Aspects of agronomy of rakkyo (*Allium chinense* G. Don) in New Zealand

JJC Scheffer[1], JA Douglas[2], CM Triggs[3], ML Shaw[4] and JA McCallum[4]

[1]New Zealand Institute for Crop and Food Research Ltd, Cronin Rd, RD 1, Pukekohe
[2]New Zealand Institute for Crop and Food Research Ltd, Private Bag 3123, Hamilton
[3]Department of Statistics, University of Auckland, Private Bag 92019, Auckland
[4]New Zealand Institute for Crop and Food Research Ltd, Private Bag 4704, Christchurch

Abstract

Rakkyo (*Allium chinense* G.Don, Syn. *A. bakeri* Regel) is an Asian bulb vegetable highly regarded in Japan for pickling. Crop and Food Research introduced the crop into New Zealand in 1997 for commercial evaluation. A series of field trials were conducted to determine the effects of time of planting, time of harvest and planting density on bulb yield and quality. A preliminary trial investigated the effect of storage temperatures on bulb quality, whilst bulbs of three maturities were analysed for dry matter content and fructan and cysteine sulfoxide levels. Delaying planting from April to June reduced bulb yields from 23 t/ha to 8 t/ha possibly due to declining quality of the planting material. The mean number of bulbs per plant declined from 17 to 9 for the April and June plantings respectively, whilst the average bulb weight was 5.3 g. Total bulb yields increased from 8 t/ha to 18 t/ha with delay in harvest from September to January. The mean bulb weight increased from 3.9 to 6.9 g between the September and October harvests, but did not vary significantly over the four remaining harvests. Plants developed flower stalks from about mid-January and bulbs harvested at that time were generally soft and of poor quality. Leaf blight (*Botrytis byssoidea*) caused extensive discolouration and decay of the outer skin of some bulbs harvested in December and January. Planting at 33 plants/m^2 produced 39% more bulbs at harvest than at 27 plants/m^2 but reduced the mean bulb size by 16%. Weight loss in bulbs stored at 5°C for about 2 months was 7% compared to 18% loss in bulbs held at ambient (20°C) temperature over the same time. Storing bulbs at 10°C induced leaf and root development after 2 weeks of storage. Enzymatic analysis showed that fructans made up 31% of the dry matter content of the rakkyo bulbs. Bulbs contained on average 0.33 mg/g fwt of 1-propenyl cysteine sulfoxide and 0.84 mg/g fwt of methyl cysteine sulfoxide. This research has shown that rakkyo can be grown successfully in New Zealand.

Additional key words: scallion, bakers garlic, plant production, Allium chinese

Introduction

Rakkyo (*Allium chinense* G. Don, Syn. A. *bakeri* Regel) - is an ancient, herbaceous, bulb-producing perennial vegetable grown almost exclusively in China and Japan, mainly for processing and the production of *tsukemono* or Japanese pickles (Brewster, 1994). It is found wild in the central eastern regions of China, Indochina and the Himalayan region of India (Iwasa, 1980), and has been cultivated in China from very early times. The crop was introduced into Japan centuries ago and 10th century writings indicate that it was used for medicinal purposes and food (Ageta *et al.* 1980). Now, it is used only for food in Japan. Rakkyo is not well known in the Western world and apart from a crop review by Mann and Stearn (1960) there are very few English references to the crop.

Rakkyo, also known as scallion, Baker's garlic, *ch'iao t'ou* (Mandarin) or *k"iu t'au* (Cantonese), produces clumps of tillers that each produce a small ovoid bulb (2 – 5 cm long) at the base. Bulbs are purplish or grayish white and covered by a semi-transparent, dry membranous skin. They have a crisp texture and a strong onion-like but distinctive odour. The leaves of rakkyo grow up to 50 cm long and resemble those of chives but are angular rather than round and less erect. In late summer, the plant produces a solid flowering stem, up to 60 cm long, which has an umbel with 6 to 30 reddish purple flowers. The flowers are sterile and rakkyo is propagated vegetatively from bulbs. Bulb formation is promoted by an increase in daylength in the spring at a temperature range between 15 to 25°C (Saito, 1983). Bulbs are planted in late summer or early autumn. The bulbs for processing are harvested the following summer when the leaves begin to wither. For fresh rakkyo, immature bulbs with blanched leaves are harvested in spring. The many rakkyo cultivars are broadly divided into small-bulbed cultivars (multiple-bulb types), which produce 10 to 25 bulbs each weighing 1.5 to 2.9 g, and large-bulb cultivars, which produce 6 to 10 bulbs each weighing 4 to 10 g. The large-bulb type is grown all over Japan (Toyama and Wakamiya, 1990).

