INFORMATION

Yacon [*Smallanthus sonchifolius* (Poeppig & Endlicher) H. Robinson]: a new crop in the Central Europe

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ABSTRACT

Yacon [*Smallanthus sonchifolius* (Poeppig Endlicher) H. Robinson, *Asteraceae*] is a tuber plant originated in Andes. In contrast to other root crops, which store the carbohydrates in the form of starch, yacon cumulates the carbohydrates in the form of fructooligosaccharides. They are not metabolized in the digestive tract and thus the consumption of yacon does not increase the level of glucose in the blood. This is one of the reasons why yacon is considered to be nourishment with a high potential for diabetics and overweight and obese people. As yacon leaves contain up to 25% of proteins in dry mass, it can be also used as forage. In the years 2001–2005, the meteorological conditions in the Czech Republic and their influence on biomass production (yield of root tubers, rhizomes and aboveground parts) were studied on yacon landraces originated in Bolivia, Ecuador, Germany and New Zealand. Yields of root tubers reached up to 35 t/ha, rhizomes up to 33 t/ha, and aboveground parts up to 54 t/ha. In terms of root tubers formation, the landrace with the highest yield (29.18 t/ha) was the one coming from New Zealand; in terms of overall biomass production, the landrace with the highest yield (92 t/ha) originated in Bolivia. The crucial factor for the root tubers yields is the precipitation; the length of vegetation period and the temperature are secondary.

Keywords: yacon; root tubers; rhizomes; cultivation system; yields; precipitation influence; influence of the vegetation period length; temperature influence

Yacon is a perennial plant; it is however considered as annual in the cultivation system. It is traditionally grown for its root tubers and leaves rich in phenolic components with strong antioxidant effects used for medicinal infusion (Lachman et al. 2003). Yacon is highly adaptable to various climates and altitudes. As far as the soil is concerned, it is unpretentious but it prefers loamy sand soil (Zardini 1991, Grau and Rea 1997). This plant can outlive long dry periods; nevertheless it leads to a significant decrease in yield. In terms of the root tubers formation, yacon was described as a crop with a negative reaction to photoperiod (Popenoe et al. 1989).

The first introduction of yacon in Europe was made in 1927 in San Remo, Italy. After 13 years of adaptation it was recommended to use yacon as a source of dietetic nutrition, as a feeding crop, and mainly as a material for sugar industry (Calvino 1940). Since Calvino's experiments yacon extended in Germany in 1941, in Hamburg and Wulfsdorf (Bredemann 1948). Yacon was also introduced in the Czech Republic, where it has been grown since 1994. Besides the Andes region growing yacon was extended in Brazil, Japan, Korea, Mexico, New Zealand, the United States, Russia, Estonia and Taiwan.

This work presents the results of the yield potential of biomass (tuberous roots, rhizomes and aboveground parts) of yacon cultivated under climatic condition of the Czech Republic in the years 2001–2005.

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MATERIAL AND METHODS

Experimental field of CUA in Prague. The complex of experimental fields of the Czech University of Agriculture in Prague lies in an average altitude of 286 m above the sea level, on 50°04' north latitude and 14°26' east longitude, and has loamy soils. The climatic area is mildly warm and mildly dry. Average annual temperature ranges around 8.7°C (average daily temperature during the vegetation period in 2001–2005 was 15.0°C); average annual time of sunshine is 1858.1 hours (1155.62 hours during the vegetation period); average precipitation is 516.1 mm (325.22 mm during the vegetation period). The meteorological information was taken from the nearest meteorological station in Prague-Ruzyne (altitude 364 m, 50°06'03" north latitude and 14°15'28" east longitude, as shown in Table 1).

Plant material. During the experiments, four different landraces of yacon were observed: 1. NZL is the first yacon landrace introduced in the Czech Republic in 1993 – rhizomes were gained in Auckland, New Zealand; 2. DEU is the yacon landrace gained in a form of young plants from the Stueckborstl Botanic Garden, Germany, it has been grown in the Czech Republic since 1994 and it is the oldest grown yacon landrace grown under the conditions of Central Europe; 3. ECU comes from Ecuador, it was introduced in the Czech Republic in 1994; 4. BOL originates in Bolivia, rhizomes were sampled directly from the original site in San Pedro – Potosí area in the altitude of 2800 m, and has been grown in the Czech Republic since 1995.

