On Ultrastructural and Nutritional Aspects of Some Tropical Tuber Starches*

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Type A starches (*Manihot utilissima*, *Dioscorea dumetorum* and *Colocasia antiquorum*) and type B starches (*Canna edulis*, *Dioscorea alata* and *Dioscorea cayenensis*) are investigated. Results show that the degradation of the pure tuber starch as compared with that of feeds made from a particular starch is more or less the same. However, type A starches are more rapidly degraded by bacterial α-amylase. The susceptibility to attack is compared to the nutritional efficiency of the feeds using axenic and holoxenic chickens. Comparison of the degree of degradation of the starch granules in the crop as well as in the feces (by *in vitro* and *in vivo* studies) is made by scanning electron microscopy. Type A starches show always a higher susceptibility to α-amylase attack. The feed efficiency tested on chicken and digestibility of tuber starches in the sheep rumen and in the chicken crop increase as their ease of degradation by bacterial α-amylase (*in vitro*) increases.

Ultrastrukturelle und ernährungsphysiologische Aspekte einiger tropischer Knollenstärken. Die Knollenstärken vom A-Typ (*Manihot utilissima*, *Dioscorea dumetorum* und *Colocasia antiquorum*) und vom B-Typ (*Canna edulis*, *Dioscorea alata* und *Dioscorea cayenensis*) wurden untersucht. Die Ergebnisse zeigen, daß die Abbaubarkeit von reinen Knollenstärken im Vergleich zu Tiernahrung aus Knollenstärken die gleichen botanischen Varietätenverteilungen haben. Die Stärken des A-Typs erweisen sich immer als empfindlicher gegenüber der Enzymaktivität. Diese Varietätenverteilung wird mit dem Nährwert der Tiernahrung mit axenischen und holoxenischen Hühnchen verglichen. Ein Vergleich der amylolytischen Angriffsformen bei verschiedenen Stärken *in vitro* und *in vivo* (Kropfinhalt und Exkremente) wird durch Raster-Elektronenmikroskopie vorgenommen. Die Ergebnisse zeigen, daß die A-Stärken immer eine größere Empfindlichkeit gegenüber der Amylaseaktivität aufweisen. Nährwert und Verdauungsnutzwert von Knollenstärken nehmen im gleichen Verhältnis zu wie ihre Abbaubarkeit durch bakterielle α-Amylase *in vitro*.

1 Introduction

Starch is the principal constituent of the diet. In Europe and other temperate countries, starchy species which are harvested for human consumption, feeds and industrial uses are essentialy cereal grains and the potato tuber. The Common Market production in 1979 was 114,890,000 t (all cereals) and 34,935,000 t in the case of potato tubers.

Nevertheless, many thousands of species of tubering plants belonging to a wide range of botanical families, synthesize and store starch granules as an energetic source for their vegetative reproduction, most of them growing under wet tropical conditions. Some are cultivated throughout large areas. Eg., *Manihot* (Cassava or tapioca) of which 42% of the world's production (i. a. 120,000,000 t) comes from Africa as seen in Table 1. Yams (20,198,000 t) are mainly produced in Africa (96%) and are mainly used for domestic consumption. Other interesting species more or less cultivated are *Ipomea* (batatas or sweet potato), *Colocasia* (taro or Arum), *Canna* and *Coleus*.

In these countries all the tubers are of great importance for the human diet but their production increases very slowly in relation to the development of newly cultivated areas. Ranking as the most important is *Manihot* whose production is increasing by 5% *per annum* in Africa but, on the contrary, is decreasing in areas like the Far East.

Agronomically, the interest of tropical tubers is in their ability to be stored underground without any damage and last for an indefinitely long time. Their reproduction by stem sucker is very efficient. Economically, they are well adapted to most tropical climates and in many cases they can be eaten in case of famine. But, in spite to these favorable features, they are scarcely used as animal feed especially when they could be utilized in these countries as substitutes for cereals as a source of energy in the diet of ruminants, pigs and chicken rearing. As an example, after showing some physical characteristics of a few tropical tuber starches, we will investigate the use of some of them in the breeding of chickens.

2 Physical Characteristics of Some Tropical Tuber Starches

Amorphous and crystalline ultrastructural constitution of the native starch granule is now well known (*Buttrose*, [2]; *Gallant*, [3]; *Kassenbeck*, [4]) and as shown by *Katz* and *Derksen* [5] X-ray diffractometry is the best method of investigation of this crystalline fraction. By this method (Fig. 1) starch granules can be separated in two groups:

a) the A type (called cereal type) showing two peaks between 8 and 9° θ and one peak around 12° θ as shown by wheat, normal and waxy maize starches;
b) the B type (called tuber type) showing one peak at 8° 30′, two peaks at 11° 30′ and 12° θ and one peak at 2° 52′ as shown by potato starch and amylomaize.

In the same manner, native tropical tuber starches can be divided into A and B types (Fig. 2), the A type including *Manihot*, *Ipomea*, Yam (*Dioscorea dumetorum*), *Colocasia* and *Coleus*, the B type including *Canna* and all other commercially important yams *eg. Dioscorea alata*, *D. cayenensis*, *D. bulbifera*, *D. rotundata* and *D. e sculenta*.