The average bulb yield in Japan is 6 t/ha, whilst in southern Japan yields of up to 20 t/ha have been achieved (Mann and Stearn, 1960). In the Sanrihama sand dune region of Fukui Prefecture, a small-bulb cultivar is grown that takes 2 years to mature. Total production is estimated at 2600 t/year (Fujii, 1988). Although some fresh rakkyo is used in cooking special dishes, most rakkyo is consumed pickled in brine or rice vinegar (Shimizu, 1993). A total of 23,706 tonnes of pickled rakkyo was produced in Japan in 1997, or 2.1% of its total *tsukemono* production (Nguyen, 2000). Since 1995, Japan has imported rakkyo from China, which supplied 99.7% of the 14,340 tonnes imported in 1997. Rakkyo is imported semi-processed, in salted or seasoned forms, then reprocessed and used as *tsukemono* or with curried rice. Pickled rakkyo is exported from Japan to many countries, particularly the USA and several south-east Asian countries (Jones and Mann, 1963).

Apart from its use as a food, recent studies in China and Japan indicate that rakkyo has anti-tumour, anti-cancer and anti-blood coagulation constituents worthy of further investigation (Jiang *et al.*, 1998; Hsing *et al.*, 2002; Baba *et al.*, 2000).

In 1997, Crop and Food Research imported a small number of bulbs of an unnamed rakkyo cultivar from Japan to investigate whether the crop could be grown here successfully and whether it had potential as a new vegetable for New Zealand. Bulbs were grown under high security quarantine at Lincoln until they were found to be free of viruses. In September 1998, they were released and planted out at Crop and Food Research's field station at Pukekohe. From 1998 to 2000, bulbs were grown alongside onions to bulk up the limited supply and, at the same time, to allow observation of the crop's performance under local conditions (Scheffer and Douglas, 2001). For ease of management the rakkyo was managed similarly to the onions in terms of planting and harvest times. Planting times varied between late June and early September, with bulbs harvested in February. These crops grew very well until the onset of dormancy, characterised by rapid leaf senescence, from mid-December. Most plants also produced flower stalks by late January. Bulb yields from these crops were low (about 4 t/ha).

In the 2001–2002 season, the first field trial was conducted to determine the effects of planting time on yield. Bulbs from a neighbouring planting were stored at various temperatures for two months to determine the effects of storage conditions on bulb weight and quality (Scheffer and Douglas, 2002). Two further field trials were conducted in the 2002-2003 season to determine the effects of harvest time and plant density on bulb yields. In addition to this agronomic evaluation, bulbs were also analysed for fructan content to investigate rakkyo's potential health benefits and for cysteine sulfoxide levels to identify flavour precursors.

Materials and Methods

The field experiments (experiments 1, 2 and 3) were conducted on a Patumahoe clay loam at the Crop and Food Research Station at Pukekohe. Apart from experiment 3, which examined different plant populations, all rakkyo was grown at a density of 27 plants/m^2 on slightly raised beds in four rows 25 cm apart, with 10 cm between plants. The planting depth was 6 cm. Crops were grown without irrigation and manually harvested.

Experiment 1 – Time of planting

This trial investigated the effect of planting bulbs at monthly intervals from April until June 2001 on crop establishment and bulb yield components. The planting dates were 5 April, 5 May and 5 June 2001. Soil fertility was amended by applying 15% potassic serpentine superphosphate (7.7% P; 7.5% K; 9.9% S) at the rate of 1.3 t/ha one or two days before planting. Calcium ammonium nitrate (27% N) was side-dressed at the rate of 50 kgN/ha about 2 weeks after planting and again 6 – 8 weeks later. Bulbs used for planting material weighed about 4 g. Plots were 3.4 m long and each of the four rows had two guard plants at either end. Treatments were compared using a randomised complete block design with four replications. Weed control was carried out manually with no fungicides or pesticides applied. Plants were lifted between 18 and 31 January 2002 and the number of plants harvested in each plot was recorded. After lifting, the bulbs were washed with a high pressure hose, air-dried and the roots trimmed to 2 mm and the necks to 2 cm. Bulbs were counted but not graded, and fresh and dry bulb weights were recorded. The percentage of bulb dry matter was determined from six to eight bulbs taken at random from each plot, sliced, and dried at 80°C for 2 to 3 days until weights stabilised.

