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Review Article

Use of sweet potato in pig production in Asia: agricultural and socio-economic aspects

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Abstract

The general economic development in Asia has resulted in the re-allocation of sweet potato utilization between pig feed and starch processing. In China, which produces 85% of the world's sweet potato, about 45% is fed to pigs. Vietnam, the second largest world producer, allocates 75% to pig feed since sweet potato cannot compete with cassava as a raw material. Papua, Indonesia, does not occupy a significant place in either global sweet potato or pig production, but its integrated human-pig-sweet potato system has a unique socio-cultural significance. Though these three sweet potato–pig systems all involve the feeding of sweet potato to pigs, contrasting qualities exist. For example, traditional belief results in Chinese farmers feeding large amounts of sweet potato at the finishing stage to boost growth and give the meat a sweet taste. As the roots and vines cannot be stored in the subtropical climate of Vietnam, the farmers feed large amount of roots and vines soon after harvest to avoid wastage. Papuan farmers feed pigs raw roots once a day, despite the slow growth caused by the presence of a trypsin inhibitor. These varied qualities influence the approach to improve the feeding systems. In China, premixed or concentrated protein supplements for sweet potato-based diets are appropriate venues; while in Vietnam the emphasis is on crop feed processing and sweet potato selection. In Papua, a systems approach taking into consideration the agro-socio-cultural contexts is necessary to improve the system.

Keywords
Sweet potatoes
pig feeding
feeds
pig farming
socioeconomics

1. Introduction

Even though pig production in the developed countries is based on balanced commercial feed, most small pig producers in the developing world are constrained by the cost of feed imports or shortage of such feed. Sweet potato, along with other crop feedstuff, has been used as an alternative feed in large-scale and feed-based livestock production as a source of energy with the leaves as a source of protein; both can be used in fresh and dried form or fermented into silage [1]. Accounting for 85% of sweet potato production in the world, China's sweet potato consumption has declined over the years as living standards have increased. Huang *et al*. [2] estimates that 40% of total sweet potato output in China went to animal feed in the mid-1990s, with regional utilization varying from 60% in Sichuan Province to 30% in Shandong Province.

Sweet potato is also substantially linked to pig production in northern and central Vietnam. In fact, since sweet potato cannot compete with cassava as a raw material for starch processing, about 70-80% of roots are fed to pigs, either directly by the producers or indirectly by the root buyers. In addition to China and Vietnam, sweet potato-pig systems used to play an important role in the rural economy of many parts of Asia, including the Philippines, Korea, and Taiwan, and continue to be important in some areas of Indonesia (Bali and Papua) and Papua New Guinea. These systems are also practised, to a lesser extent, in Latin America and Africa [3]. These systems are particularly developed on the island of New Guinea where sweet potato tubers and vines account for most of the feed. Pigs supplement this by foraging,

[1] Based on research conducted while the author was employed by the International Potato Center (CIP)

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apparently obtaining additional protein from consumption of soil fauna, particularly earthworms [4].

Although sweet potato-pig farmers complain about the low profitability of raising pigs, the practice serves three important functions: 1) it generates one of the few sources of cash income for many rural households, 2) it provides manure for maintaining and improving soil fertility, and 3) it allows pigs to convert low-value sweet potato into highly desired meat and/or highly marketable commodities. Moreover, pigs belonging to Papuan farmers enjoy a protected and almost revered status because of their socio-economic importance [4]. Pigs are equated with wealth and social importance and considered the most important living creature besides humans.

This paper reviews the characteristics of systems which use sweet potato as pig feed, and the approaches to improving these systems, in three regions: 1) Sichuan, China, 2) northern & central Vietnam, and 3) Papua, Indonesia. Most of the information presented is based on the author's research on assessment and interventions between 1996 and 2003 in all three sites. The sweet potato-pig production assessment in Sichuan Province was conducted in 1996 and 1999. The same production assessment in Vietnam was conducted in various provinces between 1997 and 2000, including a large survey in seven provinces in 1998 with a sample size of 160 households. The pig marketing survey in Vietnam was conducted in 1999 in 13 provinces, comprising 1,140 samples and nine different survey instruments for nine categories of respondents. The study of human-sweet potato-pig systems in Papua was carried out during three seasons in 2001 and 2002. The intervention research, including sweet potato selection trials, sweet potato root and vine processing technologies, pig feeding trials, and husbandry management trials, followed the assessment in each site in an attempt to improve these systems in Vietnam and Papua. Only a few trials were conducted in China. All trials were conducted on farms in collaboration with local farmers.

2. Assessment of sweet potato as pig feed in Asia

Sichuan, China, northern & central Vietnam, and Papua, Indonesia were selected for study and this review because of their distinctive characteristics of sweet potato-pig production. Sichuan, with a population of 84 million, is the most densely populated province of China, and in 2000 had a pig population of 65 million. One of the reasons for the immense pig production is attributed to the 3.76 million tons of sweet potato production of low cash value, 60-70% of which is thus fed to pigs [5]. The magnitude of the sweet potato and pig production and their interaction makes Sichuan an important example of a sweet potato-pig system.

