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RESEARCH ARTICLE

Diversity of Jerusalem artichoke clones (*Helianthus tuberosus* L.) from the INRA-Montpellier collection

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Abstract INRA hosted the national Jerusalem artichoke collection in Rennes and Clermont-Ferrand until 2005. It now takes place in Montpellier. The list of cultivar-clones and of wild accessions is provided as well as main data on expected yield, earliness, female fertility, and disease susceptibility to viruses and Oidium. Descriptions of some traits (anthocyanin, ramification, chlorophyll) were reported. Data was collected from a hydroponic experimental design which was set up with two repeats at Mauguio and Montpellier. The experimental yields are shown for nine clones chosen for agronomic production of tubers and the pictures of tubers are given.

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Introduction

INRA Montpellier has handled the Jerusalem artichoke national collection in Rennes (until 1972) and Clermont-Ferrand (1972–2004) (Le Cochec 1990). The Institute decided to focus the *Helianthus* national genetic resources at the Montpellier site (UMR-DIAPC). It has been established at Mauguio, near Montpellier, since 2005. Recurrent observations have led to information on the agro-morphologic, phenologic and genetic diversity characteristics as shown by clones kept in the collection. The *Helianthus* genetic resources centre has hosted the entire collection since 2005. The whole Jerusalem artichoke crop collection includes 140 cultivated clones. *Sensu stricto* this species has not been improved for a long time, as activity was focused on the maintenance of clones (Volk and Richards 2006).

In the *Helianthus* genus three main groups of species corresponding to peculiar typologies are preserved: the cultivated sunflower (*H. annuus* L.), the sunflower related wild Helianthus (49 species), and since 2005 the cultivated Jerusalem artichoke (*H. tuberosus* L.). Most clones are hexaploïd ($2n = 6x = 102$) except the two hybrids between sunflower ($2n = 34$) and Jerusalem artichoke that are tetraploïd ($2n = 4x = 68$). The

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Jerusalem artichoke was considered a forage species, but it is also consumed for its dietetic qualities being rich in inulin (fructan) present as vegetal fibres. It is a recommended part of the diet as a preventative for colorectal canker as reported widely (Knudsen and Hessov 1995). It also offers wide technological interest as a bio-fuel (bio-ethanol) due to its high potential for biomass production (Seiler 2007). This species has enormous potential for biomass production as tubers, stems and leaves all contain inulin. Using inulin through the ethanol chain is probably not the best way to exploit the biomass. Several studies have been undertaken to build polymers based on fructose-derived backbones as hydroximethylfurfural (HMF) and many patents have been granted.

The Jerusalem artichoke was used as genitor to improve sunflower oil via interspecific hybridization—namely to enhance resistance to diseases such as Downy mildew, Phomopsis, and Sclerotinia. A contrario it may have received earliness factors from the sunflower. Such sunflower × Jerusalem artichoke hybrids are called topinsol (Leclercq, pers. commun.). Preceding morphological and phenological characterisations were performed at INRA, Clermont Ferrand. The enlargement of the data base continues in Montpellier for additional information dealing with self-sterility, yield, and disease susceptibility.

The collection in Montpellier records 140 Jerusalem artichoke clones exclusively multiplied by vegetative propagation (Cv) mostly cultivated for tubers, and 26 wild ecotypes (WE) sexually propagated. Small tubers are also produced to ensure vegetative propagation (Table 1). The collection has 100 accessions (Cv) from France, 23 (9 WE) from Russia (VIR), 15 (WE) from USA (USDA), seven from Germany (Giessen DE), five from Serbia, one from Austria, one from Belgium, two (WE) from Canada, three from Europe (eastern), one from Guadeloupe, one from Netherlands, two from Hungary, one from Iran, one from Morocco, one from Ukrainia, one from Italy and one of unknown origin (1). *H. tuberosus* wild populations were introduced from North America which produced more seeds. Jerusalem artichokes were improved for tuber productivity, tuber morphology and resistance to Sclerotinia. The crop was virtually abandoned after the Second World War and most clones survived only in private gardens. The collection was started by François Mathon (Univ Poitiers, France), but his collection has been lost. The INRA collection gathered clones from France to other origins.

The cultivated Jerusalem artichoke clones cannot be maintained through seed propagation because the genotype is lost at each sexual generation. It is necessary to keep the plants or tubers as living organisms. Only a few tubers are sufficient to safely maintain the collection for sunflower breeding in the future. We show here the main data from an expected yield of nine clones, i.e. earliness, female fertility, and disease susceptibility (viruses and Oidium). Description of some traits (anthocyanin, ramification) and the pictures of tubers are given as supplementary data. Data was collected from a hydroponic experimental design which was set up, with two repeats at Mauguio and Montpellier. The experimental yields are shown for nine clones chosen to produce tubers.

