EDIBLE AROIDS

Post-harvest Operations

INPhO - Post-harvest Compendium

Food and Agriculture Organization of the United Nations

EDIBLE AROIDS: Post-Harvest Operation

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Preface

One of the characteristics of the post-production sector in developing countries is that it is generally subsistence-oriented in regions that are increasingly faced with high population growth rates, food insecurity, malnutrition and poverty. In addition, the incidence of post-harvest losses remains high at all stages from harvesting to consumption. Innovations in post-harvest management and agro-processing are therefore necessary in order to derive maximum benefits from crop production outputs by reducing losses and maintaining product quality and nutritional value. These outcomes will also catalyse the development of rural-based agro-processing industries which provide employment to the rural population in value-adding and processing activities, thereby reducing poverty. Although they have less economic value compared with other major root crops, the edible aroids are important food materials in the diet of many regions in developing countries. Women in particular, play the most significant roles in their cultivation and post-production operations. Improvements in the post-harvest handling and processing of these crops will take account of women's specific interests and make work easier, improve productivity and raise income through the delivery and marketing of good quality produce.

1. Introduction

Edible aroids (family Araceae) comprise of many underground food crops grown in several tropical and sub-tropical countries. Taro or cocoyam (*Colocasia esculenta*) and tan(n)ia or new cocoyam (*Xanthosoma sagittifolium*) are the most important species. Together they are also called cocoyams in many parts of the world, especially in Africa. For the purpose of this Compendium, the terms 'edible aroids' or 'cocoyams' will be used when both *Colocasia* and *Xanthosoma* are referred to collectively. Where a distinction is warranted to emphasise differences in post-harvest characteristics, the term 'taro' will be used for *Colocasia* , and 'tannia' for *Xanthosoma*. Other edible aroids, notably *Alocasia Cyrtosperma* and *Amorphophallus*, are cultivated globally to a very limited extent, and they are important food crops in some parts of India, Southeast Asia, and the Pacific Islands. However, considering their high economic importance in relation to other types of edible aroids, the information covered in this article will be based on taro (*Colocasia esculenta*) and tannia (*Xanthosoma sagittifolium*).

1.1 Economic and Social Impact of Edible Aroids

Edible aroids contribute an important part to the carbohydrate content of the diet in many regions in developing countries. They produce edible starchy storage corms or cormels. Although they are less important than other tropical root crops such as yam, cassava and sweet potato, they are still a major staple in some parts of the tropics and sub-tropics. In the South Pacific Island countries in particular, edible aroids represent a very high proportion of the root crops. In the South Pacific and parts of Africa taro is a staple food crop, and in the Caribbean and West Africa in particular, tannia is the main edible aroid. Despite the economic importance of edible aroids as a food material in these regions, there is limited scientific information on their post-harvest characteristics, which perhaps contributes to the very limited application of improved post-harvest technologies to maintain quality and improve marketing potential.

1.2 World Production and Trade

Data on world production and trade of edible aroids is difficult to estimate because of their very limited significance in terms of total production of root and tuber crops. Estimated world production in 1988 was around 5.5 million Mt, and constituting about 3.3% of all root crops (FAO, 1988). Total world production area of taro alone was estimated to be about 993 x 10^3 ha in 1983, with 80% in Africa. During this period, global production of taro was 5.607 million Mt, with about 61.33% in Africa and 38.67% in Asia. Estimates made about a decade ago indicated that total world production of the major edible aroids (taro and tannia) was about 5.23 million Mt in an area of 983 million ha, with average yield of 5314 $kg.ha^{-1}$ (FAO, 1991). Production declined by 5.3% from 5.64 million Mt in the 1979-81 period to 5.34 Mt in 1989. Current statistics indicates that increased slowly during the past 5 years from 5.6 million to 8.8 million Mt (Table 1). Although exports increased by over 23% in volume, the value of exports remained fairly uniform over this period. Farmers and exporters interested in future business must ascertain the factors contributing to this trend and the potential impacts on business.

Table 1: World production and trade in edible aroids (cocoyams)

	2000	1999	1998	1997	1996	1995
Production (Mt)	8,834,796	8,823,625	8,697,133	6,621,519	5,977,828	5,586,372
Exports, Quantity (Mt)	-	108,845	108,067	90,881	101,670	88,099
Exports, Value (1000US$)	-	70,840	88,245	73,710	80,971	70,420

Source: FAOSTAT, 2000

1.3 Primary products

Aroids are grown mainly for food. The mature corms and young shoots of edible aroids are mostly used as boiled vegetables, but the corms are also roasted, baked, or fried. Roasted or boiled corms can be eaten alone or with stew. In parts of West Africa, the boiled corms are mashed and used as weaning diet. Mature edible aroids are also processed into flour, which is used to prepare ‘fufu’ that is commonly eaten in Nigeria with stew. In southeastern part of Nigeria in particular, tannia is used in small quantity as soup thickener after boiling and pounding to obtain a consistent paste. Taro chips is another important secondary product. In the South Pacific, young taro leaves are used with coconut cream to prepare a dish called ‘luau’, which is then used to eat the boiled or roasted taro, breadfruit and banana.

Fig. 1. Taro plants in the South Pacific.

1.4 Secondary and derived product

Despite their considerable potential as animal feed, renewable energy source and industrial raw material, the development of agro-industries based on aroids as major inputs remains a theoretical concept despite several positive indicators from research and development. Some aspects of these secondary and derived products will be discussed later in detail in Sections 2.9 and 5.1.

1.5 Requirements for export and quality assurance

Edible aroids are grown mainly on subsistence farms for household consumption or sale in local and regional markets In some growing regions, however, improvements in postharvest handling and availability of airfreight have facilitated export marketing to developed countries, mainly servicing the needs of migrants from the producing areas. There are no international quality standards for export but exporting companies or individuals must meet the phyto-sanitary requirements of the importing country, in addition to the agreed product specifications. This requires good sanitation, clean produce free of debris and soil, good packaging and evidence of quality assurance system to meet the importer's requirements. Corms are susceptible to physical injury during harvesting and postharvest handling and affected corms are downgraded. Extra care should be taken to avoid damage to the corms since this may lead to rapid deterioration during subsequent handling and storage. Taros harvested for fresh marketing are normally washed and the roots and fibres discarded. They are then graded and packed in crates for transportation. Crates are preferred because they are firm and reduce the incidence of mechanical damage to corms. Corms destined for storage are ***cleaned but not washed***, and may also be cured to enhance repair of any physical injury present. Under ambient conditions of high temperature and high relative humidity common in most tropical regions, wet tissue provides conducive environment for microbial growth and spread to healthy produce.

