Nutritional Repercussions of the Differences in Physicochemical Characteristics of Starches of Two Yam Species Grown in Cameroon[1]

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Abstract

Some physicochemical characteristics of the starches of *Dioscorea dumetorum* and *D. rotundata* were studied. Their X-ray diffraction spectra are of A-type and B-type, respectively. However, with regard to swelling and solubility patterns and to rates of solubilization in dimethylsulfoxide, their behaviors differed from the classical behaviors of starches of the same X-ray diffraction type. They differed from each other in their pH value, granule size and in their susceptibility to bacterial alpha-amylase.

When these two yam species were incorporated in pellet diets, their starch granules were seriously damaged. Thus, there was no significant difference in their susceptibilities to enzymatic attack, either *in vitro* or *in vivo* in the rooster crop. Nevertheless, starch digestibility and nitrogen retention in adult roosters were significantly greater with the *D. dumetorum* diet.

This last result if checked in traditional human feeding could lead to recommend *D. dumetorum* consumption in the most vulnerable groups of yam eating population.

Introduction

Most of the studies on the nutritional utilization of yams have involved *D. cayenensis, D. rotundata* and undefined species. Fetuga and Oluyemi (1976) substituted *D. rotundata* tubers to 40 and 25% glucose in a reference chicken diet and observed an unfavorable effect of yams on animal growth. Working on chicks, Atinkpahoun (1972) found that feed efficiency, starch digestibility and nitrogen retention were all lower with a *D. cayenensis* based diet than with cassava or sweet potato based diets. The same effects were observed in rats by Cerning-Beroard and Le Dividich (1976) with a diet containing an undefined yam species in comparison to a sweet potato or corn-based diet. Szylit *et al* (1978) showed that sweet potato and cassava starches were more effective than *D. cayenensis* starch for promoting proteosynthesis *in vitro* by sheep rumen microflora.

Only Bewa (1978) and Szylit *et al* (1977) demonstrated differences in nutritional utilization related to the species of yam considered. Thus, structural differences of *D. dumetorum* and *D. cayenensis* starches led to differences in the growth of chickens and in the feed efficiency of diets to which they were incorporated.

Yams is a staple food for a large sector of the population in West Africa (Coursey, 1965, 1967). The yams found in Cameroon are primarily cultivars of *D. dumetorum* and of *D. cayenensis-D. rotundata* complex (Dumont, 1977). These species, especially *D. dumetorum,* have high tuber yield and relatively elevated protein content (Treche

and Guion, 1979a).

Delpeuch *et al* (1978), Szylit *et al* (1977) and Robin (1976) have shown that the *D. dumetorum* starch has an apparent amulose content of 9-13% with an X-ray diffraction spectrum of the A-type while the *R. rotundata* starch has an apparent amylose content of 21-27% with an X-ray diffraction spectrum of the B-type. In addition, the starch granules of *D. dumetorum* are small polygons, while those of *D. rotundata* are much longer and ovoid (Delpeuch *et al*, 1978; Seidemann, 1964; Rasper, 1971; Rasper and Coursey, 1967).

Using a local cultivar of each of these two species, we have extended existing results on the physicochemical properties of their starches. We have also studied their degradation *in vivo* in the rooster crop and have measured their digestibility and their influence on the retention of other dietary components, attempting to verify the results obtained by Bewa (1978) and Szylit *et al* (1977) with some experimental variants.

Materials and Methods

Tubers. Tubers of *D. dumetorum* (Cultivar Ex Jakiri) and *D. rotundata* (Cultivar Ex Oshei) were cultivated in western Cameroon. They were obtained in several harvests less than one month before and after maturity, were stored between 3 and 30 days before being peeled and dried *in vacuo* at a temperature less than 60°C.

Chemical analysis. The chemical composition was determined on the ground tubers:

a. Dry matter, ash and crude protein determinations were carried out by the conventional methods.
b. Lipid content was determined by Soxhlet extraction with petroleum ether.
c. Undigestible carbohydrates were estimated by the formic acid technique of Guillemet and Jacquot (1943).
d. Hemicelluloses and lignocellulose contents were determined by the procedures of Van Soest and Wine (1967) and Van Soest (1963).
e. Alcohol soluble (M.W. $< 2,000$) and water soluble (M. W. $> 2,000$) sugars were determined colorimetrically by the anthrone method (Loewus, 1952) after extraction with 80% and 40% ethanol (two hot extractions and one cold extraction).
f. Starch content of the alcohol extraction residue was determined by the glucoamylase method (Thivend *et al* 1965).
g. Glucose, fructose and sucrose contents in the 80% ethanol extract were determined as proposed by Johnson *et al* (1964) and modified by Cerning (1970).

Determination of starch characteristics

a. Starch extraction. dried tubers were grounds in 0.01 M $HgCl_2$. The suspension was then purified as described by Delpeuch *et al.* (1978) and dried at a temperature less than 45°C. The dry materials was then gently disrupted and passed through a 0.25 mm mesh sieve.
b. The size and shape of starch granules were determined by light microscope using an objective micrometer and ocular graduated in micrometers.
c. Starch density was estimated using a pycnometer as proposed by Schoch and Leach (1964)
d. The absorption spectrum of starch-iodine complexes was determined as described by Bailey and Whelan (1969) and modified by Cerning (1976).

f. Swelling power and solubility were determined at temperatures ranging from 60°C to 95°C, with 5°C intervals as described by Leach *et al* (1959) and modified by Mercier (1968).
The solubility in dimethylsulfoxide was measured as Leach and Schoch (1962), using a solvent containing less than 0.5% water.

g. Susceptibility to bacterial alpha-amylase was estimated by the method of Tollier and Guilbot (1971). The formation of ethanol soluble sugar was measured by the anthrone method of Loewus (1952).