Farmers in northern and central Vietnam plant two or three seasons of sweet potato a year, usually as a stop-gap between rice crops. These are usually short-season crops, as short as 75 days, but up to 120 days during the winter, with an average of 90 days. The winter crop is the major crop, which produces the majority of the roots for the year. The other seasons are often too short to produce significant roots so the vines are the main harvest. The high market value and demand for sweet potato vines, sold mainly as pig feed, is very unique to northern and central Vietnam.

Papua does not have a large human or pig population but pigs and sweet potato, nonetheless, account for the majority of the household economy and activities. The inseparable human-sweet potato-pig relationship in Papua represents a unique agro-socio-cultural system that warrants documentation and improvement. Papuan farmers are now going through the transition from subsistence pig raising for self-consumption, social exchange and ceremonial uses to commercial production.

The use of sweet potato as pig feed in Sichuan, northern and central Vietnam, and Papua share some common characteristics as well as diverse qualities due to the different agricultural-economic-cultural context. Specific characteristics of these three systems are described.

2.1. Sichuan, China

Yilong County in Sichuan Province alone produces 400,000 tons of fresh sweet potato a year and each household in Yilong, on average, harvests 1.5 tons of sweet potato a year. Due to the lack of processing technology in 1997, 75% of the sweet potato roots were fed to pigs. Since sweet potato is harvested at the onset of winter, the roots are stored for about six months either in pits underground or in hillside caves with very little reported loss.

Eighty-three percent of the sweet potato vines are fed to pigs, which are chopped and dried, then stored for times when farmers are too busy to prepare fresh vegetables and grass for the pigs. Silage making is not common in Yilong and only a few households engage in this practice. On average there is only sufficient vine production for approximately four and a half months of pig feeding per year.

Pigs are always fed twice daily and Sichuan farmers like to increase the percentage of sweet potato roots fed as pigs increase in size. During the growing period, sweet potato provides 28% of the total feed, with green forage 65%, and maize 2% of the total feed. Finishing pigs are fed 49% sweet potato, 42% green forage, and 5% maize [5]. Rice and wheat bran produced on-farm is commonly fed to supplement the diet. According to farmers, the increased sweet potato consumption during finishing gives the meat a sweet flavour.

Two systems of pig feeding were observed; the most common is the traditional feeding system which uses no commercial feed, additives, or protein supplements. All feed sources in this system are mixed and cooked before feeding to pigs. The second type is the mixed-feeding system, which combines some com-

Table 1. Sweet potato (SP) production and utilization in seven provinces in northern, central and southern Vietnam (n=160 households (hh) per site).

Location	Production		Sweet potato utilization (%)			
	Tonne/hh	% hh not planting SP	Fed to pigs	Sold in market	Home consumption	Processing for starch
Southern region						
Dong Nai	0	100	0	0	0	0
Vinh Long	11.8	0	0	100	0	0
Northern & Central region						
Quang Nam	0.83	0	87.8	0	12.2	0
Thanh Hoa	1.21	0	87.3	0	12.7	0
Ha Bac	1.15	0	70.0	25.0	5.1	0
Hoa Binh*	0	100	0	0	0	0
Vinh Phu	0.80	0	67.1	23.3	9.7	0

*Hoa Binh is an upland province that produces cassava as pig feed.

mercial protein supplement for piglets with other on-farm available feed sources. This system is not commonly observed, as it requires cash input. On average, the traditional system takes 12 months to raise pigs to approximately 95 kg, while it takes 10.6 months with the mixed system to raise pigs to 88 kg.

In both systems pigs are raised in pens with gaps between wooden slats to allow manure to fall into the pit below. This manure is mixed with human faeces and urine that are also deposited directly into the same pit. The resulting mixture is used as a liquid fertilizer, without composting with any other organic material, for soil fertility maintenance. The cleanliness and management of the environment is inconsistent, but there is surprisingly little reported loss to disease and illness.

2.2. Northern and central Vietnam

Vietnam produces 1.6 – 1.7 million tons of sweet potato roots a year nationwide [6], as compared to 0.4 million tons from a single county (Yilong, described above) in China. In northern and central Vietnam 70-80% of sweet potato roots are fed to pigs while only a small percentage is consumed at home or sold in the market (Table 1). The situation is quite different in the south where sweet potato is a cash crop rather than a staple crop.

Thus, the sweet potato-pig feed system is only practised in the northern and central provinces of Vietnam, and while farmers using this system traditionally raise two to five pigs per cycle with an average daily weight gain (DWG) of 288 g, the farmers of Dong Nai Province in the south raise 25 pigs per cycle with a DWG of 522 g. The difference in the growth efficiency is largely attributed to the feed. In northern and central Vietnam sweet potato roots and vines, along with cassava, maize, and rice bran constitute the major part of the diet, which is supplemented by various green forages.

