 1.5 times higher ($P < 0.01$) than that of group A between pregnancy. However, there was no difference between the PII of groups A and B during lactation. The PII decreased ($P < 0.01$), between pregnancy and lactation, to 1.4 times for group A, 1.6 times for group B and 4.5 times for group E. The PII of group E decreased from the 11th week *prepartum,* to the first week *prepartum* ($P < 0.001$).
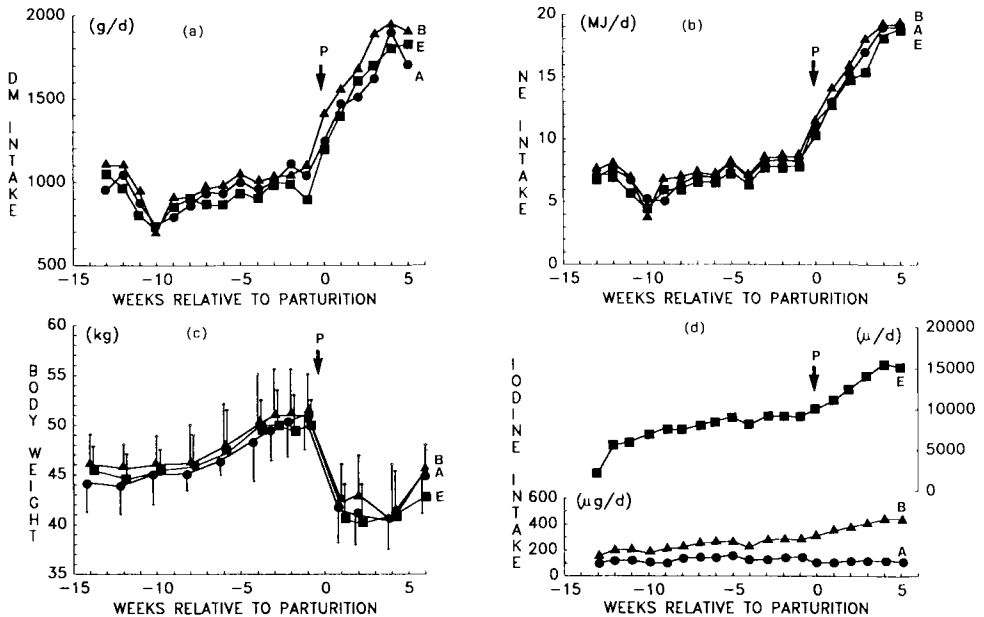

Fig. 1. Change in dry matter (DM) intake (a), net energy intake (b), body weight (c), and iodine intake (d) of ewes receiving diet mixture with different I contents. A: (●), 0.13 and 0.12 mg/kg DM; B: (▲), 0.22 and 0.20 mg/kg DM; E: (■), 10.77 and 8.88 mg/kg DM, respectively, in pregnancy and lactation.
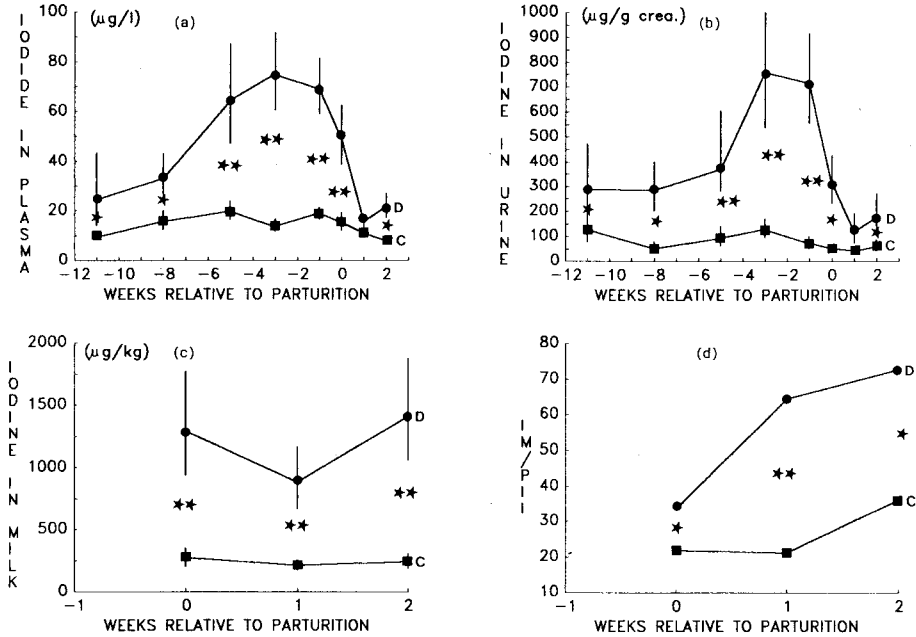
Fig. 2. Plasma inorganic iodine (a), iodine in urine (b), iodine in milk (c) and ratio of iodine in milk/iodine in plasma (d) of ewes receiving diet mixture with different I contents. C: (■), 0.36 and 0.26 mg/kg/DM; D: (●), 2.01 and 1.94 mg/kg/DM, respectively, in pregnancy and lactation. Values are means with their SD represented by vertical bars. Data are given after exponential reconversion of the logarithmic transformed variable. P, Parturition.