Composition and characterization of diets. The composition of the experimental diets (Table 1) was calculated to supply an equilibrated content of energy and crude protein. Protein supplementation was with fish meal. Thus, digestible carbohydrates in the diets were furnished exclusively by the yams. Celite was incorporated as tracer.

The chemical composition of the diets was determined using the same methods described above for tubers.

The feeds were pelleted through 2.5 mm-dia.

The extent of starch damage in the feeds after pelleting was estimated enzymatically:

a. Beta-amylase hydrolysis, with no prior gelatinization, were carried out as described by Mercier and Guilbot (1974). The quantities of water soluble sugar present before and after enzymatic hydrolysis were taken into account. Hydrolysis was limited to 5 hours, as recommended by Tollier (1965), in order to reduce the risk of bacterial contamination.

b. Alpha-amylase degradation kinetics were determined *in vitro* with the method of Tollier and Guilbot (1971). Alcohol and water soluble sugar formed, extracted with cold 80% and 40% ethanol, were distinguished.

Experimental protocol. Crop fistulation had been performed on four mature roosters (3.5 kg) as described by Ivorec-Szylit (1971). After healing, they were placed in individual cages and accustomed to ingesting 100 g of pelleted feed per day; the animals consumed the entire ration within one hour. Water was offered to the birds *ad libitum*.

Each rooster underwent four experimental periods during which the two diets were alternated. Each period was composed of four days of adaptation to the diet, three days of collection of droppings and four days during which crop content was collected each day 1.5, 3, 4.5 and 7.5 hours after the beginning of the meal.

Digestion in the crop. Crop contents were aspirated with a vacuum pump. The pH value and dry matter content were determined before freezing, drying in a vacuum oven and grinding.

Alcohol and water soluble sugar and starch were determined as performed for tubers and were compared to the corresponding levels in the feeds. Experimental results were subjected to an analysis of variance and comparisons between means were made by calculation of the least significant difference (L.S.D.).

Qualitative analysis of low molecular weight carbohydrates in 80% ethanol extracts were carried out by thin layer chromatography on silica gel plates. The solvent system was aniline acetate-isopropanol-water (10 : 6 : 3, v/v). Spots were developed as described by De Stephanis and Ponte (1968).

Glucose, fructose and sucrose contents were assayed as described by Johnson *et al* (1964).

Balance studies. Droppings were collected twice daily and were frozen. Retention of the different constituents of the diets were calculated as described by MacCarthy *et al* (1974) for pigs and used by Trade (1975) for chickens. Celite, used as tracer, was assayed in the HCl Insoluble Ash, determined by solubilization of ash in 4 N HCl and calcination at 650°C.

Assays of the various components studied were as described for tubers. Statistical comparison between means were made using paired t-test.

Results

Chemical composition of tubers and diets. The complete chemical composition of the yam tubers and the diets is given in Table 2. *D. dumetorum* tubers have primarily higher crude protein, hemicelluloses, lignocellulose and water soluble sugar contents and a lower starch content than *D. rotundata* tubers. Among the alcohol soluble sugars, the proportion of fructose and glucose is greater in the *D. dumetorum* tubers than in the *D. rotundata* tubers.

There was no difference in the crude protein content of the two diets. However, differences remain in the composition of the carbohydrate fraction.

Physicochemical properties of starches.

Extracted starches. Data on granule size, pH value and density of the starches of the two yam species are given in Table 3. *D. dumetorum* starch granule is quite much smaller than *D. rotundata* starch granule. The pH value of *D. dumetorum* starch is particularly low.

The absorption spectra of the two starch-iodine complexes are relatively similar (Fig. 1). The wavelength of peak absorption (λ max) of the *D. dumetorum* complex (623 nm) is slightly higher than that of the *D. rotundata.* According to the relationship established by Lee (1967); the mean length of linear chains and of external portions of ramified chains differ by only 4-5 anhydroglucopyranose units between the two starches.

Swelling and solubility patterns are not the same for the two starches (Figs. 2, 3). *D. rotundata* starch is slightly soluble and has a two-stage swelling pattern while *D. dumetorum* starch exhibits greater and simultaneous swelling and solubility.

In dimethylsulfoxide, *D. rotundata* starch granules have a progressive sulubilization while *D. dumetorum* starch granules undergo a two-stage dissolution which is less complete after 48 hours shaking (Fig. 4).

Various parameters of the kinetics of alpha-amylase degradation (Fig. 5) were calculated (Table 4). *D. dumetorum* starch is more susceptible to enzymatic attack than *D. rotundata* starch throughout the entire period of hydrolysis.

Starch in diets. The effect of pelleting of the starch in the diets appears in the results of enzymatic hydrolysis:

a. Beta-amylase hydrolysis. After 5 hours, 17.4% of *D. dumetorum* starch and 17.5% of *D. rotundata* starch are degraded, corresponding to 29.0% and 29.2% damaged starch, respectively.

b. Alpha-amylase hydrolysis. Comparing the alpha-amylase degradation kinetics (Fig. 6) of diet starches and whole tuber starches, it was found that the easily hydrolyzable fractions are strongly increased during feed preparation. The final rates of hydrolysis could not be calculated precisely and did not permit the two diet starches to be compared.