1.6 Consumer Preferences

There are regional differences in consumer preference and utilisation of cocoyams. In areas such as the South Pacific where they constitute a staple diet, taro (*Colocasia esculenta* (L.) Schott *and Alocasia* spp) are most widely grown and used, whereas in many parts of Africa, these of less importance. In southeastern Nigeria in particular, these are seldom eaten alone, but commonly pounded in a mixture with gari or yam. In fact this consumer preference pattern threatens the future contribution of many cocoyam varieties to the agricultural (food & raw materials) system in these regions. Local and international efforts are necessary to preserve the existing genetic biodiversity of these important crops.

1.7 Nutritional Facts

Notwithstanding their high starch content, edible aroids have a higher content of protein and amino acids than many other tropical root crops (Kay, 1987). Protein quality is essentially the same for all aroids determined with lysine as first limiting amino acid (chemical score 57-70) (Bradbury, 1988). The nutritional values of the major edible aroids are presented in Table 2. A summary of comprehensive chemical analysis of large samples of aroids from different countries is also presented (Table 3). The highlights of the nutritional and chemical composition are presented (Table 4). The purpose of these data is to assist food process engineers and many other scientists in developing improved food processing operations as well as new food products, particularly those aimed at enhancing the nutritional status of people living in regions that produce cocoyams. Considering the huge variation in compositional data of raw material in general, these data must be used only as a guide in making nutritional calculations.

Table 2: Nutritional content of the major edible aroids per 100g edible portion.

Constituent	Taro (*Colocasia esculenta*)			Tan(n)ia (*Xanthosoma saggittifolium*)		
Major nutrients	Corms	Corms	Leaf stalks	Corms	Leaves	Shoots
Calories	102	94	24	133	34	33
Protein (g)	1.8	202	0.5	2.0†	2.5	3.1
Fat (g)	0.1	0.4	0.2	0.3	1.6	0.6
Carbohydrate (g)	23	21	6	31	5	5
Fibre (g)	1.0	0.8	0.9	1.0	2.1	3.2
Calcium (mg)	51	34	49	20	95	49
Phosphorous (mg)	88	62	25	47	388	80
Iron (mg)	1.2	1.2	0.9	1.0	2.0	0.3
Vitamins						
ß-carotene equiv. (µg)	trace	trace	180	trace	3300	-
Thiamine (mg)	0.10	0.12	0.02	0.10	-	-
Riboflavin (mg)	0.03	0.04	0.04	0.03	-	-
Niacin (mg)	0.8	1.0	0.4	0.5	-	-
Ascorbic acid (mg)	8	8	13	10	37	82

Source: (FAO, 1972; Platt, 1962; Tindall, 1983)

Table 3: Data on nutritional and chemical composition of different varieties of edible aroids from different countries

	Taro	Tannia	Giant taro	Giant swamp taro	Elephant foot yam
Number of samples and countries	71 samples from 3 countries	37 samples from 2 countries	37 samples from 2 countries	27 samples from 2 countries	7 samples from one cultivar
Moisture %	69.1	67.1	70.3	75.4	77.8
Energy kJ.100 g^{-1}	480	521	449	348	336
Protein %	1.12	1.55	2.15	0.51	2.24
Starch %	24.5	27.6	21.5	16.8	16.6
Sugar %	1.01	0.42	0.96	1.03	0.14
Dietary fibre %	1.46	0.99	1.85	2.78	1.45
Fat %	0.10	0.11	0.10	0.16	0.06
Ash %	0.87	1.04	0.92	0.67	1.36
Minerals (mg.100 g^{-1})					
Ca	32	8.5	38	182	97
P	70	53	44	16	67
Mg	115	27	52	21	47
Na	1.8	6.6	30	72	4.1
K	448	530	267	67	622
S	8.5	7.9	12	3.3	12
Fe	0.43	0.40	0.83	0.61	0.51
Cu	0.18	0.19	0.07	0.11	0.18
Zn	3.8	0.52	1.57	2.3	1.05
Mn	0.35	0.17	0.62	0.69	0.31
Al	0.38	0.53	0.36	1.36	0.41
B	0.09	0.09	0.10	0.09	0.17
Vitamins (mg.100 g^{-1})					
Vitamin A (ret. + -car./6)	0.007	0.005	0	0.005	0.07
Thiamin	0.032	0.024	0.021	0.025	0.06
Riboflavin	0.025	0.032	0.018	0.019	0.05
Nicotinic acid	0.76	0.80	0.48	0.46	1.2
Pot. Nic. Acid = Trp/60	0.19	0.33	0.46	0.07	-
Total vitamin C (AA + DAA)	15	14	17	16	3.8
Limiting amino acids + score					
First	Lys 66	Lys 57	Lys 64	Lys 70	-
Seconds	Thr 94 Ileu 93	Leu 81	His 91	Leu 97	-
Organic acid anions and calcium oxalate (mg.100 g^{-1})					
Total oxalate (Ox)	65	42	42	288	18
Soluble oxalate	35	44	17	45	-
Calcium oxalate	43	23	37	399	-
Free calcium	10	0	15	10	-
Malate	107	211	320	106	105
Citrate	102	314	278	86	142
Succinate	168	506	370	295	0
Trypsin inhibitor (TIU.g^{-1})	14	0.3	269	2.5	0.56
Chymotrypsin inhibitor (CIU.g^{-1})	0	0	57	0	-

Source: (Bradbury, 1988)

Table 4: Explanatory summary on nutritional and chemical characteristics of main edible aroids.

Edible aroid	Nutritional and chemical composition
Taro (*Colocasia esculenta*)	Middle range energy, protein and vitamins, high K. Zn, low Na, medium trypsin inhibitor; some cultivars acrid.
Tannia (*Xanthosoma* spp)	Like taro, but high in nicotinic acid, lowest in free Ca (zero) and low trypsin inhibitor; some cultivars acrid.
Giant taro (*Alocasia* spp.)	Middle range energy, highest protein, lowest -carotene (zero), thiamine and riboflavin, high Fe and Mn, low K and Cu, very large amount of trypsin/chymotrypsin inhibitor; acrid.
Giant swamp taro (*Cyrtosperma chamissonis*)	Low energy and protein, high dietary fibre, low vitamins, high Na, Zn and Mn, very low K, large amount of total oxalate and calcium oxalate; some acridity.
Elephant foot yam (*Amorphophallus campanulatus*)	Low energy, highest protein, high total Ca, calcium oxalate, total oxalate, K, Mg, P, Zn, and Mn; some acridity.