Materials and methods

The Conservation experimental design at INRA includes 140 (Cv) Jerusalem artichoke clones and 26 (WE) wild Jerusalem artichokes which were grown with one clone per plastic tank (cylindrical diameter 0.60 m), filled with 100 L Vermiculite (Vermex M). Two repeats of the collection were set up in Mauguio, where the climate is more humid and windy than Montpellier city where Supagro is situated, being out of the direct wind and effects of the sea. Tanks were equipped with an automatic watering device assuring fertilizer solution (Hakhaphos 15/10/15U) N/P/K drop by drop.

A safety copy of the collection should enable us to avoid loss of clones due to climatic incident, winter freezing or tornadoes. Tubers are harvested before the first frosts and treated with Sumisclex (fungicide), then stored in a cold room at +4°C. The next investigation will be in March or April but from experiences at Supagro it has been found beneficial to leave tubers to over-winter in tanks. This shortens the next cycle and prevents the loss of clones due to pathogen rot.

Results

Phenotypes and phenology of Jerusalem artichoke clones

Morphologic analyses were based on clone vigour, height of plants and anthocyaned stem. Tubers are

Table 1 Names for the collected accessions and their code in INRA collection

Clone name	No	Clone name	No	Clone name	No
Fl	266	L232 (108)	1394	Fl 85 342.62.3 (166) (fl 342.62)	1450
No name	289	Ms.2.6 (47)	1395	Onta (208)	1451
D19 a	324	Ms81 (117)	1396	Wageningse dwarf (213)	1452
D 19-6 n°66	325	S3.1 (105)	1397	Dornburger (50)	1453
D 19 n°7	326	V102 (101)	1398	K8 (59)	1454
D19-93 n°65	327	Berno (131)	1399	Kärntner Landsorte (211)	1455
Pyri.*d 19-6°64	328	Acp 1981 (125)	1400	Rozo (86)	1456
Kharkovskij	535	Duval 1980.1 (122)	1401	Topianka (49)	1457
Nd. 1869	570	Duval 1980.2 (123)	1402	Waldspindel (34)	1458
Red river 1877 pi503262	571	Porcheron 1980 (121)	1403	Waldspindel (204)	1459
Moorhead 878	572	Porcheron (120)	1404	Waldspindel (201)	1460
Fargo nd	732	Egmond 1982 (129)	1405	Bt3 (202)	1461
2189	1013	Filio (138)	1406	Bt4 (203)	1462
Ns1	1234	Fuseau 60 (60)	1407	C12/84 (206)	1463
C6	1235	Industrie (35)	1408	Bianca (142)	1464
C7	1236	Janto (133)	1409	Ozov (210)	1465
C16	1237	Jaune de rouille (36)	1410	Sukosti (209)	1466
C675	1238	Lacho (139)	1411	Bart 70 janez (67)	1467
C1540 ames 7318	1239	Marondo (141)	1412	Beloshipke (68)	1468
C1698	1240	Medius (58)	1413	Dornaiskii (66)	1469
C1701	1241	Monteo (134)	1414	G71.39 (78)	1470
C1703	1242	Patate Vilmorin (27)	1415	Hybride 103 (77)	1471
C1705	1243	Piedallu 8 (109)	1416	Interess (85)	1472
C1945 pi503254	1244	Piriforme rouge (95)	1417	Kievkii blanc (90)	1473
C1277.63 (48)	1361	Scott (99)	1418	Kirgizskii blanc (82)	1474
C1992.63 (31)	1362	Tait (92)	1419	Kulisty cremonsky (70)	1475
C2071.63 (17)	1363	Vernet (28)	1420	Leningradskii (74)	1476
C2088 (29)	1364	Violet commun (57)	1421	M24.29 (84)	1477
C228.62 (15)	1365	Violet de rennes (69)	1422	Maikopskii 33.650 (63) (top*ts)	1478
C23.27 (2)	1366	(k8*vr) (353)	1423	Nahodka (61)	1479
C29.65 (54)	1367	(nk*f60).1 (219)	1424	Ryskii (89)	1480
C342.62 (43)	1368	(nk*f60).2 (220)	1425	Sejanetz 10 (76)	1481
C742.63 (51)	1369	(nk*f60).3 (222)	1426	Sejenetz 19 (81)	1482
C79.62 (42)	1370	(nk*f60).4 (226)	1427	Tambovskii rouge (64) (top*ts)	1483
C952.63 (21)	1371	(nk*f60).5 (234)	1428	Topinsol 63 (39) (top*ts)	1484
Auto105.62g.15 (7)	1372	(nk*f60).6 (259)	1429	Topinsol vir (62) (top*ts)	1485
Auto105.62g.2 (8)	1373	(nk*f60).7 (273)	1430	Vadim (73)	1486
Cf.11 (56)	1374	(nk*f60).8 (276)	1431	Vorstorg (79) (top*ts)	1487
Cl2 (118)	1375	(nk*f60).9 (279)	1432	Chicago (24)	1488
D13 (106)	1376	(nk*f60).10 (281)	1433	Ellijay (87)	1489
D16 (30)	1377	(nk*k8) (336)	1434	Challenger (212)	1490
D18 (103)	1378	(nk*vr).1 (321)	1435	Columbia (143)	1491
D19 (3)	1379	(nk*vr).2 (327)	1436	Gua 7 (144)	1492
D19.6 (1)	1380	(vr*f60).1 (215)	1437	Sakhalinskii (65)	1493