Changes in the quantities of water soluble sugar during hydrolysis have been measured (Fig. 7). It can be seen in all four samples that after a strong increase, proportional to the value of the easily hydrolyzable fraction of the starches, there is stabilization when the hydrolysis is performed on *D. dumetorum* tuber diet. There is a considerable decrease during hydrolysis of *D. rotundata* starch in tubers and diet.

Digestion in the rooster crop. For both diets, the pH value of crop contents decreases significantly with increasing transit times (Table 5).

The dry matter levels of crop contents (Table 6) decrease primarily during the first 90 minutes after the beginning of the meal. Thereafter, increasing moisture of the crop contents, although significant, is subsequently lower. It appears that roosters drink more when the *D. rotundata* diet is given.

a. Quantitative and qualitative evolutions of alcohol soluble sugars.

Regardless of the diet, the alcohol soluble sugar levels of the crop contents increase during the first 1.5 hour after the beginning of the meal and then decrease regularly until the seventh hour after feeding (Fig. 8).

Qualitatively, the oligosaccharide composition of the alcohol soluble carbohydrate fraction changes during digestion in the crop (Table 7). In diets, as well as in tubers, one can note a predominance of sucrose and fructose. Their levels decrease strongly in the crop simultaneously with the appearance of degradation products of starch and water soluble sugars. Among these degradation products, thin layer chromatography shows considerable quantities of maltose and maltotriose.

b. Evolution of the levels of the different components of the digestible carbohydrate fraction.

For each crop content, the levels of starch, starch + water soluble sugar and total digestible carbohydrates were calculated as percentages of the respective values in diets in order to appreciate the changes appearing in the crop (Figs. 9-11).

Decreases in starch content are primarily important during the first 90 minutes after the beginning of the meal. They are not significant at later times and do not differ between the two diets.

However, decreases in starch plus water soluble sugar content and in total digestible carbohydrate content are significantly stronger with the *D. dumetorum* diet, and for both diets, continue beyond the first 90 minutes after the beginning of the meal.

Diet constituents balance results. The retention of the different constituents of the diets are given in Table 8.

Except lipids, the retention of all components are significantly higher with the *D. dumetorum* diet. Differences in starch digestibility and nitrogen retention are relatively the most important.

Discussion and Conclusion

The technique used for separating water soluble sugars from starch, lead to the appearance of a considerable dextrin fraction in *D. dumetorum* tubers. This fraction increases in both diets after pelleting.

The chemical composition of tubers is in accordance with previous works (Ketiku and Oyenuga, 1973; Treche and Guion, 1979a, 1979b).

Cell wall constituent content of *D. dumetorum* is higher than that of *D. rotundata* tubers. This is due to the phenomenon of hardening undergone by stored *D. dumetorum* tubers (Treche and Delpeuch, 1978a, 1978b).

The thick cell wall which appears during hardening makes impossible the human consumption of long stored unprocessed *D. dumetorum* tubers. However, with regards to their crude protein content and to their stronger tuber yield, freshly harvested *D. dumetorum* tubers have greater nutritional potentialities than *D. rotundata* tubers.

Our results concerning granule size, pH value and density agree with those of Rasper and Coursey (1967) and Rasper (1969a, 1971). The low pH value of *D. dumetorum* starch is probably due to an incomplete removal of the impurities as suggested by Rasper and Coursey (1967).

Swelling power and solubility patterns differ from those registered by Rasper (1969b) who worked on ghanaian cultivars. They agree with those of Delpeuch *et al* (1978), except for the *D. dumetorum* starch solubility pattern.

The rates of solubilization in dimethylsulfoxide do not confirm the interpretation of starch granule solubility curves proposed by Leach and Schoch (1962). These authors consider that starches with X-ray diffraction spectrum of the A-type dissolve more than those of the B-type. Our results do, however, agree with those obtained by Rosenthal *et al* (1962) who observed that B-type starch granules of *D. alata* and *D. cinnamomifolia* were able to dissolve rapidly.

The present data concerning various physicochemical characteristics of the starches of the two species of yams show that the correlations usually found are not verified. *D. dumetorum* starch granules have an X-ray diffraction spectrum of the A-type and are easily hydrolyzed by alpha-amylase, but their solubility in dimethylsulfoxide is low and their swelling power is relatively important. *D. rotundata* starch granules characterized by an X-ray diffraction pattern of the B-type, are less susceptible to alpha amylase *in vitro,* but they are relatively soluble in dimethylsulfoxide and they undergo a two-stage swelling, indicating (Leach *et al* 1959; Guilbot, 1961) two sets of bonding forces which relax at different temperatures.

In pelleted diet starches, there is a considerable increase of the easily hydrolyzable fraction. The differences of susceptibility to enzymatic attack which exist among tuber starches are no longer evident. Nevertheless, the decrease in quantities of water soluble sugar, measured at the end of *D. rotundata* diet starch hydrolysis, apparently indicates that the residual starch of this yam species is more resistant to enzymatic attack.

Experiments with rooster crops *in vivo* showed that degradation of the two diets was different. This difference involved the entire digestible carbohydrate fraction but was not significant when only starch was examined.

The appearance of degradation products of glucose-containing polymer in the alcohol soluble carbohydrate fraction, as well as the quantitative evolution of this fraction, agree with the results of Szylit (1973): digestion in the crop involves the progressive degradation of a portion of starch and eventually dextrins into glucose; then, glucose is absorbed through the crop wall after its transformation into lactic acid by microbial flora.