Urine iodine (UI)

Experiment 1. A logarithmic transformation was required to normalize the distribution of UI variables. The UI of group C ewes was significantly lower (P < 0.01) than that of group D during pregnancy (2.2—9.8 times) and during lactation (2.8 times) (Fig. 2b). There was a decrease (P < 0.01) in the UI of ewes from group C (1.8 times lower) and from group D (4.2 times lower) between pregnancy and lactation.

Experiment 2. The UI of group E ewes was 10—42 times higher than other group UI levels (Fig. 3b). The UI of group B ewes was higher than that of group A from the 9th week *prepartum* (P < 0.05) to the last week of pregnancy (P < 0.01) and from the 4th (P < 0.05) to the 6th week of lactation (P < 0.01) (Fig. 3). Large standard errors in UI were recorded at 16 h *postpartum*. The UI of group A ewes decreased from the third week before birth (P < 0.01) and remained below 31 µg/g creatinine during lactation except for a significant rise (P < 0.01) at 16 h *postpartum*. The UI of group B ewes decreased at 1 week *prepartum* and remained at the same level for 3 weeks (P < 0.01). Then the UI increased during lactation to return to the level recorded during pregnancy. In group E, the UI dropped to a level that was 2.8 times lower (P < 0.01) between pregnancy and lactation.

Milk iodine (MI)

