Root Vegetables Production Technology

Sable PA, Pawar YD, Pushpraj Singh, Bhushan Bibwe, Nandre BM, Patel RP

Root vegetables are important horticultural crops cultivated for their edible underground storage organs, which serve as valuable sources of carbohydrates, vitamins, minerals, dietary fibre, and bioactive compounds. Major root vegetable crops include carrot, radish, turnip, beetroot, and other commercially important species that contribute significantly to food and nutritional security. Successful root crop production depends on the selection of appropriate varieties, suitable climatic and soil conditions, high quality seeds, proper soil preparation, optimal sowing dates, and efficient agricultural production methods. Production techniques include scientific approaches to seed treatment, planting methods, spacing, nutrient management, irrigation planning, weed control, and integrated pest and disease management. Proper cultural practices are essential for promoting uniform root development, improving marketable yield, and maintaining produce quality. Timely harvesting, grading, packaging, storage, and post-harvest handling further contribute to reducing losses and enhancing the economic value of these crops. Modern production approaches such as precise nutrient management, efficient water use, integrated crop management, and selective breeding offer significant opportunities for sustainable root crop production. Therefore, the introduction of improved production techniques is essential to increase productivity, ensure product quality, increase farmers' income, and strengthen sustainable horticultural production systems.

Keywords: *Root vegetables, Production technology, Carrot, Radish, Turnip, Beetroot, Nutrient management, Irrigation management, Root development, Sustainable horticulture*

Sable PA[1], Pawar YD[2], Pushpraj Singh[3], Bhushan Bibwe[4], Nandre BM[5], Patel RP[6]

[1]Associate Research Scientist (Horticulture) Date Palm Research Station, Sardarkrushinagar Dantiwada Agricultural University, Mundra 370 421, Gujarat (India).

[2]Associate Professor (Vegetable Science) College of Horticulture, Sardarkrushinagar Dantiwada Agricultural University, Jagudan 384 460, Gujarat (India).

[3]Scientist (Horticulture) Krishi Vigyan Kendra Sardarkrushinagar Dantiwada Agricultural University, Deesa 385 535, Gujarat (India).

[4]Senior Scientist, ICAR-DOGR, Pune, Maharashtra (India).

[5]Associate Professor (Horticulture) C. P. College of Agriculture Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar 385 506, Gujarat.

[6]Assistant Research Scientist (Horticulture) Agroforestry Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar 385 506, Gujarat.

[*]Email: sable.pating@sdau.edu.in

©2024, Cornous Publications LLP., Puducherry, India.
Advanced Researches in Agricultural Sciences (Volume 2)
Editor: Ashim Midya, Dr. Selvakumar Gurunathan
ISBN: 978-81-986832-8-1
DOI: https://doi.org/10.37446/vol2book092025/244-270

Introduction

In temperate countries carrot is cultivated during spring and summer season, while during winter season in tropical region, it is a popular cool root vegetable. Its origin is south-western Asia especially Afghanistan, which remains the centre of diversity of *D. carota*, the wild carrot. In early use, carrots were grown for their aromatic leaves and seeds, not their roots. The cultivated carrot (*D. carota* L.) has a chromosome number of 2n=2x=18. It is an annual herb for root production and a biennial for flowering and seed production. The Carrot *(Daucus carota* sub spp. *sativus*) is a plant of Apiaceae family, which is widely cultivated in temperate and tropical regions of the world (Acharya et al. 2020). Carrot posseses anti diabetic; cholesterol and cardiovascular disease decreasing; anti-hypertensive; hepatoprotective; reno-protective; anti-inflammatory effects. Carrot roots are rich in carotene; iron; thiamine; riboflavin; ascorbic acid; niacin; sugar. Roots are also high in carbs; antioxidants; minerals and fibre. They were used to treat stomach ulcers, abscesses, bladder, liver and kidney issues to help with delivery and even as aphrodisiacs. Carrot seed has an essential oil that is used to flovour liquors, dishes and it also has antimicrobial capabilities. Carrots that are orange in colour are high in beta carotene, a precursor to vitamin A. Also rich in thiamine and riboflavin. Asiatic varieties have more anthocyanin pigments and less beta carotene and they may be less nutritious. Kanji is a beverage prepared from black carrot that is supposed to be a good appetizer. It has a wide range of variations for root colour ranging from white to black; however, orange; red; black; yellow carrots are the most popular and commercially important globally, across all climates ranging temperate to tropical conditions. Orange roots are mostly used for table and freezer applications, while red roots are utilized for table; juice; halwa; pickle preparation (Singh et al. 2024). The leaves arise in the form of a rosette having long petioles. The inflorescence is compound umbel. Carrot flower is protandrous. The fruit is a very small; dry; two chumbered; inferior splitting into two indehiscent; one seeded piece called *mericarps*. Each mericarp remains attached to the forked end of the axis (carpophore) called cremocarp. A carrot taproot consists of two main anatomical parts: the pulpy outer cortex (comprising the phloem) and the inner core (comprising the xylem). The outer core consists of a thin periderm, a layer of cork cells and a relatively wide band of secondary phloem, the region where sugars are stored. The inner core consists of secondary xylem and pith. High quality carrots are those which have a relatively large outer cortex. Carotene is highest in older cells of the cortex. It increases with the age of the root and accumulates most rapidly at temperatures of 18 ^{O}C to 21 ^{O}C in well aerated soils. It is a quick growing vegetable crop (Acharya et al. 2020). There are two distinct group of carrot tropical or Asiatic and temperate or European. The temperate types form roots both under tropical and temperate condition but set seeds only under temperate condition as they need low temperature of 5 ^{O}C -8 ^{O}C for 40-60 days before throwing out the seed stalks. The Asiatic type are high yielding and produce seed under tropical conditions. But they are poor in carotene content (Natarajan and Veeraragavathatham, 2022).

Botany

Carrot is an annual or biennial herb with an erect or branched stem (30- 120 cm high) arising from a thick fleshy root. Leaves are pinnatifid. Edible portion is the fleshy tap root composed of an outer cortex (phloem) and inner core (xylem). Inflorescence is compound umbel and is produced during second phase. Anthesis in a single umbel is completed in 7-9 days. Individual flowers are bisexual with white or yellow petals. They so called carrot seed is actually a fruit, an indehiscent mericarp, which consists of a single seed. Two mericarps pair to form a single schizocarp, the real carrot fruit which develops from a two-loculed ovary.

Heterosis: The first report of heterosis in carrot upon crossing of two inbred lines was made by Poole (1937). Inbreds producing roots averaging 12.8 and 24.9, respectively, produced hybrids with roots weighing 80.5 g

upon hybridization. The hybrids obtained from male sterile yielded 34-44.9 per cent more and contained higher amount of dry matter and sugars compared to inter varietal pollination.

Inheritance of Cytoplasmic Male Sterility: Cytoplasmic inheritance of petaloidy, first described by Thompson, in carrot lines. Initialy a male sterile wild carrot plant found near Orleans, Massachusetts (USA) in 1953. It was named the Cornell cytoplasm and used to produce the majority of hybrid carrots in the United States. The studies of Morelock (1974) supported the hypothesis that petaloid sterility in wild carrot cytoplasm is controlled by two dominant nuclear genes. The brown anther type is controlled by two recessives as evident from 15 sterile: 1 fertile in domestic cytoplasm. The studies of Morelock (1974) supported the hypothesis that petaloid sterility in wild carrot cytoplasm is controlled by two dominant nuclear genes. The brown anther type is controlled by two recessives as evident from 15 sterile: 1 fertile in domestic cytoplasm (Acharya et al. 2020).

Pollination Control Mechanisms

Carrot is an out-breeding species due to being protandrous. It has no self-in-compatibility system, but inbreeding is severe. The distinctive umbels and floral nectaries attract insects, which are most responsible for performing pollination. The occurrence of two distinct genetic cytoplasmic male sterility i.e. brown anther and petaloid type provided a system for control over pollination for commercial production of hybrid carrot cultivars.

Root Development

In most cultivars, the root first grows in length and then increases its diameter. By 12-16 days after sowing, the tap root reaches its optimum length. Shape and size of roots are influenced by several factors. Varietal characters, un-decomposed organic matter, any obstruction to its downward growth etc. are a few factors causing cracking, forking and branching of roots. Temperature also influences shape of root. Variety Chantenay produces longer and more slender roots at 18 ^{O}C, while they were shorter and thicker at 24 ^{O}C. High temperature and irregular water supply cause deep depression on roots causing rough root surface. Excessive irrigation after drought results in white corky outgrowth where side roots may develop. Temperature has significant influence on colour and development of roots. A temperature range of 15.5 – 21.1 ^{O}C is the best for colour development. Carotene content decreases above 21.1 ^{O}C and below 15.5 ^{O}C. Usually the young roots are yellowish in colour which changes to whitish yellow; light yellow; dark yellow; orange or orange red as a result of accumulation of carotenoid pigments. Carotene accumulation takes place first in old phloem cells followed by old xylem vessels and finally to centre core.