We may suggest several explanations for both the low rates of degradation measured compared to those observed by Atinkpahoun (1972) with tubers or by Szylit (1973) with cereals, and the absence of any difference between the quantity of starch degraded as a function of the yam species:

– the presence of a large proportion of water soluble sugar which were presently extracted with hot 40% ethanol and are normally assayed at the same time as starch with usual analytical methods;

– the presence of non-eligible quantities of glucose in feeds, which according to Ivorec-Szylit et al (1965) could inhibit microbial degradation of starch;

– the pH value of diets which is lower than optimal pH values for the action of salivary enzymes (pH 6.5) and for the proliferation of lacto-bacilli (pH 6.1-6.4) (Szylit, 1975).

The calculation of retention coefficients, which take into account all digestive processes (action of salivary and microbial amylases in crop, action of pancreatic amylase in the duodenal loop, eventual action of other microbial amylases in the caeca) and metabolic processes, shows that *D. dumetorum* starch is more digestible and has a positive effect on nitrogen retention. These results confirm those of Bewa (1978) and of Szylit *et al* (1977).

It thus seems that the portions of starch granules of both species which are not damaged by the pelleting process, still present differences in enzymatic susceptibility which result *in vivo* in a greater digestibility of *D. dumetorum* starch.

The effect on nitrogen retention might be explained by a more rapid digestive utilization of carbohydrates, which would spare amino acids by rapidly supplying energy to sites of protein synthesis (Spivey *et al* 1958). In chickens, it is also possible that slightly digestible starches may induce a bacterial development in the caeca, thus resulting in an increased excretion of endogenous fecal nitrogen.

The nutritional utilization of foodstuffs thus appears to be closely dependent on the susceptibility of their starch to enzymatic attack. According to Robin (1976), this susceptibility would not depend directly on the A or B crystalline structure of the amorphous fraction surrounding the starch crystallites; this would be related to the amylose content and the higher cohesion of this fraction. The resistance of starch to enzymatic attack could also be due to the protection of granules by an external undefined zone which would present a differentiated resistance to enzyme penetration (Guilbot and Mercier, 1962).

In fact, the true problem is to determine if the traditional technological treatments used to prepare yams for human consumption are sufficiently drastic to suppress the differences in digestibility existing among starches with different physicochemical characteristics. By cooking only, Aumaitre *et al* (1969) could not completely suppress the differences in apparent digestiblity of organic material and crude protein observed in pigs between sweet potatoes and plantain bananas. Langworthy and Deuel (1922) found undigested starch in the feces of humans having ingested certain types of tubers. In addition, certain food technology treatments of yams may lead to differences (viscosity, consistency of gels), which were not considered here with crude starches (Rasper, 1969a).

Finally, according to eventual effects on energy and nitrogen retention, the differences observed among yams and more generally among tropical tubers in the physicochemical properties of starches could be used to recommend particular starchy staple food for human consumption. This would be particularly important for population groups which are especially vulnerable, such as children at the moment of weaning.

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Table 1. Composition (%) of the experiment diet

	D. dumetorum diet	*D. rotundata* diet
Yam tuber	77.2	72.4
Fish meal	15.9	19.3
Corn oil	4.0	4.0
Cellulose	1.4	2.8
Mineral supplement	0.7	0.7
Vitamin supplement	0.3	0.3
Celite 545	0.5	0.5

Table 2. Chemical composition of yam tubers and corresponding diets, as g/100 g dry matter

	TUBERS		DIETS	
	D. dumetorum	*D. rotundata*	*D. dumetorum*	*D. rotundata*
Crude protein (Nx 6.25)	8.2	5.8	17.5	18.0
Ash	3.1	2.3	5.7	5.5
Ether extract	0.35	0.18	7.1	6.8
Starch	59.4	78.1	41.0	53.5
Water soluble sugars	10.5	2.6	12.1	5.0
Alcohol soluble sugars	3.6	3.3	2.0	1.8
Fructose	1.17	0.49	1.05	0.48
Sucrose	1.53	2.07	0.73	1.29
Glucose	0.22	0.02	0.26	0.16
Hemicelluloses	4.3	3.6	0.9	1.5
Lignocellulose	6.9	2.2	9.5	5.7
Formic Insoluble	5.3	1.6	7.5	4.2
HCl Insoluble Ash	–	–	0.576	0.631

Table 3. Characteristics of the starch extracted from the yam tubers

	D. dumetorum	*D. rotundata*
Starch content (% dry matter)	96.9	98.9
Granule size		
Mean for 100 granules (mm)	2.8	22.3x39.4
Range (m)	1 – 5	(14x18) – (32x52)
pH value	4.61	6.49
Density	1.566	1.594

Table 4. Parameters of alpha-amylase hydrolysis of the two extracted starches

	D. dumetorum	*D. rotundata*
Initial rate 1/	3.05	1.33
Final rate 2/	2.52	0.35
Easily hydrolyzable fraction 3/	5.27	1.57

1/% of starch hydrolyzed during the first 5 minutes.

2/% of starch hydrolyzed during one hour of the linear phase.

3/Extrapolation to time 0 of the linear phase.

Table 5. pH values of diets and crop contents at various times after the beginning of the meal

	D. dumetorum	*D. rotundata*
In diet	5.68	5.92
In crop after : 1.5 h [1/]	5.65 ± 0.03^{a}	5.84 ± 0.03^{a}
3 h	5.40 ± 0.04^{b}	5.57 ± 0.07^{b}
4.5 h	5.18 ± 0.12^{c}	5.11 ± 0.11^{c}
7.5 h	4.82 ± 0.09^{d}	4.52 ± 0.04^{d}

[1/] Mean values of 8 determinations with their standard errors.

