The potential of growing Yacon and other Lost Crops of the Incas and Jerusalem Artichoke as crops and functional foods in Ireland

A report for

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Contents

Table of Figures:

List of Tables

Executive Summary

For many years I have been growing a number of crops from the highlands of South America here in Ireland. We all know that the potato originates from Peru/Bolivia but for some bizarre reason all the other amazing "Inca Crops" were never taken by the Spanish invaders for world-wide cultivation. Only the potato, sweet potato and maize have spread throughout the world. In recent years, other crops from the Incas – quinoa and amaranth – are quickly gaining popularity. Most other crops have drifted into obscurity. Only in the highlands of Peru and Bolivia do these amazing crops still exist.

There is renewed interest in these crops throughout the world. Many of these Inca crops are grown in New Zealand, UK, Czech Republic, Japan, China, and the Netherlands and are trialled in many countries throughout the world.

There is a large increase in health conscious consumers as can be seen in the number of health powders and products for sale in every shop. These health conscious consumers are rapidly changing their diet and creating a demand for new products and yet agriculture in Ireland is slow to react to these changes. All of these products are imported even if many of them could be produced in Ireland. Farm diversification could provide an additional income stream and thus more resilience in a volatile market.

While I studied many Inca crops on my travels and have grown many of them here in Ireland, in this report I focussed on the two crops which have the best commercial potential for production and the most promising health properties – namely Yacon (*Smallanthus sonchifolius)* and Jerusalem artichoke (*Helianthus tuberosus*). Yacon is from South America and Jerusalem artichoke originates from North America. Both crops are extremely high yielding and with known health benefits. A brief description is given for a number of other interesting Inca crops which are suitable for the Irish climate.

My findings are:

1. There is a massive potential for the production of yacon and Jerusalem artichoke in terms of yield potential and profitability.
2. A number of bioproducts can be derived from Jerusalem artichoke and yacon – inulin, fructooligosaccharides, fructose, natural fungicides, antioxidants and bioethanol.
3. Both yacon and Jerusalem artichoke have shown potential health benefits for people suffering from diabetes.
4. Oca, mashua and other Inca crops could find a place as a niche or specialist crop in an ever more diversified diet often promoted by TV chefs.
5. There is no expectation that these crops will replace our staple crops but that they can play an important part in a more diverse future food system.

This report has been developed as a result of visits, interviews, horticultural crop trials research organisations, plant breeders, growers, agronomists and manufacturers.

Introduction

I have been involved in organic horticulture and food production for over 25 years, running market gardens, training students, lecturing at universities and writing and publishing gardening books.

For the last 20 years I have grown and studied a wide range of food crops – many of them still little known in Ireland and even Europe. The Irish climate is ideal for crop production and yet only a small percentage of organic fruit and vegetables are produced in Ireland. This leaves a great opportunity for growers to develop new markets. Diversification of crop production and finding new crops for evolving markets especially as functional foods has great potential.

Of all the crops I researched the following two crops showed the greatest potential in Ireland due to their high yield, disease resistance and multi-use function.

The first one is one of the Lost Crops of the Incas – yacon, and the second is Jerusalem artichoke which originates from North America and had been introduced to Europe many centuries ago.

As part of the GFP group with six fellow scholars from all over the world, the countries visited included Italy, Canada (British Columbia), USA (Washington DC and Texas), Argentina and Chile. The GFP trip enabled me to understand the bigger picture of worldwide agriculture. It was enlightening to see the diversity of farming enterprises all over the world, the different scales of operations and different levels of sustainability.

On my own travels I visited Peru, Bolivia, New Zealand and Hong Kong. Peru and Bolivia are the homelands of some of the most important food crops and most importantly the potato. There are over 3,000 native potato varieties in Peru. It remains a mystery why only the potato made it to world fame and all the other crops that were developed by the Incas in the 15th Century are still unheard of. These are the Lost Crops of the Incas and only recently has there been an immense upsurge in these crops that were luckily kept alive by the native Quechuans and Aymara cultures in Peru and Bolivia.

Over the last few decades agriculture has increasingly become specialised focusing on fewer and fewer crops. Worldwide over 50% of proteins and calories are coming from only three crops – maize, wheat and rice. There are only about 150 crops which have been commercialised. However throughout the world there are over 7,000 edible plants which were developed throughout human history with many of them still present in rural areas. These crops have never been developed further by science to date and thus have the greatest potential for further development.

Many of these crops are often suitable marginal ecosystems and may grow in difficult areas where modern commercialised plant could not grow. This capacity will become increasingly important in a world with unpredictable weather conditions and more and more crop failures

as a result of it. A more diverse food system is a lot more resilient to these changing weather patterns.

Most of the underutilised crops can be grown with very low inputs both in terms of fertilisers and plant protection products.

Objectives

The main objectives of this report are to:

a. Explore the production of novel food crops in Ireland.

b. Research how the crops are grown in their native countries.

c. Research the literature on growing methods, potential as functional food ingredient, potential health benefits and other multi-use functions.

d. Evaluate growing trials of these crops in Ireland.

e. Explore potential markets for these crops as fresh vegetables or functional foods.

1. The Lost Crops of the Incas

1.1 Introduction

The Nuffield Scholarship enabled me to fulfil my lifelong dream to find and study the Lost Crops of the Incas.

For many years I had this passion for growing all these unusual and most adaptable crops from South America which for some bizarre reason were used for world-wide cultivation. Only the potato, sweet potato and maize have spread throughout the world. In recent years, other crops from the Incas – quinoa and amaranth –are quickly gaining popularity. However, most of the other incredible crops have drifted into obscurity. On my travels through Chile and Argentina these native crops had completely disappeared and people have adopted a complete western diet. Only in the remote highlands of Peru and Bolivia do these amazing crops still exist.

Apart from the potato, the Incas had 10 different edible tubers and very importantly – each one belonged to a different plant family. Each type also had hundreds of local varieties. So if one type gets destroyed by pests, diseases or unfavourable environmental conditions, the remaining ones were unaffected.

Figure 1*: Andean tuber crops*

This is quite an amazing survival strategy, especially when compared to Ireland where in 1845 the main source of vegetable was the potato and with predominantly only one variety (Lumper) grown. This was the first large-scale experiment of a monoculture with disastrous consequences when a quarter of the population died from starvation or emigrated.

Apart from the different tuber crops, the Incas also developed many grain varieties. Quinoa and amaranth (locally called kiwicha) are already well known in the western world and used as a gluten free and health promoting alternative to mass produced wheat. Quinoa is already grown at field scale in Europe. Kaniwa is the third grain and only known in the highlands of Peru. There are also a number of amazing legumes. My favourites were the Nuna popping beans and tarwi – an edible lupin.

1.2 The Andes and the Incas

The Andes Mountains are one of the tallest and most inhospitable areas in the world but yet the ancient Incas not only managed to survive in this unfriendly climate, but even managed to tame the landscape and to breed some of the most important food crops.

From 1483 until 1533, the Inca Empire comprised most of western South America. Large parts of Ecuador, Bolivia, northwest Argentina, Chile and a small part of modern Colombia made up this vast Empire. The Inca language was Quechuan. The Quechuans still live in the highlands of Peru and still follow the same traditions as long ago. It's interesting that the Incas only made up a very small percentage of their population. There were only about 15,000 to 40,000 Incas who ruled over a population of around 10 million people.

In 1533, the entire empire was destroyed by a small group of Spanish invaders under the lead of a swineherd's son – Pizarro.

