Research performed in the Western Cape area of South Africa on alternative plant protein sources in pig diets[+]

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Introduction

The need for protein in human and animal diets is increasing all over the world. Protein, especially for use in animal feed, is becoming scarcer and more expensive. This is particularly relevant as far as the traditional protein sources, such as fishmeal, meat and bone meal (Protein Advisory Committee, 1990), are concerned. Throughout the world today, there is growing resistance against the use of animal protein sources in animal feeding. Large amounts of vegetable protein (e.g. soybean oil-cake meal) are imported into South Africa at present, but the cost of import for the South African monetary unit is placing pressure on prices. These factors have compelled the Elsenburg Agricultural Research Centre, in conjunction with organizations such as the Protein Research Trust of South Africa, to investigate the potential of locally produced plant protein sources. This article is an overview of the recent research undertaken by Elsenburg on the use of alternative locally produced plant protein sources in pig diets.

Composition of locally produced grain legumes

In a first study, samples were gathered to determine the variation in protein content of a variety of locally produced grain legumes. The total crude protein (CP) content of the grain legumes from five different localities in the Mediterranean rainfall area of South Africa is set out in Table 1 (Elsenburg Feed Data Basis, 1996). It was clear that considerable variation occurred in the protein content of the six different grain legume types.

In a follow-up study by Brand *et al.* (2001) samples of sweet yellow (*Lupinus luteus*; n = 4), broad leave (*Lupinus albus;* n = 12), narrow leave (*Lupinus angustifolius*; n = 8), faba beans (*Vicia faba*; n = 2), peas (*Pisum sativum*; n = 4) and narbon beans (*Vicia narbonesis*; n = 2) were collected over a two year period.

The physical characteristics (thousand seed and hectoliter mass, HLM) and chemical composition (dry matter, ash, crude protein, ether extract, acid detergent fibre, neutral detergent fibre and mineral content) of the samples were determined (see Table 2). L. luteus had the highest crude protein (CP) content (39.36%) followed by L. albus (38.19%), faba beans (26.00%), field peas (24.74%) and narbon beans (23.76%). L. luteus had the highest lysine content (2.22%), followed by L. albus (1.96%), L. angustifolius (1.86%), narbon beans (1.75%) and faba beans (1.70%). A large variation in the composition and metabolizable energy (ME) value of grain legumes, however, occurred. Values obtained in the study may be useful in future diet formulations. It was evident that most of the grain legumes contain high levels of fibre, which may limit high inclusion levels of these sources, especially in diets for young animals. The authors concluded that further work on the anti-nutritional factors in these sources is urgently needed.

Table 1. Crude protein content of different grain legumes types collected from different localities in the Mediterranean Rainfall area of South Africa (DM-basis) (Brand, 1998)

Type of grain legume	Number of samples	Total crude protein
Yellow lupin (*L. luteus*)	9	42.3±0.7
Broad-leaf lupin (*L. albus*)	41	40.3±0.5
Narrow-leaf lupin (*L. angustifolius*)	10	35.7±1.1
Faba beans *(Vicia faba)*	30	25.9±0.4
Narbon beans *(Vicia narbonensis)*	5	22.8±0.5
Field peas *(Pisum sativum)*	12	22.4±0.9

Growth and metabolism studies with locally produced protein sources

The potential of locally produced protein sources was determined in a number of metabolism and/or growth studies. An attempt was made to substitute expensive conventional protein sources such as fishmeal and soybean oil-cake meal for locally produced protein sources. The protein sources evaluated included lupins, faba beans, canola oil cake, full-fat canola as well as field peas.

Lupins and faba beans

In a study by Brand *et al*. (1995) three diets were formulated 16% crude protein (CP), 12.8 MJ/kg digestible energy (DE) and 9g lysine/kg on an air-dry basis. The diets either contained 8.3% fishmeal, 20% faba beans plus 7.9% soybean oil-cake meal (SBOC) or 20% low alkaloid lupins plus

Table 2a. The physical characteristics, chemical composition and mineral content of the most important grain legumes cultivated in the Mediterranean rainfall area of South Africa (Brand et al., 2001)