Climate and Soil

The carrot is cool season crop. Carrot is relatively sensitive to temperature. However, it tolerant to a wide range of rainfall. The optimum temperature would be of 18-23 ^{O}C for root formation, while germination of seed can take place within a wide range of temperature 7- 23 ^{O}C. Tropical types can form roots even at a higher temperature of 25 ^{O}C (Kamalkumaran et al. 2021). The carrot crop thrives best in a deep well drained loose loamy soil for growth and development of carrot roots. The long smooth slender carrots are preferred in the markets which are produced in above soil conditions. Carrot grown on hard soils tends to become rough and coarse because the roots fail to penetrate the hard soil evenly. Carrot cannot be grown on highly acidic and alkaline soils but can stand slightly acidic and alkaline soil reactions. The optimum soil pH is 6.6

to 7.1. It is always advisable to grow carrot on soil which was manured well for a previous crop. The application of organic manures which are not properly rotten, should be avoided in the current growing season of the carrot crop because many roots will tend to be malformed, the roots being split into two or more forks. Large stones can also result in curved, deformed roots. Prior to sowing, soil should be prepared by well deep ploughing followed by cross harrowing. The soil should be thoroughly pulverized so as to obtain a fine tilth, otherwise it will result in deformed roots.

Varieties

Tropical or Asiatic varieties		
Sr. No.	**Variety**	**Salient Features**
1.	Madhuban *Gajar*	Biofortified carrot variety developed by farmer scientist which benefits local farmers. Biofortified variety with high beta carotene and iron content developed by Shri. Vallabhhai Vasrambhai Marvaniya, a farmer scientist from Junagadh district, Gujarat is benefitting more than 150 local farmers in the area. Yield 40-50 t ha^{-1}.
2.	Kashi Krishna	Attractive black self-core. Colour roots, tolerant to bolting, fewer secondary roots/scars, suitable for salad, juice, halwa, kanji (fermented juice) and nutraceutical purpose, rich source of anthocyanin (285 mg 100 g^{-1} FW), phenolics and antioxidants. Yield 20-22 t ha^{-1}. Seed rate: 4-5 kg ha^{-1}.
3.	Solan Rachna	An open pollinated variety, long, smooth, orange colour, self-core, stumpy to semi-stumpy roots, rich in beta-carotene, early in maturity. Yield 25.0 t ha^{-1}. Suitable for cultivation in HP and other hilly states.
4.	Pusa Vrishti	It is developed at ICAR-IARI. It is a first tropical carrot variety that is heat and humidity tolerant and ideal for *kharif* sowing. It has red roots and a self-coloured core. Maturity 85-90 DAS. Yield 25.0 t ha^{-1}.
5.	Pusa Rudhira	It has long red roots, a self-coloured core and an obtriangular shape. Maturity 85-90 DAS. It can be sown from mid-September to October. Roots become ready for harvest in middle of December. Yield 30.0 t ha^{-1}.
6.	Pusa Vasuda	The Delhi State Seed Sub-Committee released the first public-sector tropical carrot hybrid generated through the CMS method in 2013. The roots are self coloured, sleek, attractive, sturdy, red and juicy, with a high concentration of total carotenoids, lycopene, TSS and minerals. Suitable for salad, juice extraction, frying, and carotenoid extraction in industry. Maturity 80-90 DAS. Yield 40.0 t ha^{-1}.
7.	Arka Suraj	This variety was developed by IIHR, Bangalore through pedigree selection between Nantes and IIHR 253. Flowers and seeds are set under tropical conditions in this cultivar. Deep orange roots with such a self-colour core and a smooth, conical root surface. The root length is 15-18 cm and the root diameter are 3-4 cm. TSS of 8-10 ^{O}Brix. Tolerant to powdery mildew and nematodes.
8.	Pusa Kulfi	It is the first light mustard-coloured carrot variety developed by ICAR-IARI, New Delhi. Maturity 90-100 DAS. Yield 27 t ha^{-1}. Roots are abundant in carotenoids, lutein, thiamine and niacin.
9.	Pusa Payasa	Developed by IARI, New Delhi. OP selection from exotic lines. First mustard coloured variety.
10.	Hisar Gairic	Source: CCSHAU, Hisar (1993). Developed through mass selection. Long root, less fiber and forking.
11.	Selection No. 233	Source: Punjab Agricultural University, Ludhiana. It is a cross between Nantes and No. 29. The roots typically 15 cm long, thin, semi cylindrical orange and have a light orange core. It is a late bolting variety that is free of splitting. Maturity 90-100 DAS.

12.	Selection No. 29	Source: Punjab Agricultural University, Ludhiana. Selection from locally available materials. It grows quickly, has long, tapering, thin roots that are light red in colour and has a wide range of adaptability.
13.	Selection No. 21	Excellent for candy and juice making.
14.	Pusa Kesar	It was evolved from a cross of Local Red and Nantes at IARI in 1963. The roots are scarlet in colour. It is rich in carotene (38 mg 100 g^{-1} edible portion).
15.	Pusa Meghali	It has been developed at Indian Agriculture Research Institute, New Delhi from a cross between Pusa Kesar and Nantes. It was released in 1985. It has short top, smooth roots with orange flesh and self coloured core.
16.	Gujarat Dantiwada Carrot 1 (GDC 1)	This variety developed through selection from the local germplasm at Seed Spices Research Station, SDAU, Jagudan (Gujarat) in 2013. The roots are tender and fleshy, smooth surface, medium in size, cylindrical shape with attractive red in colour. It is suitable for carrot growing areas of Gujarat state. The crop duration is 96 to 100 days. The central core is thin, fleshy and palatable and is free from pre-mature bolting. Average yield is 40 to 45 t ha^{-1}.
Temperate or European types		
17.	Nantes Half Long	Roots are almost cylindrical terminating abruptly in small thin tail, 12-15 cm long, orange flesh with self-coloured core. Maturity 90-100 DAS.
18.	Early Nantes	It is an introduction recommended by IARI, RS, Katrain. Suitable for sowing during winter months. Roots are orange scarlet in colour with self-coloured core. Maturity 110-120 DAS.
19.	Nantes	The roots are well shaped, orange in colour, cylindrical in shape with stumped end forming a small thin tail. The skin is thin and flesh is sweet. It is a temperate type (European type) and not suitable for seed production in the plains. It is an introduction by IARI Regional Station, Katrain.
20.	Scarlet Nantes	It is a F_1 variety, having 65-75 days crop duration. It is a sweet, versatile Nantes-type carrot that forms uniform, 15-20 cm carrots that are perfect for fresh consumption or storage.
21.	Imperator	Roots of this variety are the classic long, tapered roots. Soil has to be prepared to fine tilth at least a foot deep to grow Imperator carrots. A light, sandy loam soil is ideal for growing Imperator carrots. Choose shorter varieties if soil is heavy or rocky.
22.	Red-Cored Chantenay	It is a F_1 hybrid produces 7”- 8’’ (18 cm -20 cm), deep-orange carrots with 2” (5 cm) shoulders and the classic cone shape of Chantaney carrots. Crop duration is 60-70 days. Grows well in heavy soils, stays sweet in storage.
23.	Hercules	It is F_1 produces 6-7” (15-18 cm) carrots with broad shoulders. This is good for rocky of clay soils where other carrots perform poorly. Maturity 65-70 DAS.
24.	Chantaney	This cultivar is temperate type. The roots are reddish orange in colour; square shouldered tapering slowly with an abrupt blunt tip, excellent for canning and storage. Not suitable for seed production in the plains.
25.	Zino	This cultivar developed at Ooty (Tamil Nadu) by State Deparment of Horticulture. It is introduced from Germany. This is a temperate type, high yielding and of good quality roots. Duration 110-120 DAS.
26.	Pusa Yamdagini	Developed at IARI, RS, Katrain by hybridization between EC 9981 and Nantes. Duration earlier than Nantes by a week. Roots are orange in colour with self coloured core, slightly tapering or semi stumpy with medium tops, rich in carotene. Duration 90-100 DAS. Yield 12. 0 t ha^{-1}.
27.	Danvers	A mid cultivar suitable for both fresh and processing. The roots have deep-orange cortex and yellow core.