As seen in Table 2, the starch content of all tubers is around 70 to 85%. Amylose content is always low for the A type spectrum and the starch granules are generally small. On the contrary, the B type spectrum shows an amylose content

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Table 1.
Botanical Characteristics and Production of Some Starchy Tropical Tubers.

Families	Species	Common name	Origin	Production	
				World	Africa
Euphorbiaceae	*Manihot utilissima*	Cassava Tapioca	South America	120,000,000 t (1980)	42%
Dioscoreaceae	*Dioscorea dumetorum* *Dioscorea cayenensis* *Dioscorea alata* *Dioscorea esculenta* *Dioscorea rotundata* *Dioscorea bulbifera*	Yam	Africa Africa Asia	20,198,000 t (1979)	96%
Araceae	*Colocasia antiquorum*	Taro	India Japan	4,502,000 t (1975)	80%
Convolvulaceae	*Ipomea batatas*	Batatas Sweet potato	South America		
Cannaceae	*Canna edulis*		South America		
Labiaceae	*Coleus sp.*				

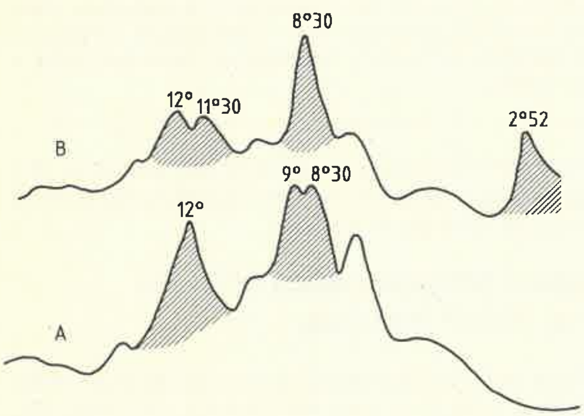

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Figure 1. A and B type X-ray diffractometry spectra.

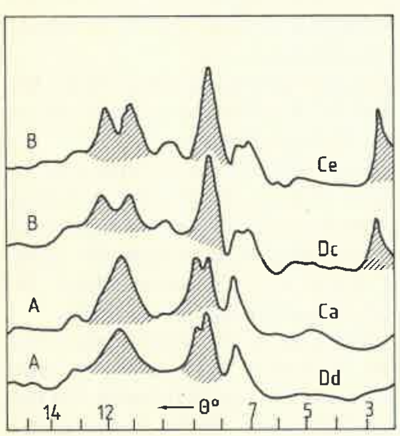

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Figure 2. Tropical tuber starches X-ray diffractometry spectra; a) A type spectrum: *Colocasia antiquorum* (Ca) and *Dioscorea dumerotum* (Dd). b) B type spectrum *Canna edulis* (Ce) and *Dioscorea cayenensis* (Dc).

Table 2.
Physical Characteristics of Some Tropical Tuber Starches.

	Tuber species	Tuber starch content (%)	Amylose content (%)	starch granules sizes (μ)
Type A	*Manihot utilissima*	85	8–16	12
	Ipomea batatas	70	18	10–25
	Dioscorea dumetorum	68–75	10–15	1–3
	Colocasia antiquorum:	77	9–17	1–4
Type B	*Canna edulis*	75–80	27	60–145
	Dioscorea alata	70	≠30	20–140
	Dioscorea cayenensis	70–82	27	10–70
	Dioscorea esculenta	70	14	1–5

between 25 to 30% and the starch granules are very large; but in this group, the starch from *Dioscorea esculenta* is an exception with a low amylose content and very small granules showing a typical A type spectrum.

Under light microscopy and scanning electron microscopy, observations of tuber starches have brought us new information. Amongst those showing an A type spectrum, starch granules of *Ipomea batatas* and *Coleus* were morphologically similar to those of *Manihot*, those of *Ipomea* being bigger hydrolysis occuring as described by *Gallant* et al. [6]. On the other hand, *Colocasia* and *Dioscorea dumetorum* starch granules are typically similar to the maize starch granule although they are smaller in size. Amongst those showing a B type spectrum, all yam starch granules are similar to the