Figure 2*: Pizarro conquering the Incas*

1.3 The Incas as plant breeders – Moray

Moray is believed to be the first agricultural research centre where seeds of wild edible plants or semi-cultivated plants from all over the Inca Empire were trialled and disseminated throughout their empire. Pollen samples found in Moray support this hypothesis.

The potato and all the other crops were already eaten thousands of years before the Incas established their kingdom, but the Incas were amazing plant breeders who developed the potato and other crops even further.

Figure 3*: Moray terraces – an ancient plant breeding centre*

The Incas were aware that only a healthy, sustainable agricultural system is the guarantee for a society's stability.

The Moray terraces are perfectly round - each terrace is about 2m tall spanning a height difference of about 300m. There is a temperature difference of 15°C from the bottom terrace to the highest one.

Not an inch of space was wasted for steps as they are built into the terrace.

Figure 4*: Steps at Moray*

As the Incas brought more and more food plants back from their conquests to Peru, they trialled them in Moray and grew them at different altitudes. The low circle in the middle is perfectly drained and never floods. This area was reserved for growing coco leaves which are still used in the highlands for medicinal and religious purposes. Coco plants would only grow in the Amazon region but a special micro-climate in the Moray terraces enabled coco plants to grow in the highlands. In the centre of Moray there is still the foundation of the Head Gardeners house. This moving of crops throughout the continent is what makes South American crops so much more adaptable even to this day.

The Incas were either lucky or possibly even knew that these crops from different regions cross-pollinated. The big jump in potato development came when many different species of potatoes were grown close together and cross-pollination occurred naturally. Their seeds (true seeds) may have fallen on the ground and germinated and produced lots of new cultivars. The better or most suitable ones were selected and grown again.

1.4 Incas as agricultural and engineering specialists

a. Structures

The Incas managed to tame the wild landscape of the Andes and not just to survive on but to build one of the wealthiest empires in the world.

They created all these incredible structures without the use of wheeled vehicles or even animals to ride on or to pull carts or ploughs. They were equally unaware of steel or iron. There was also no system of writing, except an accountancy system called Quipu using knotted strings to keep detailed accounts of harvests. The stored food was closely monitored by Inca officials.

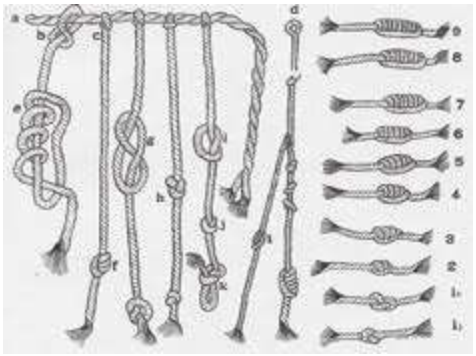

Figure 5*: Inca accountancy system – Quipu*

Without all the above, the Incas managed to create the most monumental architecture such as Machu Picchu and many other incredible buildings as well as the most extensive network of roads that connected all parts of the empire. This was no easy feat in such a mountainous region.

They also managed to build terraces into the mountains, partly to prevent erosion in an earthquake prone region and more importantly to produce food. These terraces were specially designed and cleverly crafted.

Figure 6*: Terraces in the Andes*

At the height of the Incan Empire there were one million hectares of terraces constructed in Peru for food production for the Empire. Only a very small percentage of these terraces are still in use which I thought was such a pity.

Inca engineers also designed cisterns and the most extensive irrigation systems that wound their way down the mountains.

Figure 7*: Inca irrigation system with cisterns*

b. Soil Fertility

The Incas were also fully aware about the need to restore soil fertility by using Guano fertiliser from the islands, dried llama manure and fish heads. One of the possible reasons for the decline of Machu Pichu is that the last Inca civilisation no longer had access to Guano fertilisers. Machu Pichu was possibly the last refuge of the Incas as they fled the Spanish invaders and was located in the middle of the forest with no access to the outside world.

The Incas learned how to manage the soil using ridges and furrows or raised beds (waru waru) which included both irrigation and drainage; they also installed 'Quochas' or depressions on the land which collect rainwater.

Figure 8: *Waru Waru system*

The ancient Waru Waru system of cultivation has only been re-discovered a few decades ago when aerial photos showed a unique landscape of raised beds and depressions and formed unique images.

Figure 9*: Aerial view of Waru Waru*

This system was perfect for marginal soil that suffers from drought in the summer and waterlogged conditions in winter. It captures water during dry spells and allows the water to drain away when it's too wet. Crops have ideal moisture all year round. The water levels in the drains can be modified as required and generally will be drained before harvesting. Researchers found that the temperature around the crop is 3°C higher around the crops as the water retains some warmth which is an ideal method for frost protection.

During the dormant season the drains are cleaned out and the nutrient rich sediment including algae is put back onto the raised beds. In Peru I have seen two systems – one where a river was diverted to flood the drains and the second system was on Lake Titicaca where the lake flooded the drains. Some researchers reported three-fold increases in crop production.

If there ever will be a need to make marginal land more fertile - this is a great system to learn from. Even wet counties in the West of Ireland could be made fertile using the Waru Waru system.

c. Crop rotations and mixed cropping

A potato crop would have been followed with less demanding tubers such as oca, mashua or ulluco. In some areas where land was not limited, the whole communal vegetable field would rotate around the mountain. Often the land is prepared by alpacas in the previous year where lots of animals are enclosed in a coral. They trample and plough the ground as well as fertilising it.

Different crops are grown in one field, however, they are not grown in patches or rows – they are intercropped. Each family would have at least 20 different potato varieties which are grown all over the field and only sorted after harvesting. In between there are odd tubers such as oca, mashua and ulluco grown. Apparently mashua has insecticidal properties and oca is believed to reduce potato eelworm infestations.

d. Storage of food

The ancient Incas had developed incredible methods for preserving and storing food. Freeze-dried potatoes (chunos) and other tubers were kept in storehouses 'qollqa' – these still exist in the mountain areas of the Andes. These were one roomed circular stone buildings generally built on hillside to make use of the cold air. The floor included a drainage channel, a gravel floor and ventilation in the floor and roof.

Figure 10*: Andean storehouse – Qollqa*

Freeze-drying potatoes (chunos) is quite a laborious process, but still it enabled people to have food reserves during lean times of the year and also if there was a crop failure or some environmental disaster. The local Quechuans still use this technique today.

Potatoes are harvested in late autumn and left out in the frost for 3 days and then placed in a running stream for a week. They are then walked/stamped on to squeeze out the liquids. After this they are dried indoors. They finally end up as dry rubbery potatoes that will keep for a number of years. Freeze-dried potatoes are ground up and used for cooking in soups or stews. The little girl in the photo was just grinding chunos for my stew.


Figure 11: *Grinding chunos with pestle and mortar*

e. Tools

One of the most interesting discoveries I made in Peru was the 'chakitaklla' – which is nearly identical to the Irish loy. They call it the foot plough and it's used in the same way as the Irish loy – to flop over sods of grass to grow potatoes. The system of growing potatoes in the Andes was identical to that in Ireland in the 18th century. There was even a similar feel to the landscape as it is in Connemara. I also found another tool which is used for earthing up the potatoes but unfortunately I didn't get the local name.