28.	Royal Chantaney	Introduced from USA. Suitable for home kitchen garden.
29.	Early Gem Imperator	Nantes x Chantaney. Mid-season to late maturing cultivar.
30.	Bonus	Three-way hybrid developed by GCMS technique.
31.	Oxheart	Heart shaped roots, suitable for heavy soil is orange flesh.
32.	Ooty 1(1997)	Developed at Horticultural Research Station, Ooty of TNAU. Selection from half –sib progeny. deep orange coloured. Root free from premature bolting.
33.	Pusa Nayanjyoti	It is first orange coloured temperate carrot hybrid from public sector in India (Source: IARI, RS, Katrain). It is rich in beta carotene (7.55 mg 100 g^{-1}). Sowing time is April-August (Hills), November-December (North Indian plain). Roots are coreless and self coloured. Average yield 35.0-45.0 t ha^{-1}.
34.	Kashi Arun	Root are attractive red colour, ready to harvest in 90 -100 days.
35.	Arka Suraj	Pedigree selection of (Nantes x IIHR 253) (2007). Tolerant to powdery mildew and nematodes.
36.	Chaman	Developed at SKUA&T, Srinagar; roots long, cylindrical and semi blunt, tolerant to cracking, yields 25-27 t ha^{-1}.

Imported varieties like Danvers and Imperator are also popular in the country. Gold King Indian Kuroda; Nebora and Super Kuroda are a few of the carrot varieties marketed by private seed industry.

Crop Production

Ridges and furrows at 30-45 cm apart in small plots to be prepared for convenient irrigation. Seeds are sown on ridges or on flat beds by dibbling in lines (line sowing). Seeds are first rubbed to remove fine hairs and mixed with fine sand before sowing to facilitate even distribution. For sowing in lines, a small furrow of about 1.0-1.5 deep is made at top or on either side of ridges with finger or with sharp end of a stick. Seeds mixed with sand are dropped in furrow by hand and covered lightly with soil. Seed rate varies from 8-10 kg ha^{-1} depending on variety and sowing. Seedlings should be thinned to a plant-to-plant distance of 7-10 cm, soon after they are established, otherwise, overcrowding leads to deformed roots. The optimum spacing for Asiatic types is 45 cm x 7-10 cm, while 30 cm x 7-10 cm for European types. It is advisable to give light irrigation immediately after sowing. Seed soaking in water at 20 ^{O}C for 12-24 hrs. and then drying at 20 ^{O}C before sowing hastens germination. It is better to sow the carrot seeds at interval of 15-20 days to ensure a continuous harvest.

Nutrient Management

A quantity of FYM 25 t; 40-50: 40-50: 80-100 kg NPK ha^{-1} is required. Farmyard manure; half N; entire P and K are to be applied as basal dressing. Remaining dose of N has to be applied at the time of first hoeing (30 DAS). The root quality parameters like sugar; dry-matter; carotene and Vit. C affects when excess N is applied (Natarajan and Veeraragavathatham, 2022).

Irrigation

Pre-sowing irrigation should be done for rapid and uniform germination. First irrigation should be given immediately after sowing followed by another 4-6 days after. Soil should be kept moist by frequent light irrigation for proper growth of roots. Irrigation once a week has been found to be better. Excessive irrigation,

towards the last stage, should be avoided as it may result in excessive vegetative growth. The quantity of water and frequency of application depend on multiple factors include soil, climatic conditions etc.

Thinning

This is an essential and cultural operation should be done at least twice, to provide proper distance through thinning out weak seedlings. The crop should be thinned to 7-10 cm between each root. Thus, a population of 100-130 m^{-2} has to be maintained. While, thinning care should be taken that the leaves are not bruised or broken as the pungent odour may attract carrot flies.

Interculture

At early stages of crop growth, weeds may pose a serious problem, shallow cultivation with the help of hand cultivators will keep down the weed and provide aeration and will enhance root formation. Where, the quality of water is poor, roots are exposed, soil should be placed around the plants when roots begin to form. It will protect the tops of the roots from excessive heat and greening.

Harvest

Harvesting at correct maturity is an important point to be considered in carrot cultivation otherwise the roots will become unfit for human consumption. Splitting is a main problem in carrot due to delay in harvest of roots. Roots will be considered marketable when its upper end attains diameter of 2- 4 cm. A light irrigation is usually given before harvesting for easilly pulling of root without any dammage. Yield varies with season, climate, varieties etc. Tropical types yield 25-30 t ha^{-1}, whereas European types yield 10-15 t ha^{-1}. Harvested roots are put in mulberry basket and dipped in running water for washing. Roots are then partially dried, trimmed and graded before sending to distant markets. Trimming, grading etc. are done at a cool place. Fresh Carrot roots can be stored for 2-4 days under ordinary conditions and for six months at 0^{O}- 4.4 ^{O}C with relative humidity of 93-98%.

Physiological Disorders: Any abnormality which is due to the edapho-climatic factors (Non-involvement of pathogen) is known as physiological disorder.
Following disorders are reported in carrot in India-

Split Root/ Carrot Splitting

Splitting or cracking of roots is a major problem in carrot cultivation. Though this is a genetic character, other factors are also influencing cracking. Excess nitrogen and is untimely application and sudden change in the soil moisture status promote cracking.

Management

The best control of the split root in carrot is to not allow to go in for long periods of time without water.

Forking

When the hard soil does not allow straight root growth, resulted into forking.

Reasons

- Inter varietal variation are being considered to result from the degree of secondary elongating growth. Elongated root relates closely to soil adaptation. Varieties with vigorously elongated root, short root or round root have been selected in areas of shallow arable soil and varieties with poorly elongated root, long root and huge root have been cultivated in areas with deep soil conditions.
- The disorder is due to the excess moisture during the root development of carrot.
- It also occurs in heavy soil due to the soil compactness.
- Un-decomposed organic manure favours elongated root in carrot.

Management

- It can be corrected by reducing the moisture from the field by balanced irrigation and also by sowing the radish in sandy loam or light soil having soils of loose and friable in nature.

Cavity Spot

This disorder appears as a cavity in the cortex; in most cases the subtending epidermis collapses to from a pitted lesion.

Reasons

- The cavity spot disorder is induced by deficiency of Ca.
- This is associated with an increased accumulation of K which leads to a decreased accumulation of Ca.
- Maynard et. al. 1963 reported that the cavity spot disorder of carrot roots is a manifestation of Ca deficiency which may be induced by excess K uptake during the ontogeny of carrot plants.

Management

- Increase in Ca level in the growing medium leads to significant reduction in the incidence of cavity spot.
- Jakobsen and Jorgensen (1986) suggested that application of fertilizer should be kept minimum and only be done in spring or early summer when the crop requires it the most. This would avoid a build up of K in the plant.

Insect-Pests

Carrot weevil (*Listronotus oregonesis*)

Damage

Larval feeding and tunneling can weaken plants, make carrots unmarketable.

Carrot Fly (*Chamaepsila rosae*) also known as Carrot toot fly/ rust fly (*Psila rosae*)

This is a serious pest of carrot particularly in hot, dry weather and land on very free draining soil. The carrot fly, which is 1 cm long, black with yellow legs and transparent wings is attracted by the pungent smell of the carrot foliage and finds small areas of disturbed soil near the rows ideal places to lay its eggs. The tiny pale-yellow maggots that emerge from the eggs then burrow into the roots and may devastate the crop. Wilting, reddened foliage is usually the main symptoms above ground.

Management

Sow the seed sparsely, so that will avoid thinning. Destroy the thinning materials immediately. Never use a hoe to thin out the young crop; disturbing the soil encourages the flies to lay eggs nearby. Plant rows of onion between carrot rows, because the scent of onion is said to counteract that of the carrot leaves and so distract or deter the carrot fly.

Turnip moth (*Agrotis segetum*)

Lycus bug

Damages seed crop and reduces viability and germination of seeds. Seed treatment with insecticides controls this pest.

Wireworm

The larvae, which are about 2.5 cm long, shiny and golden-yellow with six legs, live in the soil. There is wilting of leaves and round holes in roots.

Management

Cultivate soil properly.
Do weeding regularly to expose wireworms to insectivorous birds.
Treat the soil with insecticide, such as chloropyriphos.

Aphids

These are small insects suck the sap from the foliage, and some time also damage the roots. The foliage of carrot will be stunted, wilted and greyish green.