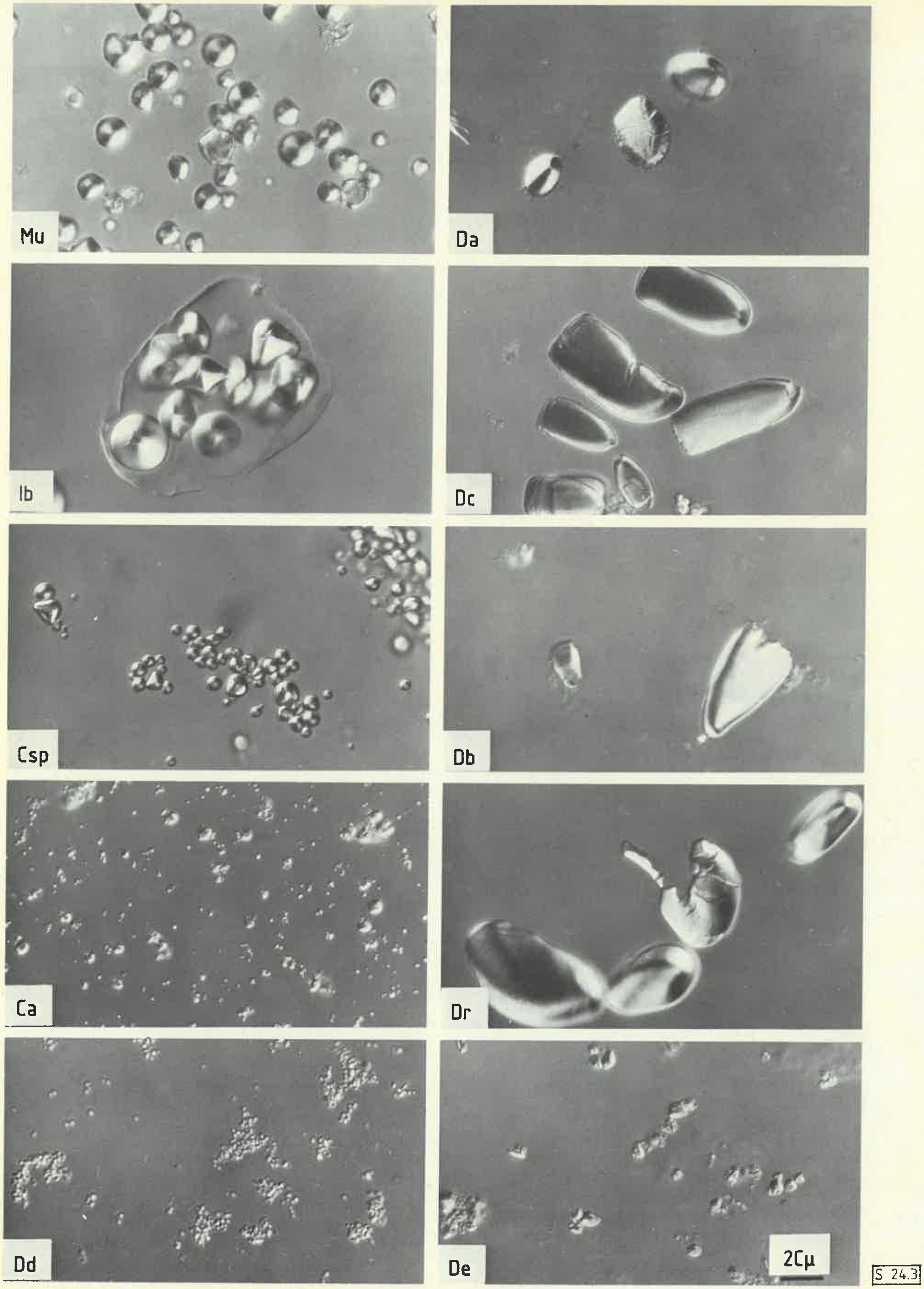

Figure 3. Tropical tuber starches observed under light microscopy (differencial interference contrast) at the same magnification after *in vitro* α-amylolysis by *Bacillus subtilis*. On the left, the A type spectrum with: *Manihot utilissima* (Mu), *Ipomea batatas* (Ib), *Coleus species* (Csp), *Colocasia antiquorum* (Ca) and *Dioscorea dumetorum* (Dd). On the right, the B type spectrum with *Dioscorea alata* (Da), *Dioscorea cayenensis* (Dc), *Dioscorea bulbifera* (Db), *Dioscorea rotundata* (Dr) and *Dioscorea esculenta* (De).

potato starch granule (even the *Canna* starch granule which is the largest, not shown) with the exception of *Dioscorea esculenta* in which starch granules are small and whose shapes are either pyramidal or tetrahedral.

2.1 Microscopy

Under the light microscopy (Fig. 3) and the SEM (Figs. 4 and 5) observations of tuber starch granules partially attacked *in vitro* by *Bacillus subtilis* α-amylase show the same pathways of degradation already described by Gallant et al. [6].

In the case of *Manihot*, *Ipomea* and *Coleus*, a preferential zone is first hydrolyzed, then endocorrosion occurs.

Dioscorea dumetorum (which is like the rice starch granule) has compound granules. During amylolysis, the amyloplastic membrane is destroyed and the resulting granule-units are dispersed. Later, as in the case of the maize starch granule, they are slowly hydrolyzed by pitting.

Hydrolysis of the other yams starch granules generally occurs by exocorrosion, the granule surface becoming very rough as already shown for the potato starch granule. But *Dioscorea esculenta* for its own part is very particular amongst the other starch granules of the B type spectrum: having very small granules, its degradation begins by preferential hydrolysis along the edges of the surface.

2.2 Hydrolysis Rates

Some of the above tuber starches in the processed form were studied by their incorporation into the diets of chickens. Yams tubers were obtained from Cameroon, the *Colocasia* tubers and Canna from Guadeloupe and they were cut in fine strips and air dried at 70 °C overnight. *Manihot* roots were prepared by an industrial process in Malawi.

The *in vitro* starch granule amylolysis carried out on the native tuber or after their incorporation in diets after mixing or after pelleting (Figs. 6a and 6b) show the very important influence of the feed manufacturing process on the integrity of the starch granule. The A type spectrum (Fig. 6a) is more sensitive than the B type spectrum (Fig. 6b). The rate of starch degradation after 4 h *in vitro* amylolysis of the respective tubers varies between 17 to 28% in the first case and only 4 to 16% in the second.