Figure 12*: Peruvian chakitaklla* *Irish loy* *Peruvian potato ridger*

1.5 Inca Agriculture and Religion

I spent a wonderful day at Kusi Kawsay organic farm in Pisac. It's a training centre for young Quechuans in bio-dynamic gardening. I was meant to teach them some organic techniques but learned far more from them. I really felt their close connection with the land and the plants as well as to the larger being – Pachamama – Mother Earth. They explained that she is all giving and how important it is to give something back to her. Every month there is a festival and it's always based around the earth, the mountain and the sun. In September they have the festival of blessing the seeds. The whole community gathers and the elders come down from the mountains, all seeds that are to be sown this season are spread on blanket and the elders chant and spit home-made chichi beer over the seeds. Then the whole community walks to the field where the crops are to be grown and chant.

Figure 13: *Quechuan ceremony - Blessing of the seeds*

The youngsters – only in their late teens – were very inspirational. I asked them if gardening makes them happy and Juan said 'Of course – when I'm in the garden and touch the soil, I share my problems with Mother Earth'. They also have a project of playing music to plants to see what effects it has on them. One of them plays the harp in the garden first thing in the morning – for the plants – just like the elders did in the past. It's wonderful to see a community reviving old traditions, rather than trying to copy our destructive methods.

Figure 14: *Quechuan mountain farmer*

2. Lesser known food crops from the Andes – Plant Profiles

2.1 Introduction

In this Nuffield report I focus on the two most promising crops for world-wide cultivation – one of them is a lost crop from the Incas – Yacon and the second is a North-American crop – Jerusalem artichokes. I focussed on these two as they show excellent growth potential as well as exhibiting excellent health benefits.

However, after having studied and grown a wide range of Inca crops I will give a brief description of number of South American crops that can be grown in Ireland and other parts of the world. South American crops are very versatile - just think of the potato which originated in the Lake Titicaca area on the Peruvian/Bolivian border at an altitude of 3,800m above sea level and here in Ireland it grows perfectly close to sea level.

2.2 Oca (*Oxalis tuberosa*)

Oca is a fascinating, beautiful as well as delicious vegetable that is particularly suited to Ireland, especially to the coastal areas which experience only very few frosts. Oca has been grown in many parts of the world and already become popular in top class restaurants. Various food writers such as Darina Allen from Ballymaloe and Dennis Cotter from Cafe Paradiso are already using and promoting this ancient Inca crop as a delicious novelty food.

Figure 15: *Oca harvest in the "Parque de la Papa" (Potato Park) in Ollantaytambo, Peru*

There are so many different varieties, colours and shapes of oca. I have grown numerous varieties of oca in the west of Ireland and some of them showed a very promising yield of up to 7kg/sqm (70t/ha) The yield is very variable though and depends on both the variety as well as when the first autumn frost occurs. Yields of 20 – 30t/ha are more common. Oca plants only start to form tubers after the 21st September and then take a minimum of 6 weeks to develop. In the west of Ireland there is often no frost until December which ensures a decent yield of tubers.

Oca has already become a very popular crop in New Zealand where the name was changed to New Zealand Yam – even if it is not at all related to Yams. Oca is also popular in many Asian countries especially Japan.

In the UK there are a growing number of people interested in oca. The Oca Breeders Society was started a few ago. They plan to develop a day neutral oca variety which will tuberise much earlier and produce a more reliable yield.

Table 1: Yields of oca variety trial in Bundoran, Co. Donegal, 2017

Oca Variety	Yield per sqm (5pl/spm)	Yield per plant
1. Bram's variety 1	2.20kg	0.44kg
2. Amarillo Europe	7.70kg	1.54kg
3. Monster	3.75kg	0.75kg
4. New Zealand variety 2 colours	2.50kg	0.50kg
5. Amarillo America	3.95kg	0.79kg
6. Bolivian Red	4.20kg	0.84kg
7. Own red variety	5.30kg	1.06kg

Figure 16: *Oca plants grown in Co. Leitrim*

Figure 17: *Field–scale oca production in Co. Kilkenny*
Photo credited to: www.beotanics.com

2.3 Mashua (*Tropaeolum tuberosum*)

Mashua is closely related to our garden nasturtium and is grown for its edible tubers, leaves and flowers. All parts have a slight peppery, mustardy taste. The tubers are the size of small potatoes, mostly conical shaped and come in various colours ranging from white, yellow, orange, red, purple and black.

Figure 18: *Mashua tubers and plant grown at the Organic Centre, Co. Leitrim*

Mashua is perfectly suited to the Irish climate and by far the easiest crop to grow. In the Andes it is the fourth most important tuber crop after the potato, ulluco and oca. It grows on any marginal soil, requires low inputs and still produces an amazing yield of up to 4 kg per plant. In the Cuzco area of Peru I have seen it intercropped with native potatoes.

Mashua contains phytochemicals that protect the crop itself as well as surrounding crops from pests (insects and nematodes) (Grau *et al.* 2003). There is a potential to use this vigorous plant as an intercrop in orchards or amongst other susceptible crops.

In Peru, this crop has always been associated with poverty and survival and as in many developing countries people are adopting modern foods. There is a serious danger that many local strains of mashua are disappearing quickly as people's diets change.

Despite its high yield, reliability and natural pest resistance, mashua is the least commercialised of the four Inca tubers. This however is changing quickly in the last couple of years. When visiting a Peruvian agronomist in Cuzco he informed me that the Chinese are now importing black mashua tubers into China and paying a premium price for it. The reason for this is that apparently Chinese scientists have identified black mashua as a cure or preventative to prostate cancer. Unfortunately I have not found any literature to confirm this. It's quite amazing how such an ancient crop from the Incas has found its way and purpose into a new world.

Black mashua tubers

2.4 Tarwi (*Lupinus mutabilis*)

It's one of the miracles why this versatile and most beautiful Inca crop has never managed to spread throughout the world. I have seen many gorgeous looking blue or purple tarwi fields in the Andes region between Cuzco and Lake Titicaca. The protein content of the seeds is over 40% - higher than peas, beans and soybeans. It also contains as much oil as soybeans. Together with potatoes, maize and quinoa it forms a staple food for most native cultures living in the Andes Mountains. This crop could make a wonderful contribution to the Irish landscape.

Figure 19: *Tarwi field and tarwi seeds at a market in Cusco*

Tarwi seeds are one of the most nutritious foods available. The protein of the seeds contains lysine which is a vital amino acid. Researchers from around the world are researching this crop and are trying to improve the quality and uniformity of it.

Tarwi grows in any soil type and some initial trials in Co. Cork showed good results. It's a hardy crop that can withstand late frosts and can thus be sown in early April. It's also a leguminous crop and may fix atmospheric nitrogen. In the Andes tarwi is often rotated with a potato crop. I was told that due to the high alkaloid of tarwi may be utilised to prevent potato cyst nematodes in the succeeding potato crop.

One of the reasons why tarwi (Andean lupin) has not achieved world fame is that the seeds contain alkaloids which are toxic. Traditionally in the Andes the seeds are soaked in running water for a few days and as alkaloids are soluble in water, these compounds are washed away. Nowadays there are methods available that can remove the alkaloids within a couple of hours.

A second disadvantage is that the seeds ripen very unevenly which would hinder machine harvesting.

Uses of Tarwi

- High protein vegetable
- Vegetable oil
- High protein meal for animal feed or food ingredients
- Margarine
- Green manure crop to fix nitrogen

3. Yacon

Latin name: *Smallanthus sonchifolia* (Poepp. & Endl.) H. Robinson – previously *Polymnia sonchifolia*
Family: Asteracea (Compositae)

Yacon originates in the subtropical and temperate areas of the Andes region at an altitude of 800-3100m and has been grown since pre-Incan times. It is closely related to the dahlia and produces large edible tubers that even resemble dahlia tubers. It's also related to chicory, sunflower and Jerusalem artichokes. In a tunnel or greenhouse it can grow into a large plant and produces a very high yield of sweet tasting tubers. In warmer parts of the country it can also be grown outdoors. The tubers can be eaten raw or cooked.