Management

Imidacloroprid 17.8% SL 0.5 ml L^{-1} of water as per infestation.
Apply irrigation water at regular interval as they attack during dry weather.

Eelworm

The microscopic, transparent worms live inside the root tissue of the carrot and multiply rapidly. Affected plants start wilting; stunting foliage and distortion of roots are commonly seen.

Management

Dig out all affected carrots and destroy them immediately.
Avoid growing carrots on such infested soil at least 5-7 years.

Diseases

Among diseases, *Cercocpora* leaf spot and root rot caused by *Fusarium oxysporum* adversely affect stand of crop. Watery soft rot caused by *Sclerotenia sclerotianum* occurs in storage.

Radish (*Raphanus sativus* L.)

Radish is a quick growing vegetable for tropical and temperate climate. It is very easy to cultivate and best suited to grow as inter crop and catch crops. It can be grown even on ridges of the beds; this way vacant area can be utilized profitably. The tops (leaves) and roots are used as salad or cooked as vegetable in various ways. The leaves are rich in minerals and vitamins partially A and C. The pods of rat tail (*R. sativus* var. *caudatus*) radish are also used as vegetable which is favourite vegetable in U. P. and Punjab states of India. Seeds are used for non-drying fatty oil which is suitable for soap making, illuminating and also for edible purposes. Radish increases appetite. It has cooling effects. It prevents constipation. It is good for patients suffering from piles, liver trouble, enlarged spleen and jaundice. Though, radish is not easily digestible but when taken with gur it becomes beneficial. Pungency in radish is due to volatile compound isothiocyanates. Pink radish colour is due to anthocyanin. The fleshy root of radish is modified root (fusiform) develop from both the primary root and the hypocotyls. Its young leaves are also consumed after cooking. Though Europe considered as original home of radish, the variability existing among the cultivated forms in morphology and ecology signifies the multi-centre origin of this crop. A few important wild species available in Mediterranean region are considered to be the probable progenitors of European radish. Japanese types would have originated from the wild species that remain in the coastal regions of Japan.

Botany

Leaves are alternate, glabrous to sparingly hispid, lower leaves in a radical rosette, petioles 3-5.5 mm long, leaf blades oblong. The primary root and the hypocotyls develop in to edible portion of radish root. Radish roots vary greatly in size, shape and other external characters as well as the time period they remain edible. *Inflorescence* is a typical terminal erect, long, many-flowered raceme. The flowers 1.5 cm in diameter; fragrant; small; white; rose or lilac in colour with purple veins in bractless racemes, pedicel up to 2.5 cm long; sepals 4 erect; petals 4; clawed; spathulate; 1-2 cm long; stamens 6 free tetradynamous (4+2) and style 3-4 mm long. Pod (Siliqua) is cylindrical 3-7 cm long up to 1.5 cm in diameter, consisting of 2 several superposed joints. In case of rat tail radish *Raphanus caudatus,* the pod length is usually 20-30 cm. Seeds are ovoid-globose, browning in colour and about 3 mm in diameter. The buds borne in racemes on the main stem and its branches open under the pressure of the rapidly growing petals. This process starts in the afternoon and usually the flowers become fully expanded during the hot day morning. The anthers open a few hours later being slightly stigma mature first (protogynous). Generally, the anthesis starts at 8 AM and 12 noons (Acharya et al. 2020). It is cross pollinated vegetables due to sporophytic system of self-incompatibility. The mode of pollination is entomophilous. Inbreeding depression founds upon selfing in Radish.

Cytogenetic: Karpechenko (1924) in *R. sativus* and *R. raphanistrum,* observed 2n = 18 chromosomes. Radish showed 2n = 18 at mitosis and n = 9 at meiosis except in case of artificial tetraploids (2n = 36). Kaneko (1980) found a spontaneous haploid plant of radish in the progenies of nucleus restored radish (2n = 18) bred by successive backcrossing to *Raphano brassica.* One hexava lent formation by the secondary association of bivalent chromosomes was reported by Maeda and Sasaki (1934) from Shogoin-Daikon cultivar of radish.

Climate and Soil

Radish is predominantly a cool season crop. Suitable temperature for good flavour, texture and size is between 10-15 ^{O}C. But Asiatic types tolerate high temperature as compared to European types. However, different varieties respond to different range of temperature that is why varieties are grouped as temperate and tropical types. Bolting before proper root development resulted due to a long day as well as high temperature. Hot weather is to be considered for hard, pithy and pungent roots. In India, radish varieties are available which suitable to grow round the year except in hotter months. Crops grow normally during main season i.e. mid-September to early October, while during spring and summer season crop, suitable variety should be selected and sown at proper time. Radish can be grown on a wide range of soil but a light friable loam soil is the best. Heavy soils produce roots of poor quality i.e. roots become rough, misshapen with a greater number of fibrous roots, so heavy soils should be avoided. Radish is moderately tolerant to acid soils (pH 5.5 to 6.8).

Varieties

Radish comes in two distinct genetically groups - European varieties and Asiatic varieties. The European varieties, produces roots in the plains of tropical and subtropical climate and seeds in the hills of temperate climate. Temperate types need closer spacing and so they are sown 20 -30 cm. European varieties yields 8.0 -10.0 t ha^{-1} in 25 -30 days and they are not very common and popular in India. While, the Asiatic varieties are grown primarily for tropical climates. They produce edible roots in the first season and seeds in the second season as a biennial crop. These varieties can resist more heat than the European or temperate varieties. The indigenous Asiatic varieties are usually white with a conical shape, attaining 25-40 cm in length and are more pungent than the introduced European types, which are icy-white; crisp; thin; mild-flavored; juicy. Asiatic varieties grow at wider spacing 45 cm as compared to European types. Asiatic improved varieties yield 15.0-25.0 t ha^{-1} in 40-60 days.

Sr.No.	Variety	Salient features
	Temperate types	
1.	White Icicle	The roots are pure white, thin and tender. It is a very short duration variety takes about 25-30 days for edible maturity. It is a sweet flavoured variety. It can be grown in pots also.
2.	Scarlet Globe	Outer skin is scarlet in colour, flesh is pure white. It is quick growing, becomes ready in 25-30 days.
3.	Scarlet Long	The leaves are 15-20 cm long and light green. Roots are long, tapering to a point, red root exterior along with soft and white root interior. It is ready for harvesting in 30-40 DAS.
4.	French Breakfast	Roots are red in colour with white tips. Shape of roots is like olive. Roots are crunchy in texture, mild and sweet.

5.	Rapid Red White Tipped	The roots are small, red in colour with white tip. It produces short foliage. It is suitable for growing in spring and summer season. It matures in 25-30 days. It is even suitable for growing in pots.
6.	Pusa Himani	A long white variety released by IARI, New Delhi. It is a good variety both for plains and hills. In plains, it is grown in December to February and in the hills during March to June. The roots are long (30-35 cm), semi-stump to tapering with green stem end.
	Tropical types	
7.	Kashi Aardra (VRRAD 150)	Source: ICAR-IIVR, Varanasi (2019). It is suitable for sowing during mid-September to mid-December; Roots are attractive white in colour, long and icicle in shape. Duration: 40-45 DAS. Root yield 24-40 t ha^{-1}. Seed rate: 8-10 kg ha^{-1}. Sowing time: *Rabi*. Recommended states are West Bengal and Assam.
8.	UHFR 12-1	Source: Ranichauri (2019). The roots are round to slightly tapering, 10-12 cm in length and width, white in colour. Weighing 180-200 g at maturity. Maturity 55-60 DAS. Root yield 35 t ha^{-1}. Seed rate: 7-8 kg ha^{-1}. Recommended states are J&K, H.P. and Uttarakhand.
9.	Kashi Mooli 40	Tolerant to high temperature (35-42 ^{O}C), suitable for summer cultivation, delayed bolting, less pithiness, icicle root shape, attractive white colour. Yield 30-35 t ha^{-1} in normal season and 20- 23 t ha^{-1} during summer season. Seed rate: 5-6 kg ha^{-1}.
10.	Kashi Lohit	Attractive red colour roots, icicle root shape, suitable for salad dressing, rich antioxidants (80- 100% higher than white radish), good source of anthocyanin and phenolic content, tolerant to pithiness. Yield 40- 45.0 t ha^{-1}.
11.	Japanese White	The roots are pure white, 20 to 30 cm or so long, at the end roots are blunt. They are mildly pungent. Roots grow better when the temperature is low. Roots may be harvested' within 45 days after sowing.
12.	Arka Nishant	This is a high yielding variety, developed at IIHR, Bengaluru. The roots are marble white in colour, non-pithy roots of excellent quality. It may give root yield up to 35 to 40 t ha^{-1} in 45 to 50 days. It is suitable to produce seed in the plains also.
13.	Pusa Chetki	Its roots are medium large and stumpy, pure white, tender and smooth and mildly pungent. It becomes ready for harvesting in 40-50 days after sowing. Being tolerate to high temperatures, it is suitable for sowing from the mid of March to the mid of August. It shows profuse seed set in the plains. It can be grown as a summer and a monsoon crop from April-September and has yield potential of 200-250 q ha^{-1}.
14.	Pusa Mridula	Roots are globular with bright red skin, mildly pungent. Average yield 130 q ha^{-1}, Maturity in 25 days.
15.	Pusa Reshmi	Roots are 30-35 cm long, medium thick, white with green shoulder, uniformly smooth, mildly pungent; tops medium, leaves light green. Suitable for mid-September to October sowing in the northern plain maturity in 55-60 days. Yield 350 q ha^{-1}.
16.	Pusa Desi	Roots are white with green shoulders, 30-35 cm long, medium thick, tapering, pungent, tops medium and leaves dark green. Suitable for sowing from mid-August to September in the northern plains, maturity in 50-55 days. Yield 300 q ha^{-1}.
17.	Pusa Jamuni	First purple fleshed, nutritionally rich radish variety. It has distinct advantage in root size, shape, yield and consumer preference over the existing varieties. It has higher anthocyanins and ascorbic acid. An average yield of 50 t ha^{-1}.