The season affects the variation in the amount of sweet potato fed to pigs. Sweet potato is cultivated up to three seasons a year (mainly two) in northern and central Vietnam; its availability is thus scattered in short spurts after each harvest because traditionally there is no means of storing either roots or vines in this sub-tropical climate. Thus, farmers feel obliged to feed large amounts to pigs within a short period after harvest to avoid loss.

Most pigs are kept in pens on concrete floors covered with straw during the winter. These pens often have a dunging area for the pigs and manure is collected behind the pens in a pit, composted with other organic material and applied to crops as green manure. A small proportion of pigs is raised on dirt floors, usually covered in soggy manure. Diseases are commonly observed and reported in Vietnam, particularly in the upland areas. These diseases are serious enough to deter much cash investment for fear of financial loss due to mortality.

2.3. Papua, Indonesia

Pigs are regarded as gold among the Dani people in the Baliem Valley in Papua, and the sweet potato is the currency used to obtain the gold. The sweet potato production system has a high labour requirement, with the work mainly done by women. This is both because of the number and distance of the fields from the home and the extensive work required for preparing and maintaining the fields. Humans and pigs both consume an unusually large quantity of sweet potato roots and vines as the staple of the diet (Table 2). Pigs are fed sweet potato roots and vines once a day in the evening when they come home from a day of foraging grasses and worms in the field or forests. Roots are cooked for pigs only once or twice a week when the farmers carry out *bakar batu* using hot stones to cook large amounts of roots, enough for both humans and pigs. The rest of the week pigs are fed raw sweet potato roots which not only contain a trypsin inhibitor, but also have low protein and mineral content. Foraging results in excessive exercise

Table 2. Sweet potato root and vine consumption by humans and pigs in each sampled housing compound in Baliem Valley, Papua, Indonesia (kg/compound/day).

	December 2001	June 2002	December 2002
Roots for humans[a]	8.9	8.5	8.0
Vines for humans[a]	5.1	5.6	3.4
Roots for pigs[b]	10.4	9.9	9.9
Vines for pigs[b]	6.9	5.3	4.2

[a]The number of people recorded sharing these roots and vines include 1.7 adult men, 1.6 adult women, 2.0 boys, and 2.1 girls, an average of 5.2 people/compound.
[b]On average, 2.5 sows, 2.0 male pigs (mainly castrated), and 6.3 piglets per compound were fed these amounts of sweet potato.

and exposure to disease. Consequently pigs take 3-5 years to reach 70-80 kg from birth, that is if they do not get stolen or die from disease.

Premature deaths are common since parasites are rampant in the absence of the lack of separation between human faeces and pigs. Although Dani farmers are acquainted with almost every aspect of sweet potato cultivation, they lack basic knowledge of pig husbandry and disease control. When these highly valued pigs are struck by illness, Dani farmers routinely pray, conduct rituals, or apply traditional healing methods on the pigs, but seldom consult veterinarians.

3. Improvement of the sweet potato-pig systems

As there are substantial differences among the three countries in the sweet potato-pig systems used, the general approach to improvement includes situation analysis, participatory technology development, and scaling up, with an additional monitoring and evaluation component for impact assessment. The situation analysis required a systemic understanding of the human-sweet potato-pig system in Papua, while in China separate assessments of sweet potato production and pig production were required; an additional pig market chain assessment in Vietnam was necessary due to the importance and complexity of pig marketing.

Based on the situation analysis, the participatory technology development designed for each of the sub-systems included improvements in sweet potato genetic selection, root and vine processing, and animal husbandry including feed, health, management, and fertility. Different technologies are relevant for the various sub-systems and their socio-cultural-agronomic contexts. The following section reviews the participatory technology development efforts undertaken by the International Potato Centre (CIP), partly funded by the Australian Council for International Agricultural Research (ACIAR), to improve each of the sub-systems in northern and central Vietnam, and in Papua, Indonesia.

3.1. Sweet potato selection for pig feed

Farmers in Vietnam grow a range of sweet potato varieties, many of which come from China with the others of unknown origin, most of which have a low starch yield because the more popular varieties were selected for taste for humans and not for pig feeding. Sweet potato breeding and selection trials in Vietnam in earlier years produced two advanced clones (KB1 and K51) which have been widely adopted by farmers [7]. Recent trials on another six clones, from four seasons in 2001 and 2002 identified a promising clone that yields high total dry matter and starch content suitable for pig feed (Table 3). These selections emphasized the total dry matter yield (DMY) from both roots and vines and the total starch yield from the roots. Although pigs do show a preference for the roots or vines of certain clones, they do not reject any of them.