In a given column, means with no common superscript are significantly different ($P < 0.05$).

Table 6. Dry matter levels in the diets and in the crop contents at various times after the beginning of the meal

	D. dumetorum	*D. rotundata*
In diet	92	91
In crop after : 1.5 h [1/]	47.7 ± 4.2^{a}	37.0 ± 2.4^{a}
3 h	43.0 ± 3.0^{ab}	34.5 ± 3.5^{a}
4.5 h	39.1 ± 3.2^{bc}	28.8 ± 1.9^{b}
7.5 h	37.0 ± 2.6^{c}	26.8 ± 2.3^{b}

[1/] Mean values of 8 determinations with their standard errors.

In a given column, means with no common superscript are significantly different ($P < 0.05$)

Table 7. Changes in the composition of alcohol soluble carbohydrate fraction in rooster crop at various times after the beginning of the meal

		D. dumetorum diet				
		0 h	1.5 h	3 h	4.5 h	7.5 h
Alcohol soluble sugars	(1)	2.03	3.21	2.91	2.56	1.79
Sucrose	(1)	0.77	0.44	0.08	0.00	0.00
	(2)	38	14	3	0	0
Fructose	(1)	1.05	1.04	1.00	0.72	0.43
	(2)	52	.32	34	28	24
Glucose	(1)	0.26	0.35	0.34	0.22	0.17
	(2)	13	11	12	9	9
Degradation products	(1)	0.00	1.38	1.49	1.62	1.19
	(2)	0	43	51	63	67
		D. rotundata diet				
		0 h	1.5 h	3 h	4.5 h	7.5 h
Alcohol soluble sugars	(1)	1.82	3.50	3.42	3.00	2.05
Sucrose	(1)	1.36	0.63	0.09	0.00	0.00
	(2)	75	18	3	0	0
Fructose	(1)	0.48	0.57	0.74	0.39	0.15
	(2)	26	16	22	13	7
Glucose	(1)	0.16	0.24	0.28	0.24	0.17
	(2)	9	7	8	8	8
Degradation products	(1)	0.00	2.06	2.31	2.37	1.73
	(2)	0	59	67	79	85

(1) g of the considered sugar expressed as g glucose/100 g dry matter.

(2) as percentages of total alcohol soluble sugars.

Table 8. Retention (% intake) of the different constituents of the diets

	D. dumetorum diet	*D. rotundata* diet	Level of significance
Dry matter	76.4± 0.5	66.4± 0.5	P 0.001
Organic material	79.7± 0.5	69.3± 0.5	P 0.001
Ash	21.2± 2.6	17.3± 2.2	P 0.05
Lipids	90.0± 1 1	89.0± 1.4	N. S.
Formic Insoluble	11.0± 1 i	1.4± 0.6	I 0.001
Nitrogen	39.4± .4	28.5± 2.8	P 0.001
Starch 1 1/	99.6± 0.2	82.4± 1.0	P 0.001
Digestible carbohydrates	99.1± 0.2	79.8± 1.0	P 0.001

1/ Starch retention may be assimilated to starch digestibility.

Values are means of 8 determinatior ± their standard error.