After mixing, the rate of hydrolysis goes up from 30 to 35% (A type spectrum) and only 15 to 18% (B type spectrum). After pelleting we noticed an increase in the quantity of degraded starch from 40 to 45% (A type spectrum) but only 27 to 40% for the B type spectrum. The A type spectrum is shown to be more susceptible to α-amylolysis. But concerning the native tuber starches after 4 h *in vitro* α-amylolysis, with the exception of *Canna Edulis*, feed processing causes increased physical damage to the B type spectrum tuber starches.

3 Nutritional Value of Tropical Amylaceous Feeds in Connection with the Characteristics of Their Starch

Chicken rearing experiments were carried out in order to estimate the nutritional efficiency of five tropical tubers *Manihot utilissima* (cassava) *Dioscorea dumetorum* (yam),

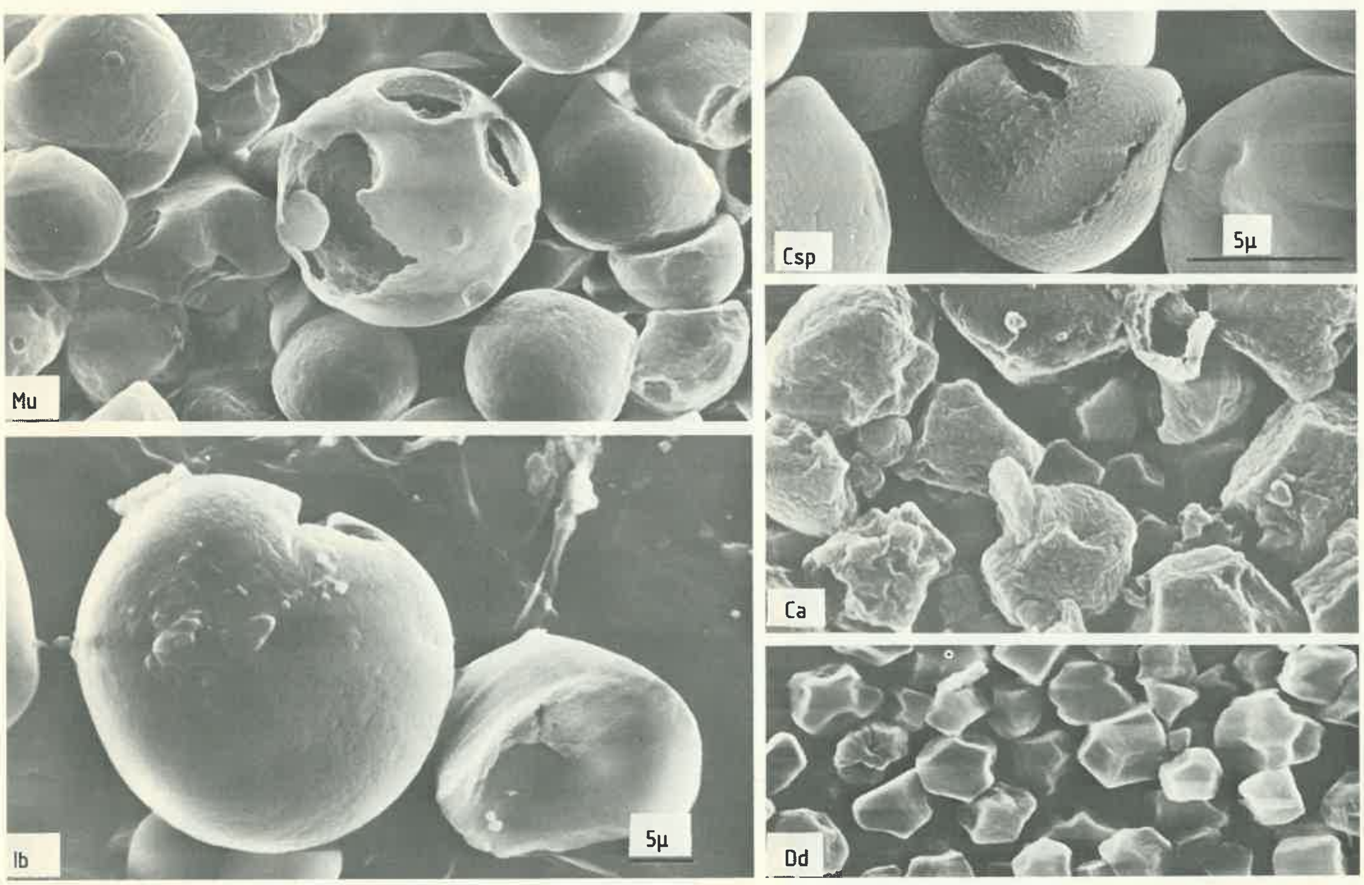

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Figure 4. Type A starch granules observed under scanning electron microscopy after *in vitro* α-amylolysis by *Bacillus subtilis*. On the left, *Manihot utilissima* (Mu) and *Ipomea batatas* (Ib) at the same magnification. On the right, *Coleus species* (Csp), *Colocasia antiquorum* (Ca) and *Dioscorea dumetorum* (Dd) at a higher magnification.