Planting. The planting on a field site was done when the spring frosts were definitely over (mostly in the second half of May) to soil treated with an organic fertilizer (cattle manure, 20 t/ha). The height of pre-grown plants ranged between 0.20–0.30 m; they were planted in ridges with spacing 0.70 × 0.70 m. Number of plants per 1 ha was 20 408.

Cultivation during the growth. Yacon starts to grow somewhat slowly and at the beginning phase its resistance to weeds is very small. Hoeing was performed approx. 30 days after the outplanting, so the inter-rows were ploughed and the weeds were destroyed. The ridging was performed approximately two months after the outplanting; it not only formed the ridges, but it also helped to get rid of the weeds. Once the growth was fully evolved, there was no need for other cultivation actions as yacon was resistant to weeds and further interventions could seriously harm the developing tubers. At the beginning of the growth and during the development of the storage organs, it was necessary to water the plants sufficiently, especially in the dry seasons.

Harvest. Although it is advisable to shift the harvest as late as possible, the aboveground biomass, and especially the root tubers, must not be damaged by the first autumn frosts (October). The aboveground part was removed before harvest to facilitate the manipulation with the underground parts and the manual harvest. For the purpose of mechanical harvest, a test of a truncated puller constructed specially for the harvest of yacon was performed, and it was successful. After the harvest of the underground part, the roots and stem tubers were separated. All cut spots on the stem tubers

Table 1. Meteorological data of investigated years

Year	Mean air temperature during the growing season (°C)	Total precipitation during the growing season (mm)	Length of growing season (days)
2001	14.84	356.00	156
2002	15.25	387.02	149
2003	15.90	211.49	170
2004	13.90	310.20	161
2005	15.08	361.40	177
Average value (2001–2005)	14.99	325.22	163
Long-term climatological normals (1961–1990)*	14.12	356.20	–

*long-term climatological normals for the period May–October; source: http://www.chmi.cz/meteo/ok/infklim.html

were treated with charcoal or at least they were let dry. Bigger cut parts on the root tubers were treated in the same way. The tubers determined for consumption were placed in boxes and stored in a cool and moist room at the temperature of around 10°C; this prevented the tubers from losing water and shrinking.

Growing season. Growing season varied in the reviewed years. Planting outside was influenced by spring frosts in May; harvest season depended on the first autumn frosts in October. The plants were harvested even though they did not finish the complete growing period; absolute maturity of yacon comes after the stalks fade away, when they begin to dry up and bend over to ground.

Statistic evaluation. The results (the comparison of average yield among the landraces, and the influence of the meteorological conditions on the yields of biomass of different landraces) were subjected to the analysis of variance (ANOVA) and the means were compared using the Least Significant Difference (LSD).

RESULTS AND DISCUSSION

Harvest

At the harvest time the root tubers had different size, weight, shape and quantity. The biggest tubers measured up to 250 mm and weighed up to 1 kg; their shape was affected by the physiological state of the plant and the soil texture. The required shape of tubers is round or oval with a little neck.

Yield of biomass

Yacon crop has an aptitude to adapt to different climatic conditions. Thanks to this, high yields of biomass were achieved in conditions of the Czech Republic. A plant forms in average 1.25 kg/plant of tuberous roots (i.e. 25.51 t/ha), 1.18 kg/plant of rhizomes (24.08 t/ha) and 1.81 kg/plant of overground part (36.94 t/ha, Table 2). According to the averages of the yield of tuberous roots obtained during the observed years, the landraces can be arranged in decreasing order: NZL (29.18 t/ha) > ECU (26.33 t/ha) > BOL (25.10 t/ha) > DEU (21.43 t/ha); and according to the whole yield of biomass: BOL (92.24 t/ha) > ECU (91.63 t/ha) > NZL (86.53 t/ha) > DEU (75.51 t/ha).