Source: (Bradbury, 1988).

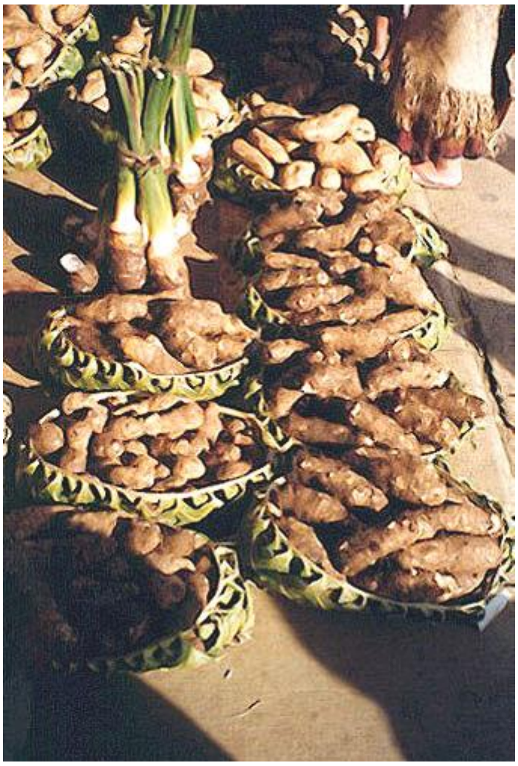

Fig. 2. Edible Aroids at thr local market, Nuku'aloga, the Kingdom of Tonga, Infront are tannia and at the back with the stem intact are tano.

2. Post-Production Operations

2.1 Pre-harvest Operations

The condition of the leaves is a good maturity index for assessing the readiness of corms for harvest. The length of the growing season and yield varies among the cocoyam varieties. Taro matures in 240-300 days from planting but the eddo type matures in 180-210 days. Taro yields may range from 4-6 $t.ha^{-1}$ and up to 15 $t.ha^{-1}$. Tannia matures in 240-420 days after planting and produces small edible cormels 15-22 cm in length attached to large corms. These cormels should be harvested before they produce new shoots. Tannia yields about 6-12 $t.ha^{-1}$ of corms, but yields of 12-20 $t.ha^{-1}$ can be achieved. Data on length of growing season and crop yield are useful in planning harvesting and post-harvest requirements for labour, packaging, transportation, storage, quality control and marketing.

2.2 Harvesting

Edible aroids are mature for harvesting when the leaves begin to turn yellow and start to wither. Harvesting is carried out by lifting the corms by hand. Simple tools such as hoe and knife are used to remove the soil around the corm. Shovels are also used. Although experimental mechanical lifters have been studied, there are no commercial equipment dedicated to harvesting aroids. Mature taro produces a large edible main corm and a few lateral cormels, about 4-10 in number. The main tuber is often harvested with the smaller corms left to develop later. For tannia, on the other hand, mature cormels may be harvested continuously for 500 days or more, leaving the main corm in the ground to develop new cormels.

The main objective of harvesting is to remove the mature crop without physical damage. Most subsistent small-scale farmers harvest their crop for immediate consumption and/or sale while the rest are left underground as a storage strategy until required. Corms are susceptible to damage during harvesting. Damage can occur as a result of the harvesting tool injuring the corm, or as a consequence of rough handling (e.g. corm-to-corm impact by throwing harvested corms into a pile). Physical damage such as punctures, cuts or abrasion lead to high rates of moisture loss and provide avenues for microbial infection. These conditions lead to high incidence of shrinkage and postharvest losses down the handling chain. In many regions, corm harvesting is generally carried out by women who also have to trek considerable distance back to the family house or market. Developing simple and appropriate tools to remove the drudgery of manual harvesting, particularly when the soil is dry and ‘hard’ would be beneficial engineering inputs under these conditions.

2.3 Transport

Harvested corms are stored on-farm or transported immediately to the home, nearby market or handling facility. In many rural subsistence farming systems, the corms are put in a woven basket and carried on the head as in parts of West Africa or on the shoulder where a basket is tied to each end of a stick as in the South Pacific. Bicycles and motorised transport are increasingly being used for transportation, especially where a large quantity of crop is harvested. The quantity of crop and expected market value are important considerations is selecting an appropriate transport system. Mechanised transport has the potential to induce physical damage during haulage on “bumpy” roads. Good shock and vibration absorbers and careful driving will assist in reducing the incidence of damage.

Fig. 3. Baskets for transporting root crops and other food crops in the South Pacific.

2.4 Corm Curing

Although not desirable for good quality produce, wounding of corms occurs during harvesting and trimming, and it is therefore important that harvested crop is cured before long-term storage so as to promote a rapid wound repair process. Curing slows down the rates of physiological and pathological deterioration which lead to losses in quality and quantity. Several wounds are made on tannia corm when the cormels (usually 4-10 in number) are removed, and one wound is ultimately made on taro cormels when they are cut off from the parent corm. Additional wound is also made during trimming to remove the residual planting material from the base of the corms and the petiole of leaf base. These regions have poor healing properties and require curing to prevent subsequent infection and spoilage.

Under traditional post-harvest systems, curing is accomplished by placing corms in the sun until the wounded surface dries out. Corms can also be cured in naturally ventilated barns or other storage structures. Curing is less effective if damage on corms is extensive. Fungicide treatment may be necessary if base trimming is practised. Curing can also be achieved at elevated temperatures in high humidity environment, but chemical application to suppress sprouting has been suggested to cause an inhibitory effect on wound healing and periderm formation (Passam, 1982). Curing corms at 35°C and 95% rh for 5 days reduced the rate of sprouting and weight loss in tannia (Passam, 1982; Been et al., 1975), and temperatures below 20°C have been reported to cause very slow wound healing of dasheen cormels. It was recommended that brief storage of corms under tropical ambient conditions (24 or 30°C with 85% rh) promoted curing in taro and tannia corms (Agbo-Egbe and Rickard, 1991). Other studies reported that the best conditions for wound healing were 34-36°C with 95-100% rh (Rickard, 1981). Under these conditions, wound healing occurred more readily at the top of corms than at the base and sometimes did not occur at the base.

