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REVIEW ARTICLE OPEN ACCESS

ORIGIN, DISTRIBUTION, GENETIC DIVERSITY AND BREEDING OF RASDISH (*Raphanus sativus* L.)

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ABSTRACT

Radish (*Raphanus sativus* L. ssp. *sativus* or *Raphanus sativus* L.) belongs to the genus *Raphanus* and the family Brassicaceae (Crucifereae). It is a diploid species with chromosome numbers 2n = 2x = 18. The genus *Raphanus* originated from coastal regions along the Mediterranean and Black Seas. Most scholars believe that cultivated radish (*R. sativus* L.) was originated from wild radish (*Raphanus raphanistrum* L.) while others thought *R. sativus* was derived by the hybridization between *R. maritimus* and *R. landra.* Other names of radish are wild radish, garden radish, daikon. It is an economically important crop grown and consumed all over the world, especially in East Asia. Radish is grown all over the world for its fleshy, edible taproot. Radish is one of the most common root vegetables, while in some cultivars it can be used as a leafy vegetable, silique vegetable, or oil crop. Various types of radish landraces and traditional varieties with different root sizes, shapes, colors, and taste have been developed through domestication, evolution and breeding. Depending on the variety, the edible root ranges in shape from spherical to long and cylindrical or tapered, and the outside skin can be white, yellow, pink, red, purple, or black. Today, radishes are grown throughout the world. Different local people prefer to use various parts of the radish plants including roots, leaves, sprouts, seed pods and oil from seeds as their food according to their own custom. The early domestication of radishes, evolutionary processes and human selection of preferred types have led to significant variations in size, color and taste of this vegetable crop. In this review article origin, geographic distribution, taxonomy, botanical description, genetic diversity, genetic resources, breeding, nutritional value, health benefits, cultural significance of radish are discussed.

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INTRODUCTION

Radish (*Raphanus sativus* L. ssp. *sativus* or *Raphanus sativus* L.) belongs to the family Brassicaceae (Crucifereae) and is a diploid species with chromosome numbers 2n = 2x = 18 (Genebank, 2022; Gupta *et al*., 2003; Schippers, 2004; WIKI, 2022c). Species of *Raphanus* are derived from an ancestor that originated by hybridization between two different lineages of *Brassica*—the *B. nigra* clade and the *B. rapa* clade. Therefore, species of *Raphanus* are actually members of the genus *Brassica*. The generic name Raphanus derives from the Greek ra, meaning quickly, and phainomai**,** meaning to appear, in reference to the rapid germination of radish seeds. The common name radish derives from the Latin for root, radix (PWO, 2022)**.** Raphanus is a latinized form of the Greek rephanos, which means 'easily reared.' Radish was a common food crop in Egypt (Gupta *et al.,* 2003). The genus *Raphanus* originated from coastal regions along the Mediterranean and Black Seas (Kaneko *et al,* 2007). Most scholars believe that cultivated radish (*R. sativus* L.) was originated from wild radish (*Raphanus raphanistrum* L.) while others thought *R.sativus* was derived by the hybridization between *R. maritimus* and *R. landra* (Kaneko *et al,* 2007). During the process of spreading, different variations gradually evolved in different places all over the world, such as mostly fresh edible cherry radish (*R. sativus* L. var. *radicola* Pers), oil radish (*R. sativus* L. var. *oleifera*), feed radish (*R. sativus* L. var. *caudatus*), black radish (*R. sativus* L. var. *niger*) and large root radish (Daikon) (*R. sativus* L. var. *longipinnatus* Bailey) (Shen *et al*., 2013). It is an economically important crop grown and consumed all over the world, especially in East Asia. Radish is one of the most common root vegetables, while in some cultivars it can be used as a leafy vegetable, silique vegetable, or oil crop. Various types of radish landraces and traditional varieties with different root sizes, shapes, colors, and taste have been developed through domestication, evolution and breeding (Chaturvedi, 2008). Depending on the variety, the edible root ranges in shape from spherical to long and cylindrical or tapered, and the outside skin can be white, yellow, pink, red, purple, or black. Radishes vary in size from a few grams in the most-popular early American and European varieties up to 1 kg in the Japanese daikon radish (Editor, 2022).