18.	Pusa Gulabi	First entire pink fleshed nutritionally rich radish variety. Pusa Gulabi has medium root size, cylindrical shape, optimal yield and consumer preference over the existing varieties. It contains high total carotenoids, anthocyanins and optimal ascorbic acid. An average yield of 60 t ha^{-1}.
19.	Kashi Sweta	This has been developed through selection from the Chetki materials. Early variety, matures in 30-35 DAS. Roots are 25-30 cm long, 3.3-4.0 cm in diameter, straight, tapering with pointed tip. It yields of 45.0-47.0 t ha^{-1}.
20.	Kashi Hans	This has been developed through selection. It is suitable for September to February sowing and matures in 40-45 DAS. It can stand in the field up to 10-15 days after edible maturity. Leaves are soft and smooth like spinach. Roots are straight, tapering, 30-35 cm long, 3.5-4.2 cm diameter. It yields 43.0-45.0 t ha^{-1}.
21.	Hisar Sel 1	High yield, roots medium long, smooth white, tender and mildly pungent with white shoulder and short tops. Its root: shoot ratio (1.70: 1) is higher than the check varieties (1.3: 1). Average yield is 30.0-32.5 t ha^{-1}.
22.	CO 1	Roots are milky white, less fibrous, suitable for growing throughout the year. Average yield 22 t/ ha.
23.	Palam Hriday	The roots are characterized by pink heart and green shoulders. It is crispy and free from being pithy. Rich in vitamin C. Yield potential 25- 30 t/ ha.
24.	Hisar Mooli No. 1	Roots are long, soft, white and straight. It is grown in September-October. Duration 50-55 DAS.
25.	Punjab Ageti	Roots are red skinned at the top and white at the lower half, tapering, long (25.5 cm), medium thick (2.9 cm). It is most suitable for sowing during April to August.
26.	Punjab Pasand	It is an early maturing variety. Roots are long, pure white, semi-stumped and free from hair. It is suitable for sowing in main season.
27.	Punjab Safed	Its roots are 30-40 cm long, 3-5 cm thick, white, tapering, smooth, mild pungent and free of forking.
28.	Chinese Pink	An introduction identified by Dr. YSPUA&F, Nauni, Solan. Roots are 12-15 cm long pink with white towards tip, semi stumpy to stumpy. Maturity 50-55 DAS.

Besides, there are several other varieties are under cultivation. They are Newari; Jaunpuri Giant (root may grow more than one meter long and weigh up to 5-15 kg or so); Kannauji; Long White; Long Rose; Baramasi; Black Spanish; Yellow Gold; Bombay Red; Chinese Rose; Contai. Baramasi is suitable for growing throughout the year, though yield varies with the season. In order to use long thin, immature radish pods as vegetable which is a delicious dish in Punjab and Haryana, the rat-tail radish (Sengri or Mongri) (*Raphanus sativus* var. *caudatus*) is cultivated.

Crop Production

It can be grown throughout the year except during very hot season and heavy rainfall. The first fortnight of the March till late October or beginning of November is the sowing time of radish in northern hills. Asiatic types are sown during August - January in northern plain. European types are sown in September to March. The best sowing time for south Indian hills is from April- June, while, the best sowing time of radish in the plain is October- December for winter crops sowing is done in the month of August-September and for spring season crop, it is done in December-January. About 9 -12 kg ha^{-1} seed would be required. Seed may be subjected to 2 cycles of wetting and drying at 22 ^{O}C for better germination and crop growth. This hastens water absorption to a tune of 25% of their original dry weight. Radish is sown directly in the field. The seeds

of Asiatic types are sown 1.25 cm deep at 6-8 cm between the plant and 45 cm between rows on well leveled field. European varieties have to be sown at spacing 5-10 cm x 3 cm. The temperate types are early less growth; therefore, they should be sown closely whereas tropical types take longer duration and having more foliage and root growth, should be planted at wider spacing. The round varieties seed have to be sown in line and covered by thin layers of soil. The long varieties seeds have to be sown at a depth of 1.5- 3 cm.

Nutrient Management, Irrigation and Intercultural Operation

Well rotten compost should be incorporated at least 3 weeks before sowing the seeds. It should be remembered that undecomposed organic matter should not be applied because it will result in forking of the roots. A quantity of FYM 20 t; 80-100: 40-60: 80-100 kg NPK ha^{-1} is required (Acharya et al. 2020). Soil moisture will enhance quick germination of seeds. Seed germinates within 4 to 5 days under normal conditions. Pre-sowing irrigation is better for rapid germination. Irrigation has to be given immediately after sowing, on third day and subsequent irrigations at an interval of 5-7 days. In order to provide proper plant spacing additional plants should be thinned at required spacing as soon as they are large enough to handle. Shallow hoeing will keep down the weeds and will provide good condition for root development. Radish crop is quick growing and competes with weeds due to its shading effects of canopy, many weeds do not grow, if somehow other weeds grow by that time radish becomes ready for harvesting. Sometimes, large varieties need earthing up which will help to prevent radish root from greening effect.

Harvest; Yield and Storage

The harvesting of radish should be done when the roots are still tender. Root becomes ready for harvesting in 25 to 55 DAS depending upon variety. Temperate types which are quite early, 25- 30 DAS. Delayed harvesting may cause pithiness and such roots become unfit (bitter) for human consumption. The method of harvesting is very easy. Prior to harvesting, light irrigation is given, it will soften the soil. The roots are pulled out along with the tops and washed in running water. After cleaning, they are packed for the market. Yield varies according to the types. European types (White Icicle; Scarlet Globe; Rapid Red and White Tipped) yields about 5- 7 t ha^{-1}, whereas the Asiatic types (tropical types) yield about 15-35 t ha^{-1}. Besides types of cultivars, the yield may vary due to soil types; climatic conditions; management practices etc. Radish roots can be stored under ordinary conditions (ambient temperature) for 3 to 4 days. However, under cold storage at 0- 1 ^{O}C with 90 to 95 per cent relative humidity for about two months.

Physiological Disorders

- **Hollow Root**

High temperature during 16-30 days of sowing inhibits the formation of secondary meristem in the centre of root leading to development of intercellular spaces which would otherwise have been filled with parenchyma this results in the hallow root formation.

- **Akashin**

Akashin is caused by boron deficiency. It is induced by high day and night temperature 30/ 20 ^{O}C as well as by low soil temperature.

- **Pithiness**

Pithiness is more in summer crop than spring or autumn. It is more related with high temperature 3 weeks before harvest. Application of NPK in heavy doses also results in pithiness as well as soil moisture stress is also responsible for these physiological disorders.

Insect-Pests

- Aphids (*Myzys persicae, Brevicoryne brassicae*)
- Flea beetle (*Phyllotreta striolata*)
- Mustard sawfly (*Athalia proxima*)

Diseases

- Damping off (*Rhizoctonia solani*)
- White rust (*Albugo candida*)
- Alternaria blight (*Alternaria raphani*)
- Radish Mosaic Virus (RMV)

Beet (*Beta vulgaris* L.)