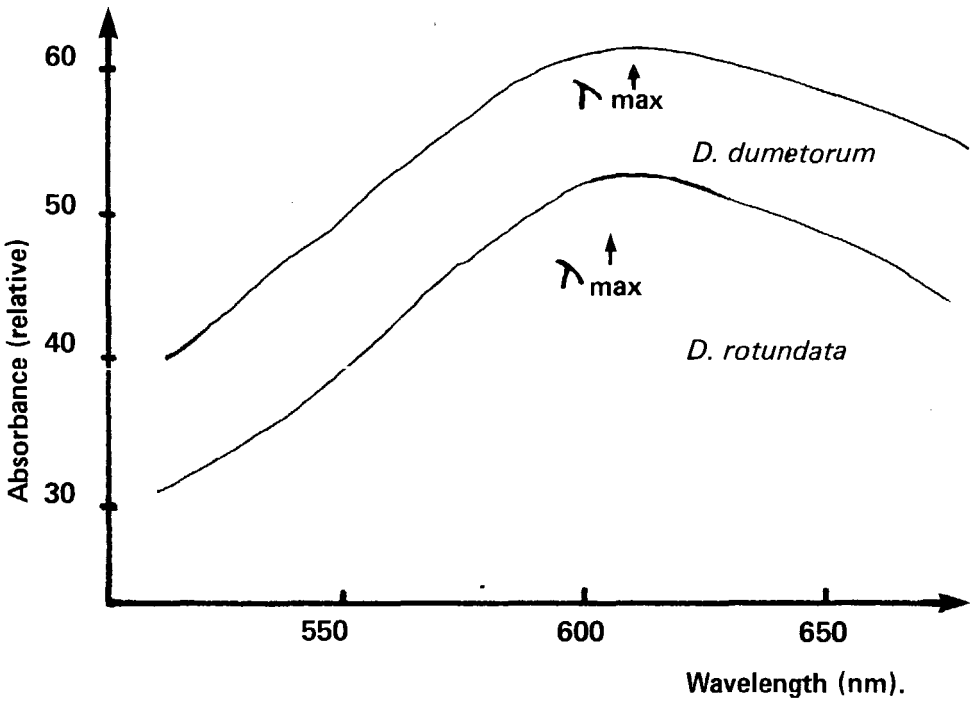

Fig. 1. Absorption spectra of starch-iodine complexes

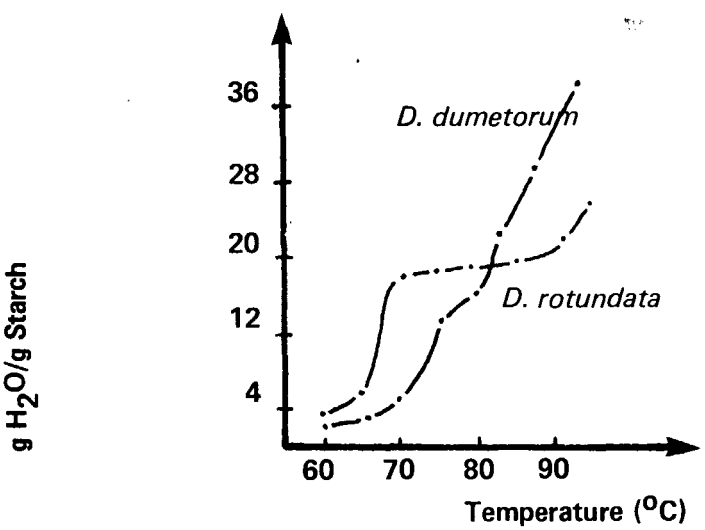

Fig. 2. Swelling of extracted starch

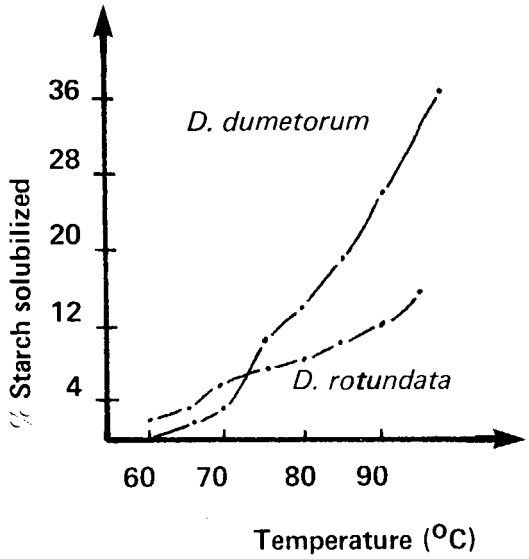

Fig. 3. Solubility of extracted starch

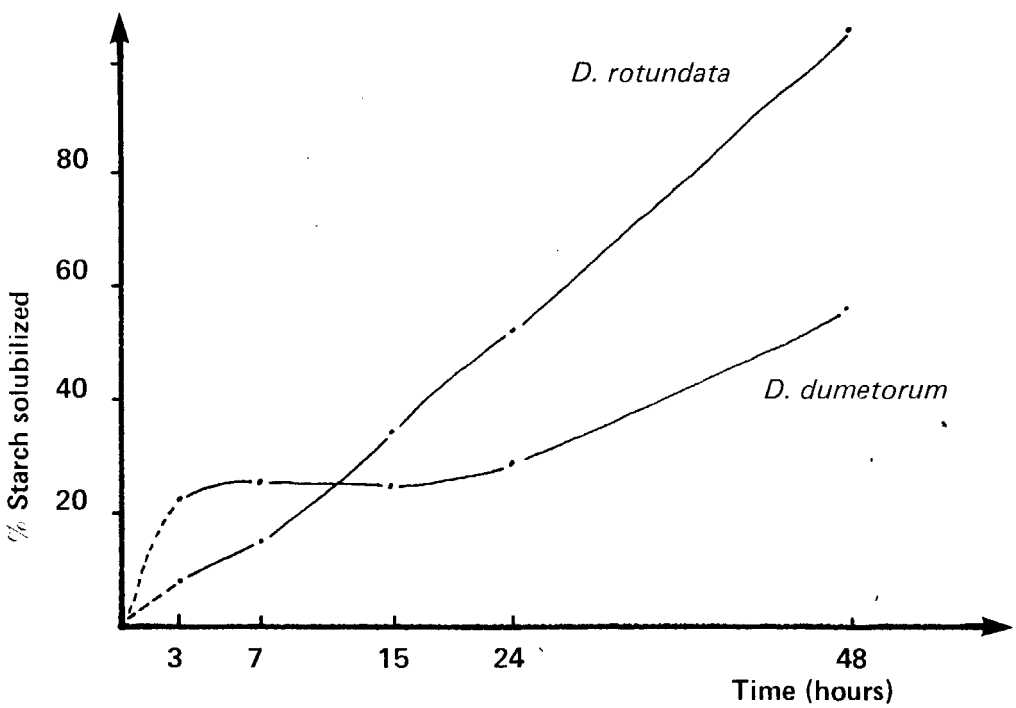

Fig. 4. Solubilities of starch granules in dimethysulfoxide