2.5 Cleaning

Cleaning the edible aroids to meet strict export quarantine requirements is an essential part of the postharvest handling system. Currently, New Zealand regulation stipulates that no more than 25 grams of soil per 600 units (or corms) samples. Scraping and/or washing in water at the packhouse clean taro destined for export by hand. Hand cleaning is labour-intensive and takes considerable time and work quality is difficult to control. Although experimental washing of taro corms grown in paddy conditions has been reported, no mechanised cleaning equipment is yet available (IRETA, 1997). Based on an assessment of several crop cleaning machines in Samoa in terms of time taken to clean to export crop standard, uniformity of cleaning, damage to corms, complexity of the machine, and cost, it was recommended that the carrot barrel washer with some manual finishing could be used for cleaning taro corms to meet export standards. The cost of this machine was about US$5000 in 1995.

2.6 Packaging

The two main packaging systems used are woven baskets and crates. The baskets are made of palm tree leaves or coconut leaves. They are suitable for manual transport due the lack impacts and/or vibration that can lead to physical damage of corms. When used in mechanical transport systems, these baskets collapse easily under compression loading. During mechanical transportation, wooden or plastic crates are preferred because they are firm and reduce the incidence of mechanical damage to corms. Crates can be cleaned, thereby contributing to better hygiene and reduced microbial infection of corms. They are also most suited for long distance marketing and exportation.

2.7 Storage

Storage of fresh corms is important for distant marketing, to free farmland for new cropping, and to ensure the availability of seed cormels in the next planting season. But edible aroids have a short period of shelf life, and this creates specific problems with the supply of new planting materials. In particular, storage at ambient temperatures is considered impossible due to very high incidence of fungal decay.

There is considerable variation in the storage behaviour of the different edible aroids. For the two most important edible aroids, taros are more difficult to store than tannia. Under high storage temperature (25°C and above) and humidity (85% and above), it has been found that more sprouting and decay occurred with taro than with tannia cormels (Agbo-Egbe and Rickard, 1991). However, less sprouting and decay occurred with taro at high temperature and low humidity than at high temperature and high humidity but weight loss was higher. Under tropical ambient conditions, tannia cultivars were stored successfully for about 5-6 weeks but up to 60% decay occurred in taro corms.

Traditional Storage

Aroids are stored in a variety of traditional low-cost structures such as shade, hut and underground pits. Sometimes, the corms are placed in boxes before loading into the building while others are placed directly on the storage floor. Corms may also be stored in heaps in a shade and/or covered with straw or plantain leaves. In parts of southern China, it is common practice to pile the corms in heaps and cover them with soil or seal them in leaf-lined pits in the ground (Plucknett and White, 1979). In parts of the Philippines, corms are stored in wooden platforms with the corms arranged in irregular rows and covered with dry grass and finally with soil. As practised in some parts of the South Pacific, corms may be harvested with about 30 cm of their basal petioles attached, tied into bundles and stored suspended in the shade. In pit storage, corms are placed inside pits and covered with leaves and soil.

Storage in leaf-lined soil pits is also practised. The pits or trenches are usually dug in well-drained soil in shaded areas. The trenches may also covered with dry grass and finally soil. These traditional storage conditions reduce moisture loss and promote the curing of wounds. Under these conditions, the storage life of taro corms has been extended for up to 4 weeks with no beneficial effect on the storage of tannia. Fungal infection is also reduced.
Storage losses can be reduced by minimising the occurrence mechanical damage and leaving the corms untrimmed during storage (Cooke et al., 1988). Taro can be stored in shaded pits for about 4 months without significant losses in quality and quantity, and satisfactory storage has been achieved for up 3 months under a variety of tropical conditions. In general, tannia keeps better in traditional pit storage better than ventilated room or barn storage. Mature tannia corms do not deteriorate if left in the ground and it is also common practice to harvest corms for immediate utilisation as required.
Traditional storage systems are mainly suited for short-term storage and have limited success with long-term storage, which is necessary for marketing beyond the harvest period. Existing results are largely variable and in many instances the corms decay and become unfit for human consumption after a short period. Different levels of corm wastage and losses have been reported for different lengths of storage and for the different types of edible aroids (Section 3). It has been shown that edible aroids can be stored at tropical ambient conditions (24-29°C with 86-98% rh) for at least 2 weeks without significant changes in nutritional values (Agbo-Egbe and Rickard, 1991) such as crude protein content and total amino acids. However, resulted in a significant reduction in starch content and increase in total sugar content. The limitations of traditional storage structures have resulted in the search for improved storage systems such as ventilated and refrigerated storage. Appropriate storage technique must be selected based on crop economic value of crop, the intended use, and the skills necessary to operate and maintain the technology under local conditions.

Ventilated Storage

During storage in well ventilated stores (~26°C and 76% rh), tannia corms had 1% weight loss per week but sprouting occurred after 6 weeks. The corms were still edible after 9 weeks storage (Thompson, 1996). Other studies showed that tannia corms may be stored in well-ventilated conditions for up to 6 months (Kay, 1987), although loss of eating quality was observed after 8 weeks. Ventilated storage of corms in the dark at 24°C resulted in 30% decay after 1-3 weeks (Kay, 1987). Factors such as corm maturity, environmental condition, agro-climatology, degree of physical damage, and a host of pre-harvest factors contribute to the variability of results reported. Results in the literature must be tested and adapted under local conditions.

Refrigerated Storage

There is considerable evidence that corm storage life is improved under refrigerated storage conditions (Tables 5 and 6). It must be noted though, that refrigeration technology cost more than traditional and ventilated storage methods, and investments in capital equipment, packaging, technical skill, and power supply are necessary.

Table 5: Recommended storage conditions for tannia (*Xanthosoma* spp. *X. sagittifolium*, Araceae).

Temperature (°C)	Relative humidity (%)	Length of storage
7	80	17.1-18.6 weeks
7.2	80	18 weeks
7-10	80	16-20 weeks
15	85	5-6 weeks

Sources: (Tindall, 1983; Agbo-Egbe and Rickard, 1991; Snowdown, 1991)

Table 6: Recommended storage conditions for taro (*Colocasia esculenta*, Araceae).