Yacon has the potential to become one of the new superfoods as its carbohydrates are not stored as starch but in the form of fructooligosaccharides and could thus play an important part as a prebiotic food in a diabetic's diet as well as an aid for weight loss. Fructooligosaccharides are not metabolised in the digestive tract and do not increase the glucose level in the blood.

The sweet tasting root tubers are generally eaten raw – in Andean markets the tubers are sold as fruits. Yacon can also be cooked as a sweet tasting vegetable. It doesn't soften during cooking and remains crunchy a little bit like bamboo shoots in a Chinese dish. When roasted it turns into a deliciously sweet treat similar to caramel.

Up to very recently, yacon was an underutilised and scientifically neglected crop. This has changed dramatically in the last decade when it was discovered that yacon is the plant source with the highest content of fructooligosaccarides (FOS). FOS are sugars with a low calorific value and are also known to promote better health of the intestinal tract.

This report evaluates if yacon could become a viable crop for Irish or European producers.

Figure 20: *Yacon plants Co. Cork*

Figure 21: *Pat Fitzgerald with yacon crop in Co. Kilkenny*

Photo credited to www.beotanics.com

Figure 22: *Commercial yacon production in Co. Kilkenny by Beotanics*
Photos credited to www.beotanics.com

3.1 Common names

Spanish: Yacon, llacon, jicama,
English: yacon, yacon strawberry
German: Erdbirne
Italian: Polyhymnia
French: poire de terre
English: Yacon strawberry
Bolivia: Aricoma, aricuma, ipio
Ecuador: Jicama, chicama, jiquimilla
Colombia: Arboloco
Aymara: Aricoma, aricona
Quechua: Yacu, llacuma, llacum, llaqon, yacumpi

The Spanish name Yacon derives from the Quechua word “yaku” which means “watery”. This reflects the watery nature of yacon root tubers which can be up to 90% of the fresh weight.

3.2 Plant description

Yacon is a tall perennial plant but always grown as an annual when the tuber-like storage roots are harvested in autumn. These can weigh between 100g to 1kg. Yacon is a tall growing plant which can reach a height of well over 2m if grown in a polytunnel or 1.5m if grown outdoors.

Figure 23: *Yacon grown in a polytunnel at the Organic Centre, Co. Leitrim*

The form and size of the tuberous storage roots are similar in appearance to sweet potatoes and can easily be confused when looking at them in an Andean market.
The shape of the roots ranges from spherical to lemon-shaped and inverse pear-shaped. They have a thin skin. The high water content of the roots makes them prone to damage during harvesting and transportation.

There are several horticultural forms with different flesh colour white, cream, white with purple striations, yellow, orange, pink and purple. The skin colour varies from brown, pink, purplish, cream and ivory white.
Yacon is a day-neutral plant for stem and tuberous root formation.

3.3 History

The first introduction to Europe was in 1927 in Italy. It was used as a vegetable crop and for animal feed. Experiments were also carried out as a source material for the sugar industry (Calvino 1940). Further research was carried out in Germany in the 1940's (Bredeman 1948).

3.4 Countries where yacon is grown

Yacon grows from Ecuador to north-western Argentina all along the foothills of the Andes Mountains. It is grown in many areas of Peru and Bolivia, Ecuador, Venezuela, Colombia and Argentina.

As yacon is very tolerant to a wide range of climate zones and growing conditions it is grown in many diverse countries and altitudes apart from its native areas in the Andes mountains: Brazil, Argentina, Ecuador, Japan, Korea, Taiwan, India (Sikkim area), the Philippines, Mexico, New Zealand, the United States, Russia, Estonia, Czech Republic, Germany, the Netherlands, Belgium and Ireland.

In 2015, the Belgian Department of Agriculture actively funded the growing of new food and functional food crops and €150,000 were given to investigate the potential of yacon production in Belgium. This has resulted in many farmers now growing this crop as well as an increased consumer awareness.

The largest yacon producer in the EU is an organic grower in the Netherlands – Wiel and Joep van de Bool who produce 1 ha of yacon every year. They started growing yacon in 2012 and were developing new markets.

3.5 Soil and site

Yacon prefers a deep, free draining, fertile and well balanced loamy soil and should be grown in full sun. It is quite a forgiving plant though and will grow in most soil types, but growth is poor on heavy poorly drained soils. It's a very adaptable plant and grows in various climates and altitudes.

The best growing temperature for yacon is between 18 and 25°C. Low night-time temperatures are also important for tuber formation (Grau and Rea, 1997). However, yacon can survive a slight frost and high temperatures of 40°C. A long growing season of around 6 to 7 months is needed for good tuber formation and a high yield. In Ireland frosts generally occur quite late in the year and thus a good yield of yacon tubers is ensured. I usually wait until the first hard frost has killed of the leaves (around November) before harvesting the tubers.
In warmer areas or if grown in a polytunnel the plants flower profusely and produce dozens of small sunflower-like flowers.

Figure 24: *Yacon growing in Ollantaytampo, Peru*

Figure 25: *Yacon flowers*

Photo credited to www.beotanics.com

Fernandez *et al.* (2006) found that the amount of rainfall plays a more important role in tuber yield than the length of growing season. Another good reason why Ireland is very suited to yacon production. The higher the rainfall the better the yield.

3.6 Sowing and planting

Yacon is traditionally propagated from stem tubers (also known as crown pieces) with dormant buds (turions). The plant produces smooth edible root tubers which have no growth points and cannot be used for replanting as is possible with potatoes and many other tubers.

Figure 26: *Yacon tubers (smooth, large, edible tubers on the outside and knobbly tubers for propagation)*

Yacon plants have two types of tubers – very knobbly ones that cluster around the stalk and beautiful, large, smooth and succulent tubers that grow outside of the knobbly ones. Obviously the smooth succulent ones are for eating and the knobbly ones for propagation. The knobbly tubers (also known as propagules, crown pieces or caudices) can be separated in late March/early April and provided that they have a growth point will make a new plant. The propagules should be about 6-12cm and have a number of buds (at least 3-5 buds). From a mature yacon plant you can get up to 10 new propagules. Each part should be potted on into a 1 or 2 litre pot depending on the size of the stem tuber using good potting compost. The pots are placed in a polytunnel or greenhouse. The plants can be planted into a tunnel in April or outdoors in May.

Yacon can also be propagated through aerial shoot cuttings and mature stem cuttings (Osip *et al*. 2008). The cuttings take easily and the plants grow as normal, however, I found that the plants propagated from aerial shoot cuttings did not produce edible root tubers in the first year of production.

3.7 Spacing

The plants grow huge with a spread similar to a courgette plant and a height of about 1.5 to 2m.

Spacing: 1.2m x 70cm
Between plants: 0.70m
Between rows: 1.20m

Aim for 8,000 to 20,000 plants per hectare.
In Italy and the Czech Republic they experimented with closer spacing of the crop but the closer the spacing of the plants the smaller the individual tuber size.
In Kilkenny, Pat Fitzgerald plants 15,000 plants/ha. Wiel van de Bool in the Netherlands spaces the plants 1.5m x 0.83m which gives about 8,000 plants/ha giving a yield between 60-80t/ha depending on the season. Up to 2018, only own planting material was used by dividing stem tubers. In 2019 new varieties were purchased from Beotanics in Ireland.