Beet (*Chukandar*) is not so popular vegetable crop in India. Its root contains high percentage of sugar. It is mainly used as salad in five-star hotels in India and also cooked as vegetables preferably mixed with other vegetables. Beet is also suitable for pickling. It is a popular root crop grown for its fleshy roots which are used as cooked vegetable, salad and for pickling and canning. It is very popular in USA. Beet root is a rich source of protein (1.7 g 100 g^{-1}); carbohydrates (88 mg); calcium (200 mg); phosphorus (55 mg) and vitamin C (88 mg). Leaves are rich in iron (3.1 mg); vitamin A (2100 I.U.); thiamine (110 µg) and ascorbic acid (50 mg 100 g^{-1}). It is also source of sugar. The fleshy roots containing mainly bands of two types, one type band is known as conducting tissues and the other one type is storage tissues. These bands are arranged alternatively. Sometimes, colour differences are seen when roots are cut, which is due to differences in colour of two types of tissues. Beet is short-stem plant, the simple leaves have very close spiral arrangement at the crown. The colour of the leaves may vary from dark red to light green. The stomata occur on both the upper and lower surfaces.

Genetic Resources and Inheritance of Colour

Genetic material collected from breeding work in sugar beet and fodder beet can be used in breeding vegetable beets. Collections of wild and cultivated beta material from eastern Mediterranean and secondary centers of diversity are kept by sugar beet breeders in western Europe and North America. Colour is an important characteristic feature of garden beet as it plays an impressive role in adorning the salad plate. Watson and Gabelman (1984) studied the genetics of pigments betacyanine; betaxanthine and sucrose concentrations in roots of table beet and found their quantitative inheritance, whereas, qualitative pattern was observed by other researchers. Highly significant GCA and SCA for both pigment concentrations and pigment ratio.

Origin and Floral Biology

Beet probable origin is Mediterranean region for *B. vulgaris* L. spp. *maritima* possibly by hybridization with *B. patula*, a closely related species of Portugal and the Canary Island. *B. vulgaris* L. spp. *maritima* has been found to grow wild on seashores in Britain and through Europe and Asia to East Indies. The chromosome number of cultivated types is 2n=2x=18. The roots are thick and fleshy and store amounts of reserve food. Upper portion of root develops from the hypocotyl and the lower portion from the taproot, from which the secondary roots arise. Genotypes and temperature, soil and nutrition etc. factors influence the colour and shape of root. The vascular tissues and storage parenchyma tissues form alternatively during the development of fleshy roots, which shows concentric rings and are visible in a median cross section of mature root. Depending upon cultivars, the exterior root colour varies from orange- red to dark purple -red, whereas the interior colour is varies by cultivar; temperature; season; soil; nutrition; etc. The colour of root is due to red violet pigment Beta- cyanins and yellow pigment Beta-xanthins. Roots are taproot types goes up to depth of 30 cm. The strong lateral roots grow diagonally for a distance and then downward to the length of tap root which contributes to the drought-resistance nature of the crop. Leaves are often ovate and cordate, dark green or reddish. The rosette of leaves develops in a close spiral with the oldest one the outside. It has a long, paniculate, more or less open spike, 50-150 cm long. Flowers are greenish; sessile; bisexual; usually 2-3 (5) together in clusters; subtended by minute bracts. The flowers are small, inconspicuous without corolla, but with green calyx, which becomes thicker towards base as the fruit ripens. Perianth 5 partite, turning thicker at base as fruits ripen. The flowers have five stamens and three stigmas. The ovary is three carpellate, but has only one ovule per ovary. It is allogamous and anemophilous. The anthesis starts at 7 AM and continues up to 5 PM but the peak hours are from 11 AM- 1:00 PM. Anther dehiscence begins at 8:00 AM and continues up to 6:30 PM, however the peak period is from 12:30 PM to 2:30 PM depending upon temperature and humidity (Acharya et al. 2020). High temperature and low humidity favor anthesis as well as anther dehiscence. Fruits are mostly aggregate formed by the cohesion of the two or more fruits and held together by swollen perianth (calyx) base and thus forming an irregular dry cork- like body known as seedball or seed (Kamalkumaran, 2021). The true seed is small about 3 mm long, kidney shaped and shiny to reddish- brown in colour. The seedball contains more than one seed, which is viable for 5- 6 years under normal storage conditions.

Heterosis

Heterosis breeding is at infancy in beetroot. Although with the introduction of CMS, the production of hybrids has been facilitated. Male sterility was governed by the segregation of a gene X in S-cytoplasm, with fertility dominant to sterility. Another gene Z with partial male fertility and complete dominance over male sterility was also reported but it was independent and hypostatic to X.

Pollination control mechanisms

Beet is predominantly wind pollinated. Its pollens are dust like and produced abundantly. For isolation of plant for breeding work pollen proof conditions are required. Since for hybridization, emasculation process is cumbersome, therefore mass pollination of selected root was used for development of improved cultivars of beet. The transfer of CMS system from sugar beet has now facilitated this process.

Climate and Soil

Beet is hardy to low temperature and prefers cool climate. Though it grows in warm weather, development of colour, texture, sugar content etc. of roots is the best under cool climate in the plains of India during winter. High temperature is responsible for zoning i.e. appearance of alternate light and dark red concentric circles in the root. Low temperature of 4.5-10.0 ^{O}C for 15 days will result in bolting. It requires abundant sunshine for development of storage roots. High sugar content is accumulated under cool weather. High temperatures usually result in poor colour development of the root. The optimum temperature for root growth is reported to be 18 ^{O}C to 21 ^{O}C.

Sandy loam soils with high organic matter or loam soils with well drainage capacity are best suitable. Beetroot is sensitive to high acidity as it is slightly tolerant to acidity (pH as low as 6.0 only). It grows well in pH of 6-7, while pH below 5.8 affects the root yield. This is only vegetable which can be grown in saline- alkaline soils, however, on alkaline soil, scab may be serious problem. Open and sunny site should be selected.

Varieties

Sr.No.	Name	Salient features
1.	Detroit Dark Red (DDR)	Tops are small, leaves glossy, dark green tinged with maroon veins, roots perfectly round with deep red skin, flesh deep blood red with light red zoning, tender and fine grained. Corrosive in taste when taken raw. Maturity 80-100 DAS. Yield 18.0 t ha^{-1}.
2.	Crimson Globe	Tops medium, leaves bright green with maroon shade, roots globular to flattish globe, medium red skin, flesh dark-crimson red with indistinct zones, non-corrosive in taste. Yield 18.0 t ha^{-1}.
3.	Ooty 1	Selection from local type. Roots are blood red in colour with thin skin and good quality. Average yield is around 31 t ha^{-1} and potential yield 31- 45 t ha^{-1}. Duration 120-130 DAS.
4.	Crosby Egyptian	Roots are flat globe with a small tap root and a smooth exterior. The internal colour is dark-purplish-red with some indistinct zoning. It shows pronounced white zoning in warm weather. Maturity 55-60 DAS.
5	Early Wonder	Roots are flatted globe with rounded shoulders and a smooth, dark red skin. Yield is about 31-45 t ha^{-1}.

Some other varieties are Queen; Burpee's Golden; Snow white; Golden Beet etc.

Crop Production

Being a cool season crop, beet is raised during winter in plains and as a spring-summer crop in hills by March-April. In plains, sowing is practiced during September-November. Land is to be ploughed followed by hoeing to get loose and friable, pulverized soils. Clods are to be removed completely. Well decomposed organic manure to be applied at the time of final ploughing. Flat beds or ridges and furrows are prepared. Seedballs which contain 2-6 seeds are sown 2.5 cm deep at spacing of 45-60 x 8-10 cm. Seed rate 5-6 kg ha^{-1} is required. Staggered sowing at 1-2 weeks interval ensures steady supply of roots during the season. At College of Horticulture, S. D. Agricultural University, Jagudan, Mehsana, Gujarat (India) beet sowing at 15 cm x 10 cm gave higher yield and net return (Chaudhari et al. 2023). As per this 10-20 kg ha^{-1} seed rate is required. Seeds are sown in narrow furrow 2- 3 cm deep 10 cm apart keeping row to row distance of 15 cm. Just after sowing rows are covered with soil and raked properly. It will be better if adequate soil moisture is available at the

time of sowing, if not, then light irrigation may be done. Prior to sowing, seeds are soaked in water for overnight which stimulate germination as the protective corky coat of seedball restricts water and gaseous exchange during germination as well as containing germination inhibitors. Beet is a biennial for seed production but it is an annual for its root production. The sowing should be such that there should not be heavy frost and also dry and/or hot conditions. Under both these conditions, beet bolts on the expense of root development. Mild climatic conditions are most suitable for beet growing. Beet is sown during September-November in the northern plains of India, while during March- July in the hills. However, sowing is taken up from July- November in the southern plains of the India. At College of Horticulture, S. D. Agricultural University, Jagudan, Mehsana beetroot sowing in 3rd week of October gave higher yield and net return.