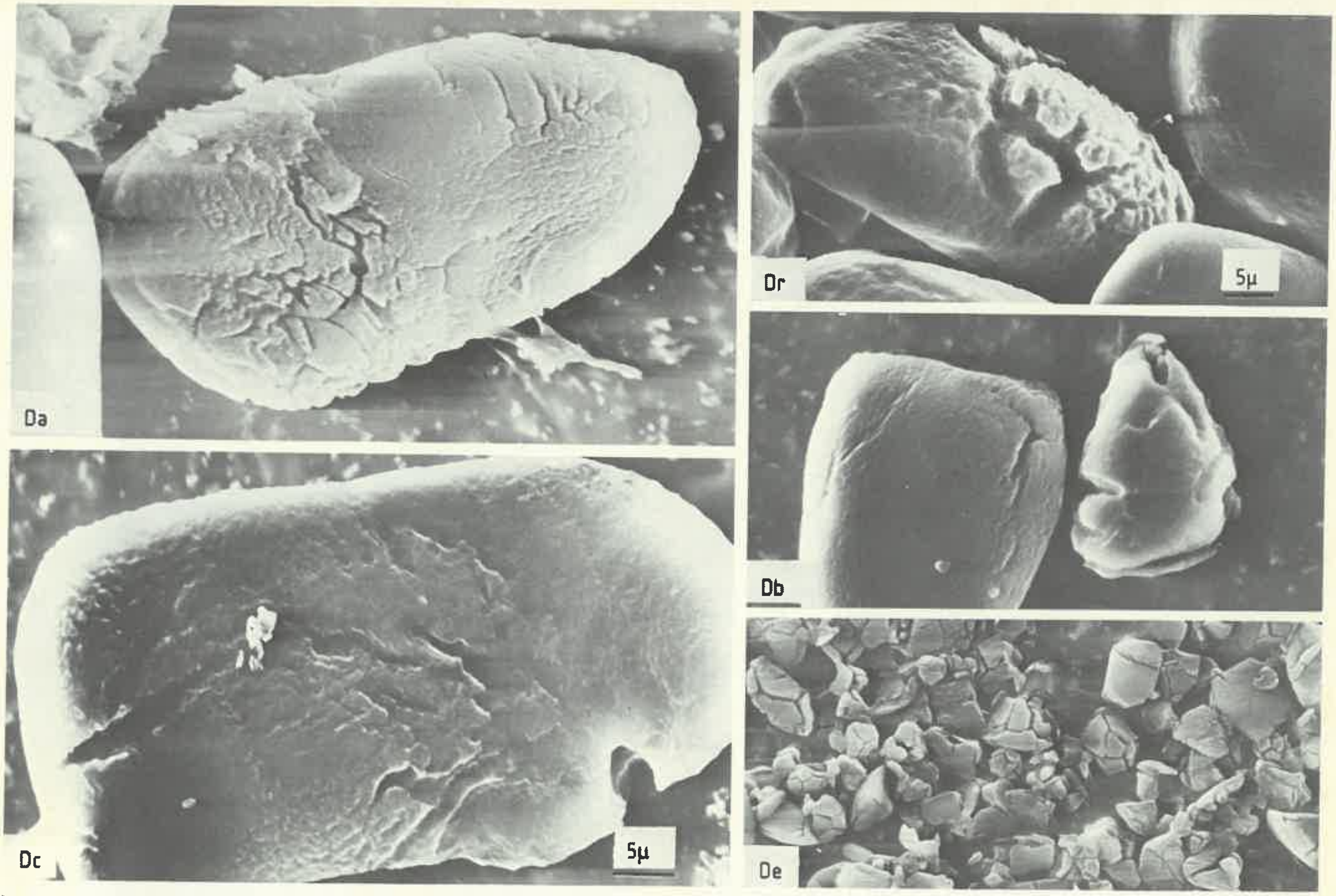

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Figure 5. Type B starch granules observed under SEM after *in vitro* α-amylolysis by *Bacillus subtilis* at the same magnification as Figure 4 (left): *Dioscorea alata* (Da), *D. cayenensis* (Dc), *D. rotundata* (Dr), *D. bulbifera* (Db) and *D. esculenta* (De).