A conservative estimate of the number of local sweet potato cultivars in Papua puts the figure at well over a thousand, with the number in a single area or community ranging between 28 and 81 [8]. Papuan

Table 3. The total dry matter yield (DMY) of roots and vines and starch yield of roots of the various sweet potato clones included in varietal selection trials during four seasons in Vietnam from 2001 to 2003 (tonne/ha).

	Winter 2001		Spring 2002		Winter 2002		Spring 2003		Average	
Variety	DMY	Starch yield	DMY	Starch yield	DMY	Starch yield	DMY	Starch yield	DMY*	Starch yield*
98-8-24	6.0	2.35	10.05	4.13	5.3	2.27	6.45	4.41	6.95 a	3.29 a
98-5-15	5.36	2.07	9.81	3.92	5.12	2.22	5.60	3.32	6.47 ab	2.88 ab
KL5	5.53	2.26	9.17	3.37	5.24	2.20	5.42	3.18	6.34 ab	2.75 abc
KL6	5.40	2.16	8.99	3.11	4.73	1.75	5.26	3.25	6.10 ab	2.57 bc
98-8-48	6.36	2.68	7.41	2.30	4.68	1.79	4.49	3.10	5.74 b	2.47 bc
98-8-118	5.83	2.05	7.94	2.52	4.6	1.55	3.58	2.46	5.49 b	2.15 c
Control	4.76	2.21	9.36	3.53	4.41	1.85	5.96	4.05	6.12 ab	2.91 ab
CV (%)									10.6	14.5

* Letters to the right of the means indicate significant difference ($P<0.05$) across rows.
** As peanut oil demand is increasing, spring fields are now increasingly allocated to peanut production in the spring, hence reducing sweet potato production.

Table 4. Fresh yields and dry matter yields from three on-farm selection trials in the Baliem Valley, Papua, Indonesia from December 2002-May 2003 (tonne/ha).

	Root yield				DM yield			
Variety/clone	**Holima**	**Sinatma**	**Napua**	**Mean**	**Holima**	**Sinatma**	**Napua**	**Mean**
BB 97256-9	30.48	17.24	7.29	18.34*	10.63	6.56	2.42	6.54*
BB 97258-2	20.84	8.40	11.20	13.48	6.62	2.55	2.67	3.95
BB 97083-4	23.46	5.15	10.93	13.18	6.49	2.11	3.62	4.07
BB 97089-12	27.15	10.62	9.24	15.67*	10.05	3.30	3.05	5.47*
MSU 99021-5	16.04	5.11	6.93	9.36	4.08	1.24	1.84	2.39
MSU 99051-1	22.48	9.55	10.00	14.01*	7.90	3.45	3.12	4.82*
Cangkuang	27.77	10.89	12.53	17.06*	10.30	3.41	3.68	5.80*
Siate [a]	26.39	7.91	10.04	14.78*	9.34	2.79	3.44	5.19*
Helaleke Lama [b]	15.91	7.73	8.89	10.84	5.28	3.07	2.91	3.75
Mean	23.39	9.18	9.67	14.08	7.85	3.17	2.97	4.66
Significance	**	*	NS	-	**	*	NS	-
CV (%)	19.10	22.30	21.10	-	19.10	25.10	21.50	-
LSD 0.05	7.75	6.70	-	-	2.60	2.43	3.00	-

NS, $P>0.05$; *, $P<0.05$; ** $P<0.01$

[a] Siate was from Napua and previously not planted in valley sites such as Holima; it was planted here not as a check clone, but as an introduced clone for Sinatma and Holima.

[b] Local variety as control.

farmers generally maintain all the clones that have been informally introduced or crossed, in the absence of any systematic breeding or selection locally. Therefore the author's project undertook to conduct all sweet potato breeding activities on farms in various villages in the Baliem Valley. Trials were conducted in villages at different elevations since sweet potato cultivars are highly site-specific. The villages were Holima, Sinatma and Napua at elevations of 1700, 1850 and 2000 m, respectively. Due to the large number of sweet potato clones in Papua, it was anticipated that it would be difficult to improve on the local material. The results, however, showed that some clones had the potential for improvement over the best of the local varieties (Helaleke Lama) after four seasons of on-farm trials (Table 4). The farmers' interest in these introduced clones, even the ones that did not perform better than the local check variety, was far greater than had been expected. From each on-farm trial harvest, on average at least half of the trial clones was well received by the trial participants and their neighbours and friends.

3.2. Root and vine processing

The development of sweet potato root and vine processing technology in Vietnam had four objectives: 1) to increase nutritional value, 2) to eliminate the need for cooking, 3) to increase storability and shelf life, and 4) to save labour.

The production of vine silage enables the women to process the vines during the off-season when labour is more available, and store the silage for use when feed is limited. Moreover, there is also the economic advantage of ensiling/storing vines: to process and store the sweet potato vines during the harvest season when vines are cheap and feed them to pigs during the off-season when vines are expensive. Ensiling may also increase nutritional value and feed efficiency if it involves a fermentation process which can convert nitrogen into protein.