Irrigation: Nutrient Management and Intercultural Practices

Regular irrigations are to be provided to maintain adequate soil moisture for proper development of roots. Excess watering is also harmful so during rainy season, the water management can be done by reducing irrigations accordingly as per the need. Water can be given through 5-7 irritations. About 25 t well rotten FYM; 70:110:70 kg NPK ha^{-1} is applied to the crop. Entire organic manure at land preparation, half of N and entire P and K has to be applied as basal dressing and rest half N at 25 DAS as top dressing. Beets have a relatively high boron requirement and its deficiency is common in alkaline soils or in soils relatively high in calcium, causes internal breakdown as black rot or dry rot so it is necessary to apply borax depending upon soil test, soil moisture and soil reaction. Thinning is an important operation in this crop particularly, because beetroot fruit (seedball capsule^{-1}) contains two to six seeds and they germinate in cluster. At least twice thinning are required to maintain optimum 10 cm of distance between two plants depending upon type of varieties; round and short varieties require close spacing, whereas long and tall varieties wide spacing. Delay thinning can be done to get large number of roots, which can be marketed. Gap filling has to be done in case where germination is poor. This will maintain desired plant population. Shallow cultivation at early stage of crop growth between the rows may be done. Care should be taken not to damage any root while hoeing. Generally, hoeing at early stage of crop will keep down the weeds. Later, when plants established well, they produce thick foliage which suppresses the weeds. Hand pulling of tall weeds is advisable. Earthing up is usually done to cover the swollen roots.

Harvest: Yield and Storage

Roots are harvested after attaining a diameter of 3-5 cm. Harvesting is done 8-10 weeks after sowing by pulling the top with hand. Later tops are removed, graded and marketed. Over matured and oversized tubers become woody and crack. Less developed roots are also used which are available at last thinning. For supply to the market roots are washed; cleaned and bunched. Tops may also be removed by twisting them off at 5 to 7 cm above the crown. All fibrous roots are removed. Yield varies from 25- 30 t ha^{-1} and the root stores well at 0 ^{O}C with relative humidity of 90%.

Physiological Disorders

Boron Deficiency (Crown Rot or Heart Rot)

This is due to boron deficiency. The central leaves die back and become blackened and the roots may turn black on the inside and the cankered on the outside.

Management

- Avoid planting in too sandy soils.
- Apply water regularly to avoid dry conditions.
- Avoid planting in limey soil.
- Apply borax before sowing at the rate of 20 kg ha^{-1}.
- Apply well rotten compost.
- Avoid over liming the soil because it creates boron deficiency.

Magnesium Deficiency

Magnesium is one of the constituents of chlorophyll. Deficiency of Mg causes pale areas between the leaf veins. Eventually these discoloured areas turn brown and die. Very acid or limey soils cause unavailability of Mg.

Management

- Spray magnesium sulphate at 0.1% concentration once or twice at a fortnight interval.
- Apply well rotten farmyard manure or compost.
- Apply lime in very acidic soils.

Manganese Deficiency

Affected plants have leaves with yellow blotches between the veins and the leaves tend to curl up, usually in mid-summer. Generally, Mn deficiency occurs in very sandy soil and very alkaline soils.

Management

- Apply manganese sulphate at 0.02% as a foliar feed.
- Avoid too sandy soil for growing beet crop.
- Avoid growing beet on alkaline soils.
- Add adequate amount of well rotten farmyard manure or compost during land preparation.

Insect-Pests

- Beet leaf miner (*Pegomyia* sp.)
- Flea beetle
- Beet web worm (*Hymenia fascialis*)

Diseases

- Damping off
- Downy mildew (*Peronospora schachtii*)
- Leaf spot (*Cercospora beticola*)
- *Rhizoctonia* root rot

- Sclerotium root rot (*Sclerotium rolfsii*)
- Beet yellow (*Beta virus* 4 or *Corium betae* Holmes)

Vector: Aphids like *Myzus persicae* and *Aphis fabae*.

Turnip (*Brassica campestris* var. *rapa*)

Turnip is a quick growing root vegetable in North India. It is an herbaceous, biennial crop for seed production and an annual for root production used as salad, cooked or pickled. In India, turnip is grown mainly in Punjab; Uttar Pradesh; Delhi; Jammu and Kashmir and Himachal Pradesh. The fleshy thickened, underground swollen portion of turnip is hypocotyl, which is generally known as root (form of root is 'napiform'). Distinct tap root and secondary roots arises from lower part of swollen portion hypocotyl. Skin colour may be red; purple; white; yellow or green and flesh may be white or yellow. Good pickle is prepared from roots. In India, turnip leaves are not used as vegetable but these are used as a green fodder for feeding cattle. Though, leaves are rich in vitamins A and C; calcium and iron. Turnips are a very nutritious vegetable, they are a good source of vitamin C; fiber and potassium; as well as other minerals and vitamins. They are also low in calories and high in antioxidants. The root contains a compound called glucosinolate, which has been shown to have anti-cancer properties.

Two types are found in turnip like radish, annual/ Asiatic/ tropical types and biennial/ European/ temperate. European types are sweeter and more palatable, while Asiatic types are pungent and used for making pickles.

Origin

Turnip is said to have two main centers of origin. The Mediterranean region is to be the primary centre of European types, while eastern Afghanistan with adjoining area of Pakistan is considered to be another primary centre with Asia minor. Transcaucacus and Iran as secondary centers. The Parents of cultivated turnip are found wild in Russia, Siberia and Scandinavia (Natarajan and Veeraragavathatham, 2022).

Taxonomy

The wide Brassica family includes turnips (*Brassica rapa* L., 2n = 2x = 20, formerly *B. campestris* subsp. *rapifera*), which have similar yellow (and usually white) blooms. It belongs to a different species called *B. campestris* and does not readily cross with the *oleracea* (types of cabbage). Turnip and another type of swede, *B. napus* L. var. *napobrassica*, are closely related. The swede is an amphidiploid vegetable with 38 chromosomes that has been naturally developed from *B. oleracea* (2n = 18) and *B. campestris* (2n = 20). Although neither of the ancestral kinds can be determined with accuracy, it is believed that the cross occurred very often where the two species overlap in their natural environment from Western Europe to Eastern Asia. (Kumar et al. 2024).

Inheritance pattern and heterosis

Major germplasm collections are present in the gene banks in Japan, the UK and the USA. Frandsen (1945) reported that *Brassica rapa* hybridizes readily with *B. napus* to produce triploid hybrids (3n = 29) which are almost sterile. Davey (1931) who reported that white flesh is dominant to yellow in both species and is determined by a single locus in turnip and by two homologous loci in Swede. Skin colour in turnip is

determined by two independent loci conditioning the presence or absence of green or red pigmentation, respectively. Gene interaction and linkage study revealed that genes for flower color were non-allelic and independently inherited. Cours and Williams (1977) reported that characters, cream corolla (cr); light yellow corolla (ly); dark yellow corolla (dy); cupped petal (cup); apetalous (pi); anthocyanin less bud tip (ab); anthocyanin-less anther tip (aa) and anthocyaninless style tip (as) are governed by a single recessive gene, whereas, rolled petal margin (Ropm) is controlled by a single dominant gene. Polypetalous (Pp) is also dominant but strongly influenced by environment. Gene interaction and linkage study revealed that genes for flower color were non-allelic and independently inherited (Acharya et al. 2020). Improvement for uniformity is an important breeding objective in turnip. Wit (1966) observed heterosis for number of characters including dry matter yield of root and leaf in this crop. Several F_1 hybrid cultivars in turnip have been bred by Japanese breeders. Heterosis for root yield, root length, root diameter and number of leaves per plant was observed.

Pollination Control Mechanisms

There are two pollination control mechanisms in turnip, sporophytic self-incompatibility system and cytoplasmic male sterility (CMS). Effective self-incompatibility avoids the need for emasculation and crosses can be made by enclosing flower heads from two compatible plants in a cellophane or muslin bag with blow flies as pollinators (Acharya et al. 2020).