Table 1 continued

Clone name	No	Clone name	No	Clone name	No
D19.63.122 (14)	1381	(vr*f60).2 (217)	1438	Sakhalinskii rouge (83)	1494
D19.63.340 (13)	1382	(vr*f60).3 (218)	1439	Iranian (80)	1495
D.29 (96)	1383	(vr*nk).1 (297)	1440	Ms.2.6 (46)	1496
D31 (37)	1384	Fl83fc (151b) (issu de fl)	1441	Huguette 93	1497
D.42 (98)	1385	Fl 83 nk (154.1) (fl nahodka)	1442	Croix leonardoux	1498
D5 (91)	1386	Fl 84 el1 (157.1) (fl ellijay)	1443	Antonin	1499
D8 (104)	1387	Fl 84 el2 (157.2) (fl ellijay)	1444	99b	1500
Dl12 (100)	1388	Fl 85 jt1 (161) (fl janto)	1445	Mont st Michel	1509
H54.1 (102)	1389	Fl 85 jt2 (162) (fl janto)	1446	St Beauzile Montana (courgettes précoce)	1510
I2.1044.344 (145) (i2)	1390	Fl 85 k8 (163) (fl k8)	1447	St Beauzile Montana (courgettes précoce)	1511
I3.2017 (146) (i3)	1391	Fl 85 342.62.1 (164) (fl 342.62)	1448	St Beauzile Montana (courgettes tardif)	1512
K.4 (93)	1392	Fl 85 342.62.2 (165) (fl 342.62)	1449	St Beauzile Montana (courgettes tardif)	1513
K.5 (94)	1393				

Table 2 Traits recorded on the plants, height, anthocyanin, forms and sizes of tubers

	Height (m) 1–2.5	Pigmentation (crop) 140		Tubers (crop) 140		
		Anthocyanin	No anthocyanin	Long	Branched	Round
Number of accessions	140	19	121	18	51	71

Anthocyanin, form and size of tubers were reckoned on each original picture with at least 6 tubers per accession

not widely described but pictures are given of each clone (Table 2; Fig. 1; In supplemental materials Fig. 1).

Blossoming dates

Phenological examinations throughout the year show that blossoming dates among clones remained constant with a variation of less than 1 week (data not shown). Ten percentages of clones will blossom between the beginning of June and August. Most accessions (80% of the collection) begin to blossom between September and October. The remaining 10% did not blossom at all due to the climatic conditions in Montpellier. They are from the Northern USA and Canada, and probably require very short days to induce flowering. They did not produce floral organs (or much atrophied ones) due probably to the long days in Montpellier at latitude 42° north. Figure 2 presents the distribution of flowering dates in 2005. Other traits used to describe tubers and which may be important for consumer choices are given (Table 2). All tubers were photographed separately (supplementary materials) and the overview of all the clones is displayed to make broad comparisons between them (Fig. 5).

Estimation of production potential for clones

The yield for clones was estimated in the conservation device *hors sol* for the collection. The set up started in April with three tubers per tank and the harvest was in December, after complete drying of the stems. Frequency distribution for production per tank of the 140 clones is given Fig. 3. The potential yield varies from 0.060 to 1.75 kg/tank.

Estimation of female fertility from Jerusalem artichoke clones

Seed sets on Jerusalem artichoke plants were determined before 2005. Ten heads were left in open pollination, the pollen cloud being determined by the whole collection in isolation in the experimental field. Of the 166 clones or wild populations observed, 142

Fig. 1 Overview of tubers from 164 clones. Supplementary materials display each clone separately

clones blossomed and displayed normal heads. No other Helianthus were grown around the plot.