Regarding tuberous roots, statistically significant differences among all landraces except ECU and BOL were determined; in rhizomes no significant differences between DEU, ECU and BOL were found. On the contrary, in aboveground part statistically significant differences exist among all landraces except NZL and DEU (Table 3).

Table 2. Average yield of biomass in the period 2001–2005

Landrace	2001	2002	2003	2004	2005	Mean (2001–2005)
Tuberous roots (kg/plant)						
NZL	1.38	1.65	1.14	1.66	1.34	1.43 (i.e. 29.18 t/ha)
DEU	0.70	0.95	0.86	1.27	1.47	1.05 (i.e. 21.43 t/ha)
ECU	1.19	1.68	1.13	1.08	1.37	1.29 (i.e. 26.33 t/ha)
BOL	1.16	1.55	1.00	1.11	1.32	1.23 (i.e. 25.10 t/ha)
Mean	1.11	1.46	1.03	1.28	1.38	1.25 (i.e. 25.51 t/ha)
Rhizomes (kg/plant)						
NZL	1.40	0.78	0.73	1.62	0.88	1.08 (i.e. 22.04 t/ha)
DEU	0.87	1.08	1.13	1.10	1.41	1.12 (i.e. 22.86 t/ha)
ECU	1.18	1.07	1.18	1.49	1.37	1.26 (i.e. 25.71 t/ha)
BOL	1.16	1.16	1.17	1.31	1.41	1.24 (i.e. 25.31 t/ha)
Mean	1.15	1.02	1.05	1.38	1.27	1.18 (i.e. 24.08 t/ha)
Aboveground part (kg/plant)						
NZL	2.64	1.88	0.88	1.78	1.47	1.73 (i.e. 35.31 t/ha)
DEU	1.39	1.53	1.32	1.68	1.74	1.53 (i.e. 31.22 t/ha)
ECU	1.99	2.07	1.53	1.93	2.18	1.94 (i.e. 39.59 t/ha)
BOL	2.65	2.44	1.25	1.65	2.25	2.05 (i.e. 41.84 t/ha)
Mean	2.17	1.98	1.25	1.76	1.91	1.81 (i.e. 36.94 t/ha)

Table 3. Effect of different landraces on the yield of taxon tuberous roots, rhizomes and aboveground part

Landrace	Tuberous roots	Rhizomes	Aboveground part
NZL	1.43[c]	1.08[a]	1.73[a]
DEU	1.05[a]	1.12[b]	1.53[a]
ECU	1.29[b]	1.26[b]	1.94[b]
BOL	1.23[b]	1.24[b]	2.05[c]

[ab]means in columns denoted by the same letters are not significantly different by LSD at $\alpha = 0.05$

The approximate proportion of the yield of rhizomes (rh) and the aboveground part (op) to the yield of tuberous roots (tr = 1) is 1:1:1.5 (tr:rh:op), which means that the yield of biomass of rhizomes has the same proportion as the yield of tuberous roots. The yield of the overground biomass is higher by 50% than the yield of tuberous roots and rhizomes. The proportion of the yield for each of the landraces is as follows: NZL (1:0.8:1.2), DEU (1:1.1:1.5), ECU (1:1:1.5) and BOL (1:1:1.7).

As for tuberous roots, the NZL landrace was the most productive in yield, but at the same time it had smaller yields of aboveground part and rhizomes in comparison with other landraces. BOL landrace gave a better yield of aboveground part, but it gave a lower yield of tuberous roots in comparison with other landraces, except DEU, which had absolutely the lowest yield.

The correlation coefficients of the yield (Table 4) between all parts of yacon were not significant or determinant, which means that no correlation exists between the yields of the biomass of different parts of yacon. The overground part did not show a direct effect on the yield of tuberous roots and rhizomes.