		Chemical Composition[+]						Physical[++] Characteristics	
Legume	**n**	**DM (%)**	**ASH (%)**	**CP (%)**	**EE (%)**	**ADF (%)**	**NDF (%)**	**HLM (kg/hl)**	**TSM (g/1000 seeds)**
L. albus	12	94.33	3.59	38.19	9.32	17.02	17.31	73.50	341.69
L. angustifolius	8	94.29	3.30	33.89	4.52	24.13	23.65	77.45	127.64
L. luteus	4	93.00	4.52	39.36	5.35	20.06	22.80	78.18	115.93
Faba beans	2	92.24	2.79	26.00	1.38	13.26	16.07	81.34	442.21
Narbon beans	2	93.08	3.04	23.76	1.14	16.05	17.87	80.33	169.90
Field peas	4	91.32	3.01	24.74	1.23	8.29	10.86	81.82	207.18
LSD (P≤0.05)		1.33	0.28	4.29	3.14	3.04	4.92	2.88	42.25
SE (pooled)		0.64	0.14	2.08	1.52	1.48	2.38	1.40	20.02

\+ Dry matter basis
++ Natural moisture basis

Table 2b. *The physical characteristics, chemical composition and mineral content of the most important grain legumes cultivated in the Mediterranean rainfall area of South Africa (Brand* **et al.**, *2001)*

Legume	n	Mineral Composition[+] Ca (%)	P (%)	Mg (%)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)
L. albus	12	0.16	0.45	0.16	5.00	33.89	404.97	33.66
L. angustifolius	8	0.19	0.42	0.18	3.41	34.64	26.93	50.00
L. luteus	4	0.17	0.76	0.26	5.01	55.26	59.13	53.71
Faba beans	2	0.10	0.46	0.11	4.26	20.17	15.34	90.33
Narbon beans	2	0.09	0.59	0.11	4.82	41.92	20.37	79.50
Field peas	4	0.07	0.51	0.13	4.80	39.03	26.28	67.20
LSD ($P \leq 0.05$)		0.02	0.08	0.03	3.54	13.34	345.84	33.54
SE (pooled)		0.01	0.04	0.01	1.18	6.46	167.88	16.28

[+] Dry matter basis
[++] Natural moisture basis

8.8% SBOC as protein sources. The latter two diets were compared in a metabolism and nitrogen (N) balance trial using a completely randomized design and six pigs per treatment. All three diets were evaluated in a growth trial using ten pigs (five boars and five gilts) over the growth interval 30-90 kg. The experimental design was a 3 (diets) x 2 (sex) factorial arrangement. Carcass characteristics were determined at the end of the growth trial. Pigs in the metabolism and N balance trial consumed 5% less ($P \leq 0.01$) of the lupin diet compared to the faba bean diet (1 370 vs. 1 440 g/d). No significant differences in the digestible energy (DE) content and in apparent N retention between the two diets occurred. In the growth trial lower intake levels ($P \leq 0.01$) were once again observed in pigs on the lupin diet (2 489 g/d) compared to the faba bean (2 637 g/d) and fishmeal diets (2 668 g/d). Pigs on the lupin diet grew ($P \leq 0.01$) slower than pigs on the other two diets (768 g/d vs 857 g/d and 869 g/d for the faba bean and fishmeal diets respectively). The feed conversion ratio of pigs on the lupin diet (3.27 kg/kg gain) tended to be poorer than those on the faba bean (3.03 kg/kg gain) and fishmeal diets (3.12 kg/kg gain) (see Table 3). No significant differences were observed in dressing percentage (mean value of 78%), eye muscle area (mean value of 41.3 cm^2) or P_2-back-fat thickness (mean value of 16 mm) of pigs on the different diets.

The authors concluded from the study that the poorer utilization of the lupin containing diet could not be ascribed to high alkaloid levels, since the alkaloid was only 0.01% and production is adversely affected only when diets contains alkaloid levels of 0.03% or higher (Pearson & Carr, 1997). The effect of unbalanced amino acids was unlikely, since rations were constituted to contain sufficient essential amino acids. The most probable reason for the lower performance on lupins was probably related to the higher fibre content of the source, the presence of α-galactosides and the associated higher percentage of digestion in the lower alimentary canal (Kemm *et al*., 1987), which probably lead to lower utilization of the energy and nitrogen released after digestion. The results obtained with faba beans indicated that no adverse effect on production, compared with fishmeal, was found. The relatively good results obtained with the faba bean containing diets could possibly be ascribed to the fact that faba beans did not supply all the supplementary protein (van der Poel *et al*., 1992). Various researchers reported a decline in the performance of pigs in cases where faba beans were used as the only protein source (Thacker & Bowland, 1985). It was concluded from the study that both faba bean and low alkaloid lupins can be used at levels up to 20% in diets of growing pigs, although lower production figures may be expected on lupin diets. High levels of ∝-galactose sugars probably also effected the utilization of the lupins (Bourdon *et al*., 1987).