3.8 Intercropping

In the Andes, yacon is sometimes grown in a patch of its own but more often it is intercropped with corn, potatoes or bush beans. You still need to give the plant plenty of space (1m² is ideal).

3.9 Plant care

Apart from regular watering there is no additional maintenance required.

3.10 Harvesting and storing

The plants should be left in the ground until the first frost has killed off the leaves. The roots seem to grow a lot during the end of the season so the later the first frost, the higher the yield. In subtropical areas with no frost wait till the leaves have dried and died back naturally.
Carefully dig out the whole plant and remove the smooth succulent tubers and use them immediately or store them in moist sand in a frost-free shed. Due to their very high water content, yacon roots are susceptible to physical damage during harvesting and transportation.

Yacon root tubers have a sweet taste and are traditionally eaten raw after a period of sun drying of between three days which further sweetens the tubers. This procedure is called *ckochascca* in the Andes Mountains. They are considered ready for eating when the skin becomes slightly wrinkled.

After harvesting the FOS are being hydrolised into simple sugars (i.e. fructose, glucose and sucrose). After a week at room temperature approximately 30-40% of the FOS will have transformed into simple sugars (Graefe *et al.* 2004). If refrigerated this process is much slower (Asami *et al*. 1991) and the roots will keep much better.

To summarise – either consume fresh or cool stored roots for high FOS content or sun-sweetened roots taste sweeter but have a lower FOS content.

What is left is the knobbly part of the plant. Store that in a bucket of moist sand in a frost-free shed. This can be split up in the following spring and you can give some new plants to your friends.

3.11 Yield

There appears to be quite a difference in recorded yields from various researchers. The individual root weight can be quite variable even on the same plant and generally ranges from 200-500g but individual roots can weigh over 1 kg each in good growing conditions. Under reasonable conditions a single plant can yield up to 8kg of roots. In a polytunnel in Co. Leitrim with high organic matter inputs, each plant yielded over 10kg of roots.
The yield of tubers can be truly phenomenal and only a few other vegetables can match it. In one year I got 12 tubers each weighing nearly a kilogram. These were grown in a polytunnel in Co. Leitrim with high organic matter inputs. The spacing was 0.75m x 1.00m – 1.5 plants per m^2.
The total yield was 15kg/m^2 or 150t/ha.
In the field scale production in Co. Kilkenny by Beotanics a yield of 50t/ha was recorded in 2018. With larger planting material an increased yield is anticipated for the 2019 harvest.
In the Netherlands, Wiel can de Bool gets yields ranging between 60-80 t/ha. The Dutch wholesale price for yacon is currently €2.00.

Tuber yield comparison:
Czech Republic –35t/ha (Fernandez *et al.* 2006)
Ecuador – 41t/ha (Rea 1992)
New Zealand – 96t/ha (Douglas *et al.* 2002)
Peru – 107t/ha (Huaman 1991, Seminario *et al*. 2003)
Brazil – 80t/ha (Vilhena *et al*. 2000)

3.12 Properties of yacon

Table 2: Chemical composition of yacon roots (summarised by Lizarraga *et al.* 1997)

	Fresh weight basis	Dry weight basis
Water (%)	70 - 93	
Ash (%)	0.3 - 2.0	1.1 – 6.7
Protein (%)	0.4 – 2.0	1.3 – 7.3
Fat (%)	0.1 – 0.3	0.4 – 1.0
Fiber (%)	0.3 – 1.7	1.0 – 5.7
Calcium (mg/g)	23	
Phosphorus (mg/g)	21	
Iron (mg/g)	0.3	
Retinol (mg/g)	10	
Carotene (mg/g)	0.08	
Thiamin (mg/g)	0.01	
Riboflavin (mg/g)	0.1	
Niacin (mg/g)	0.33	
Ascorbic acid (mg/g)	13	

3.13 Uses of yacon

a. Raw consumption - as a fruit

The tubers are delicious raw and cooked. When eaten raw they have a surprisingly sweet taste especially after sun exposure for a number of days. In Andean markets yacon is always sold as a fruit next to pineapples, oranges and apples; rather than with vegetables such as potatoes or maize. The root tubers need to be peeled and are usually eaten in a fruit salad with other fruits.

Figure 27: *Fruit salad with yacon*

b. Cooked

Yacon tubers can also be roasted or steamed. They will always remain crunchy. The tubers are also delicious fried. In some areas the young stems are used as a vegetable. I have not yet tried this yet.

c. Yacon Syrup

Yacon syrup is similar in consistency with honey and maple syrup.
It is made by pressing the peeled root tubers into juice which is then concentrated into syrup by an evaporation process. The process is similar to maple syrup processing. The calorie levels of yacon syrup are only a quarter of the calorie level of conventional sugar. This makes it an ideal sugar replacement. Yacon syrup has great potential as an ingredient for the development of new healthy food products.

The quality of various syrups can vary substantially and both the raw product as well as the processing technique has an effect on the FOS content. When the juice is boiled higher than 120°C the complex FOS sugars will break down into simpler sugars such as fructose, glucose and sucrose and again more calories.
Yacon syrup manufacturers aim for a FOS content of 50%.

d. Yacon powder

The roots are dried and then ground into a powder.

e. Herbal tea from foliage

Douglas *et al.* (2002) found that the Quechuans are using the leaves of yacon plants as a medicinal tea. In Peru, dried yacon leaves were traditionally used as an antidiabetic tea (Grau and Rea 1997). The use of leaves as a medicinal herbal tea was made popular in Japan in more recent times. They found that aqueous extracts of the leaves have the ability to reduce glucose levels in the blood.

3.14 Nutrition

Yacon has always been known as a low calorie food and this is possibly the reason why it has become endangered even in its native countries especially during times of poverty and famine when starchy food was more demanded. In modern times our attitude has changed completely. In the developed world yacon may provide the low calories and fibres to compensate for the overconsumption of carbohydrates and fats.

3.15 Fructooligosaccharides (FOS) and potential health benefits

FOS are classified as a prebiotic food that are not digested in the human gastrointestinal tract and are transported to the colon. In the colon, FOS stimulates the proliferation of beneficial microflora such as *Bifidobacterium* and *Lactobacillus* while reducing pathogenic bacteria populations such as *Clostridium* spp. and *Escherichia coli*.

FOS are fructans which are synthesised from sucrose in the cell walls of leaves, stems and roots. They protect the plants from drying out and act as a carbohydrate reserve. Small quantities of FOS can be found in garlic, onion, asparagus, banana and wheat. The highest concentration of FOS in any known food plant is found in yacon (Caetano *et al*. 2016).
FOS benefits all the good bacteria in the stomach. Yacon is a natural prebiotic food plant.

Definition of prebiotic:
Roberfroid (2002) defines a prebiotic as "a selectively fermented ingredient that allows specific changes, both in the composition and/or activity in the gastrointestinal microflora that confers benefits upon host well-being and health."

The global prebiotics market was worth USD 2.9 billion in 2015 and is estimated to reach USD 5.75 billion in 2020. Europe has a 39% share of this market. This is despite European legislation which restricts health claims on product labels for prebiotics as the effects of prebiotics vary between individuals.

Studies have shown that the consumption of prebiotic foods modifies the gut flora composition and its metabolic activities and may help with alleviate immunity defects, allergies, chronic fatigue syndrome, high cholesterol levels and stomach problems.