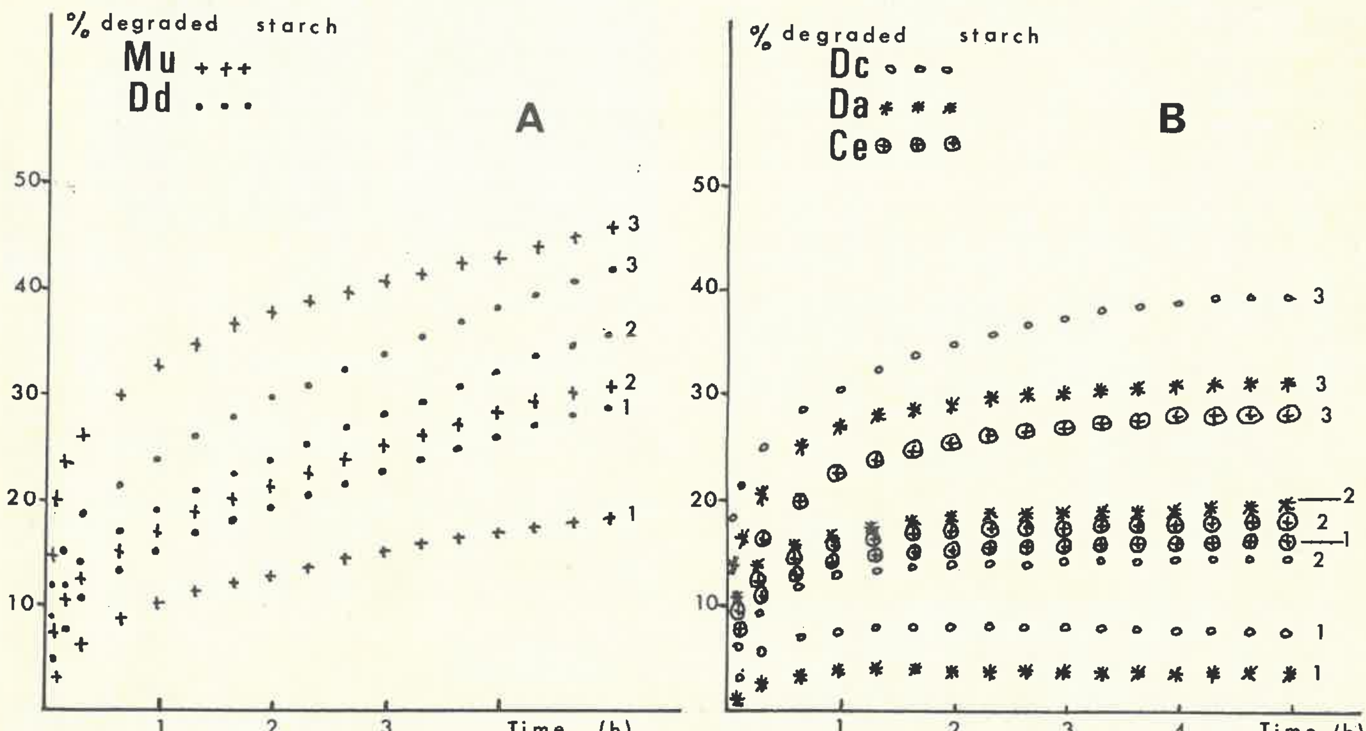

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Figure 6. (1) *In vitro* starch granule α-amylolysis carried out on the native tuber; (2) after their incorporation in diets after mixing or (3) after pelleting. On the left, (after *Bewa*, [1]), type A starches: *Manihot utilissima* (Mu) and *Dioscorea dumetorum* (Dd); on the right, (after Szylit et al., [5]), type B starches: *Dioscorea cayenensis* (Dc), *D. alata* (Da) and *Canna edulis* (Ce).

Table 3.
Growth of Chickens (Feed Efficiency, Daily Feed Intake and Digestive Balances of Starches) after *Szylit* et al. [7].

X-rays type spect.	Starches	Amylose Content (%)	Daily weight gain (g)	Daily food intake (g)	Feed conversion ratio	Starch digestibility (%)
A	*Manihot utilissima*	16.8	40.0	82.3	2.10	99.1
	Dioscorea dumetorum	13.5	36.0	83.4	2.38	97.2
	Colocasia antiquorum	8.8	37.3	99.5	2.70	–
B	*Canna edulis*	26.8	36.1	91.3	2.53	90.0
	Dioscorea alata	30.0	–	–	–	68.1
	Dioscorea cayenensis	26.7	12.4	63.6	6.64	68.6

Colocasia antiquorum (taro), *Canna edulis and Dioscorea cayenensis* according to the physio-chemical properties of their starches (*Szylit* et al., [7]). Three weeks old chickens were fed on a diet based on peanut meal and tropical tubers for 21 days. Only slight differences were observed after comparing the first four diets when average weight gain was considered, but daily food intake differed.

Results show that the nutritional efficiency was best with the *Manihot* diet whereas the poorest growth and the lowest feed intake were recorded with the *D. cayenensis* diet (Table 3). Starches with X-ray diffraction spectrum of the A type were all completely digested whereas digestibility of those of the B type was lower *e.g.* 90% for *C. edulis* and 69% for *D. cayenensis*. In the case of the latter, reduction in the level of protein utilization was observed. Similar results have already been obtained with high amylose maize starch which also has a B type X-ray diffraction spectrum (*Szylit* et al., [8]).

Influence of digestive microflora changes on A type and B type starches. Three of these tropical tubers were studied in order to determine the effects of tuber starches on urea utilization by sheet rumen microflora *in vitro*, and starch breakdown in the crop *in vivo* namely *M. utilissima*, *I. batatas* and *D. cayenensis* (*Szylit* et al., [9]). In this experiment, *M. utilissima* and *I. batatas* starches proved to be good sources of energy for rumen microbial growth. The fermentation of *I. batatas* starch in the rumen and crop led to increased acidity as compared to *M. utilissima*.

On the other hand with *D. cayenensis* starch microbial proteosynthesis in the rumen was lowest and degradation in the crop was slower than with A type starches. The influence of microflora on the utilization of starches according to their X-ray spectrum *i.e.* A or B was studied by balances and carcass analysis using isolated axenic and/or holoxenic chickens (*Bewa* et al., [10]). In this experiment 5 tuber starches were used *M. utilissima* and *D. dumetorum* (A type); *D. cayenensis*, *D. alata* and *C. edulis* (B type).

Microflora decreased feed intake with starches of the A type. Dry matter intake, weight gain and nutritional efficiency values decreased by 25%, 35% and 15% respectively.