In a further study on lupins, the composition and potential nutritional value of whole and dehulled lupin seed (Brand, 1996) were studied. The chemical composition of whole and dehulled seed of four locally produced lupin cultivars is set out in Table 4. According to the study, dehulling can increase the nutrient value/price of lupins by approximately 30%. If the lupins are dehulled, they can be included at higher levels in the diets of monogastric animals, due to a much lower fibre content of the kernels.

Field peas

The field pea (*Pisum sativum*) cultivar Glenroy (187 g/kg CP) was evaluated as an alternative protein source in diets of grower-finisher pigs (Brand *et al*., 2000). Four diets were formulated on an iso-nutrient basis (± 14.4 MJ/kg DE, 160 g/kg CP, 9.3 g/kg lysine, 5.3 g/kg methionine and cystine and 2.1 g/kg tryptophan) so that soybean oil-cake meal and maize meal were substituted by increasing levels of field peas (16%, 32%, 48% and 64%). Forty castrated pigs (21.7±2.6 kg) were individually housed and 10 pigs were fed on each diet *ad libitum* for 84 days. DM intake, average daily gain and feed conversion efficiency, all decreased on the highest pea level in the diet (Table 5). The DE content and N-retention of the 64% pea diet were significantly ($P > 0.05$) lower than those of the 16% and 32% pea diets. Though dressing percentage was not affected by dietary treatment, P_2 back fat thickness was significantly decreased in the 64% pea inclusion group resulting in leaner carcass. This was mainly due to lower slaughter weights. It was concluded that up to 32% of the field pea cultivar Glenroy, in the diets of growing pigs, can be recommended. This value corresponds well with the maximum inclusion level of 20% for pigs prior to 60 kg.

Canola

Full-fat canola

Full-fat canola seed (*Brassica napus* cv. Oscar) (260 g/kg crude protein

Table 3. *Means (± SE) for performance data of pigs calculated for the growth interval 30-90 kg live mass on the experimental diets containing either fishmeal, sweet lupins or faba beans (Brand* **et al.**, *1995)*

Treatment	**Measurement** DM intake (g DM/day)	**Live mass gain (g/ day)**	**Feed utilization[*] (kg/kg gain)**
Diets			
Faba beans	2 637[a]±46	857[a]±26	3.08±0.07
Sweet lupins	2 489[b]±46	768[b]±26	3.27±0.07
Fishmeal	2 668[a]±46	869[a]±26	3.12±0.07

[a, b] Values with different subscripts differ significantly ($P \leq 0.05$)
[*] On an as-fed basis

Table 4a. The chemical composition of whole and dehulled lupin seed of four different cultivars[a] (Brand, 1996)

Composition[a], %	*L. albus*					
	cv Hamburg			cv Kiev		
	Whole seed	**Hull**	**Kernel**	**Whole seed**	**Hull**	**Kernel**
Physical composition, %	100.0	19.5	80.5	100.0	16.8	82.3
Dry material, %	91.1	91.3	91.6	90.5	89.4	89.4
Ash, %	3.2	2.6	3.6	3.2	2.5	3.1
Crude protein, %	37.0	5.5	43.6	34.7	3.6	41.6
Ether extract, %	9.8	1.3	10.5	8.4	1.0	12.3
Crude fibre, %	12.9	50.2	3.9	13.4	50.7	4.9
NDF, %	18.0	72.4	4.5	19.2	73.9	4.0
ADF, %	15.0	59.6	3.9	16.3	61.4	5.2
Calcium, %	0.2	0.6	0.2	0.2	0.6	0.2
Phosphate, %	0.3	0.1	0.5	0.3	0.1	0.4