Temperature (°C)	Relative humidity (%)	Length of storage
4.4	-	3½ months
6.1-7.2	80	-
7.2	70-80	90 days‡
7.2	85-90	120-150 days#
7-10	85-90	4-5 months
10	-	up to 180 days†
10	-	6 months
11.1-12.8	85-90	21 weeks
11-13	85-90	5 months
12	90	5 months
13.3	85-90	42-120 days
20	60	2-4 weeks

†= Dasheen type; ‡= Malanga type; #= taro root.
Sources: (Tindall, 1983; Thompson, 1996; Snowdown, 1991; Wardlaw, 1937; SeaLand, 1991; Mercantilia, 1989)

Storage life is generally improved at conditions of lower temperature and high humidity. If storage environment can be maintained at 11-13°C and 85-90% rh, the length of storage of taro can be extended to about 150 days. At low temperature (15°C) and high humidity (85%), both taro and tannia were successfully stored for 5-6 weeks (Agbo-Egbe and Rickard, 1991). For tannia, storage at 7°C and 80% rh was found to maintain corms in good condition and good eating quality for about 120-130 days (Tindall, 1983). Storage of taro packed in soil in brick-built containers or in pits stored for up to 5 months in China at ambient temperature of 8-15°C or lower (Cooke et al., 1988). Storage periods of 6-7 months have also been recorded under similar conditions (Plucknett and White, 1979).

International sea- and air-freighting of taro in refrigerated containers and chambers and subsequent storage at 3-5°C in market stores is a common practise for taro grown in the South Pacific and destined. The corms remain in good condition for up to 6 weeks, but once they are exposed to ambient conditions they deteriorate rapidly after 24 hours (Wilson, 1983). Tannia export shipments at 13-14°C from Puerto Rico to the USA were generally in poor condition on arrival after the 9-day journey. The corms decayed after subsequent storage at 15°C and 65% rh for 30 days.

Other Storage Techniques

Successful storage of aroids in plastic bags alone or in combination of traditional storage structures has been reported. The conditions created inside the bag reduce moisture loss and facilitate the curing of wounds. Packing taro corms in plastic bags and closely tying the open end with rubber bands reduced the decay severity and percentage weight loss (Quevedo et al., 1991). For commercial handling purposes, packing in polyethylene bags often follows the selection of good quality corms, fungicide application and draining, and air-drying. It was reported that the storage life of corms in such bags was 26-40 days over those packed in cartons (Kay, 1987). Taros stored in polyethylene bags showed a 6% loss in fresh weight and 50% decay while tannia suffered a 9% weight loss and 30% decay (Passam, 1982). In comparison with traditional storage in trenches or pits, corms kept in polyethylene bags survived well for up to 30 days without appreciable changes in taste and texture. Dipping corms in NaCl (1%) before storage in polythene bags provided additional protection against fungal infection (Rickard, 1983), and the best storage results were obtained when the petioles and corm apex were left intact.

Other storage environments such as coir dust and hull ash have been reported to increase storage life and reduce the severity of decay of corms. In trials with *Colocasia* (dasheen type), placing corms in a medium of rice hull ash extended its usual storage life of corms by 14 days and reduced the incidence of decay (Quevedo et al., 1991). Tannia corms can be stored satisfactorily in damp coir media with significant reductions in weight loss and decay incidence. During a 6-week storage trial in which edible aroids were put in boxes containing coir dust and stored under ambient conditions (27-32°C), taro corms showed a 28% weight loss and 50% decay, while weight loss and decay were 30% and 25%, respectively (Passam, 1982). When corms were stored in boxes containing moist coir, taro showed a 21% weight loss and 50% decay, while weight loss and decay were only 7% and 5%, respectively. For best results, it is important to ensure that the moisture content of the coir is damp and not wet as the latter would facilitate the decay of corms.

2.8 Processing

Taro small starch grains (1-4 µm) compared to the large grains of tannia (17-20 µm), and this makes taro suitable for several food products, especially as food for potentially allergic infants, and persons with gastro-intestinal disorders. Among the root crops, taro is perhaps most widely prepared or processed into more consumable forms. These include poi (fresh or fermented paste, canned, and canned-acidified), flour, cereal base, beverage powders, chips, sun-dried slices, grits, and drum-dried flakes.

Flour can be produce in several ways, but the key unit operations include: peeling fresh or pre-cooked corms and cormels, drying, and grinding into flour. In commercial practice, the flour is made by peeling the corms and cormels, slicing them, and washing them thoroughly with water to remove adhering mucilage. After soaking in water overnight, the slices are washed and immersed in 0.25% sulphurous acid for 3 hr. Finally, the slices are blanched in boiling water for 4-5 min, dried thoroughly at 57-60°C, and then milled into flour. Readers interested in a much detailed and comparative analysis of alternative processes for manufacturing cocoyam flour in different regions should consult Wang (1983).

Taro can also be processed into "poi" which is very a purplish-gray paste, which is considered an excellent food and is popular in Hawaii and the South Pacific. It is sold commercially in plastic bags, jars, or can in Hawaii. Poi is prepared in the following way: (1) the corms and cormels are pressure-cooked, washed, peeled, and mashed into a semi-fluid consistency; (2) the product is then passed through a series of strainers, the final strainer having 0.5 mm diameter grade; and (3) the product is bagged and sold as fresh drink or stored in room temperature to ferment owing to the action of *Lactobacills* spp bacteria. Following the fermentation, the product becomes more acidic (pH declines from about 5.7 to 3.9). In some areas, coconut products may be added to the fermented "poi" before consumption.

Canned fresh poi ("ready-to-eat" poi) is the unfermented product less than 4 hr old containing 18% total solids or more. For a standard 566-gm can, the thermal process requires about 100 min. cooking time at 116°C (54). On the other hand, canned-acidified poi is the unfermented product less than 4 hr old to which 1% w/w commercial grade lactic acid (50% lactic acid) has been added. It usually contains 18% or more total solids, with a shelf life comparable to other canned foods (Sherman et al., 1952). In trials with gamma-radiation, a minimum of 7 kGy was required to increase the shelf life of poi to 7-10 days (Moy et al., 1967). High quality dehydrated poi made by freeze drying which had acceptable quality has been reported; however, the process was considered expensive.

The edible aroids and in particular taro, can be made into about a dozen of different food products. An extensive review of the experimental and commercial processes for these products can be found in Wang (1983), and readers interested in these details are advised to consult this reference. In summary, these reports contained this publication demonstrate that stable, intermediate products such as flour and dried slices could be prepared and further extruded into convenient, ready-to-use, stable forms such as taro rice, noodles, and macaroni.

Manufacture of Animal Feedstuff

Edible aroids have considerable potential in the livestock industry in rural areas that is dominated by small-scale farmers. In many parts of the tropics and sub-tropics where cocoyam and other root crops are grown as staple food, development of the livestock industries is still hampered by the lack of or inadequate production of feeds. Often, imported feeds are too expensive for farmers in these subsistence environments. The use of cocoyam by-products including leaves has the potential to maximise animal production at minimum expense to assist in meeting the food requirements in these areas. Producing animal feed from cocoyams could become a new source of income for some families, and also increase the ability to feed more domestic livestock. Additionally, removal of the leaves would improve field sanitation, and reduce the subsequent land preparation required.