Experiment 2 - Storage temperature effects

In this trial we investigated the effects of different storage temperatures on bulb keeping quality. Bulbs were obtained from a rakkyo crop planted on 21 April 2001 alongside experiment 1. Plants were lifted on 21 February 2002. Dry soil was manually removed from the bulbs and trimmed as described in the previous experiments. A sample of 300 bulbs was taken at random and divided into six groups of 50 bulbs. Each group was then divided into five replications of 10 bulbs for storage at 5, 10, 15, 20, 25°C and ambient temperature for 2 months. The mean ambient temperature was about 20°C (range 16.6 - 21.8). Bulbs were kept in closed polystyrene boxes and weighed at weekly intervals from 28 February to 22 April 2001. Data at each storage time were analysed by analysis of variance using the plot weight at harvest as a covariate.

Experiment 3 - Harvest time and bulb chemistry

The effect of harvest time on the yield and quality of rakkyo was investigated in a trial planted on 4 April 2002. Bulbs were harvested on 17 September, 16 October, 22 November, 22 December 2002 and 17 January 2003. Plots were 1.4 m long x 1.5 m wide with 40 fully guarded recorded plants. Treatments were replicated four times in a randomised complete block design. Base fertiliser of "Potato Mix" (N: P: K = 6: 6: 6) was applied at the rate of 1.6 t/ha on 3 April 2002 and the crop side-dressed on 11 July 2002 with "12: 10: 10" at 50 kgN/ha. For weed control, Stomp (pendimethalin) at 2.0 l/ha was applied one day after planting, and a mixture of Totril (ioxynil) and Tribunil (methabenzthiazuron) at 1.0 l/ha and 1.0 kg/ha, respectively, was applied on 9 May 2002. Hand-weeding was also needed from time to time to remove perennial weeds resistant to the herbicides used. The crop was sprayed twice on 11 and 23 December 2002 to control leaf blight (*Botrytis byssoidea*) with a mixture of Amistar (azoxystrobin) at 0.4 g/litre + Rovral (iprodione) at 1.0 g/litre + the sticker-spreader NuFilm 17 – TM (di-1-p-menthene) at 0.4 ml/litre. Yields of both the tops and bulbs were recorded. Harvesting procedures were the same as in experiment 1.

Bulbs harvested in November and December 2002 and January 2003 from the above field experiment were analysed for fructan and cysteine sulfoxide levels. Four replicate bulb samples were taken on 21 January 2003 from each of the three treatments. Bulbs from the November and December harvests were held in a coolstore at 5°C for 2 months and one month, respectively. For analysis of S-alk(en)yl cysteine sulfoxide (ACSO) flavour precursors, samples were directly extracted in methanol: chloroform: water (12:5:3 v/v; (Lancaster and Kelly, 1983)). Free ACSOs and amino acids were analysed by reverse-phase HPLC following phenylisothiocyanate derivatization (Randle *et al.*, 1995). Sliced bulb tissue was freeze-dried for dry matter determination and fructan analysis. Ground freeze-dried material (100 mg) was extracted according to AOAC method 99.03 and total fructans were determined using a Megazyme assay kit (McCleary *et al.*, 2000).

Experiment 4 - Row number per bed

This experiment compared the results of planting five rows per 1.5 m wide plot instead of four and maintaining the same in-row plant spacing of 10 cm. Row spacing in the four row plots was 25 cm (plant density 27 plants/m^2), and in the five row plots rows it was 20 cm (33 plants/m^2). Plots were 3 m long x 1.5 m (bed width). Treatments were replicated four times in a randomised complete block design. The bulbs were planted on 8 April 2002. The fertiliser, weed and disease control programmes were the same as for experiment 2. Bulbs were harvested on 23 January 2003 from a 1.5 x 1.5 m fully guarded area of the plot taken at random. Harvesting procedures were as for experiment 2 except that the bulbs were not washed as soil conditions were dry and soil was easily removed manually. Bulb numbers and weights were recorded.