Among the 166, 96 (67.6%) produced seeds in free-pollination. A set of 24 clones did not produce any seeds. The 26 wild natural Jerusalem artichoke populations produced more seeds (20.9 seeds per head) than cultivars (6.2 seeds/head). The distribution of female fertility measured on 142 Jerusalem artichoke accessions is shown in Fig. 4.

This data shows that under a favourable pollen environment many Jerusalem artichoke clones can provide enough seeds to open the doors for a genetic

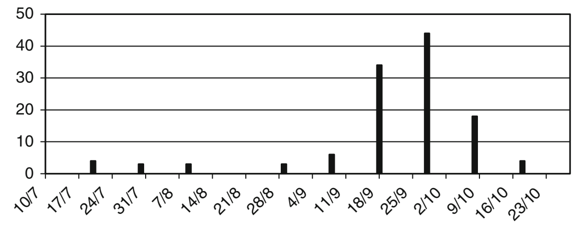

Fig. 2 Histogram of blossoming dates for the 142 crop (Cv) clones

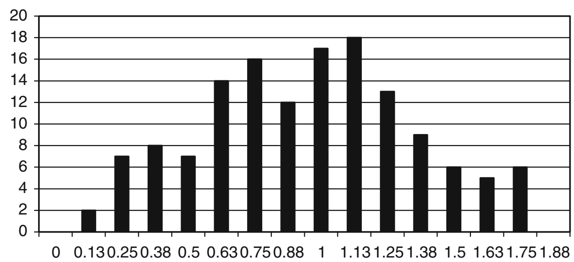

Fig. 3 Potential yield for clones experimented in hydroponic conditions

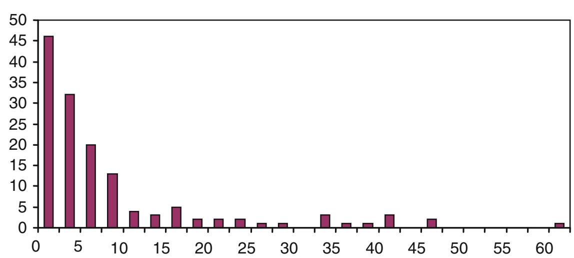

Fig. 4 Seed number harvested by head with free pollination ensured by bees for 142 accessions studied

improvement (missal selection as example) of Jerusalem artichoke by crossing clones with complementary traits.

Chlorophyll intensity

We applied this measurement due to visual differences in green colour between clones. It was determined using SPAD-502 (Minolta Camera Co), we displayed the variance analysis for twelve measurements onto 169 plants in Montpellier. Leaves were sampled at random. It shows that differences in chlorophyll between clones vary significantly ($P < 0.05$) (Table 3).

Two disease notations

Ring spot viruses

Due to the vegetative propagation clones accumulate viruses. We recorded the number of spots on leaves during the very hot summer of 2003. For 166 clones only one appeared to be resistant (Table 4). Six other newly introduced clones were also checked that year, totalling 172 clones.

Powdery mildew caused by Oidium neolycopersici

The plants were ranked according to the number of leaves under attack. Some plants were less attacked than others (Table 5).

Sampling of 9 clones

A choice was made to grow up No. 1369, 1.2 kg/No. 1400, 0.4 kg/No. 1411, 1.1 kg/No. 1422, 0.9 kg/No. 1435, 0.5 kg/No. 1436, 0.8 kg/No. 1440, 0.9 kg/No. 1471, 0.3 kg/No. 1477, 0.8 kg in a field beside the nursery with fertilizers NPK (60–150–300) and watering. Ten small tubers were chosen and planted a metre apart with 1.5 m between lines. (0.7 plant/m^2; Table 6).

Yield at harvest

Ten clones were grown in the experimental field of Supagro for production of tubers with watering in July, August and during blossoming in September. Tubers were harvested in November and weighed. Estimated yield per ha varies from 27 to 93 T/ha.