Root crops in general and taro in particular can make an excellent source of animal feed (Coursey and Halliday, 1975). Silage made from the entire crop has been specifically suggested. Indeed, taro corms, cormels, and leaves are used to a limited extent as animal feed. This limited use is attributed to the acridity problem, which renders the leaves, petioles, and corms unacceptable for use without costly, high-energy preparation (Tang and Sakai, 1983). All parts of the plant contain acrid principles, which are irritating to the mouth and oesophagus, and these can be removed by cooking or fermentation.

The potential of cocoyams as an animal feed is considerable and should not be ignored because of the high yield of petioles, top, and leaves. Based on an average of 2 kg of taro tops per plant per 31 weeks and a spacing of 80 x 80 cm, a yield of 52.5 metric tonnes per ha per year was estimated (Carpenter et al., 1983). Some aroids such as giant taro can yield up to 167.8 metric tonnes of leaves and stems per ha per year. Optimum fertiliser application raised the yield from 226.8 metric tonnes per ha per year, the equivalent of 27.2 metric tonnes dry matter with 34% crude protein and 17% carbohydrates. Experimental trials indicate that up to 7 metric tonnes of taro leaves and petioles per ha can be achieved in a 3-month period. Yields of 9-14 and 16-25 tonnes per ha per year fresh weight of tops have been reported for some varieties (Carpenter and Steinke, 1983).

Experimental trench silos have been constructed and used successfully to ensile the leaf, petiole, and whole parts of taro (Wang et al., 1981). Based on test results, it was found that the acrid factor or factors in taro was either neutralised or destroyed whereas the raw, unensiled material was quite acrid and caused irritation to workers handling the material. In addition to these results, other studies on the feeding value of taro silage showed that the fermentation characteristics were comparable with other silage, and that taro silage could meet much of the feed needs for brood sows with no reproductive problems and good litter performance (Carpenter and Steinke, 1983). The problem posed by the high moisture content of taro silage (90-92% water) as an animal feed can be minimised by ensiling taro tops along with other feedstuffs (Table 7). This ensiling process also allows the preservation of taro forage without the use of energy for drying.

Table 7: Types of feeds satisfactorily ensiled with taro tops

Energy Feeds	Dry roughness + grasses	Agricultural by-products
Rolled barley	Rice straw	Rice bran
Rolled corn	Guinea grass hay	Chopped banana plant
Pineapple bran	Pangola grass	Whole pant sugarcane
Molasses	Paragrass	Seedcane tops; Cane trash

Source: (Carpenter and Steinke, 1983)

In many tropical developing countries, edible aroids and other indigenous non-conventional feedstuffs can help to lower feed energy costs and save some quantity of cereals for human food. Results of chicken feeding trials have demonstrated that root crops like taro can serve as base feeds in replacement of cereal (corn) at better cost and performance (Anigbogu, 1995 & 1996; Galvaz, 1980). Analysis of the economic costs of using taro in broiler rations in the Philippines showed that the use of taro meals at 12.5% yielded a profit better and had better rate of return on investment than the control with corn as the base feed, and it was concluded that taro meal can replace corn in terms of profit for broilers at 49 days (Anigbogu, 1996). A minimum of 20 chicks were used for each treatment. Typical composition of different rations and the performance evaluation on broiler chicks are shown in Tables 8 and 9.

Table 8: Composition of different taro-based rations and a control used in feedstuff evaluation.

Feedstuff	Rations				
	A%	B%	C%	D%	E%
Taro	0	12.5	25.0	37.5	50.0
Corn (yellow)	50.0	37.5	25.5	12.5	0
Rice bran	5.0	5.0	5.0	5.0	5.0
Copra meal	12.0	9.8	7.7	5.6	3.5
soybean oil meal	18.0	20.0	22.0	21.0	26.0
Fish meal	10.0	10.0	10.5	10.0	10.0
Ipil-Ipil leaf meal	3.0	3.0	3.0	3.0	3.0
Bone meal	1.0	1.0	1.0	1.0	1.0
Vegetable oil	0	0.2	0.3	0.4	0.5
Salt	0.5	0.5	0.5	0.5	0.5
Vitamin-mineral premix	0.5	0.5	0.5	0.5	0.5
Total	100.0	100.0	100.0	100.0	100.0
Calculated analysis					
Protein (%)	21.79	21.79	21.84	21.84	21.86
Fat (%)	4.33	4.17	3.92	3.66	3.37
Fibre (%)	4.96	4.91	4.86	4.82	4.78
Energy (Kcal.kg^{-1})	2993.27	3025.23	3052.04	3078.85	3105.66
Protein-energy ratio	1:137.37	1:138.34	1:139.75	1:140.97	1:142.07

Source: (Anigbogu, 1996)

Table 9: Cost and feed performance analysis on broiler chicks fed on taro meal.

	Treatment					
Taro meal	0%	12.5%	25%	37.5%	50%	CV (%)
Cost of production (P)†	25.85 a‡	24.24 abc	25.44ab	25.04 abc	22.04 d	4.73
Profit (P)	4.36 b	6.16 a	0.84 c	-3.72 d	-3.77 e	48.59
Return on investment (P)	16.89 b	25.41 a	3.21 c	-14.87 d	-17.11 e	23.54
Feed cost per kg live weight (P)	15.26 d	14.99 d	17.77 c	24.95 b	30.97 a	3.97
Initial weight (kg)	46.9	46.9	46.9	46.9	46.9	-
Weight gain (kg)	1324.8 ab	1335.1 a	1148.6 c	922.1 d	798.47 d	6.28
Feed consumption (kg)	3634 cd	3638.2 cd	3770.9 c	4342.2 b	4678.3 a	4.25
Feed conversion efficiency	2.05 cd	2.02 cd	2.35 c	3.24 b	4.12 a	8.34

† P=Philipine pesos; ‡ Any two means having a common letter in a row are not significantly different at 5% using DMRT. Source: (Anigbogu, 1996).

2.9 Aroids for Rural Agro-Industrialisation

Industrial Raw Materials

Industrial use of edible aroids is very limited although the starch content of taro, for instance, accounts for nearly 78% of the carbohydrate fraction (Table 10). The small size of the taro starch grains (1-4 µm) makes them readily digestible as a food material, but unsuitable as a source of industrial starch. The protein content of taro corms (1.4-3.0% fresh weight basis and about 7% on dry weight basis) is slightly higher than that of other major root and crops. It is also rich in essential amino acids, it is rather low in histidine, lysine, isoleucine, tryptophan, and methionine.