FOS effects on cancer and colitis
There is growing evidence that the intestinal microbiota plays an important role. A dysfunction in the gut is associated with several human diseases, including colitis and colorectal cancer which is the most commonly diagnosed type of cancer (Caetano *et al.* 2016)

FOS effects on diabetes
The recommended care for diabetes 2 prevention and management is dietary intervention. Yacon is an interesting niche product for diabetic consumers. It's low glycaemic index (GI) and level of fructooligosaccharides (FOS) makes it an attractive food ingredients. A low GI index indicates that it takes longer for the body to process the sugar and that blood sugar levels rise slowly. In 2015, 9% of the European population was diabetic and this percentage is increasing.

FOS effects of weight loss
Obesity is one of the main public health challenges worldwide because of its associated increased risk of developing heart disease, diabetes 2 and many others. The World Health Organisation (WHO) estimated that 13% of the world's adult population in 2014 were obese.
There is a popular claim that yacon syrup can aid in weight loss, but there is little or contradictory scientific evidence to support this hypothesis. The high FOS content is generally attributed for the weight loss claims. However, FOS levels are very variable between fresh tubers and for the syrup.

Other favourable health effects which have been associated with the fermentation of FOS in the colon include:

- Higher calcium absorption by the body
- Reduction of cholesterol level
- Strengthening of immune system
- Inhibition of the production of toxins and other carcinogenic substances in the colon

(Caetano *et al*. 2016)

Legality and Marketing Potential

Only in 2014 did European market open for yacon imports. The British company Alara received approval from the European Food Safety Authority (EFSA) for the use of yacon as food.

Compared to other alternative sweeteners such as stevia or agave syrup, yacon as a sweetener and functional food is still in its infant stages. European manufacturers are starting to launch some products with yacon as an ingredient. Potential uses of yacon are in juices, yogurts, dairy products, infant formula, cereals, biscuits, cakes and desserts. The application of yacon syrup in natural and luxury chocolate has a lot of potential, especially as a low calorie natural product.

Peru is the leading supplier of yacon syrup and powder to Europe. The main buyers are the United Kingdom (9 tonnes), Germany (7 tonnes) and Norway (2 tonnes). Between 2011 and 2015, Peruvian exports of yacon syrup have increased by 53% annually.

To my knowledge there is only one commercial grower of yacon in Europe. It's an organic farm that specialises in yacon production since 2014. Through an organic wholesaler fresh yacon tubers are available to Irish retailers, but due to urrent lack of demand there is very little uptake.

In Ireland, Pat Fitzgerald from Beotanics in Kilkenny is preparing and investing in yacon production and processing. He is in his second year of production with a large growing area in Co. Kilkenny. His aim is to produce a high grade, high FOS syrup to sell into the food processing industry. The aim of the company is to provide the food and beverage industry with access to a range of unique sources of plant-based ingredients.

3.16 Potential problems

One of the advantages of 'new' vegetables is that they are often free of any specific pests and diseases (even the potato was grown for centuries in Europe without blight!). Apart from the occasional slug nibble on the leaves they grow completely healthy.

3.17 Varieties

The diversity of yacon much lower than that of other crops especially potato and sweet potato. According to the International Potato Centre in Lima there are only 20 varieties of yacon.
The colour of the roots and the stem is generally used to distinguish the different cultivars of yacon. Four distinct types of yacon have been identified in Peru:

- Yurac (white creamy fleshed root and a red to purple skin)
- K'ello (yellow to orange flesh with purple skin)
- Ch'ecce (white creamy fleshed root with streaks of purple)
- Puka (reddish flesh with pink skin)

The company Cultivariable (www.cultivariable.com) sells the following varieties:

Bekya
Blanco

Cajamarca
Kalaloch
Late Red
Morado
New Zealand
Rojo
Rose
Quinolt

3.18 Economics of yacon production

Yacon: Case Study 1

Dutch Growers: Da Waeg

a. Seed

Planted at 8,000 stem tubers/ha each containing 5 buds. All stem tubers are saved from the previous crop. No cost.

b. Fertiliser

Application of farmyard manure is sufficient @ €500/ha

c. Sprays

One application of ferric phosphate (approved organically) after leaf emergence @ €134/ha

d. Harvesting costs

Yacon needs to be harvested carefully to avoid bruising – ideally by hand. Pat Fitzgerald accounts for €15,000/ha. (This compares to €2,000 for potatoes).

GROSS MARGIN DATA

Yield: t/ha :	70 t/ha

OUTPUT:

Yacon tubers @ €2,000/t	€140,000

VARIABLE COSTS:

Seeds/Plants	€ 0
Fertiliser	€ 500
Sprays	€ 134
Harvesting Costs	€ 15,000
Other Expenses	€ 2,000
	€ 17,634
GROSS MARGIN	€122,366

WARE PRICE SENSITIVITY

€1,000/t	€52,366
€1,500/t	€87,366

Yacon: Case Study 2

a. Seed

Planted at 15,000 stem cuttings/ha each containing 2 buds. All stem cuttings are purchased at €0.50 each.

b. Fertiliser

Application of farmyard manure is sufficient @ €500/ha

c. Sprays

One application of ferric phosphate (approved organically) after leaf emergence @ €134/ha

d. Harvesting costs

Yacon needs to be harvested carefully to avoid bruising – ideally by hand. Pat Fitzgerald accounts for €15,000/ha. (This compares to €2,000 for potatoes).

GROSS MARGIN DATA

Yield: t/ha:	50 t/ha
OUTPUT:	
Yacon tubers @ €2,000/t	€100,000
VARIABLE COSTS:	
Seeds/Plants	€ 7,500
Fertiliser	€ 500
Sprays	€ 134
Harvesting Costs	€ 15,000
Other Expenses	€ 2,000
	€ 25,134
GROSS MARGIN	€ 74,866

WARE PRICE SENSITIVITY

€1,000/t	€24,866
€1,500/t	€49,866

4. Jerusalem artichoke

Latin name: *Helianthus tuberosus* L.

Family: Asteracea (Compositae)

Related to: Lettuce, endive, chicory, globe artichoke, dandelion

Botanical classification:
Helianthus derives from the Greek helios, the sun, and anthos, a flower.

4.1 Introduction:

The Jerusalem artichoke is definitely one of the easiest and most highly productive vegetables to grow. It is grown for its edible tubers which have the appearance of a knobbly potato. It can also be grown as livestock feed and sometimes as an ornamental plant especially for the flowering types.

There are a number of varieties available in Europe, but none of them are well known or easily available. Unlike the potato it is completely free of any diseases. The Jerusalem artichoke is extremely high yielding and can grow in relatively poor soil. In appearance
it is very similar to the sunflower.

In hot summers and depending on the choice of variety, you may even get small sunflowers on the plant. The name 'Jerusalem' has nothing to do with the place. It was simply a false interpretation from the Italian Girasola articiocco, the sunflower artichoke. Girasola means 'turning to the sun'. For some reason this mispronunciation of the word has stayed until today.

Figure 28: *Jerusalem artichokes grown in Co. Cork*

I am surprised why not more people grow this vegetable especially given the fact that it is very nutritious and highly beneficial for people suffering from diabetes. In Germany it is commonly known as the "Diabetiker-Kartoffel" (diabetes potato). It's also very delicious and can be used in various ways in the kitchen. It can be eaten raw – grated in a salad or cooked, boiled, roasted or blended in a soup.

However, for beginners it can have an antisocial effect, hence often nicknamed ‘fartichoke’! Jerusalem artichoke is also one of the best pre-biotic foods and encourages all the good bacteria in the lower gut. The rumbling in your stomach and other side-effects are the result of the feeding of all the good bacteria.

Jerusalem artichokes are still an underutilised crop but due it’s highly beneficial medicinal uses it is gaining in popularity in many countries.

