SILPHIUM PERFOLIATUM (CUP-PLANT) AS A NEW FORAGE

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Abstract. Cup-plant, *Silphium perfoliatum* L., is native only to prairies of the eastern parts of North America. It was introduced to Europe and western USSR around 1750; since then it has been prized there as a showy, long-flowering, horticultural perennial. Around 1957, it was noticed to show potential as a productive low-maintenance fodder crop for ensiling for livestock feeding. In 1972, Sokolov and Gritsak published, in English in *World Crops*, a summary of their 15 years findings. Since then more than 100 papers have been published from eleven countries—but none from the United States. This paper summarizes those reports, supplemented by personal observations. Field trials have now begun here. It is a long-lived perennial herb; its high productivity, ease of husbandry, high protein content, good feed value for meat and milk production, and good palatability rival alfalfa; these qualities make it worthy of study in its home country.

INTRODUCTION

Protagonists for scholarly study of the fast-vanishing tropical rainforests emphasise the potential for pharmaceutical, biological, or commercial values of as-yet unrecognised constituent species. American Indian lore suggests that prairie plants may hold comparable promise.

This paper briefly reviews and summarises the extensive work that has been done at many overseas centers over several decades on cup-plant (*Silphium perfoliatum* L.) which, although endemic to our all-but vanished North American prairie, has not been studied previously in the United States as a fodder.

METHODS

This literature review is culled mainly from papers that have been abstracted in two English-language journals: Biological Abstracts (Biosis, 2100 Arch St, Philadelphia, PA 19103) and C.A.B International Abstracts (845 North Park Avenue, Tucson, Arizona, United States 85719). The majority of the original papers abstracted there are written in Cyrrilic script or in Japanese ideograms, and full copies are not generally available in libraries in the United States. When those papers that I have obtained contain summaries in English or in French I have used those also. Many of the papers cover only the first two or three years of a field study, and so cannot give valid information about the characteristics of a plant that does not achieve full production and quality until after the fourth year after seeding. I have supplemented this paper, especially in the historical section, from books in the libraries of Kew Gardens, London, England, and of the Herbarium at the Southern Methodist University, Dallas, Texas. In addition to the agronomic papers reviewed here, Biological Abstracts records another 15 papers of biochemical or pharmaceutical studies on the constituent chemicals of the plant. If you want the citations for those papers, please let me know.

My most important references, each covering many years work, are from copies of full-length papers: Professors Sokolov and Gritsac published in English in 1972 a review of their fifteen years fieldwork. Professor Kawahara, who worked on cup-plant for over a decade before he retired, sent to me from Japan six of his papers in Japanese; they have summaries in English, and some of his tables and illustrations are captioned in English. Dr Niqueux started his field-work in 1974; he published his results in French in 1981. I went to France in 1990 to talk with him, but he had retired, and could not be traced. This literature review continues; I will gladly send a full, updated list of over 130 references on request.

This paper is further supplemented by my observations made in 1990 on a 40 x 40 ft trial plot in Arkansas, United States, and on another plot 10 x 20 ft in Arlington, Texas, United States; both of these areas have acid sandy soil (cup-plant does not thrive on the highly alkaline soils of Dallas).

Table 1. Countries that have published reports, listed in order of first publication.

Russia	33	1972
Ukraine	6	1973
Lithuania	6	1973
Japan	12	1976
France	2	1978
China	?	1980?
G.D.R.	2	1982
Switzerland	1	1982
Bulgaria	3	1984
New Zealand	1	1987
Chile	1	1987

Table 1 lists published reports by country and date of first publication. This list is certainly incomplete. For example, one author numbered his sequential reports as far as 22, yet only 6 of them appear in the Abstracts. Again, others have not been abstracted: for example, China is reported as having supplied seed to New Zealand, but no abstracts appear from China. There are no abstracts from the United States or from Canada.

HISTORY

Origin

All species in the genus *Silphium* in the tribe Heliantheae (family Asteraceae) occur natively only in eastern North America. Cup-plant is today found in the wild sporadically from southern Canada to northern Arkansas, in open prairie clearings in bottomland woods.