NDF = neutral detergent fibre; ADF = acid-detergent; TDN = total digestible nutrients fibre; cv = cultivar
[a] All values on a natural moisture basis

Table 4b. The chemical composition of whole and dehulled lupin seed of four different cultivars[a] (Brand, 1996)

Composition[a], %	**L. angustifolius**					
	cv Eureka			**cv Stevens**		
	Whole seed	**Hull**	**Kernel**	**Whole seed**	**Hull**	**Kernel**
Physical composition, %	100.0	25.5	74.5	100.0	26.5	73.5
Dry material, %	91.5	89.2	90.4	1.1	91.3	91.3
Ash, %	2.9	2.3	3.0	2.8	3.0	2.8
Crude protein, %	30.7	5.1	39.0	29.3	4.3	38.5
Ether extract, %	4.2	1.2	5.8	4.4	1.0	5.8
Crude fibre, %	16.7	49.0	2.8	16.5	50.0	3.4
NDF, %	24.5	69.8	4.9	24.9	71.3	4.7
ADF, %	21.4	56.9	6.4	22.0	58.8	4.9
Calcium, %	0.3	0.7	0.2	0.3	0.8	0.3
Phosphate, %	0.3	0.1	0.5	0.4	0.1	0.5

NDF = neutral detergent fibre; ADF = acid-detergent; TDN = total digestible nutrients fibre; cv = cultivar
[a] All values on a natural moisture basis

Table 5. Means ± SE for performance data of pigs (21.7 – 81.3 kg) fed four diets (iso-nutrient basis) with graded levels of field peas (Brand** et al.**, 2000)

Measurement	**Experimental diets**			
	Diet 1 16% peas	**Diet 2 32% peas**	**Diet 3 48% peas**	**Diet 4 64% peas**
Production data				
DM intake (g/day)	$2413^{a}\pm129$	$2541^{a}\pm65$	$2324^{a}\pm75$	$2001^{ab}\pm121$
Live weight gain (g/day)	$796^{a}\pm44$	817a±25	$751^{a}\pm32$	$505^{b}\pm37$
Slaughter mass (kg[d])	$88.7^{a}\pm3.2$	$90.4^{a}\pm3.1$	$82.6^{a}\pm3.0$	$63.7^{b}\pm7.0$
Feed utilization (kg feed/kg gain)	$3.04^{a}\pm0.09$	$3.13^{a}\pm0.12$	$3.11^{a}\pm0.07$	$4.02^{b}\pm0.13$

[a,b,c] Means followed by common superscripts in a row do not differ ($P \geq 0.05$)
[d] Calculated with initial mass as co-variance

and 410 g/kg ether extract) was evaluated as an alternative protein source in diets fed to weaner and grower-finisher pigs, Brand *et al*., 1999). Four diets for weaner pigs were formulated on an iso-nutrient (about 198.9 g/kg crude protein, 15.2 g/kg lysine, 8.3 g/kg methionine and cystine and 2.4 g/kg tryptophan on a dry matter basis) and iso-energy basis (16.2 MJ DE/kg dry matter) to substitute full-fat soybean with increasing levels of full-fat canola seed meal (0, 8, 16 and 24%). Similarly, 4 diets for grower-finisher pigs were formulated on an iso-energy and iso-nutrient basis (about 14.9 MJ DE/kg dry matter, 178 g/kg crude protein, 10 g/kg lysine, 6.8 g/kg methionine and cystine and 2.2 g/kg tryptophan on a dry matter basis), where soybean oil-cake meal was similarly substituted. Weaner pigs (n = 80) were fed *ad libitum* from 9.6 to 26.7 kg liveweights. Piglets were kept in groups of 4 (2 gilts and 2 castrated boars combined at random) in cages (1.5 by 1 m) with solid floors, fitted with a self-feeder and equipped with an automatic water nipple. Grower-finisher pigs (n = 52), individually housed in flat deck-type cages (1.6 by 1.0 m), fitted with a self-feeder and equipped with an automatic water nipple, were fed *ad libitum* from 22.9 to 91.1 kg, where after pigs were slaughtered, carcass characteristics determined and back-fat samples taken. Energy and nitrogen metabolism data were evaluated in a digestion and metabolism trial for the 4 grower-finisher diets. No significant difference in the intake, growth rate or feed conversion of weaner pigs was observed (see Table 6).