A silage trial was conducted to compare the nutritional value of twelve different ensiled mixtures of sweet potato vines, corn and cassava meal, rice bran, sun-dried chicken manure and salt. The nutritional analysis showed that vines ensiled with chicken manure had significantly higher crude protein, dry matter and ash content, and lower unit costs for each nutrient than the other silage products (Table 5). None of the preparations were found to contain aflatoxin or *Salmonella*. *Escherichia coli*, although present in the original samples, disappeared after 14–21 days of fermentation [9]. A simple and inexpensive vine-chopping machine was introduced which transformed hours of work into minutes and this has been adopted by farmers in several provinces as a labour-saving device.

The use of sweet potato roots as feed faces the constraint of low protein content, poor starch digestibility, high trypsin inhibitor content, and limited storage time. To overcome these constraints, farmers in China and Vietnam diligently cook sweet potato-based feed daily to eliminate the trypsin inhibitor and increase starch digestibility. In turn, the farmers pay the price of high labour and fuel inputs. Where labour or fuel is in short supply, limiting the cooking option, farmers suffer the consequences of low pig growth rate and minimum economic return on their investment. Such is the case in Papua where roots are fed raw three out of four times and pig growth is exceedingly slow (dis-

Table 5. Nutrient composition of the 90-day sweet potato vine silage (% of dry basis).

Treatments[1]	pH	Dry matter (DM)	Crude protein (CP)	Ash	Ether extract (EE)	Crude fibre (CF)
1	a3.65	a25.04	bc14.86	b11.85	b3.43	bc17.04
2	b3.98	c31.31	e18.59	d16.46	bc3.53	abc15.66
3	a3.71	b28.57	b14.32	a10.7	de5.01	bc16.69
4	b3.99	c31.85	e18.62	de17.35	c4.14	abc15.19
5	a3.73	a25.72	a13.19	bc12.25	a2.44	bc16.64
6	bc4.05	c30.09	d17.63	de17.1	ab2.99	ab14.47
7	a3.75	b28.47	a12.76	a10.16	ab2.96	a13.97
8	bc4.03	c31.92	d17.53	de17.33	b3.23	a13.98
9	a3.66	a25.85	c15.45	c13.54	e5.62	c17.32
10	c4.12	c31.63	e19.11	e18.34	de5.41	abc16.06
11	a3.74	b29.26	a12.60	ab11.45	de5.21	abc15.95
12	b4.03	c31.45	d17.78	de17.16	d4.91	abc15.11
P	0.000	0.000	0.000	0.000	0.000	0.000
With chicken manure	4.03	31.38	18.21	17.29	4.04	15.08
Without chicken manure	3.70	27.15	13.86	11.66	4.11	16.27

[1]The even numbers contain 10% of sun-dried chicken manure while the odd numbers do not. The other ingredients include 3-6% of various combinations of corn meal, cassava meal, and rice bran.

[2]Letters to the left of and to the right of the means are significantly different ($P<0.05$) across rows.

cussed in a later section). The need to cook in order to fully utilize the nutrients in a sweet potato-based feed becomes a socio-cultural limitation to pig growth in sweet potato-based diets.

In an attempt to overcome these constraints without requiring extra input, sweet potato root silage was investigated to address the constraints of storage, protein content, starch digestibility, and the trypsin inhibitor. The first root silage trial tested twelve different ways of ensiling sweet potato roots. Six treatments with sliced sweet potato roots and six with grated roots were ensiled with cassava leaf meal, rice bran, sun-dried chicken manure and salt. The laboratory analysis showed that silage with chicken manure and cassava leaf meal had significantly higher crude protein content than rice bran silage ($p< 0.001$) (Table 6). However, only treatments with chicken manure had higher dry matter and ash content than the other silage products. No difference was found between chopped or grated roots. Results for aflatoxin, *Salmonella* and *E. coli* were the same as in the vine trial [10].

Based on the results of the sweet potato varietal selections, root and vine processing, and balanced crop-feeding methods, a manual covering these issues and pig health was produced in Vietnamese

Table 6. Nutrient composition of the 90-day sweet potato root silage (% of dry basis).

Treatments[1]	pH	DM	CP	CF	EE	Ash
Fresh roots		18.64	4.35	4.74	1.02	4.02
1 (20% rice bran)	^{a}3.28	^{a}27.63	^{a}9.18	^{bc}12.17	^{c}9.00	^{b}9.13
2 (20% CLM)	^{a}3.31	^{ab}28.85	^{c}16.62	^{bc}11.31	^{a}4.69	^{ab}8.42
3 (20% CM)	^{e}4.09	^{c}30.48	^{c}16.59	^{a}8.85	^{a}3.82	^{d}16.50
4 (10% RB, 10% CM)	^{c}3.69	^{bc}29.30	^{b}13.35	^{ab}9.70	^{b}6.03	^{c}13.15
5 (10 CLM, 10 CM)	^{d}3.81	^{c}30.75	^{c}17.10	^{ab}9.53	^{a}4.36	^{c}12.39
6 (10 RB, 10 CLM)	^{b}3.48	^{ab}28.51	^{b}13.17	^{bc}10.92	^{b}6.30	^{ab}8.63
P	0.000	0.000	0.000	0.000	0.000	0.000
With CM	3.91	30.00	15.14	9.36	4.74	14.79
With CLM	3.38	29.09	14.93	11.11	5.54	8.47

[1]CLM: cassava leaf meal, CM: chicken manure, RB: rice bran. Six treatments used grated roots and six treatments used sliced roots.