Horticulture

The most recent comprehensive review (Puia and Szabo 1985) revealed that the early reports on its cultivation mention cup-plant only as an ornamental. It was listed in the inventories of central European gardens as early as 1830, but Puia and Szabo (1985) could find no reference about when, where, or by whom it was first introduced from North America.

Linnaeus (1759) named it. The earliest mention in European gardens that I have found is in 1762, in a taxonomic listing of the holdings of the Montpelier Gardens in France (Gouan 1762). The Royal Botanic Gardens in England (`Kew Gardens') record it as introduced to them by Peter Collinson in 1766 (Aiton 1789). In the United States, the first horticultural record is from 1860 (Sokolov and Gritsak 1972).

Agriculture

The published literature suggests that around 1950 the USSR planned a nationwide search for innovative and alternative winter forage crops—but I have not found this inference stated explicitly. The first publication in English about cup-plant as a fodder and silage crop was made by Sokolov and Gritsak (1972), who started to evaluate it in 1957 and continued the investigation for many years, working from the Feed Resources Laboratory of the Chernovits State University in Russia. Vavilov and Kondratev (1975) reviewed some 50 candidate novel and traditional species that had been investigated for high-yield silage fodder; 10 promising species were selected for further study. Part one of the *Proceedings of the All-Union Conference on Technology of Cultivation of New Fodder Crops* was published in Russian only (Saratov-Engels 1978); the performance of some 30 species was reported. The finalists in this search were *S. perfoliatum* and *Heracleum sosnovskyi*, which is native to the USSR. Many other foreign centers around the world have started trials on cup-plant since then, but I have no information on which are presently active.

CHARACTERISTICS

Habitat

Cup-plant is a perennial herb of the northeastern United States and southeastern Canada; it grows in moist sandy bottomlands and floodplains, near streambeds, in or adjacent to open woodland.

Genetics

It assimilates atmospheric CO_2 through the Type C_3 pathway; the chromosome count is haploid 7 (R.Fisher, personal communication Bowling Green University, Ohio, U.S.A.).

Climatics

The winter-dormant roots can survive freezing to -30 C, and they can survive flooding for 10-15 days (Niqueux 1981, Koshkin 1975). The plant needs full sun for optimal growth and can withstand high summer heat provided it has enough water. Best growing temperatures are around 20 C.

Year One

Germination.

Cup-plant germinates in the spring from seeds which have cold-stratified in the soil. Germination is not photo-dependent and does not need fluctuating temperatures (Kawahara et al. 1977a). During the first year, the seedling forms a long deep taproot, nourished by 12-14 leaves in the form of a rosette; the leaves measure up to 75 cm long and are chordate-triangular in shape (Kawahara et al. 1976). After midsummer, several buds begin to form underground at the base below the leaves and are fully formed by first frost; then the summer leaves wither and die. A small winter rosette of several leaves may now form.

Year Two

Basal leaves.

In the spring of the second year, as the soil warms, the winter leaves, if any, die, and one or more of the dormant buds develop broad chordate-triangular alternate leaves up to 30-35 cm long. At first they are nourished from the reserves in the thickened base of the seedling's taproot.

Roots.

As the new leaves develop, adventitious roots arise from the base of the bud, which is now seen to be a compressed rhizome; these roots originate from the axillae of its scale-leaves. These roots are 30-150 cm long, and 1.5-2 mm diameter for most of their length. Some grow down, others spread radially under the soil surface; they do not branch (Stanford, personal observations 1990).

Flowering stem.

After midsummer, when roots are well established and the rosette has 12-15 alternate leaves (Sokolov and Gritsak 1972), a single flowering stem develops from the apex of each large rhizome. This stem at maturity is 1-3 cm wide, 2-4 m high, and bears up to 17 leaves (Niqueux 1981); it is remarkably square and sharp-cornered in section, hence a colloquial name for this plant: square-weed. From the fourth or fifth node upwards, the leaves become opposite. After first frost, the flowering stems die back to the ground.

Stem leaves.