The dry matter digestibility of the grower-finisher diet differed significantly ($P < 0.05$) between diets and decreased linearly by 0.56% ($P < 0.01$; SEb = 0.04) for each percentage increase in the canola inclusion level. The digestible energy content of the diets was not affected. Regression analysis demonstrate a linear decrease [0.25 g N/day ($P < 0.01$; SEb = 0.02)] in nitrogen retention rate for each percentage increase in canola inclusion. The inclusion of up to 24% canola had no significant effect on feed intake, liveweight gain or feed conversion ratio of grower-finisher pigs, although regression analysis revealed a linear decrease of 2.71 g/day (SEb = 0.73) in growth rate with every one percent increase in canola levels (see Table 7) The back-fat of pigs consuming diets with 16 and 24% full-fat canola in their diets had 13% ($P < 0.05$) higher iodine numbers than pigs that received 0 and 8% full-fat canola in their diets. Generally all saturated fatty acids decreased while mono-unsaturated and poly-unsaturated fatty acids increased, with increasing levels of canola in the diets. It was concluded from the study that milled Oscar full-fat canola seed can provide a viable alternative to soybean and soybean oil-cake meal as the protein source in diets for weaner, and grower-finisher pigs. In diets for both weaner and grower-finisher pigs, inclusion rates of up to 24% did not affect production significantly, although slightly lower growth rates might be expected with grower-finisher pigs due to canola inclusion. Inclusion rates of 24% also reduced N-retention. Inclusion levels of 16% canola in the diets of grower-finisher pigs are therefore recommended for maximum efficiency. Thacker and Kirkwood (1990) similarly recommended inclusion levels of 15% full-fat canola for starter and grower-finisher pigs with no significant reductions in growth rate, feed intake or efficiency of feed utilization. The inclusion of full-fat canola in diets for pigs will have a major effect on the fatty acid composition of the carcass and will increase unsaturated fatty acids at the expense of saturated fatty acids. Although such products may be perceived to be healthier, the effects of softer fat on carcass processing (Castell and Falk 1980) and the quality of the fat (Irie and Sakimoto, 1992) must be kept in mind. Overall, full-fat canola is a viable substitute for other conventional protein sources used in diets for starter and grower-finisher pigs.

Canola oilcake

Canola meal (CM) from both the solvent (3.27% fat) and expeller (9.28% fat) oil extraction processes were used as replacement for fishmeal in grower-finisher pig diets in two separate experiments (Brand *et al*., 2001). Diets were formulated on an iso-nutrient basis (approximately 13.6 MJ/kg DE, 160 g/kg CP, 9.0 g/kg lysine, 6.5 g/kg methionine and cystine, 6.5 g/kg threonine and 2.0 g/kg tryptophan on DM basis) to contain 0 g/kg, 80 g/kg, 160 g/kg, and 240 g/kg CM in the first (solvent process) and 0 g/kg, 97 g/kg, 195 g/kg, and 292 g/kg CM in the second (expeller process) case. In Experiment 1, 13 pigs per diet were individually housed and fed *ad libitum* from 25.4 kg to 84.4 kg liveweight, where after pigs were slaughtered and carcass characteristics determined. In Experiment 2, randomly selected groups of 4 pigs (16 per diet) were fed *ad libitum* from 21.6 kg to 88.4 kg liveweight, where after pigs were slaughtered and carcass characteristics measured. The inclusion of CM in the diets at levels of up to 24% in Experiment 1 and 29.2% in Experiment 2 had no significant effect on dry matter intake (DMI), feed conversion ratio (FCR), or liveweight gain (see Table 8). In Experiment 1, P_2 backfat thickness was significantly lower and percentage of meat in the carcass was significantly higher in the 24% CM diet group. In Experiment 2, dressing percentage was significantly lower in the 29.2% CM diet group. Optimum inclusion rates found in this study were much higher than the 12-18% inclusion levels proposed by the Canola Council of Canada (1989). Pigs on high CM diets in our study also outperformed those in studies by McKinnon & Bowland (1977), who found a significant influence on performance at 100% replacement of soybean meal by CM (19.8% inclusion level) during the growing phase. Lower performance of canola-fed pigs is normally associated with the influence of the breakdown