Experiment 1. Logarithmic transformation was required to normalize MI variables. The MI of group D ewes was significantly
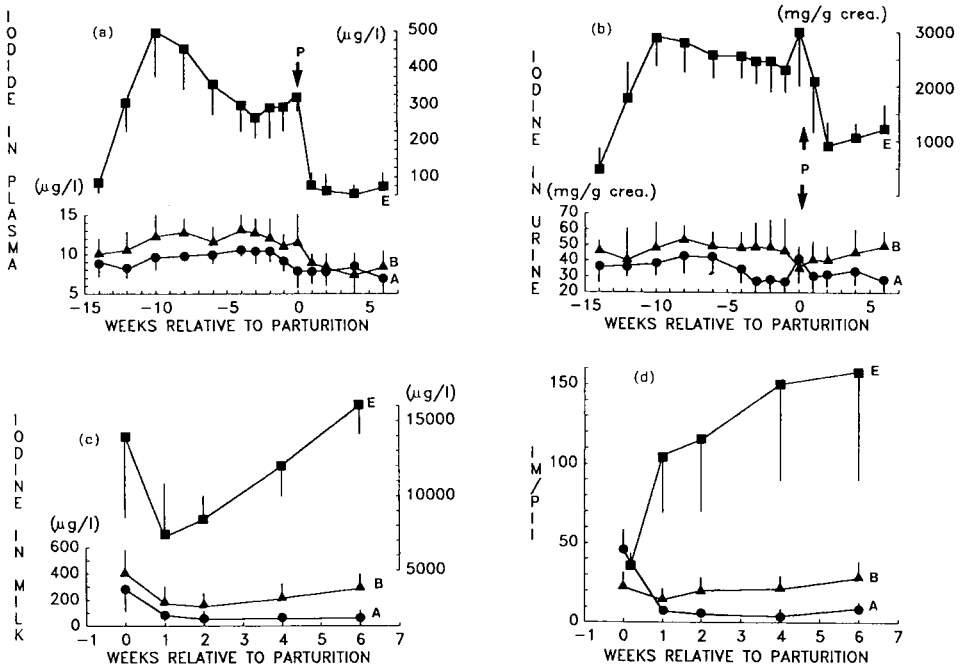
Fig. 3. Plasma inorganic iodine (a), iodine in urine (b), iodine in milk (c) and ratio of iodide in milk, iodine in plasma (d) of ewes receiving diet mixture with different I contents. A: (●), 0.13 and 0.12 mg/kg DM; B: (▲), 0.22 and 0.20 mg/kg DM; E: (■), 10.77 and 8.88 mg/kg DM, respectively, in pregnancy and lactation. Values are means with their SD represented by vertical bars. P, Parturition.

higher ($P < 0.001$) than that of group C (Fig. 2c). The I in colostrum (16 h *postpartum*) was higher than the I content of milk from the first week of lactation : up to 1.3 times for group D ($P < 0.01$). The MI returned to the initial level during the 2nd week of lactation. The MI/PII values for group C ewes were significantly lower ($P < 0.01$) than those of group D (Fig. 2d). The MI/PII increased from the 2nd week of lactation ($P < 0.01$) in group C and from the first week of lactation ($P < 0.01$) in group D.

Experiment 2. The MI of group E ewes was up to 48—57.6 times higher than in the other groups (Fig. 3c). The I content of colostrum was higer than the milk content during the first or second week of lactation : as much as 6.69 times ($P < 0.001$) in group A, 3.97 times

($P < 0.01$) in group B, and 1.9 times ($P < 0.01$) in group E. The MI of ewes from group A remained low (below 56 µg/kg), whereas it significantly increased ($P < 0.001$) from the first to the 6th week of lactation in group E (Fig. 3d). The MI of group B ewes remained unchanged (< 210 µg/kg) until the 4th week of lactation, then it significantly increased ($P < 0.01$). Iodine intake had no effect on the MI/PII at 16 h *postpartum* (Fig. 3d). For group A ewes this value decreased ($P < 0.01$) during the first week of lactation and remained below 7.5. The MI/PII remained unchanged for group B ewes. Thus, it was higher ($P < 0.05$) than the MI/PII values of group A from the 2nd week of lactation (Fig. 4). The MI/PII value of group E ewes increased from parturition until the 6th week of lactation

(P < 0.001). It was higher than that of the other groups from the first week of lactation onwards (P < 0.01).

Plasma T4 and T3 concentrations

Experiment 1. The plasma T4 concentration of ewes correlated inversely to the litter weight (r = −0.4119, n = 87, P < 0.01). Plasma T4 concentration (nmol/l) 1 week after mating did not differ significantly between groups (litter weight as covariable, F = 16.98, coefficient of regression (CR) = −0.3406, SD = 0.0827); for the C group, 73.4 ± 13.4 and for the D group 69.8 ± 11.8 or 16 h *postpartum* C : 53.8 ± 14.3, D : 50.1 ± 18.4.