[2]Letters to the left of the means are significantly different ($P<0.05$) across rows.

Table 7. Performance traits of pigs fed ensiled sweet potato vines under on-farm conditions in Vietnam.

Weight	100% fresh sweet potato vine		93.5% sweet potato vine, 6% cassava meal, 0.5% salt		83.5% sweet potato vine, 6% cassava meal, 10% chicken manure, 0.5% salt		P
	Mean	SD	Mean	SD	Mean	SD	
Initial weight (kg)	20.35	3.24	20.75	4.06	21.85	3.92	0.657
Final weight (kg)	60.40a	7.79	66.10ab	10	73.40b	10.47	0.018
Total weight gain (kg)	40.05a	7.86	45.35ab	8.18	51.55b	7.99	0.013
Daily weight gain (g)	431a		488ab		554b		
Relative weight gain (%)	100.00		113.20		128.70		
Feed cost (vnd/kg weight gain)	10784		8875		7383		

* Letters to the right of the means indicate significant difference (P<0.05) across columns (Tukey test in Minitab 12.21).
vnd: Vietnamese dong, 15000vnd≈USD$1

for farmers and extension personnel. This manual was later published in English but covered only the issues that had been researched (i.e., the section on pig health was not included) [9].

Due to the large volume of sweet potato root and vine production in China, particularly in Sichuan Province, it is logical to consider manufacturing dry pellet feed with sweet potato as the major ingredient instead of maize. This is particularly relevant in Sichuan where there has been an enormous increase in small-scale rural backyard feed manufacturing in recent years. If the technology can be developed, such feed could have large implications for animal feed production and marketing in China. A premix developed by the Sichuan Academy of Animal Sciences (SAAS) contains a mixture of amino acids, minerals and vitamins, and a protein concentrate to supplement a sweet potato-vines/roots-based diet which is deficient in these elements. SAAS experiments indicated a 20% improvement in feed efficiency with the premix while achieving 30% improvement by supplying protein concentrate and lowering the feed/kg weight gain cost by 15-20% [5].

3.3. Pig husbandry

On-farm feeding trials followed the processing trials in Vietnam to test the effects of these silage feeds on pig growth. Sweet potato vine silage feed trials compared vines ensiled with cassava meal and vines ensiled with sun-dried chicken manure and cassava meal in terms of pig growth and economic efficiency. The results showed that pigs fed the preparation containing chicken manure achieved statistically higher growth rates than those fed fresh vines (Table 7). The chicken manure preparation was also significantly cheaper (cost per kg of weight gain) than the other two preparations [9].

Another root silage trial compared the effects of uncooked root silage plus rice bran, uncooked root silage plus sun-dried chicken manure, and cooked fresh sweet potato roots (control group) on growth and economic efficiency. The results showed DWG of pigs to be 605, 640, and 552 g, respectively (Table 8). These differences were, however, not statistically significant because of the small sample size involved (n=42) and the large standard deviation, resulting from high variation among the seven households and the types of pigs. The most important result was that the modest increase in growth was achieved without cooking. With such constraints lifted, farmers subsequently tripled their pig production [10].

A number of silage trials followed to help farmers manage the seasonal variation of feed sources. Trials were conducted to combine cassava roots with sweet potato vines, sweet potato roots with peanut stems, and sweet potato roots with sweet potato vines. These trials compared the use of fresh, dried, and

Table 8. Performance traits of pigs fed fresh sweet potato (SP) roots and two types of grated sweet potato root silage under on-farm conditions in Vietnam.

Weight	100% fresh SP roots cooked		79.5 SP roots, 20% rice bran, uncooked		79.5 SP roots, 20% manure, uncooked		P
	Mean	SD	Mean	SD	Mean	SD	
Initial weight (kg)	21.75	4.78	22.96	2.86	21.89	2.86	0.628
Final weight (kg)	70.96	13.31	76.82	12.19	78.93	10.58	0.208
Total weight gain (kg)	49.21	9.92	53.86	10.04	57.04	8.73	0.108
Daily weight gain (g/d)	552	186	605	158	640	145	0.283
Rate of weight gain (%)	226		234		261		
Cost wt. gain (vnd/kg)	6724		7354		6767		

ensiled roots, vines and stems on pig growth so that farmers could have a host of choices of feeding methods and combinations. The results of one trial showed that feeding sweet potato roots ensiled with 15% fresh sweet potato vines yielded the same growth with less cash input: this silage uses up the farm crop while yielding better economic efficiency [7].