Discussion, conclusions

The collection of the Jerusalem artichoke is unique in Europe although some clones can be found in other countries (Key and Nottingham 2008). This collection was set up and used for original basic work on *Helianthus* genomes (Cauderon 1965; Leclercq et al. 1970) as well as for a breeding sunflower crop (Leclercq et al. 1970) and it is the source of a new trend to consume organically grown Jerusalem artichokes, in collaboration with Fleuron d'Anjou, for the release of ancient cultivars. Our estimation of the

Fig. 5 Photographs for tubers of the nine clones selected

Table 3 Variance analysis for SPAD measurements on 169 plants with 12 repeats

Variance analysis one factor

Elementary measure	Size	Sum	Mean	Variance
SPAD1	169	6,390.11	37.81130178	33.68222925
SPAD2	169	6,336.4	37.49349112	32.49061214
SPAD3	169	6,304.9	37.30710059	31.51792547
SPAD4	169	6,292.1	37.23136095	36.45811778
SPAD5	169	6,387.1	37.79349112	43.14596929
SPAD6	169	6,382.1	37.76390533	36.07648704
SPAD7	169	6,430.8	38.05207101	35.24596295
SPAD8	169	6,349.8	37.57278107	37.6977071
SPAD9	169	6,332.9	37.47278107	28.08889758
SPAD10	169	6,338.1	37.5035503	32.71379684
SPAD11	169	6,324.2	37.42130178	34.18787687
SPAD12	169	6,328.4	37.44615385	38.07666667

Variance analysis

Variation source	Square sum	Freedom degree	Mean squares	F	Probability
Between groups	104.6219907	11	9.511090062	0.272145712	0.990751563
Inner groups	70,456.21783	2016	34.94852075		
Total	70,560.83982	2027			Critic value 1.79

Table 4 Number of virus spots or rings by leaf (Average of 3 leaves) during the summer 2003

Symptoms	Size of samples
Not determined	2
Susceptible about ten spots	25
Very susceptible more than 10 spots	144
Resistant only a few spots	1

Table 5 Powdery mildew symptoms notations in the field at end of August 2003

Symptoms	Size of samples
Not determined	14
Susceptible most no attacked leaves	142
Very susceptible most leaves attacked	12
Very very susceptible all leaves attacked	1

yield of ten plants was too wide to enable further discussion of yield variations. Fleuron d'Anjou did not indicate any differences in agronomic conditions either for clone multiplication or for commercial production of tubers.

Consumption of tubers either boiled or fried was carried out by lab staff. Judgements were diverse but most appreciated the artichoke taste. Fried tubers tended to be hard, but the taste was appreciated in a ragout where the consistency is soft with boiled meat and other vegetables.

Special attention was drawn to female fertility of Cv clones to understand whether populations established along streams should be clones or sexual populations (Bervillé et al. 2005; Kowarik 2005). It was observed that most clones provide enough seeds to warrant both sexual and vegetative propagation. An extensive study of these populations remains to be performed to determine sexual versus vegetative propagation rates.

Several attempts had been made by the 1970's to grow Jerusalem artichokes as a source of ethanol by transforming the inulin (Galzy and Moulin Supagro) using different yeast fermentation systems. Agronomic constraints more than technical ones have limited the efficiency of the chain, since tubers are costly to transport, their aptitude to storage before transformation is poor, and fermentation and inulin degradation was fast. It was found that when left in plastic trays, tubers dehydrated in 4–5 days, becoming soft. Storage in wet conditions is recommended to keep tubers turgescent.

In the collection is a wide genetic base of earliness and morphology. However, all crop Cv are late and it could be possible to enlarge the timescale of tuber production to avoid long shelf storage of tubers. The female fertility observed for most clones enables us to plan genetic improvement for the main traits examined.

Due to Vegetative propagation, it is probable that viruses accumulate in clones. Clones could be cured of viruses by in vitro culture of apex before starting such programmes. It is probable that the yield would be enhanced. Average yields are in agreement with

Table 6 The nine clones chosen according to earliness characteristics and tuber yields in hydroponic culture

INRA_code	Clone designation	Plantation	DAT_FLO	Tuber (kg) hors sol	Weight field
1369	742.63 (51)	6-April	23-Sept.	1.093	
1400	ACP 1981 (125)	6-April	16-Sept.	1.177	
1411	LACHO (139)	6-April	21-Sept.	1.188	
1422	VIOLET DE RENNES (69)	6-April	18-Oct.	1.295	
1435	(NK*VR).1 (321)	6-April	18-Oct.	1.552	
1436	(NK*VR).2 (327)	6-April	18-Oct.	1.249	
1440	(VR*NK).1 (297)	6-April	27-Sept.	1.109	
1471	HYBRIDE 103 (77)	6-April	27-Sept.	1.314	
1477	M24.29 (84)	6-April	9-Sept.	1.011	

Mean 10 plants in the field year 2007

average values given by Seiler (2007), but such experiments are costly and no funding was available for this objective.

All clones were used to prepare total DNAs which are available upon request to those with an interest in diversity analysis or diversity of genes. All clones are available upon request.

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