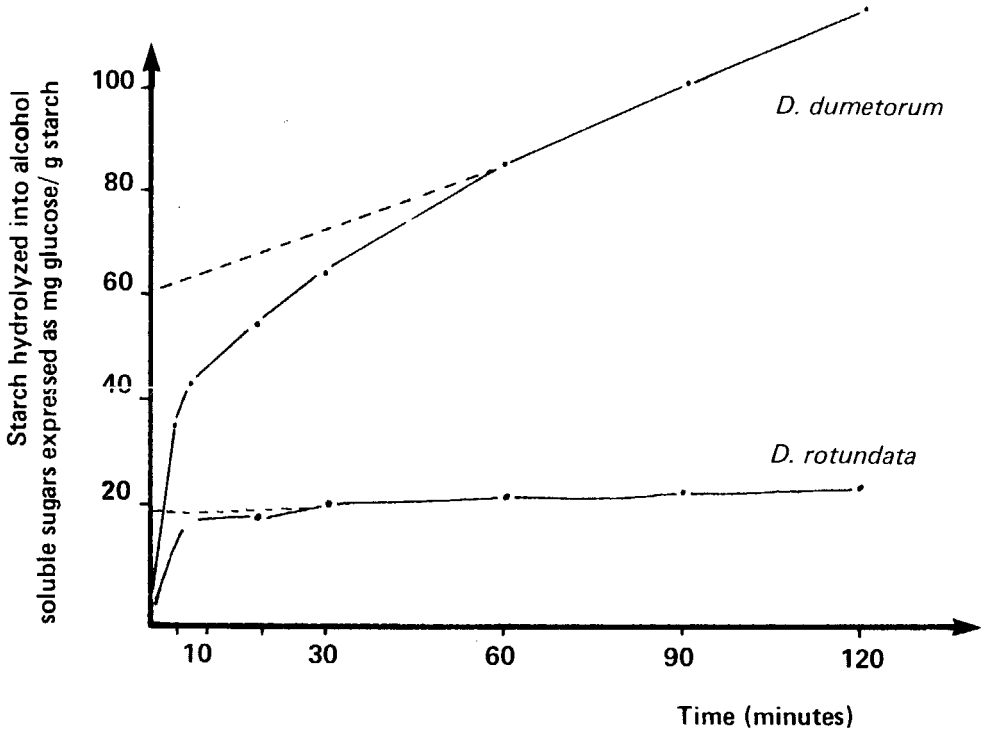

Fig. 5. Kinetics of alpha-amylase degradation of extracted starches

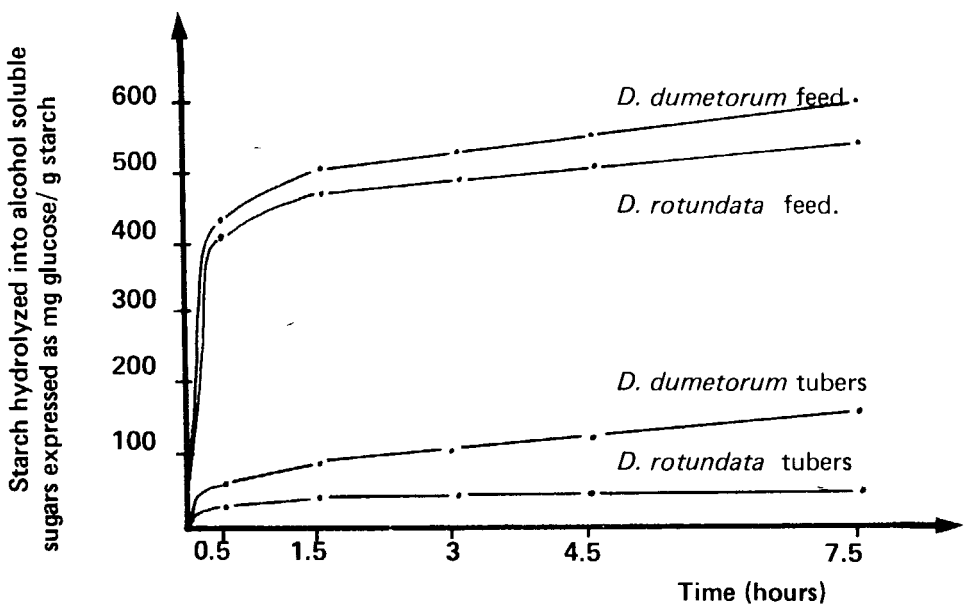

Fig. 6. Kinetics of alpha-amylase degradation of whole tubers and of feeds

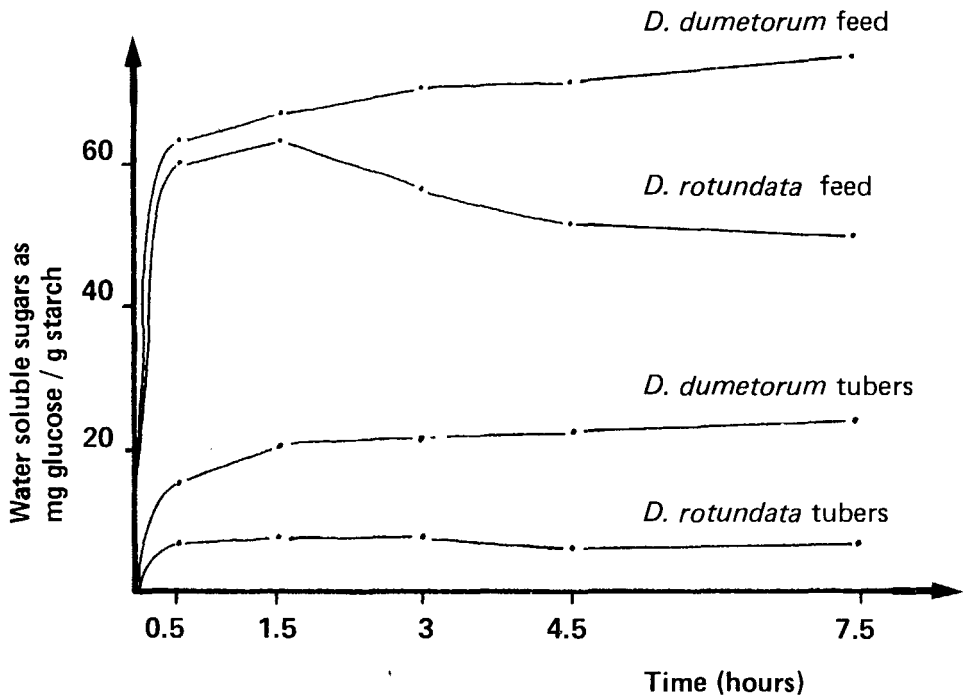

Fig. 7. Changes in quantities of water soluble sugars during alpha-amylase hydrolysis of whole tubers and of feeds