Table 10: Fractional analysis of carbohydrate content of taro corm.

Component	%
Starch	77.9
Pentosans	2.6
Crude protein	1.4
Dextrin	0.5
Reducing sugars	0.5
Sucrose	0.1
Amylose	17-28

Source: (Coursey, 1968; Oyenuga, 1968).

The special quality attributes of aroid starch, which are important for industrial application includes particle size, pasting temperature, and amylose content. The particle size of starch of aroids sets them apart distinctly from more familiar commercial starches. Comparison of the results of microscopy and laser light scattering studies showed that several taro varieties have particle size 1-6.5 µm mean diameter, compared with rice starch at about 5 µm which is the finest of the commonly available starches (Griffin and Wang, 1983). Thus, taro starch literally takes over where the commercial starches finish. On the other hand, the starch of tannia has relatively large grains with average diameter of 17-20 µm. Edible aroids, therefore, cover a unique wide range of particle sizes. In addition to particle size, pasting or gelation temperature of starch is also important during processing and industrial applications. Data available indicates that aroids have high gelation temperatures compared with traditional starch sources (Table 11). These data indicate that edible aroids and taro in particular, could provide a unique combination of small particles with high gelation temperatures.

Table 11: Particle size and gelation temperatures of taro starch, cereal starches, and potato starch.

Type of crop	Particle size (µm)	Pasting or gelation temperature (°C)
Taro-Akalomama	6	64
-Bun-Long	5	71
-Antiquorum (cv Martin)	3.5	68
Wheat	15 (circa)	54
Rice	5	64
Potato	50	60

Source: (Griffin and Wang, 1983).

The literature on starch application technology highlights specific areas in which the properties of aroids starch can be applied in commercial industries. These areas include cosmetics, syrups, gums, modified atmosphere packaging film, fillers/modifiers for plastics, and renewable energy. These industrial applications have been extensively reviewed elsewhere (Wang, 1983) and only a summary of the major potential uses is warranted here.

Syrup Production

World production and demand for industrial syrup has increased considerably in the last few decades and is predicted to continue in the future. Like other vegetable starches, aroid starches could be processed into high fructose enriched syrups (HFES) which is a liquid sugar (sweetener) made from starch. The nutritional value of HFES is similar to that of sucrose, and it is also desirable, inexpensive, and easy to use sweetener. Facilities can be built in areas where starch is available and inexpensive. Local uses include canning, jams, jellies, and soft drinks.

Gum Production

Aroids contain a gum-like substance, which swells in water and becomes hydrated. This gum has potential usefulness as an emulsifying, thickening, and smoothing agent for creams, suspensions, and other colloidal food preparations. Extraction of the gum would also alter the properties of aroid products and reduce their stickiness and viscosity.

Renewable Energy Source

There is considerable global concern on the depletion of non-renewable energy sources and the deleterious effects of fossil fuel on environmental degradation. In most developing countries, low-energy input is often a major limitation to increasing agricultural productivity and overall rural development. Many countries could reduce their dependence on imported oil appreciably by replacing part of their petroleum consumption with alcohol produced from sugar or starch-containing crops Given a favourable domestic economy, the edible aroids would serve well as a feed material for energy generation. The alcohol yield of taro is lower than that of cassava and cereal crops but higher than that of sugarcane and sweet corn (Table 12). The accepted starch-to-alcohol conversion ratio is about 1.67 kg of starch to 1 litre of alcohol, and in the USA alcohol production cost from taro was considered similar to cassava or sugarcane and estimated to be $0.15 per litre in 1978 in comparison to ethanol production from corn at $0.11 per litre.

Table 12: Estimated alcohol yield per tonne (wet weight) and cropping cycle for selected crops.

Crop	Alcohol yield(litre.t^{-1})	Cropping cycle(months)
Taro	142	9-15
Sweet potato	142	5
Sugarcane	67	10-22
Sweet sorghum	76.7	4
Cassava	180	12
Corn	385	3.5
Spring wheat	368	4
Grain sorghum	389	3.5

Modified from (Wang, 1983).

Modification of Plastics

Starch can make up to 40% of plastic compounds based on such polymers as polystyrene, polyethylene, polyvinyl chloride (PVC), and the addition of modest amounts of starch does not materially affect the original physical properties of the plastics. Taro starch is biodegradable and when it is used in appropriate formulation in the production of plastics, it accelerates the biodegradability of the parent polymer. In addition, the starch does not exclude the possibility of recycling the majority of plastics composition. With the increasing global demand and utilisation of processed food and raw materials in general, biodegradability has become increasingly an important requirement in agro-industrial waste management. The small size of taro starch granules (about one-tenth of the size of maize starch granules) makes them superior to other starches for the production of biodegradable plastics. The advantages of using taro starch in plastic production are summarised in Table 14.

Aroid-based Edible Films for Modified Atmosphere Packaging (MAP)

MAP technology utilises the permeability characteristics of films and other packaging materials to influence the exchange of O_2 and CO_2 mainly to control the rate of ripening and other physiological activities of fresh food products inside a package. Starch-filled polyethylene films showed a significant decrease in gas permeability with increasing starch content, and this effect was attributed to the high degree of crystallinity of the starch filler material, a property that is also shared by mineral fillers (Griffin and Wang, 1983). The low fixed gas permeability of taro starch makes it a potential candidate in developing appropriate MAP technologies, especially in the tropical root crops regions where production of root crops is a major part of agricultural production. A taro-based packaging film has been successfully developed but was found expensive compared with low-cost synthetics (Simmonds et al., 1943).

Table 13: Advantages of using taro starch in plastic production compared with other minerals

	Taro starch	Minerals
1.	Density comparable with plastics 1.49 $t.m^{-3}$	High density, ranging from 2.6 $t.m^{-3}$ for silica to 4.6 $t.m^{-3}$ for barytes.
2.	Narrow particle size range. Low porosity. Very small particle size; can therefore be used in surface coatings or very thin films.	Broad particles size range with often a high fines content. Very low porosity, except certain chalks, dolomites and clays.
3.	Simple particle geometry approaching spherical and regular, minimum disturbance to melt rheology.	Irregular particles, mostly fracture fragments from grinding operations. High surface area.
4.	Very low abrasive properties.	Often extremely abrasive.
5.	Colourless and most transparent, can yield translucent or near-transparent products.	Usually colourless but of high refractive index, e.g., calcite-1.66; wollanstonite-1.63; talc-1.59; blends with polymers are white and opaque.
6.	No significant metallic content, starch itself is an accepted food product.	Transition metals may be released, possible interference with antioxidant function, possible toxicity questions.
7.	Thermally stable to 250°C.	Thermally stable to very high temperatures.