About 8-14 pairs of opposite leaves form at intervals along the stem (Niqueux 1981); these can attain 30 cm in length and 20 cm in width. Because their petioles are widely winged, each leaf seems to be triangular, with its base at the stem; each base is fused with that of the other in its pair, forming a cup which the stem appears to pierce (connate-perfoliate); hence the alternative colloquial name: cupweed.

Branches.

The stem terminates in a single flower-bud. While this is developing, each leaf of the upper cupped pair produces one sidestem from its node. These side-stems each terminate in a flower-bud and have a pair of opposite leaves half-way up their stem. Each of these pairs of secondary leaves subtend a similar flowering stem, and this symmetrical branching process repeats itself 4-6 times over a period of 6-10 weeks, until first frost stops further growth.

Flowers.

Each flower looks superficially to be of the typical sunflower type, with a central disc and two ranks of ray florets. But, as is the distinguishing feature of all silphia, these disc florets are atypical in that although structurally they appear to be bisexual, only the stamens are fertile. The ray florets are female only (Barkley 1986). Seeds are produced through cross-fertilisation with insect pollinators. Each flowerhead produces 20-30 seeds (Niqueux 1981).

Seeds.

Each seed is 9-15 mm long, 6-9 mm wide, strongly flattened, with a maximum thickness of 1 mm; 1,000 seeds weigh about 23 gm (Niqueux 1981).

Year Three and Beyond

Spread.

The pattern of multiple budding at the base of each mature flowering stem is repeated annually. Strong competition by the leaves of the largest buds quickly shades out those of the smaller ones, which abort, but many buds (rhizomes) remain dormant. During the next winter, the above-ground central core of each now-dead stem rots away, but the underground periphery that bears the next year's buds persists for several years, as a woody storage organ. After four to seven years, the growing centers are so far from the original taproot that it ceases function and rots away.

Longevity.

The multi-rhizomed clone from a single seed has been observed to persist in this way for over 15 years; roots are known from botanical gardens which are probably more than 50 years old (Niqueux 1981).

Stem density.

Each seed gives rise to five to seven stems in the second year and to

Table 2. Cup-plant harvest compared to alfalfa (t/ha), modified from Sokolov and Gritsak (1972)

Crop and method of sowing	*Harvest as-cut* (WW)	*Yield* *Dry matter*	*Protein*
Cup-plant, 70 cm row spacing	11.38	1.926	0.29
Blue Alfalfa, 15cm rowspacing	5.6	0.995	0.21

over 50 by the fifth to seventh year; they stabilize at a density of 38-40 flowering stems/m^2 (Niqueux 1981, Puia and Szabo 1985).

AGRICULTURE

Biotype

It is remarkable that all these reports originate from seed that went to central Europe a century or two ago. The New Zealand trial (Douglas et al. 1987) used seed sent from China, which in its turn probably came from the early central European accessions.

Soil

Cup-plant prefers good rich sandy bottomland, which perhaps is flooded some years and is risky for conventional winter row-crops. A good soil-moisture throughout the summer is essential for large yields, and even for survival (Vavilov et al. 1974).

Establishing from Seed

In the spring, after the the previous winter's rowcrop has been harvested, the soil should be tilled. Emergent weed seedlings should be killed with commecial Treflan at 7-8 kg/ha (Filatov et al. 1986) or 2-4 kg/ha of active compound (Vavilov et al. 1978). Cleaned, pre-chilled seed is then applied at 10-40 kg/ha at 40-70 cm spacing.

The first year's growth is not strong: to control weeds, inter-row harrowing must be done three to four times, or paraquat applied (Niqueux 1981); in-row weeds must be hoed or pulled by hand. In the second year, harrowing may be needed early in the season, while the leaves of the crop are emerging (Vavilov et al. 1978).

Establishing from Roots

Alternatively, for small trials and for breeding selection, the entire root system can be dug up while dormant. The large root cluster should be divided into sections, each containing at least one large and several smaller buds. They should be planted with the crowns just below soil surface. There is no need to dig deeply to plant the old roots, for they are mainly storage organs to feed the growing crown; they will cease function before the soil heats up, while the first few leaves feed the rapidly growing new roots (Stanford, personal observation).