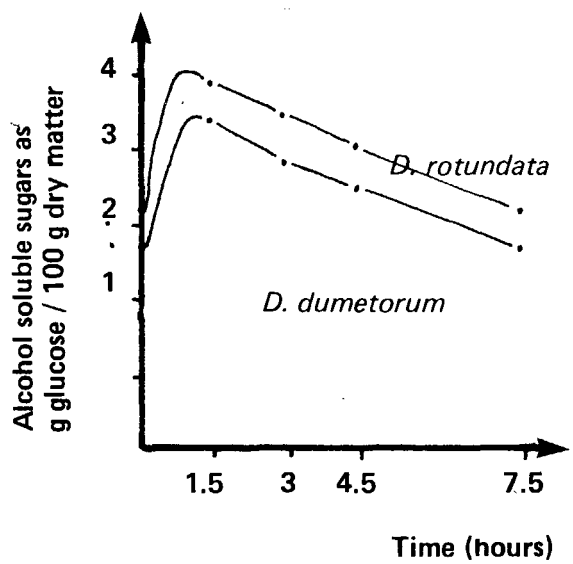

Fig. 8. Changes in the levels of alcohol soluble sugars in the crop contents

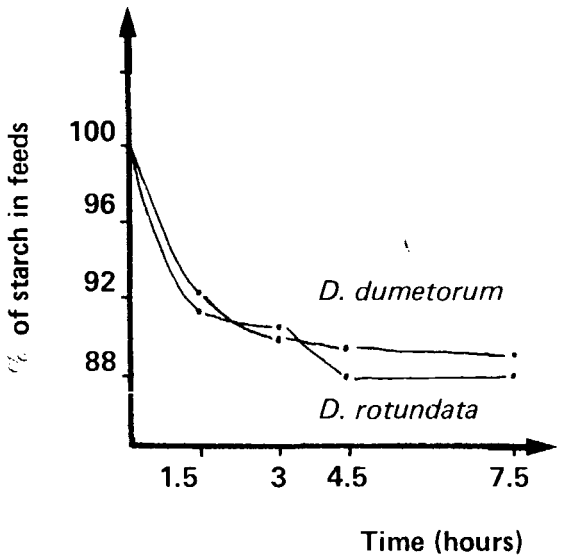

Fig. 9. Changes in the levels of starch in crop contents, expressed as per cent of that in feeds

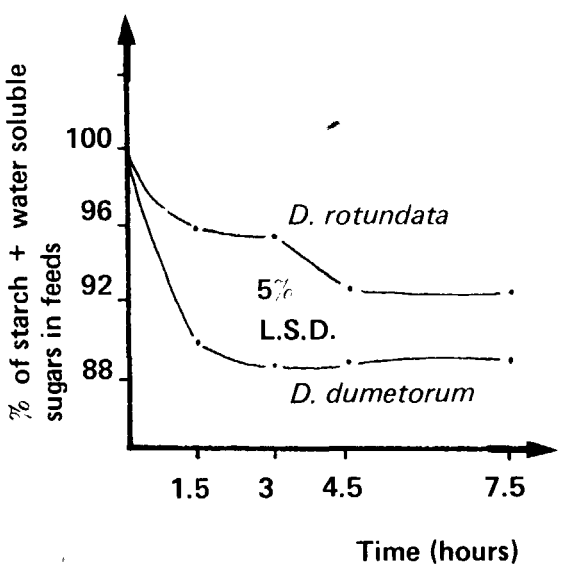

Fig. 10. Changes in the levels of starch + water soluble sugars in crop contents, expressed as percent of that in feeds.

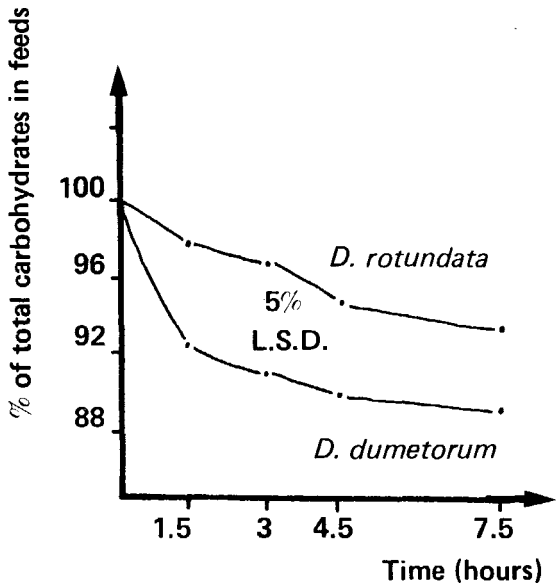

Fig. 11. Changes in the levels of total digestible carbohydrates in crop contents, expressed as percent of that in feeds.