Statistical Analysis

Analysis of variance was carried out on all results presented using the statistical package GENSTAT (2002).

Results

Experiment 1

Plant survival declined when planting was successively delayed by one month from April to June 2001 (Table 1). The percentage loss after a delay of one month was 4%, increasing to 34% after 2 months.

With the decline in plant numbers, bulb numbers per hectare at harvest decreased significantly ($P<0.05$) by 28% with a one month and by 60% with a 2 months delay in planting. The number of bulbs per plant also decreased significantly (P<0.05) from 17 in the April to nine in the June planting (Table 1). For every month that planting was delayed, total bulb yields were reduced by 8 t/ha.

Table 1. Effect of planting time on plant survival and bulb yield components of rakkyo at harvest.

Planting time (2001)	Plant survival (%)	Bulb number (10^3/ha)	Bulb number (no./plant)	Mean bulb size (g)	Total bulb yield (t/ha)
5 April	96 (78)[1]	4200 (8.34)[2]	17	5.5	23
4 May	93 (75)	2990 (8.00)	12	5.5	16
5 June	66 (55)	1680 (7.42)	9	4.9	8
$LSD_{0.05}$ (df = 6)	(7.0)	(0.083)	1.5	1.0	2.1
P value	(<0.001)	(<0.001)	<0.001	0.36	<0.001

[1] Mean of angular transformed data in brackets; LSD applies to transformed data only. Survival (%) backtransformed from mean of angular transformed data.

[2] Mean of log transformed data in brackets; LSD applies to transformed means only. Bulb numbers backtransformed from mean of log transformed data

Experiment 2

Bulb weight loss occurred at all storage temperatures beginning one week after storage (Fig.1). Three distinct storage regimes were evident: 5°C and 10°C; 15°C, 20°C and ambient; and 25°C. At each date, bulbs stored at 25°C had significantly (P<0.05) lower weights than all the other treatments, whilst bulb weights at 15°C, 20°C and ambient at all dates were significantly (P<0.05) lower than at 5°C and 10°C.

After two weeks of storage at 10°C, bulbs developed new roots and leaves, which did not occur in the other treatments, and these continued to develop slowly throughout the storage period. Bulbs lost most weight in the 25°C storage treatment and also produced odours towards the end of the storage time, indicating a bacterial breakdown of bulb tissues. There was some visual evidence of unidentified black and white moulds on bulbs in both the 5 and 10°C temperature regimes at the end of the storage period.

Experiment 3

Fresh and dry herbage yields were greatest with the October 2002 harvest and declined with delay in harvesting (Table 2). Bulb numbers per hectare were significantly greater (P<0.05) for the November to January harvests than the September and October harvests. The mean bulb weight increased from 3.9 to 6.9 g between the September and October harvests (P = 0.002), but there was no significant difference between the October to January harvests.

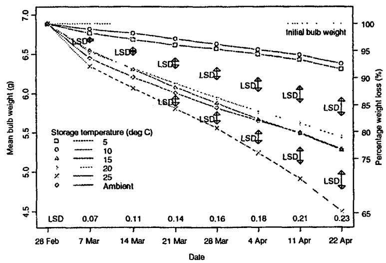

Figure 1. Effect of storage temperature on weight loss (%) of rakkyo bulbs. (Initial bulb weight at 28 Feb 2002 used as a covariate.)

Table 2. Effect of harvest time on herbage and bulb yield components from rakkyo planted 3/04/02.

Harvest time (2002/03)	Green herbage yield (t/ha)	Dry weight of herbage (t/ha)	Bulb number (10^3/ha)	Total fresh bulb yield (t/ha)	Mean bulb weight (g)	Dry weight of bulbs (%)
September	6.2	1.3	1970 (7.6)[1]	8	3.9	38 (-0.49)[2]
October	9.1	2.6	1828 (7.5)	12	6.9	39 (-0.49)
November	6.3	1.7	2440 (7.8)	14	5.9	36 (-0.56)
December	4.1	1.3	2450 (7.8)	17	6.7	33 (-0.70)
January	3.4	1.2	2529 (7.8)	18	7.3	35 (-0.62)
$LSD_{0.05}$	0.86	0.26	(0.19)	3.6	2.0	(0.12)
P value	<0.001	<0.001	0.008	<0.001	0.021	0.004

[1] Mean of log transformed data in brackets; LSD applies to transformed means only. Bulb numbers backtransformed from mean log transformed data.