HARVESTING

Seed

When starting a new trial from only a small, seed sample, the usual first objective is to multiply the seed stock. While the extended flowering season is splendid for bees, it also makes seed harvesting difficult since the seeds shatter almost as soon as ripe, even while new flowerhead production is continuing. Repeated hand collecting over the season can produce a high seed yield, but machine collection must be timed to secure the best return from a single annual cut. The first four orders of blooming yield the highest seed production: 100-250 kg/ha (Sokolov and Gritsak 1972). If the stems have been left standing, they should be cut and chopped or shredded immediately after the first hard frost; this disposes of the standing trash and mulches the rhizomes.

Silage

For silage, a higher total biomass dry-weight (DW) yield, richer in protein, is gained by double-harvesting: the first harvest is in the summer just as the first flowerbuds start to open; the second harvest should be as the flowerbuds of the second flush begin to open seven to nine weeks later. The dry weight (DW) is 13-16% of the as-cut wet-weight (WW) (Niqueux 1981).

Harvest Composition

The leaves have 15-20% DW, the stem 12-15% DW; this averages 14.3% DW at first harvest. At second harvest, the figures are >18%, >17%, and 17.5%, respectively (Niqueux 1981).

Yield

The first year's yield is poor, but it increases quickly in subsequent years. By the fourth or fifth year, the as-cut yield of the two harvests combined is about 80-120 t/ha/yr under good moisture and fertilization regimens (Filatov et al. 1986). This should continue for many years, because although the root is perennial, each successive crop is annual and so has youthful vigor. Analyses of average yields are given in Tables 2, 3 and 4.

Table 3. Essential amino-acids content of the dry weight from Sokolov and Gritsac (1972).

Vegetative stage of plants	*Date of sampling*	*Height of plants, cm*	*Percent-age of leaves*	*Part of plant*	*Protein as % of dry matter*	*Content of amino acids as % of total protein* *Argi-nine*	*Valine-methio-nine*	*Histi-dine*	*Leucine*	*Lysine*	*Threo-nine-glutamic acid*	*Tryp-to-phan*	*Phenyl-alanine*
Before budding	Apr 10	76	69	leaves	24.47	3.06	7.35	3.39	4.69	5.39	9.72	0.98	8.70
				stalks	14.28	1.68	3.99	2.24	3.71	2.10	8.68	0.37	3.78
Start of budding	Jun 25	193	56	leaves	20.10	3.23	8.50	3.12	5.22	7.76	6.27	9.85	7.51
				stalks	9.15	3.28	2.29	4.59	2.51	3.93	2.40	0.34	2.18
Budding	Jul 10	207	50	leaves	19.65	3.15	6.61	4.47	4.83	4.07	3.05	0.46	6.16
				stalks	7.85	2.55	3.95	4.71	2.55	5.73	2.16	0.38	2.29
Start of budding of aftercrop plants	Sep 1	95	44	leaves	16.38	7.32	10.87	1.22	9.40	6.41	11.72	0.61	7.33
				stalks	4.65	4.30	3.87	4.73	1.94	2.58	2.79	0.97	5.59
Budding of aftercrop plants	Oct 15	102	43	leaves	14.17	5.79	8.98	4.09	8.35	5.91	14.63	0.92	8.20
				stalks	3.83	4.38	4.64	2.06	3.61	2.81	5.41	0.90	7.22

Table 4. Chemical composition of compass-plant compared with other fodder plants, expressed as % of dry matter, from Sokolov and Gritsak (1972).