This report evaluates if Jerusalem artichokes could become a viable crop for Irish or European producers.

Figure 29: *Jerusalem artichoke tubers*

4.2 Common names

Jerusalem artichokes are also known as sunchokes, tobinambur, woodland sunflower and earth apple. The Native Americans called them sunroots which is definitely the best name for this wonderful vegetable.

Spanish: Castana de tierra, tupinambo
English: Jerusalem artichoke
German: Topinambur, Zuckerkartoffel, Diabetik-Kartoffel
Italian: Carciofo di Gerusalemme
French: Topinambour, truffe du Canada

4.3 Plant description

Jerusalem artichoke is a perennial tuber plant grown as an annual. Its appearance is very similar to the sunflower and produces numerous small yellow sunflower–like flower heads around 5cm in diameter.
The plants grow to a height of 1.5m to 3m. The leaves are arranged opposite along the bottom part of the stem and alternate nearer to the top of the stem. They are rough with a sandpaper-like feel and about 25cm long with a broad ovoid-acute shape.

The stems are very sturdy and can become woody later in the season. The tubers come in many shapes and colours depending on the variety and growing conditions. They can be white, pale brown, dark brown, red and purple in colour and knobbly, elongated, round and club-shaped in form. The size of the tubers ranges from 7cm to 15cm.
Jerusalem artichokes are sensitive to day-length hours and need decreasing day-length hours for tuber formation.

Figure 30: *Tuber diversity in Jerusalem artickokes*

4.4 History

The Jerusalem artichoke originates in the temperate region in north central parts of the America. It is a native of the North American plains and has been cultivated by the Indians. The sunflower (*Helianthus annus*) and Jerusalem artichokes (*Helianthus tuberosus*) were some of the very few plants that were domesticated in North America since prehistoric times.
It has been grown in Europe since 1640.

4.5 Countries – Distribution

Jerusalem artichokes are currently cultivated in North America, Northern Europe, Eastern Europe, China, Russia, and Korea and also in Egypt, Australia and New Zealand.

4.6 Soil and site

Jerusalem artichokes grow in a wide variety of soils and sites. Even on poor soils with no inputs a reasonably good crop can be harvested. Obviously yields will improve with increased soil fertility. Jerusalem artichokes are sometimes used to "clean up" polluted areas as they can thrive anywhere.
They can be grown with suitable average temperature of 6.3 – 26.6°C. They grow in any soil pH ranging from 4.7 – 8.2, however slightly alkaline soils are preferable. They are also very hardy plants that can withstand frosty spells well**.**

4.7 Sowing and planting

Jerusalem artichokes are very hardy and frost tolerant plants and can thus be planted early in the year from late February to early April. The tubers are dormant at temperatures of below 5°C. The optimal soil temperature for planting is 7°C.
Tubers should be planted about 10cm deep into reasonably fertile soil. It is best to plant the tubers sideways as it can be confusing which part is the top. However, it makes little difference if they are planted the wrong way round. Machine planting with a potato planter is suitable.

4.8 Spacing

The plants grow very tall and from each tuber there will be a number of shoots emerging – each growing over 2m in height.

Between plants: 0.40 m
Between rows: 1.00m
Around 25,000 plants/ha

4.9 Intercropping

Jerusalem artichokes are not suitable for intercropping as they are a very strong competitor and have allelopathic effects on other crops.

4.10 Plant care

Jerusalem artichokes are possibly the easiest vegetable to grow and hardly any care is needed. Earthing up once or twice like with potatoes is the only task. This also helps with weed control.

The aggressive nature of the plant makes it a very weed suppressing crop which is also never bothered by pests and diseases.
Starovoytov (2017) found in Russia that Jerusalem artichoke effectively displaces the following weeds including couch grass and bindweed due to its allelopathic effects.

4.11 Harvesting and storing

On a larger scale potato harvesting machinery can be used. The tubers should be harvested carefully as they are more prone to bruising.
Any tubers remaining in the ground are posing a weed problem for the following crop. As it is nearly impossible to find all the tubers, I would recommend growing the crop on the same space every year. I have done so with the same tubers for over ten years and the yield has never declined. Neither has there been any outbreak of a pest or disease.
The ideal storage conditions are at 2°C at a relative humidity of 95%. Tubers will last for 4-5 months. I usually store the tubers in sand in a cool but frost free shed. They will easily keep for 4 months.

4.12 Yield

There appears to be quite a difference in recorded yields from various researchers. Some researchers show figures of 20t/ha but in my trials in Co. Cork, Ireland a yield of over 100t/ha was achieved in 2018. This compares very favourably to potato yields that ranged between 25 and 40t/ha.

Table 3: Results of Jerusalem artichoke variety trial in Innishannon, Co. Cork, 2018

Variety	**Yield/m²**	**Yield t/ha**
Topstar	9.6kg	96
Gotlanst Lilafleckig	11.3kg	113
Patate	13.3kg	133
Butler Berta	10.9kg	109
Earthing White	14kg	140
Gfoler Rote	13.2kg	132
Red Flame	8.0kg	80
Gigant	10.6kg	106
Chipolata	8.1kg	81
Fleuron de Anjou	12.2kg	122
Total	**111.2kg**	**111t/ha**

Figure 31: *Jerusalem artichoke variety trial*

4.13 Properties and uses of Jerusalem artichokes

a. Raw consumption

Jerusalem artichoke tubers are delicious eaten raw in a grated salad mixed with raw carrots, onions, beetroot and/or celeriac.

b. Vegetable

The tubers can also be boiled, roasted or steamed. They also give a wonderful flavour to many soups. In recent years, Jerusalem artichoke has found a niche as a gourmet vegetable, used in various top-class restaurants throughout the world. The Chinese use it as a replacement to water chestnut which has a similar taste and texture.

c. Functional food ingredient

Jerusalem artichokes contain inulin, oligofructose and fructose which can be isolated and used as a food ingredient. The tubers also contain well-balanced proteins with nearly all essential amino acids.

d. Livestock Feed/ Pet Food - tubers

In many countries, Jerusalem artichokes have been used as a livestock feed, mainly for pigs but more recently it was found that the leaves can also be used. However, the tuber yield drops dramatically if leaves are harvested during the summer.

Figure 32: *Organic dog food biscuits with Jerusalem artichokes (Topinambur)*

e. Forage crop

In some countries, Jerusalem artichokes have been used as a forage crop. The best time for harvesting is before the flowering stage before the plants become woody. Kays *et al*. (2008)

reported yields of 40.5 t green matter/ha. Seiler *et al*. (2006) reported dry matter forage yields ranging from 3 to 30 t/ha.
In our small scale trial in Co. Cork we achieved a yield o 45 t green matter/ha and the cows devoured the fresh leaves.

f. Alcoholic drinks

In France and Germany a uniquely flavoured brandy was made from ethanol extracted from the tubers and in Japan a sake drink was made from the plant (Hui, 1991).