Influence of precipitation and temperature on the yield of tuberous roots

The biggest yield of tuberous roots was obtained in the year 2002 (1.46 kg/plant); no statistically significant differences were found in the years 2004 and 2005 (Table 5); the lowest yield of tuberous roots was obtained in 2003 (1.03 kg/plant) (Figure 1). In 2002 the highest precipitation during the vegetation period was measured (387.02 mm); the lowest precipitation (211.49 mm) was recorded in 2003 (Table 1). The highest average temperature during the vegetation period was measured in the year 2003 (15.90°C, Table 1), and at the same time this year was the driest. The year 2004 was the coldest of all growing seasons with the average temperature of 13.90°C and the average yield of tuberous roots in this year was 1.28 kg/plant. In the most productive year (2002), the average temperature during the vegetation period was 15.20°C.

These results confirm that precipitation is the key factor influencing the formation of tuberous roots in yacon, compared to temperature which

Table 4. Yield correlation coefficients of different yacon plant parts

Part of the plant		Aboveground part	Tuberous roots	Rhizomes
Aboveground part	NZL		0.3630	0.6620
	DEU		0.3661	0.2512
	ECU		0.4810	0.2925
	BOL		0.5163	0.2400
Tuberous roots	NZL	0.3630		–0.1905
	DEU	0.3661		0.1784
	ECU	0.4810		0.0043
	BOL	0.5163		0.2531
Rhizomes	NZL	0.6620	–0.1905	
	DEU	0.2512	0.1784	
	ECU	0.2925	0.0043	
	BOL	0.2400	0.2531	

Table 5. Effect of growing year on the yield of different plant parts of yacon (kg/plant)

Year	Tuberous roots	Rhizomes	Aboveground part
2001	1.11[b]	1.15[bc]	2.17[c]
2002	1.46[c]	1.02[a]	1.98[b]
2003	1.03[a]	1.05[ab]	1.25[a]
2004	1.28[c]	1.38[cd]	1.76[b]
2005	1.38[c]	1.27[d]	1.89[b]

[ab]means in columns denoted by the same letters are not significantly different by LSD at α = 0.05

seems not to have a significant effect. Yacon is a crop tolerant to the oscillation of temperatures; it can withstand high temperatures in summer as well as the temperatures around the freezing point in autumn. The first frosts (–1°C) in autumn can cause yacon frost burns on the overground parts (1 meter above the ground). Basal parts of the stem resist –2°C, and underground organs –3°C. In lower temperatures the tuberous roots crack.

Influence of growing season on the yield of tuberous roots

The average growing season observed in the period 2001–2005 was 163 days (Table 1). In the year 2005 the growing season was the longest (177 days), in the year 2002 the shortest (149 days). The highest yield of tuberous roots (1.46 kg/plant) was obtained in 2002, followed with the year 2005 (1.37 kg/plant). Moreover, the highest value of the yield of the total biomass (4.55 kg/plant) was obtained in this year (Table 2). In 2002 the precipitation sum during the vegetation period (387 mm) was higher than in 2005 (361 mm). These results indicate that the main factor for the formation of tuberous roots is the precipitation, not the growing season.

In climatic conditions of the Czech Republic yacon had a high yield of the biomass, in average 86.53 t/ha, from which 25.51 t/ha form tuberous roots, 24.08 t/ha rhizomes and 36.94 t/ha overground part. Yield data achieved from more complex experiments realized under climatic conditions of Europe were presented by Calvino (1940): yield of overground part (36 t/ha), of tuberous roots (38 t/ha) and total yield 74 t/ha. With spacing 0.90 × 0.30 m, which is equal to 37.000 plants/ha, the yield would be only 1 kg of fresh tuberous roots and approximately 1 kg of fresh top per plant. The plant is able to provide high yields, of both roots and overground part, under convenient climatic conditions. According to Nieto (1991), a potential yield could be as high as 70 t/ha, but it varies strongly according to different clones. In Ecuador yield of tuberous roots was 41 t/ha (Rea 1992), in Peru 7–107 t/ha (Huamán 1991, Seminario et al. 2003), in Brazil 80 t/ha (Vilhena et al. 2000) and in Russia 57–86 t/ha (Tjukavin 2001). In Japan, relations of yield and growing manners (pre-growing or direct planting in the ground) were researched and it was achieved 46.8 t/ha with direct planting and 27.8 t/ha with pre-growing (Tsukihashi et al. 1991).