Plant	*Parts of plant*	*Dry matter*	*Proteins*	*Albumin*	*Fat*	*Cellulose*	*Nitrogen-free extracts*	*Ash*	*Calcium*	*Phos-phorus*
Silphium — before budding, May 10	leaves	14.8	24.5	22.0	3.5	11.8	46.8	13.4	1.72	0.57
	stalks	7.6	14.3	10.8	2.7	19.7	50.4	12.9	0.93	0.62
Silphium — budding, July 10	leaves	21.5	19.7	16.3	3.5	15.0	48.8	13.0	3.06	0.41
	stalks	17.9	7.9	4.9	2.4	35.1	47.4	7.2	1.54	0.36
Silphium — before budding of aftercrop, Aug. 15	leaves	13.2	26.2	22.3	3.3	13.0	49.6	7.9	2.16	0.52
	stalks	9.9	8.2	5.2	1.7	29.0	50.8	10.3	1.72	0.45
Silphium — budding of aftercrop, Oct. 15	leaves	21.5	14.2	11.8	3.2	14.3	48.5	19.8	3.33	0.47
	stalks	22.8	5.9	3.9	1.5	32.2	41.6	18.8	1.55	0.43
Blue alfalfa — start of flowering	leaves	25.4	22.8	15.1	4.5	16.3	40.6	15.8	2.85	0.26
	stalks	24.3	11.2	6.5	1.6	36.8	41.7	8.7	1.24	0.27
Maize — waxy ripeness	whole plant	33.2	8.7	5.0	2.3	20.9	61.8	6.3	1.20	0.20
Red clover — start of flowering	whole plant	21.8	16.7	13.2	2.6	31.4	40.8	8.5	1.88	0.23

Fertilizing

Such high annual productivity places a great demand on the soil nutrient reserves. Each season some 250-300 kg of N, 75-100 kg of P_2O_5, and 500-750 kg of K_2O are exported; this must be replaced to maintain productivity (Niqueux 1981).

Ensiling

Silage made from as-cut WW biomass is high in butyric acid and low in lactic acid, with a pH of 5.2. Several authors report that as-cut ensiling gives too wet a mash, and they warn that the runoff liquors contain a lot of the nutrients (Maslinkov and Donev 1987; Nedwaras and Marchulenis 1987) and should be retained.

Enrichment

Some authors recommend that formic acid be added at the rate of 3.5-5 litres/WW ton (Niqueux 1981, Puia and Szabo 1985); others recommend that the freshly harvested biomass be wilted or partially hayed before ensiling. When prewilted from 85-80% WW moisture down to 70%, the butyric acid in the silage falls to 0.03%, and lactic acid rises to 1.93%, with an overall pH of 5.5. This makes a good feed (Kawahara et al. 1977b). Alternatively, a dry forage can be mixed in: wood pulp (Niqueux 1981), grains (Sokolov and Gritsak 1972), or grain chaffs (Niqueux 1981).

Silage Quality

Quality of cup-plant silage compares well with maize silage (Niqueux 1981) (Tables 2 and 3).

Grazing

Livestock must not be allowed to open-graze the growing crop: their hooves would do too much damage to the newly-forming underground buds that will provide next year's crop. Niqueux (1981) reports that sheep will eat fresh-cut plants. Puia and Szabo (1985) report that cattle will not do so, but I have watched cattle freely eating it in the field. A middle-aged lady told me that the tender young leaves newly emerging in the spring make a good culinary vegetable, either as fresh salad or cooked; her mother frequently served them thus when she was a child.

Pests and Diseases

Cup-plant is generally disease-free. In summertime, the stems are sometimes attacked by Sclerotinia. In cool damp autumns, some flowerbuds wilt and turn black before opening, attacked by Botrytis (Niqueux 1981). Puia and Szabo (1985) reported that some of their seedlings' roots were eaten by a ground-dwelling beetle ('courtilier').

Honey Production

The long blossoming season and the profusion of flowering heads under seed-production management provide a rich source of honey; 150 kg/ha/yr is mentioned (Sokolov & Gritsak 1972).

Other Products

The Silphium genus provides a number of compounds in their saps, some of which have pharmaceutical properties. Cup-plant for example contains silphiocide A—a triterpene glycoside (Davidyants et al. 1984), substances having nematocidal properties (Gommers 1973), and extracts that hasten burn-wound healing in rats (Kuyantseva and Davidyants 1988).The summary presented here is a condensation of a longer paper which contains over 100 references and many more tables. If you would like to receive that, please write to me for a copy.

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