ORIGIN AND DISTRIBUTION

The origin of *Raphanus sativus* is not known but the area of maximum diversity runs from the eastern Mediterranean to the Caspian Sea; the variability diminishes gradually from the Caspian

Sea to China, and still more to Japan (Piluek and Beltran, 1993). The origin of R. sativus is not known, but the area of maximum diversity runs from the eastern Mediterranean to the Caspian Sea; the variability diminishes gradually from the Caspian Sea to China, and still more to Japan (CABI, 2019). The origin of cultivated radish (R. sativus L.) is not clear. In any case, cultivated radish is considered to have originated somewhere in the Mediterranean region by natural or artificial crossing between R. landra and R. maritimus. On the other hand, the cultivated radish may also be differentiated from R. raphanistrum by the fact observed in scientific exploration that the wild species grows preferentially in the region of the Mediterranean and the Black Sea where the soil is composed of mixed sand and clay (Kaneko and Matsuzawa, 1993). Radish originated in China, India, Egypt and the Mediterranean and it has been cultivated since 3000 BC (Singh, 2018). The common radish is likely of Asian or Mediterranean origin and is cultivated worldwide (Britannica, 2023).

Raphanus sativus is a cultigen (a plant that has been altered by humans through a process of selective breeding). Because it has been in cultivation for thousands of years, its exact origins are unknown. It is thought that *Raphanus sativus* evolved in the eastern Mediterrane an region and may have been selected from R. raphanistrum subspecies landra (sometimes known by the synonym R. landra) (PWO, 2022). The highest crop diversity is found in the regions running from the eastern Mediterranean to the Caspian Sea, probably the primary gene center (Singh, 2021). It most likely originated in the area between the Mediterranean and the Caspian Sea (Crisp, 1995). It may come from the wild radish in southwest China. It is possible that radishes were domesticated in both Asia and Europe (Cheo *et al.,* 1987). The eastern Mediterranean region, China, and middle Asia are considered to be the origin of radish. China is the center of origin because wild radish still exists in China (Gupta *et al.,* 2003). Radish is derived from the wild radish *Raphanus raphanistrum* L., which is frequently found as a weed in cooler parts of Africa and may act as a host for a range of pests and diseases affecting cruciferous crops (Schippers, 2004). *Raphanus raphanistrum* L. is the most likely ancestor of the polymorphic *Raphanus sativus*. The area of maximum diversity of radish lies between the eastern Mediterranean and the Caspian Sea, which is probably the original gene centre for this species (Schippers, 2004). There are several wild *Raphanus* spp., particularly between the Eastern Mediterranean and the Caspian Sea, and it is thought that *R. sativus* must have arisen in this region of Europe and Asia Minor (NRI, 1987).