No changes were observed with B type starches except in the case of *D. cayenensis*.

Figures 7 and 8 (left) show respectively *Dioscorea dumetorum* and *Manihot utilissima* starch granules from axenic crop and feces. In the crop, hydrolysis is poor, while in the feces hydrolysis is severe especially with the small units of the compound starch granules of *Dioscorea dumetorum* which are almost completely digested. In holoxenic chickens (Figs. 7 and 8, right) the starch granules are more severely attacked in the crop. Starch granules are completely hydrolyzed in the duodenum and only very small residues are found in the feces.

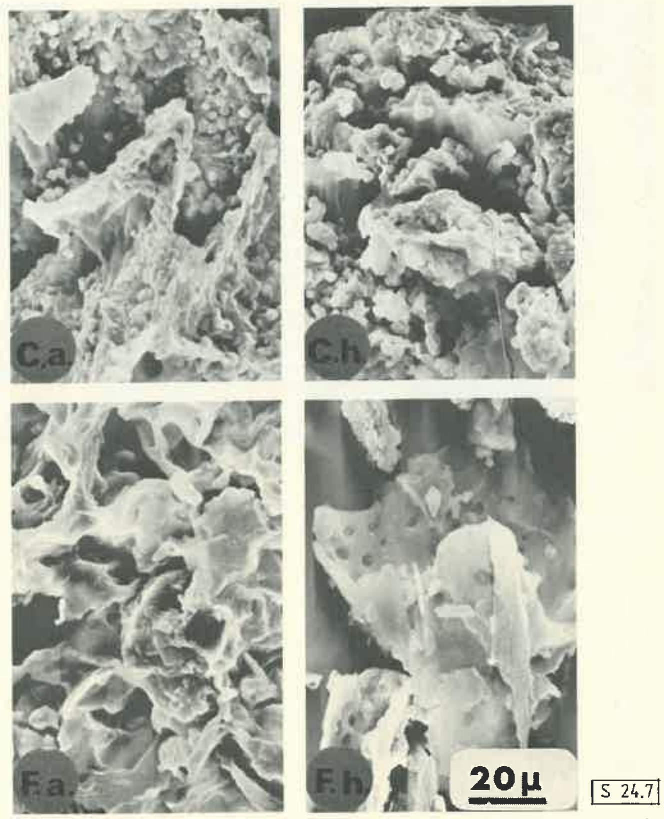

Figure 7. SEM of *Dioscorea dumetorum*. On the left, from axenic chicken and on the right, from holoxenic chicken. Above, starch granules from the crop; below, the feces content.

In the case of *Dioscorea dumetorum* secondary cell walls resistant to attack remain.

SEM examinations (Figs. 9 and 10) of *Dioscorea alata* and *Canna edulis* show less pronounced degradation. Entire starch granules are still found in the feces of the axenic and the holoxenic chickens but these granules are less attacked in the case of *Dioscorea alata*. This corresponds to the starch digestibility which is 90% with *Canna edulis* showing many fissures and only around 70% in the other samples studied.

4 Conclusion

Some tropical tubers can be digested without cooking. *Manihot* and *Ipomea* starches have been very well studied before the present work. We have shown here that other tropical tubers are economicaly interesting for feed manufacture and that they have good nutritional value.

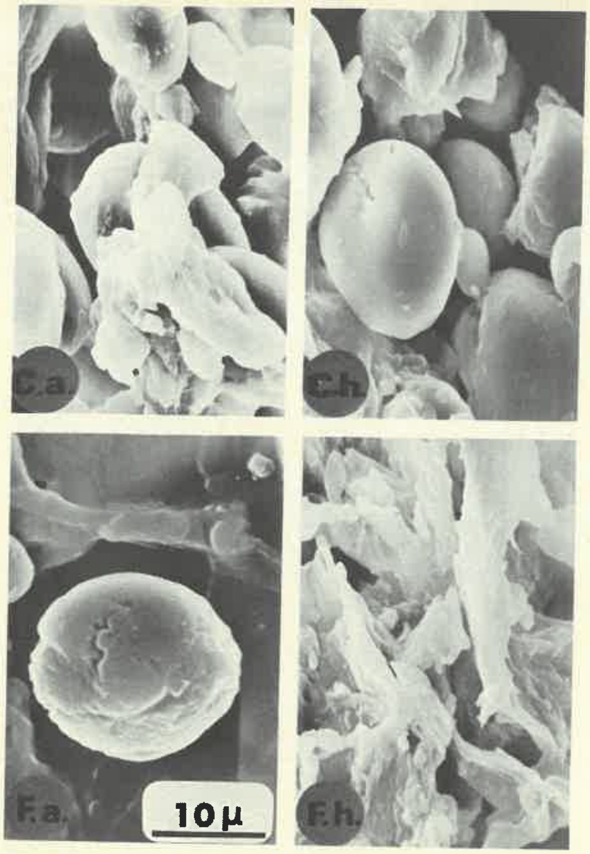

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Figure 8. SEM of *Manihot utilissima*, same as in Figure 7.