Moisture is the main factor for the formation of the tuberous roots. In regions with high precipitation yacon reaches the highest yields. In our experiments the highest average yield (29.80 t/ha)

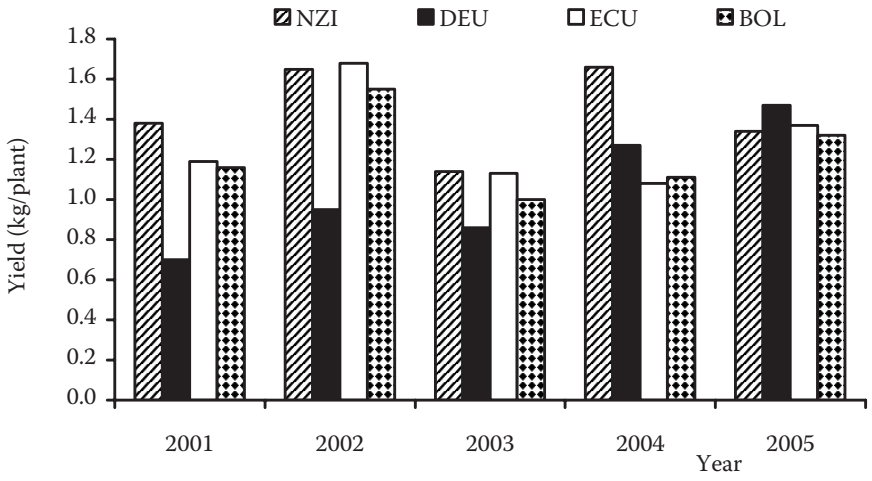

Figure 1. Yield of tuberous roots of different landraces per year

of tuberous roots was obtained in the year 2002. In the same year the precipitation during the vegetation period was the highest (387.02 mm) in comparison with other years. In the driest year (2003, 211.49 mm) the yield of the roots was the lowest (21.02 t/ha). In the productive zones of the Andean region of Bolivia, the rainfall ranges between 300 and 600 mm per year (Rea 1997); in the zones of production (valley Marcapaty, Lares and Convención) in Cusco (Peru) the precipitation in the period of vegetation ranges between 800 and 1200 mm, whereas in the Andean valleys the annual rainfall is from 500 to 700 mm (Meza 1995).

The ideal temperature for the growth of the yacon ranges between 18 and 25°C. The low night temperatures are probably important for the formation of tuberous roots (Grau and Rea 1997). In conditions of the Czech Republic, the average temperature during the vegetation period was around 15°C. The highest average temperature during the vegetation period was recorded in 2003 (15.9°C); in the same year the yield of tuberous roots was the lowest. In the coldest year 2004 (13.9°C), the production of tuberous roots was almost similar to the values of the most productive year 2002, when the average temperature was 15.20°C. Hence, it can be concluded that the temperature does not have a significant effect on the formation of the yield of tuberous roots. Yacon is a relatively tolerant crop both to low (–4°C) and high (up to 40°C) temperatures (Grau and Rea 1997), which our results confirm.

For a successful growing of taxon plants it is necessary to achieve long growing season, necessary for forming of roots and for the maturity of the whole plant. The plant matures usually in 6–7 months. The growing season ends with drying up and fading away of tops of the plants. According to Shuar Aja (1994), the growing season lasts 240 days. In lowland areas it ranges around seven months, in very high locations approximately one year (Rea 1992). In the altitude of 3100 m the yacon plant flowers after 256 days of growing season, and the time till the phase of flowering differs maximally by 15 days (Nieto 1991). Meza (1995) claims a growing season within 210–270 days. The average length of a growing period in the Czech Republic was 163 days. The growing season is influenced by spring frosts (May) and the harvest season depends on first autumn frosts (October). In the year 2002 the growing season was only 149 days, however this year was still the most productive, mainly due to higher precipitation.

To conclude, our results confirm that the main factor influencing the formation of the yield of yacon is the sum of precipitation during the vegetation period and not the length and temperature of growing season. An ideal solution for the cultivation of yacon would be to select the clones with a rapid growth and development (i.e. with short growing season) and to provide sufficient irrigation for the crop.

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