[2] Mean of angular transformed data in brackets; LSD applies to transformed data only. Survival (%) backtransformed from mean of angular transformed data

Total bulb yields increased over the five harvests from 8 t/ha at September 2002 to 18 t/ha at January 2003. A linear regression of bulb yield on harvest date explained 96% of the variation between the means at each harvest. Delaying the harvest by one month increased the yield by 2.6 t/ha (P <0.001). Bulb dry matter was lowest in the December harvest (33%) and significantly lower than in the September to November harvests (mean 37%). About 6% of all bulbs harvested in January had flower stems at different stages of development, whilst most of these bulbs also had small leaves and roots. A few bulbs harvested in December showed discolouration and tissue breakdown caused by leaf blight. The incidence was considerably higher in the January harvest. Many bulbs harvested in January had split and felt "spongy".

Total fructans constituted a high percentage of the bulb dry matter, but there was no significant difference between harvests (Table 3). There was no significant difference in 1 – propenyl and methyl cysteine sulfoxides between the harvest dates (Table 3).

Table 3. Dry matter, fructan and cysteine sulfoxide levels in rakkyo bulbs harvested in November and December 2002 and January 2003.

Harvest (month)	Dry matter (%)	Fructan (%)	Cysteine sulfoxide 1-propenyl (mg/g fwt)	Cysteine sulfoxide methyl (mg/g fwt)
November 2002	41	31	0.41	0.81
December 2002	39	31	0.31	0.82
January 2003	38	33	0.29	0.90
$LSD_{0.05}$ (df = 9)	4.4	4.1	0.17	0.46
P value	0.37	0.48	0.40	0.47

Experiment 4

Planting at 33 plants/m^2 produced 39% more bulbs at harvest than at 27 plants/m^2 (P<0.001) (Table 4). The mean bulb size was smaller at the higher density (10 g compared with 13 g, (P = 0.08)), but total bulb yield was not significantly greater (Table 4). The incidence of sheath decay as a result of leaf blight was variable. Overall bulbs tended to be quite soft and some were uncommonly large (up to 50 g). Many also showed chewing damage caused by the white-fringed weevil (*Graphognathus leucoloma*).

Table 4. Effect of varying row width and plant density on bulb yield components.

Plant density (no/m^2)	Bulb number (10^3/ha)	Total bulb yield (t/ha)	Mean bulb weight (g)
27	2085 (7.6)[1]	26.5	13
33	2854 (8.0)	29.3	10
$LSD_{0.05}$ (df = 3)	(0.12)	2.7	3
P value	0.004	0.12	0.080

[1] Mean of log transformed data in brackets; LSD applies to transformed means only. Bulb numbers back transformed from mean of log transformed data.

Discussion

The series of field trials has shown that rakkyo can be grown successfully in New Zealand. Planting in the autumn rather than winter, as is recommended for onions (*Allium cepa*) in the Pukekohe district, increased bulb yields almost entirely as a result of an increase in bulb number. Yields from the April planting were similar to the highest yields quoted from southern Japan (20 t/ha) (Mann and Stearn, 1960), but no recent yield data from Japan were found. The mean bulb weight of 5.5 g agrees with the average bulb weight (4 to 10 g) of the large-bulb types grown in Japan (Toyama and Wakamiya, 1990). Planting still earlier, in February or March, could further increase yields but could induce premature bolting and affect bulb quality.

The results of the time of harvest trial suggest that, for April plantings, December is the optimum time to harvest rakkyo in Pukekohe. Harvesting earlier reduced yields and harvesting later adversely affected bulb quality due to bolting and sprouting. Sprouting was probably initiated by 9 days of wet weather in the second week of January which brought 117 mm of rain. Herbage yields between October and December declined by 50%, but bulb yields increased by 41%. This increase was again due to a significant increase in bulb number, rather than an increase in bulb weight. Bulb yields of the November, December and January harvests were probably adversely affected by leaf blight (*Botrytis byssoidea*) which caused premature death of part of the leaf canopy. This disease was not identified until early December when tan lesions on young leaves were observed. *Botrytis byssoidea* is not usually regarded as being as pathogenic as *B. aclada,* the common *Botrytis* on onion. It was originally recorded in Japan on *Allium* species grown there, and the pathogenicity of *B. byssoidea* could well be greater on oriental *Allium* species (M. Dance, pers comm.).