Climate and Soil

Turnip is cool climate vegetable. In the plains of northern India, sowing time is September- December, in lower hills, July - October, while in higher hills, the seeds are sown from July- September. They can tolerate light frosts and mildly freezing temperature. High temperature adversely affects quality, the roots become woody, tough and bitter in taste in hot weather. Temperature below 10 ^{O}C induces flowering. The most favourable weather for the root development is 10 ^{O}C- 13 ^{O}C and soil temperature 18-23 ^{O}C (Natarajan and Veeraragavathatham, 2022). It can be grown in wide range of soils. A moderately deep; friable; fertile well drained soil is ideal. High clay and high sand content soils should be avoided. The optimum pH is 5.5.- 6.8.

Varieties

Varieties are grouped into white fleshed and yellow fleshed based on morphology of root and top. Top may be purple, green or white in white fleshed varieties, whereas top is purple or yellow in yellow fleshed varieties. Brief descriptions of varieties are given below.

Sr.No.	Variety	Salient features
	Temperate types	
1.	Purple Top White Globe (PTWG)	Its tops are dark green, erect with cut leaves, roots large, round, smooth, bright purplish-red in upper half and lower portion creamy white. Flesh is white, firm and crispy, suitable for sowing from October to December in plains. Matures in 60-65 DAS. Yield 30.0 t ha^{-1}.
2.	Pusa Chandrima	It is developed by crossing Asiatic and European type. Its root is medium- long, 8-9 cm in length and 9-10 cm in diameter, skin is pure white with tender flesh. Matures in 55-60 DAS. It is a temperate or biennial variety and does not produce seeds in the plains of India.

3.	Pusa Swarnima	It is developed by hybridization and selection by involving Asiatic (Japanese White) and European (Golden Ball) types. It is earlier than Golden Ball by about a fortnight and gives 40% higher yield. Roots are flattish-round, 6-7 cm long and 7-8 cm in diameter with creamy yellow, amber coloured, fine textured and mild flavoured flesh. Matures in 65-70 DAS.
4.	Snow Ball	It takes about 55-60 days from sowing to root formation. The roots are round medium with pure white skin. Flesh is light-yellow and mildly sweet flavoured.
5.	Golden Ball	The roots are perfectly globe-shaped, medium sized and smooth. It has bright creamy-yellow skin and pale amber coloured flesh of fine texture and flavour.
	Tropical types	
6.	Pusa Kanchan	It has been developed from a cross between tropical type (Local Red Round) and a temperate type (Golden Ball). It has all the good qualities of both the parents. The skin is red and the flesh is creamy yellow and it has excellent flavour and taste. It produces seed in plains.
7.	Pusa Sweti	It is suitable for both Tropical and sub-tropical areas, roots are attractive pure white, medium in size, round to flattish round, tender, flesh white; leaves finely lobed and light green, suitable for sowing in October in plains, maturity in 45-50 days. Yield 20.0-30.0 t ha^{-1}.
8.	*Turnip L* 1	It is developed at Ludhiana. Roots are medium in size, round and pure. Yield 20.0-30.0 t ha^{-1}. Maturity 45-50 DAS.

Cultivation and Intercultural Operations

Turnip seeds are mixed with fine sand while sowing as its seeds are small. The seed rate is 3- 4 kg ha^{-1}. Seeds are sown at a depth of 1.5-2.5 cm in the flat beds or on top of ridges at row to row spacing 30-45 cm and plant to plant distance after thinning 10 cm for small varieties, while 15 cm for large varieties. In order to maintain optimum plant to plant distance as well as plant population, thinning is an important operation in turnip. Depending on cultivar types plants has to be thinned at plant to plant spacing of 7.5- 15 cm. Weeding is to be done accordingly to keep field weed-free. At the time of half dose of nitrogen top dressed application during 25-30 DAS earthing up is to be done.

Irrigation

Better germination requires pre-sowing irrigation. Generally, the crop is irrigated at an interval of 7 days till harvest.

Nutrient Management

A quantity of FYM 20 t (at the time of land preparation), 60-80: 40-50: 40-50 kg NPK ha^{-1} is required. Half N and entire P and K are to be applied as basal dressing. Remaining half dose of N has to be top dressed at the time of root formation.

Harvest and Yield

Turnip roots are harvested at tender stage when they attain a diameter of 5-7.5 cm by pulling out along with top. After harvest, top is removed and roots are washed for removing soil and packed in baskets. Yield varies from 20-40 t ha^{-1} based on varieties; growing season and management practices.

Handling and Storage

Timely harvest is essential for getting quality roots. Just after harvesting, the tops are completely removed. The roots are washed and cleaned in the water (better if running water is used). All the side roots are removed. This will give attractive appearance to the finished roots which are to be sent to the markets. The keeping quality is poor. Under ordinary conditions, away from sun but under well-ventilated shed, turnip roots can be stored for about 4 to 6 days.

Physiological Disorders

Physiological disorders can be caused by a variety of factors, including environmental conditions and improper cultural practices. Some of the most common physiological disorders of turnip are:

Bolting

This is a disorder caused by changes in temperature or day length, which results in the plant producing a flower stem instead of a root. Management includes using varieties with good bolting tolerance and avoiding planting during extreme temperatures.

Nutrient Deficiencies

A lack of essential nutrients such as nitrogen, phosphorus and potassium can result in stunted growth, yellowing leaves and poor root development. Management includes soil testing and applying the appropriate fertilizers (Kumar et al. 2024).

Pest and Diseases

Major pests: Aphids, mustard saw fly; flea beetle and gall weevil.
Major diseases: Powdery mildew; downy mildew; soft rot; dry rot; brown heart.



Crimson Globe



Radish crop



Carrot Crop

References

Acharya, S. K., Shukla, Y. R., & Kaushik, R. A. (2020). Root vegetables. In P. A. Sable, S. N. Saravaiya, & A. Sharma (Eds.), *Vegetable crops: Package of practices* (pp. 582–623). Narendra Publishing House.

Chaudhari, P. P., Patel, C. K., & Khaniya, J. (2023). *Research accomplishments and recommendations* (Publication No. 08/2023, p. 21). Directorate of Research, Sardarkrushinagar Dantiwada Agricultural University.

Cours, B. J. (1977). *Genetic studies in Brassica campestris L.* [Master's thesis, University of Wisconsin–Madison].

Davey, V. (1931). Colour inheritance in swedes and turnips and its bearings on the identification of commercial stocks. *Scottish Journal of Agriculture, 14*, 303.

Frandsen, K. J. (1941). Contribution to the cytogenetics of Brassica napus L., Brassica campestris L., and their hybrid, the amphidiploid Brassica napobrassica. *Årsskrift for K. Vet.-Landbohøjskole*, 59.

Kamalkumaran, P. R., Kavitha, P. S., & Anand, M. (2021). Production technology of tuber and root vegetable crops (tapioca, sweet potato, potato, carrot and beetroot). In T. Arumugam (Ed.), *Horticulture (for ICAR JRF and competitive examinations)* (pp. 395–423). Brillion Publishing.

Kumar, A., Ramadugu, S., Singh, J., Singh, S., & Kumar, P. (2024). Advances in production technology of turnip. In A. Kumar, S. Prakash, M. Wamiq, C. Bihari, & S. Ahmad (Eds.), *A textbook on advances in production technology of temperate vegetable crops* (pp. 185–197). PMW.

Natrajan, S., & Veeraragavathatham. (2022). Radish (*Raphanus sativus* L.). In S. Thamburaj & N. Singh (Eds.), *Vegetables, tubercrops and spices* (10th reprint, pp. 147–151). Directorate of Knowledge Management in Agriculture, Indian Council of Agricultural Research.

Natrajan, S., & Veeraragavathatham. (2022). Turnip. In S. Thamburaj & N. Singh (Eds.), *Vegetables, tubercrops and spices* (10th reprint, pp. 161–164). Directorate of Knowledge Management in Agriculture, Indian Council of Agricultural Research.

Singh, J., Prakash, S., Kumar, R., Kumar, A., Kumar, P., & Gautam, P. (2024). Advances in production technology of carrot. In A. Kumar, S. Prakash, M. Wamiq, C. Bihari, & S. Ahmad (Eds.), *A textbook on advances in production technology of temperate vegetable crops* (pp. 135–147). PMW.

Watson, F. J., & Gabelman. (1984). Genetic analysis of betacyanine, betaxanthin, and sucrose concentration in roots of table beet. *Journal of the American Society for Horticultural Science, 109*(3), 386–391.

Wit, F. (1966). Quality plant material. *Vegetable Growing, 13*, 305–310.