Table 6. Feed intake, liveweight gain and feed conversion ratio (mean ± s.e.) of weaner pigs (9.6-26.7 kg) fed four diets (iso-nutrient basis) containing graded levels of full-fat canola seed meal respectively (Brand et al., 1999)

Measurement	Level of canola, %				Variance		Tendency	
	0	8	16	24	SEm.	P-value	Linear	Quadratic
Dry matter intake (g/day)	925	966	954	886	28.1	n.s.	n.s.	P < 001
Liveweight gain (g/day)	460	475	503	465	21.4	n.s.	n.s.	n.s.
Feed conversion ratio (kg DM/kg gain)	2.03	2.04	1.90	1.91	0.05	n.s.	n.s.	n.s.

Table 7. Feed intake, liveweight gain, feed conversion ratio and carcass data (mean ± SE) of pigs (22.9-90.70 kg) fed four diets (iso-nutrient basis) containing graded levels of full-fat canola seed meal respectively (Brand et al., 1999)

Measurement	Level of canola, %				Variance		Tendency	
	0	8	16	24	SEm	P-value	Linear	Quadratic
Growth data								
Dry matter intake (g/day)	2240	2365	2220	242	65	NS	NS	NS
Liveweight gain (g/day)	856	834	794	797	29	NS	P < 0.06	NS
Feed utilisation (kg DM/kg gain)	2.63	2.88	2.82	2.82	0.11	NS	NS	NS
Carcass data								
Iodine number	66.7a	69.4a	76.3b	78.0b	5.35	P < 0.01	-	-
Refractive index	1.4591a	1.4597b	1.4603c	1.4608d	0.0007	P < 0.01	-	-
U : SA	1.11a	1.22a	1.49b	1.94c	0.359	P < 0.01	-	-

[A]Ratio of unsaturated to saturated fatty acids
Means within each row followed by the same letter are not significantly different at $P = 0.05$

Table 8. Production data and carcass characteristics of growing-finishing pigs fed diets with increasing levels of canola meal originating either from the solvent or expeller process

	Level of canola meal, %				
Measurement	**0**	**8**	**16**	**24**	**SEm**
Experiment 1 (Solvent process) Production data DMI (g day^{-1}) ADG (g) FCR (kg feed kg^{-1} gain)	 2197 838 2.61	 2192 834 2.61	 2261 870 2.60	 2068 827 2.50	 65 23 0.04
	Level of canola meal, %				
	0	9.7	19.5	29.2	SEm
Experiment 2 (Expeller process) Production data DMI (g day^{-1}) ADG (g) FCR (kg feed kg^{-1} gain)	 2130 729 2.93	 2279 762 3.00	 2290 738 3.10	 2222 724 3.07	 47 22 0.07

Values in rows with the same letter are not significantly different ($P < 0.05$) (Brand *et al*., 2001)

products of glucosinolates on thyroid function and/or reduced palatability (Baidoo *et al*., 1986). Since no effect on intake or performance was observed, it may be concluded that the meal processed from recently released canola cultivars, which contain lower levels of anti-nutritional factors (Mailer & Colton 1995), are more acceptable for growing-finishing pigs and may be included at higher levels. These results corresponded with the earlier reported results on full-fat canola where full-fat canola seed meal of cultivar Oscar was included up to 24% in diets of weaner and grower-finisher pigs.

Conclusion

The grain legumes, full-fat canola and canola oilcake shows potential to replace expensive animal or conventional plant protein sources in pig diets. In many cases, anti-nutritional factors like alkaloids, ∝-galactose sugars and high levels of manganese in lupins (Hill & Pastuszewska, 1993; Bourdon *et al*., 1990; Batterham, 1979), trypsine-inhibitors, tannins and haemaglutonin in faba beans (Marquart *et al*., 1976; Jansman *et al*., 1993; Marquart *et al*., 1974), glucosinolates erucic acid and sinapines in canola (Bell, 1993) and tannins, chemotrypsine and trypsine in field peas (Savage & Deo, 1989) may limit inclusion levels. Other general limitations include high fibre levels (Todorov *et al.,* 1996) and the presence of pentosans (xylose and arabinose) (Chesson, 1990). The price and availability of the alternative protein sources will, however, be the determining factor for their use in pig diets.

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