Experiment 2. No significant difference was noted between plasma T4 concentration of the 3 groups during pregnancy. The plasma T4 concentration decreased (P < 0.01) regularly from the 15th to the first week before lambing (Fig. 4a). This decrease was correlated significantly to the litter weight (r = 0.3634, n = 30, P < 0.05). Plasma T4 concentration of groups B and E ewes increased between pregnancy and lactation (P < 0.01), whereas during the same period, the plasma T4 concentration of group A remained unchanged and became significantly lower than that of the other groups (P < 0.01). There was no significant differ-

ence between groups and within groups in plasma T3 concentration until the 6th week of lactation (Fig. 4b). From then on, the plasma T3 concentration of group E ewes decreased (P < 0.01) and became significantly lower than that of the other groups (P < 0.02).

Discussion

The two experiments allowed us to study a gradient of 5 levels of I content in the food given to productive ewes. Taking into account the DM intake, the I concentrations of the whole diets (mg/kg DM) were A: 0.13; B: 0.22; C: 0.36; D: 2.01; E: 10.77 during pregnancy and A: 0.26; B: 0.20; C: 0.26; D: 1.94; E: 8.88 during lactation. In experiment 1, the logarithmic distribution of the I content in biological fluid variables was due to the large variations in the intake of I as a mineral supplement. Iodine intake was more readily controlled with the experimental diets. In fact, these diets allowed an I intake ranging from a subdeficient to a subtoxic level. However, they provided adequate amounts of fibre, net energy, nitrogen and all the other nutrients required for lactating ruminants. There were some contaminations during the experimental prepara-
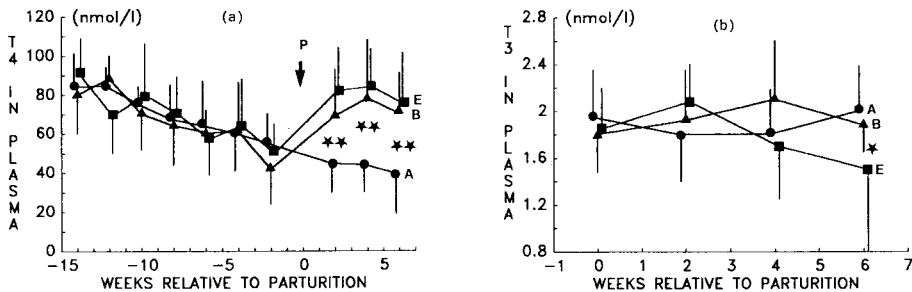

Fig. 4. Thyroxinemia (a) and triiodothyroninemia (b) of ewes receiving diet mixture with different I contents. A: (●), 0.13 and 0.12 mg/kg DM; B: (▲), 0.22 and 0.20 mg/kg DM; E: (■), 10.77 and 8.88 mg/kg DM, respectively, in pregnancy and lactation. Values are means with their SD represented by vertical bars. P, Parturition.

trate used in pregnancy in group A. However, our results show that the preparation of foods with an I content below 0.08 mg/kg DM is feasible. Hard wheat had poor palatability for ewes when distributed with a good-quality forage (Aguer et al., 1971; Thériez, 1984), but its I concentration was undetectable (below 0.02 mg/kg DM), whereas its N content was high. In experiment 2, the concentrates were well ingested (no refusal), probably because they were associated with poor-quality fibrous food. Groppel e t al. (1981, 1985) reproduced an I deficiency in goats with lower I content foods, i.e. below 0.05 mg/kg DM. Potter et al. (1980) carried out an experiment for the same purpose but the amount of DM supplied to the sheep was below 500 g. Despite the moderate amount of DM intake, i.e. about 1.0 kg/day during pregnancy and 1.5 kg/day during lactation, our experimental diets could be considered adequate for inducing experimental I deficiency in ruminants.