Responding to the farmers' need to turn the voluminous, currently unusable peanut stems into a viable pig feed, trials were designed to seek ways of ensiling these stems alone or with sweet potato roots. The results showed that sweet potato roots ensiled with 15%, 30% or 45% peanut leaves, had higher pH (i.e., not as acidic) and crude protein levels than roots ensiled with an equal amount of sweet potato vines. This generates additional income because peanut leaves have no cash value while the price of sweet potato vines for pig feed can be quite high during the off-season. As farmers in northern Vietnam increase peanut production to meet the demand for export peanut oil processing, the use of peanut stems as feed has the potential of contributing considerably to rural incomes. An on-going pig feeding trial indicates higher growth rate in those fed on sweet potato roots ensiled with 15% peanut stems than those ensiled with 30% peanut stems or 15% sweet potato vines.

The use of the uncooked diet with silage has resulted in farmers increasing pig production; many now raise enough pigs per cycle to utilize the manure for biogas production while applying the residue as fertilizer. The author's project contributed half of the funds (US$130) necessary for the construction of the biogas facility for the main collaborating farmer, using it as a working model for other farmers to observe. This has transformed the kitchen from a slow and smoke-filled, firewood-utilizing environment to that of a clean and rapid, gas-utilizing one. Assisting additional farmers with biogas use is beyond the scope of the research project but it is hoped that other farmers will be able to afford such construction with the extra income generated from improved pig production.

While pig husbandry interventions in Vietnam mainly focused on feed, the emphases in Papua have been more diverse, because Dani farmers have very limited knowledge of pig production.

The widespread diseases in the Baliem Valley made it clear that if health was not addressed, the improvement of nutrition would be in vain. A disease survey in the Baliem Valley, based on the clinical post-mortem examinations of 37 pigs from several villages showed that parasites were the most important disease problem [11]. Parasites with a direct life cycle, as well as parasites with an indirect life cycle, were recorded. Modifying husbandry techniques to reduce parasite burdens and limit their impact on production was suggested as a sustainable improvement.

To convert the husbandry technique to one of confining pigs in pens 24 hours a day, as in the rest of the world, would require changes in the Dani's whole way of life. Instead of proposing this drastic measure, various modified models that take an integrated approach to enhance this system were planned and tested. The extended Dani families live in a compound known as a *sili*, which consists of a few stick and mud structures with straw roofs. These structures include a man's round hut, one or more women's round huts which house the multiple wives and children, a long rectangular kitchen which consists of several fire pits, one for each woman, and a row of rectangular pig pens across from the kitchen. In another model the women's hut is attached to the kitchen which in turn is attached to the pig pens. There is little separation of humans and pigs, and pigs often eat human faeces and walk freely around the kitchen and over the food.

The modified design proposed involves setting aside a *laleken*, which is a holding field behind the pig pen that is large enough for pigs to roam, graze, and root for worms. High-protein grasses can be planted in the *laleken* in a closed-in area so that the pigs cannot get out to access human faeces. This modified system is designed to address various problems with the following specific points built into the design:

- Separate human faeces from pigs in order to break the chain of diseases;
- Plant fences around the *laleken* consisting of tree species whose leaves can be used as pig feed while the fast-growing species can be cut for firewood. This avoids the high expense of wood fences and allows the farmers to build the *laleken* large enough for pigs to find sufficient feed during the day. The World Agroforestry Center (ICRAF) recommended three genera of trees (*Gliricidia, Calliandra* and *Erythrina*) for this purpose. Mulberry (*Morus* sp.) trees, the leaves of which were tested as pig feed at the Livestock Research Center of Indonesia (Balitnak) with success, were also included;
- Plant fodder trees in a few places in the *laleken* in order to provide shade;
- Plant high-protein grasses identified in the local area, such as *wurikaka*, a local grass eaten by pigs and often by humans, containing 18.3% crude protein. Two other grasses, *Calopogonium* sp. (17.1%) and *Sida rhombifolia* (15.5%) also have higher protein and lower fibre content than introduced forage grasses such as *Paspalum atratum* and *Stylosanthes guianensis* (Table 9).
- Retain pigs in the *laleken* to eat forage grasses and root for worms during the day and return them to pens at night.
- Provide a water container and a pool in the *laleken*; the former for drinking water and the latter for pigs to wallow in when the temperature gets high.
- Divide the *laleken* into two paddocks; while one is being grazed, fallowed grasses should be allowed to grow in the other one.

Table 9. Nutritional contents of dried local grasses and introduced alternative dried forage in the Baliem Valley, Papua, Indonesia.