The density trial demonstrated that bulb yields could be improved by 11% by planting five rows per bed instead of four. The higher density increased bulb numbers and reduced bulb size showing that bulb weight can be manipulated by varying plant spacing and density. Bulb weight requirements will vary according to end use and customer preference. Relative to the other trials, bulb yields in the density trial were high (26 to 29 t/ha) and the bulbs were large (10 to 13 g). Yield differences may possibly be attributed to a lower incidence of leaf blight infection.

No references were found on storage of rakkyo. Other *Allium* crops such as green onions and green shallots, which are quite perishable, can be stored satisfactorily at 0°C for 3 to 4 weeks at 95 to 100% humidity (Hardenburg *et al.*, 1990). The high humidity is achieved by spreading crushed ice over the bulbs. Unfortunately, we did not include this low storage temperature regime in our storage trial. Generally, storage conditions will depend on the purpose of storing the bulbs, i.e. fresh use, or processing, or planting. If bulbs are marketed or processed promptly, results have shown that weight losses can be kept to a minimum by storing at 5°C. Bulbs required for planting, on the other hand, can probably be left in the ground until the end of January or early February before they re-sprout. In a field planting at Pukekohe, plant survival from dormant bulbs stored at ambient temperature (20°C) for 2 months from February to April was 99%, the same as for bulbs stored for the same period at 5°C (J. Scheffer, unpublished data).

Bulbs harvested in December had a significantly lower dry matter content than the earlier harvested crops. The reason for this is not understood. The dry matter content of bulbs is important in assessing cooking and processing quality as well as storage life. The high dry matter content of rakkyo bulbs is similar to that of garlic, but the range of fructan percentage of the dry matter (25 to 35%) is similar to the range observed in storage onions (J. McCallum and M. Shaw, *unpublished data*). Comparative studies of *Allium* fructans have shown that the species can be classified according to their relative balance of smaller and larger fructan oligomers (Ernst *et al.*, 1998), but there are no published reports of rakkyo fructans to date.

Analysis of the rakkyo bulbs showed that they contain several compounds with potential health benefits. They provide a rich source of fructan, which reduces risks of cancer and heart disease and enhances mineral absorption through probiotic effects on gut flora (Roberfroid and Delzenne, 1998; Hirayama, 2002)). The level of ACSO flavour precursors was found to be high, but because the methyl/propenyl ratio is high, rakkyo tastes 'cabbagey' rather than hot. S-methyl cysteine and S-methyl cysteine sulfoxide occur in cruciferous and *Allium* vegetables and have been shown to exhibit cancer preventative properties in model systems (Stoewsand, 1995; Fukushima *et al.*, 2001). The selenium analogs of these compounds have even more potent anticancer activity (Cai *et al.*, 1995;

Block *et al.*, 1996). There is, therefore, potential to enhance the anticancer attributes of rakkyo by Se supplementation on low-Se New Zealand soils. A number of recent studies suggest that steroidal saponins in *Allium* vegetables may also confer benefits for prevention of cancer and heart disease (Fattorusso *et al.*, 2000; Matsuura, 2001). Studies have also shown that rakkyo has a characteristic saponin content (Baba *et al.* 2000; Itakura *et al.*, 2001).

The crop in general was easy to manage. Herbicides used in onions have been found to be safe for rakkyo, whilst a fertiliser programme used for onions (as in experiment 1) also seemed to be satisfactory for rakkyo. Up to now there has been no evidence in any of the trials of downy mildew or thrips, which are common problems in onions in the Pukekohe district. However, the outbreak of leaf blight was a concern, and it is recommended that bulbs designated for planting are thoroughly cleaned and then dipped for 30 minutes in Amistar (azoxystrobin) at 0.4 g / litre.

There is still much to learn about growing rakkyo, and its performance in other locations in New Zealand needs to be evaluated. If the crop is to be grown successfully on a commercial scale, issues such as planting, harvesting and processing techniques, and bulb quality will have to be considered. In the meantime, producing rakkyo in New Zealand would provide further variety for vegetable consumers and an opportunity to develop new gourmet pickled products. The potential health benefits of this new crop are promising and also need to be fully explored.

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