Figure 33: *Jerusalem artichoke schnapps – the German poteen*

g. Fuel ethanol

In the 1920's the British Department of Scientific and Industrial Research developed fuel ethanol from the Jerusalem artichoke tubers. They found the same amount of fermentable carbohydrates for alcohol compared to sugar beet and more than the potato. Cheap oil prices interrupted this research, but there is renewed interest due to the negative effects of oil-based fuels on the environment such as climate change, acid rain and ozone layer depletion. As Jerusalem artichoke tubers are rich in inulin and can easily be hydrolysed and converted into biocatalysts making it one of the most promising energy crops and lots of research is carried out in China and New Zealand.

h. Paper pulp

The strong woody stems of Jerusalem artichokes make a good raw material for the pulp for the paper industry. Simakov and Staravoytov (2007) reckon that one hectare of Jerusalem artichoke can save five hectares of forest.

i. Carbon sink

According to Simakov and Staraovoytov (2007) are one of the best crops for absorbing carbon dioxide. They calculated that one hectare of forest can absorb 3-4 tons of carbon dioxide, while one hectare of Jerusalem artichoke can absorb 6 tons of carbon dioxide.

j. Natural fungicide

Chinese researchers found important anti-fungal properties in Jerusalem artichoke leaves. Chen *et al.* (2013) showed that butanol fraction from *Helianthus tuberosus* L. leaves was the most active against *Botrytis cinerea*, *Colletotrichum gloeosporioides*, *Phytophthora capsici* Leonian, and *Rhizoctonia cerealis*.

k. Natural herbicide

Tesio *et al.* (2011) found that aqueous extracts of dried artichoke shoots show an inhibitory effect on germination and seedling growth of various plants. This is due to the natural allelopathic effect of Jerusalem artichokes. To date there is no natural weedkiller permitted in organic systems. Due to various side-effects of conventional herbicides there is a likelihood

that some conventional herbicides will be phased out. Thus there is a great potential to utilise natural allelopathic plants.

l. Soil reclamation

Jerusalem artichoke is one of the most vigorous plants and is used for soil reclamation on polluted soils where it's extensive root systems breaks down organic and inorganic contaminants (AITF 2011). Apart from soil reclamation large amounts of carbon are absorbed from the atmosphere and there is the potential to harvest the stalks annually for paper pulp.

4.14 Nutrition

Jerusalem artichokes have the following nutritional benefits:

a. The most important benefit is the high concentration of the rare natural biologically active substance – inulin which can be up to 17% (Staravoytov *et al.* 2017).
b. Jerusalem artichokes contain an optimal ratio of minerals (iron, magnesium, potassium, manganese, calcium, phosphorus, silicon and zinc).
c. Jerusalem artichokes contain Vitamins B, C and E as well as carotenoids (60-70mg/kg) (Kays and Nottingham, 2007)
d. They contain large amounts of polyacids, including citric acid, malic acid, succinic acid, raspberry acid and fumaric acid which in combination with Vitamin C possess antioxidant properties.
e. The tubers are rich in protein. These proteins contain 10 essential amino acids that are not produced by the human body and come from food (Staravoytov *et al*. 2017).
f. Jerusalem artichokes are rich in pectin (11% of dry matter weight). Pectins can reduce the cholesterol levels, normalise bowel movements and improve metabolic processes.

4.15 Inulin

There is a growing demand for inulin within the food industry throughout the world. Human and other mammalian digestive enzymes cannot break down the inulin and it moves on into the large intestine. In the large intestine the beneficial bifidobacteria ferment it.
Inulin is often added as a prebiotic ingredient for food products to improve gut health. These foods are often marketed as low-calorie foods and weight-loss foods.
It is also a very important food for people suffering from diabetes. The evidence for the role of inulin in decreasing blood cholesterol and in enhancing positive health benefits has been firmly established (Kays and Nottingham 2007).
Inulin is also added to livestock feed to compensate for the banning of antibiotic dietary supplements.

Figure 34: *Inulin powder*

4.16 Potential problems

One of the advantages of 'new' vegetables is that they are often free of any specific pests and diseases (the potato was grown for centuries in Europe without blight!). Apart from the occasional slug nibble on the leaves they grow completely healthy.

4.17 Varieties

Braganca
Butler Berta
Chipolata
Dwarf Sunray
Earthing White
Fleuron d'Anjou
Fuseau (long, smooth, white tubers, excellent yield)
Gerard (round, red, slightly knobbly tubers, very good yield)
Gigant
Gfoler Rote
Gotlanst Lilafleckig
Harlighet Ruud
Patate
Red Flame
Topstar

4.18 Economics of Jerusalem artichoke production

a. Seed

Planted at 4 t/ha @ €700/t (that's more than double of potato)

b. Fertiliser

Application of farmyard manure is sufficient @ €500/ha

c. Sprays

One application of ferric phosphate (approved organically) after leaf emergence @ €150/ha

d. Harvesting costs

Jerusalem artichokes can be harvested with a traditional potato harvester but it will take longer to clean. Also the tops need to be cut and mulched prior to harvesting which is an extra cost @ €15,000 (compared to €2,000 for potato crop)

GROSS MARGIN DATA

Yield: t/ha :	100 t/ha

OUTPUT:

Yacon tubers @ €1,500/t	€150,000

VARIABLE COSTS:

Seeds/Plants	€ 2,800
Fertiliser	€ 500
Sprays	€ 150
Harvesting Costs	€ 15,000
Other Expenses	€ 2,000
	€ 20,450
GROSS MARGIN	€ 129,550

WARE PRICE SENSITIVITY

€1,000/t	€79,450
€ 800/t	€59,550

4. Research Needs

Both Jerusalem artichokes and yacon have shown great potential both as suitable crops for Irish conditions. However, more research is needed before these crops can be commercialised on a wider scale.

Further research should focus on:

- Variety trials to identify the most commercially acceptable types as well as the variety with the highest inulin (Jerusalem artichoke) and fructooligosaccharide (yacon) content.
- Exploring uses of Jerusalem artichoke and yacon for the food industry – e.g. as a healthy sugar alternative, prebiotic and healthy snack food.
- Exploring new markets for these crops, e.g. Jerusalem artichoke crisps, yacon caramels etc.
- Identify food processing businesses that are innovative and open to new functional healthy food ingredients

5. Conclusions

a. Yacon has the potential to become a commercial crop if further processing procedures are put in place, possibly less so for the fresh market.

b. If properly marketed, Jerusalem artichoke, can become a major crop for direct human consumption as well as a functional food.

c. Both yacon and Jerusalem artichoke have shown potential health benefits for people suffering from diabetes.

d. A number of bioproducts can be derived from Jerusalem artichoke and yacon – inulin, fructooligosaccharides, fructose, natural fungicides, antioxidants and bioethanol.

e. There is a massive potential for the production of yacon and Jerusalem artichoke in terms of yield potential and profitability.

f. Oca, mashua and other Inca crops could find a place as a niche or specialist crop in an ever more diversified diet often promoted by TV chefs.

g. There is no expectation that these crops will replace our staple crops but that they can play an important part in a more diverse future food system.

h. With increasing climate change and unpredictable weather patterns a more diverse food production system is more resilient.

6. Recommendations

a. Yacon can only become a commercial crop if processing facilities are in place. This is happening at present in Co. Kilkenny (www.beotanics.com). More research on processing yacon is required.

b. Variety trials are essential especially for Jerusalem artichokes to identify the smoothest variety as knobbly tubers do not sell. This should also involve breeding of new varieties through hybridisation.

c. Virus elimination for all crops is essential. Universities and plant breeders need to work together to produce virus free crops which are higher yielding and the risk of spreading virus diseases to other crops is eliminated.

d. The most suitable Inca crops could be promoted by Bord Bia, Teagasc or DAFM as a valuable side enterprise for small farms to increase farm incomes.

e. More research and farm trials are needed to explore the potential of Jerusalem artichoke as a crop for livestock feed for a number of livestock species. Both foliage and tubers are suitable.

f. The Russian research that found that Jerusalem artichokes can absorb twice as much carbon from the atmosphere must be explored further. This crop could play an essential role in mitigating climate change.

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