	% crude protein (on dry basis)	% water	% crude fibre (on dry basis)
Locally found grasses			
Wurikaka	18.32	7.70	30.96
Calopogonium	17.13	8.43	31.86
Sida rhombifolia	15.48	8.89	32.05
Dokop	13.80	10.15	28.00
Yelaga	13.78	7.77	28.03
Girimi	11.81	8.07	--
Lukaka	11.19	9.46	26.98
Suwiriwi	10.55	9.98	27.77
Jagat	6.53	7.64	37.69
Introduced forage crops			
Stylosanthes guianensis	12.18	9.17	34.64
Paspalum	8.90	8.35	34.36
Setaria	6.39	8.34	27.02
Sweet potato vine*	16-20		14-22

*CP content of sweet potato vines varies with the varieties.

- Cultivate sweet potato fields behind the *laleken* with clones of high DMY in the roots and/or high protein yield in the vines to provide easy access of feed. Jerusalem artichoke (*Helianthus tuberosus*), which is also used as a pig feed, has been introduced to test its adaptability in the Baliem Valley; if adaptable, it will be planted with sweet potato to diversify the diet.

Other related trials were also designed and tested to complement the overall design of the modified management system. All the trials were implemented on-farm by local farmers, under the supervision of project personnel. These include:

3.3.1. Nutrition and feeding trials

These trials were designed to test the effects of feeding cooked sweet potato roots or silage, instead of mainly uncooked roots (the roots are cooked only 28% of the time), on pig growth. Unlike in Vietnam where a wide range of supplemental crop feeds is available, the available feed here is limited to sweet potato roots and vines, rice bran that is used for silage, and banana trunks. So far the results have shown the positive effects on growth of feeding cooked roots, and the effects of silage are currently being tested.

3.3.2. Water intake trials

Local pigs are rarely given water except that which comes with the occasionally cooked roots. It is hypothesized that the lack of water has adverse effects on pig growth, though it is highly possible that pigs find enough water while roaming the forest. It is also speculated that local pigs may have evolved to need less water than exotic pigs. The water intake trials tested the effects of a constant water supply versus water that only comes with cooked roots on local and exotic pigs. The unexpected result from the trial is the observation that a higher water intake seems to contribute significantly to growth in local pigs while it made little difference to the exotic pigs. Further trials with greater control are needed before definite conclusions can be drawn.

3.3.3. Disease control with laleken trials

It was hypothesized that pigs kept in the *laleken* are less susceptible to parasites and therefore grow faster. The trial consisted of three treatments: A) small *laleken* with a dunging area, B) medium-size *laleken* without a dunging area, and C) large *laleken* without a dunging area to control disease but large enough to provide additional feed. The laboratory results of the postmortem examination of one pig from each group showed worms in the kidney, stomach, and intestines in groups B and C, but none in Group A. This result, combined with the growth data, suggests that: 1) a small *laleken* or a dunging area is helpful in controlling parasites, and 2) a larger *laleken* provides additional feed that compensates for the disadvantage of parasite infestation. Therefore, one can hypothesize that the combination of having enough space to root for additional feed and having a dunging area will help reduce the parasite burden while improving growth. The subsequent trial which is currently underway was designed specifically to test this hypothesis.

3.3.4. Fertility trial

The postmortem examinations, the systematic observations of sow/piglets, the long nursing period (up to 6 months), and the post-weaning practice (lack of boar stimulation) all indicated significant below-average fertility. A fertility trial tested the length of time for freshly-weaned sows to come into oestrus in the presence of a boar. The data thus far show that 4 out of 5 sows that received boar stimulation mated within 3 days.

4. Conclusions

Chinese farmers use the greatest volume of sweet potato as pig feed, Vietnamese farmers allocate the greatest proportion of sweet potato production for pig feed, while Papuan farmers depend the most on sweet potato as pig feed. These three cases constitute the most significant examples of feeding sweet potato as pig feed, though such a practice is widespread throughout the world. Though these three systems share the same characteristics of using sweet potato as pig feed, the agronomic, ecological, marketing, and even socio-cultural contexts vary greatly resulting in distinctly different production and marketing systems. A comprehensive assessment of the production and marketing system of each case was thus essential before technological research could be designed or launched to improve the system. Where a substantial volume of sweet potato is available and widespread backyard supplemental feed manufacturing is mushrooming, as in China, the logical method for improving the system is to devise the technology to make sweet potato-based pellet feed, or to balance the sweet potato-based diet with specific commercial supplements. Where sweet potato is harvested at various seasons during the year and other supplemental farm crops are available, the logical methods for improvement are to select clones that are suitable for the different seasons and examine ways of combining different crops in different seasons through processing. In the unique situation of Papua, Indonesia (and Papua New Guinea) where pigs and sweet potato are completely integrated into the lives of humans, it is essential to approach the subject in a holistic manner, taking into consideration the socio-cultural contexts and implications. This review of the assessment and enhancement of these three cases serves as examples of approaches to improving traditional livestock systems.

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