	Taro starch	Minerals
8.	Not water soluble, but hygroscopic. Also hygroscopic *in situ*.	Some minerals retain traces of water tenaciously, but not normally hygroscopic *in situ*.
9.	Low fixed gas permeability.	Very low fixed gas permeability.
10.	Biodegradable formulations possible.	Permanent in a biologically active environment.

Source: (Plucknett, 1979).

Fig. 4. Taro leaves on sale in the local markets in Nuku'aloga, the Kingdom of Tonga.

3. Overall Losses

Reliable data on the extent of post-harvest losses of the edible aroids is very limited. Published estimates on magnitude of post-harvest losses in taro ranges from 12 to 15% (NAS, 1978). Different levels of corm wastage and losses have been reported for different lengths of storage and for the different types of edible aroids (Table 14).

Table 14: Storage losses of corms under traditional storage methods in ambient conditions.

Type of aroid	Length of storage	Nature of losses
Taro	5-10 days	became unfit for human consumption
Taro	1-2 weeks	became unfit for human consumption
Taro	2 weeks	decayed rapidly
Taro	6 weeks	28% fresh weight loss & 53% decay
Taro	2 months	50% loss
Taro	3 months	more than 30% wastage
Taro	5 months	95% loss
Tannia	2 weeks	5% decay
Tannia	6 weeks	35% fresh weight loss & 40% decay.

Source: Compiled from (Passam, 1982; Gollifer and Booth, 1973; Baybay, 1922; Rickard, 1983).

4. Control of Pests, Diseases and Disorders

Like most root and tuber crops, the edible aroids are susceptible to some pests and diseases during growth and post-harvest. Slugs may damage corms creating wounds, which provide entry of secondary disease organisms. Weed-free fields and hilling may help reduce slug infestations. The snail has become a major threat to taro production in many growing areas, and yield losses of over 60% can occur from feeding in both the foliage and the corm. There are currently no blue-prints to eradicating the problem, but hand-picking, irrigation with saline water, and copper based pesticides are among the practices currently being tested for control of this pest at the University of Hawaii. With increasing concern about chemical sprays, farmers should monitor their crop regularly and remove these pests when they appear. Several cultural practices are recommended to reduce the incidence of pests and diseases in field including the use of healthy planting material, avoiding contaminated fields, physical removal of diseased plants growing in the field, and increased plant spacing to enhance ventilation. Weeds may also contribute to poor yields by competing for available nutrients and growing space. It is recommended that planted fields be weeded regularly to ensure that crop is free from weed competition during the first three months following planting.
Post-harvest rots and decay of stored corms is a problem in edible aroids and can be caused by representatives of all the major taxonomic groups (Cooke et al., 1988). Fungicide application is often necessary and to be effective, they must have a large spectrum of activity to cover the broad range of decay causing microbial organisms. Tannia suffers from far fewer postharvest problems than does taro and fungicide treatment is often recommended (Agbo-Egbe and Rickard, 1991). Microbial rotting and decay in stored edible aroids has been delayed with varying degrees of success following pre-storage application of fungicides as dips and dusts. A summary of major fungicides applied and their effectiveness is presented in Table 16. It should be noted that Sodium hypochlorite is cheaper and safer to handle than other fungicides and leaves no residue on the corms (Jackson et al., 1979). To be effective, the fungicide must be applied within 24 hours of harvest. In addition to fungicide treatment, waxing and chlorine dips also reduce storage losses of tannia (Burton, 1970). As in all cases, the use of fungicides and indeed all agro-chemicals, must be checked with appropriate local agrochemical authority or agency as well as importers since there are many regulations limiting the use of certain materials.

Table 15: Fungicides commonly used to control postharvest decay of edible avoids

Fungicide	Effectiveness
Benomyl	- effective where *Botryodiplodia theobromae* is the predominant decay organism - ineffective against *Phycomcyetous* fungi - recommended in countries where *Phytophthora colocasiae* and *Pythium splendens* cause major storage losses.
Copper oxychloride	- control corm rots caused by *P. colocasiae*
Captafol	- only delays *B. theobromae* rots by ~10 days
Mancozeb	
Sodium hypochlorite	- effective against all common storage decay fungi in the Pacific except *Sclerotium rolfsii*

Source: (Cooke et al., 1988).

The onset of dormancy is influential in edible aroids because it determines the storage life of corms. Storage is no longer possible once sprouting occurs. Although it is believed that corms generally exhibit short dormancy (O'Hair and Asokan, 1986), no experimental evidence is available to support this. Edible aroids are susceptible to chilling injury (CI) at low temperature storage although the phenomenon has not extensively investigated. Internal browning due to CI can occur after storage of taro at 4°C for 10 days.

5. Economic and Social Considerations

5.1 Overview of costs and losses

Edible aroids are important food materials in many parts of the world. Most of the crop is grown at subsistence level and there is a dearth of information on costs and extent of losses. Despite the general hardiness of the corms compared with other root and tuber crops, they are very susceptible to physical injury during harvesting and post-harvest operations. These losses have been estimated at about 15%. High incidence of pests such as the snail can reduce losses by up to 60% in worst affected areas. The taro blight disease is still a major obstacle to production in many areas such as Samoa, which suffered a total loss of the industry in the early to mid 1990s.

5.2 Major problems

Edible aroids have short storage life under the ambient conditions prevalent in most growing areas. Harvesting is a difficult operation, particularly during the dry season. Harvested corms are also susceptible to water loss reduces the saleable weight and income of farmers. These problems demand innovations in harvesting and storage technology that are appropriate to the smallholder farmers who cultivate these crops. Improvements in harvesting systems that reduce the occurrence of physical injury to corms while reducing the drudgery of hand harvesting will also be beneficial.

5.3 Gender aspects

Women carry out most of operations, from planting to weeding and harvesting and dominate the edible aroids industry. In many parts of Nigeria, these are planted in home gardens and do not represent the major crops for the family. Industrial use of these crops is very limited at present. Technologies that improve the harvesting and post-harvest handling operations will assist in improving the working condition of the women who provide the backbone to the industry.

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7 Annex –

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