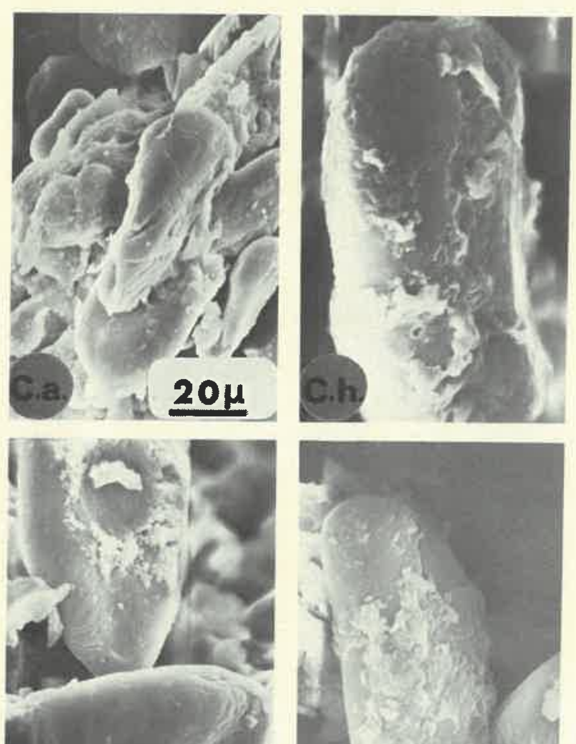

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Figure 9. SEM of *Dioscorea alata*, same as in Figure 7.

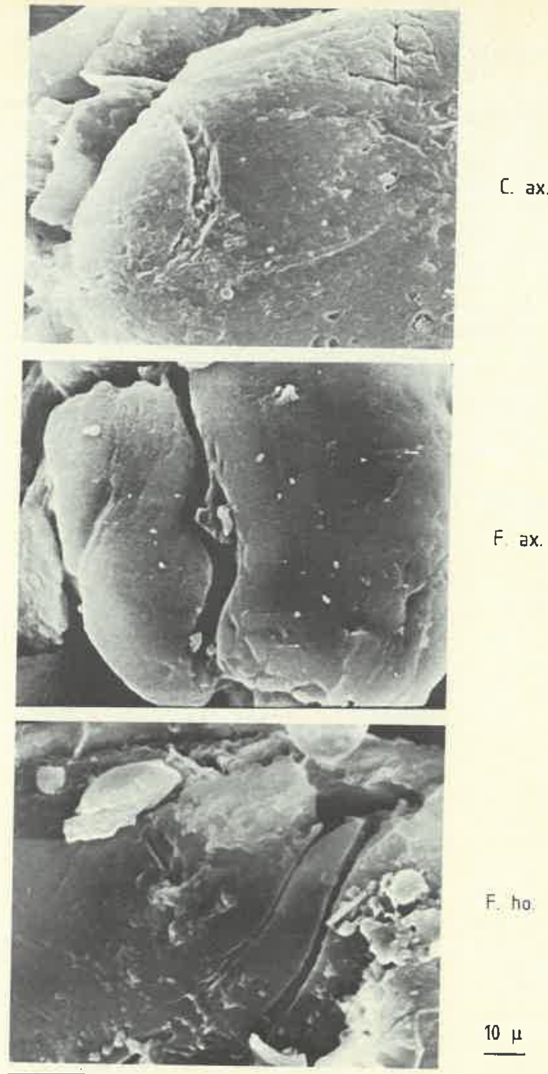

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Figure 10. SEM of *Canna edulis*. On the uppermost picture, starch granule surface from the crop of an axenic chicken; middle: starch granule surface from the feces of an axenic chicken; the bottom picture shows a starch granule surface from the feces of a holoxenic chicken.

None of the physico-chemical or enzymatic parameters studied can be used as the sole criterion for estimating the nutritional value of a given starch. However, small diameter, a low amylose content and a X-ray diffraction spectrum of the A type are all favourable factors contributing to a good apparent digestibility of starch granules. In addition, it appears that feed efficiency of a tuber starch is more especially related to the rate of the *in vitro* amylolysis of starch.
It should be interesting to study in greater details the behaviour of *Dioscorea esculenta*, type B spectrum, morphologicaly similar to the type A starch granules and very susceptible to the α-amylase amylolysis. Nutritional experiments would show if the use of such a tuber starch, very particular amongst the numerous varieties of starchy tuber plants could be of real interest in the breeding of the chicken.

Summary

In the present paper type A starches (*Manihot utilissima*, *Dioscorea dumetorum* and *Colocasia antiquorum*) and the type B starches (*Canna edulis*, *Dioscorea alata* and *Dioscorea cayenensis*) are investigated.

Results show that the rate of degradation of the pure tuber starch as compared with that of feeds made from a particular starch is more or less the same. However, type A starches are more rapidly degraded by bacterial α-amylase. The susceptibility to attack is compared to the nutritional efficiency of the feeds using axenic and holoxenic chickens. Comparison of the degree of degradation of the starch granule in the crop as well as in the feces (by *in vitro* and *in vivo* studies) is made by scanning electron microscopy.

Observations show that type A starches are always highly susceptible to α-amylase attack. In the case of type B starches, the degree of hydrolysis is always lower but starch granules are generally large, much bigger than type A. The feed efficiency tested on chicken and digestibility of tuber starches in the sheep rumen and in the chicken crop increase as their ease of degradation by bacterial α-amylase (*in vitro*) increases.

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