A comparison of our results with other reports on the changes of PII was not possible since no such findings on ovines have been recorded. Among all the variables described, MI would appear to be better adapted to the assessment of the dietary I status of pregnant ewes than UI or PII. This is well known for cows (Hemken, 1979) i.e. lactation onset induced an increase in DM intake and thus a greater I intake. However, despite this increase, the excretion of I in milk caused a drop in UI and in PII. The large fluctuations recorded in PII and in UI from the last week of pregnancy until the first week of lactation suggested that parturition induced large variations in the volume of I distribution in the different compartments of the organism. The significant correlation between the decrease in the PII of ewes at parturition and the I intake indicates that I metabolism was largely governed by I intake. The weight of the fetus increased abruptly during the last third of pregnancy. Thus, a quantitatively important pool of I appeared in the fetal organism. Furthermore, the transplacental iodine passage involves active mechanisms allowing only inorganic iodine transfer (Dussault et al., 1971, 1972). However, the decrease in ewe PII, recorded for the highest I intake group and not for the other, remains unclear.

In dairy cows, the excretion of I in urine largely depends on the level of unbound protein iodine in plasma (Lengemann, 1963; Miller & Swanson, 1973). The decreased UI of ewes noted in the low I diet group is a sign that the I stocks were depleted from the last third of pregnancy. The change in the I content of milk during lactation that we recorded is similar to that found in dairy cows (Binnerts, 1956; Swanson, 1972; Franke et al., 1983). Bustad et al. (1963) and Iwarsson et al. (1973) have shown that the I of colostrum is 40% higher than the I in the first milk of dairy cows. However, Swanson (1972) and Stolckl & Leskova (1967) did not record such variations. In our experiment, colostrum and I was higher than milk I. The difference between the DM concentration of colostrum that of milk has been estimated to be 30% (Williams et al., 1976; Eales & Small, 1981). Thus, the higher I content of colostrum compared to that of milk could not be explained by the DM concentration. Furthermore, MI/PII at parturition was higher than during lactation in the low I diet group (group A). Thus, the high I content of colostrum was due to an improved iodide uptake in the mammary gland during the first hours of lactation. The values of MI/PII recorded in our experiments were similar to those reported by Falconer (1963) and Daburon et al. (1968), who used radioactive iodide. This confirms the high ability of the ovine mammary gland to concentrate iodide from plasma to milk.

The decrease in plasma T4 concentration during pregnancy recorded in both experiments has already been reported by Sharma & Sharma (1976) and Riis & Madsen (1985) in goats, and by Blum *et al.* (1983) and Pethes *et al.* (1985) in the last week of pregnancy in the dairy cow. Rasedee & Falconer (1977), Oei *et al.* (1983), Riis & Madsen (1985) and Pethes *et al.* (1985) have shown that a decrease in the thyroxine secretion rate could be caused by an energy deficiency that might occur during pregnancy in the ewe or during the first week of lactation in dairy cows. The fact that the decrease in plasma T4 concentration correlates with the litter weight agrees with this hypothesis. From the decreased I in urine before parturition, the unchanged low level of I in milk, and the MI/PII value, and from the drop in plasma T4 concentration during lactation, a feed I content level below 0.12 mg/kg/DM could be assumed to be deficient.

Wagner *et al.* (1984) did not note any I toxicity symptoms in growing lambs that received 12 mg I/day. McCauley *et al.* (1973) reported that oral doses as high as 93 mg I/day had no adverse effects on lamb performances. However, the drop in plasma T3 concentration in ewes that were fed ≈ 9—10 mg I/kg DM showed that such levels of dietary I could induce disturbances in thyroid hormone metabolism. Despite the lack of *in vitro* studies, the high levels of iodide in plasma could be expected to inhibit the conversion of T4 into T3 by peripheric deiodase and/or thyroidal 5'-deiodase.

Our experiments show that 0.1 mg I/kg/DM is the I-deficient limit for yielding ewes and that the 8 mg I/kg DM level is the upper limit which cannot be exceeded. Although many authors have proposed these limits (Agricultural Research Council, 1965; Harper, 1973; INRA, 1978) no experimental evidence has confirmed that the dietary I allowances of ruminants in lactation, expressed in mg I/kg DM might be 2 or 3 times higher than in pregnancy. However, further investigations into the effects of low to high I intake on newborn and young lambs are needed to confirm these findings.

Acknowledgments

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