Radish probably originated in Europe and Asia. Radish does not exist in wild state, it is believed to have originated from *R. raphanistrum* which is widely distributed as weed in Europe (Vidhi, 2022). Radish is originated in Europe and Asia. It is believed to have originated from *Raphanus raphanistrum*, which is widely distributed as a weed crop in Europe. However, scientists tentatively locate the origin of *Raphanus sativus* in Southeast Asia, as this is the only region where truly wild forms have been discovered (Weebly, 2022). The genus *Raphanus* originated from coastal regions along the Mediterranean and Black Seas. Most scholars believe that cultivated radish (*R. sativus* L.) was originated from wild radish (*Raphanus raphanistrum* L.) while others thought *R. sativus* was derived by the hybridization between *R. maritimus* and *R. landra* (Shen *et al*., 2013). Radish is a crop of ancient cultivation in the Mediterranean (before 2000 BC), from where it spread to China in about 500 BC and to Japan in about 700 AD. It has now spread throughout the world. Cv. group Chinese Radish is most important in Japan, Korea, China and South-East Asia. Cv. group Leaf Radish is gaining importance in Europe as forage and green manure. Cv. group Rat-tailed Radish is most important in India and eastern Asia. In Southeast Asia it is important in Northern Thailand and Burma. Cv. group Small Radish is most important in temperate climates (Piluek and Beltran, 1993). During the process of spreading, different variations gradually evolved in different places all over the world, such as mostly fresh edible cherry radish (*R. sativus* L. var. *radicola* Pers), oil radish (*R. sativus* L. var. *oleifer*a), feed radish (*R. sativus* L. var. *caudatus*), black radish (*R. sativus* L. var. *niger*) and large root radish (Daikon) (*R. sativus* L. var. *longipinnatus* Bailey) (Shen *et al*., 2013). Wild radish, *R. raphanistrum* L. ssp. *raphanistrum*, has successfully colonized in a variety of locations, leading to its naturalization on all continents except Antarctica. It has also become a major agricultural weed, causing yield losses in a number of crops in North America, Europe and Australia (Shen *et al.,* 2013). Radish has numerous categories, varying in leaf morphology; color, size, shape and flavor of the root; vernalization requirement and period of maturity. Ancient varieties were long and tapered rather than cylindrical, apically bulbous, elliptic or spherical. There are three independent domestication events for black Spanish radish, European cultivated forms and Asian cultivated radish. The different types of radishes arose in the various time sequences of domestication: black radishes were the earliest in cultivation, white radishes were being cultivated in Europe by the 1500s, and red and round radishes were developed in the 1700s, altogether belonging to two botanical varieties *i.e. R. sativus* L. var. *radicula* or (*sativus*) and *R. sativus* L. var. *niger* (Singh, 2021). The early domestication of radishes, evolutionary processes and human selection of preferred types have led to significant variations in size, color and taste of this vegetable crop. Among them, small-rooted radishes are grown in temperate regions of the world and harvested throughout the year (Crisp, 1995). Larger-rooted cultivars such as Chinese radish are predominant in East and Southeast Asia (Schippers, 2004). Today, radishes are grown throughout the world. Different local people prefer to use various parts of the radish plants including roots, leaves, sprouts, seed pods and oil from seeds as their food according to their own custom (Genebank, 2022).

It has now spread throughout the world. Cultivar group Chinese or Oriental Radish (R. sativus var. niger) is the most important in Japan, Korea, China and Southeast Asia. Cultivar group Leaf Radish (R. sativus var. oleiformis) is gaining importance in Europe as forage and green manure. Cultivar group Rat-tailed Radish (R. sativus var. caudatus) is most important in India and Eastern Asia. In Southeast Asia it is important in Northern Thailand and Burma. Cultivar group Small or Western Radish (R. sativus var. sativus) is the most important in temperate climates (CABI. 2019). The ancient Greeks prized radishes so much that they made small replicas of them in gold. In 1544, a German botanist reported seeing radishes that weighed 45 kg. Radishes were common in England in 1586 and were among the first European crops introduced to America by the Spaniards. By 1629, they were being cultivated in Massachusetts (Gupta *et al*., 2003). Radish can now be found as a cultigen throughout the world in many different forms, from small leafy annuals to biennials with large fleshy roots. The cultivars with relatively small roots (small radish) are most important in temperate climates of the world and only of limited importance in Africa, mostly in francophone or French speaking countries (France, Congo-DRC, Canada, Cameroon, Belgium, Ivory Coast, Madagascar and Haiti) amongst people originating from Europe. Larger-rooted cultivars (like Chinese radish) are most important in East and Southeast Asia. In East Africa and elsewhere in the cooler parts of the African continent, large, white radishes are known under the Swahili/Arabic name ‘fijili’ and the Hindi name ‘mooli’ and these are becoming increasingly popular. In francophone West Africa Chinese radish is becoming popular, replacing the traditionally grown vegetable turnip (*Brassica rapa* L.), which is very susceptible to anthracnose. Large radishes with a dark grey-brown surface are occasionally seen in Southern Africa and are sold under the name ‘black Spanish radishes’; they are more commonly grown in Europe under the name ‘black radish’ (Schippers, 2004).

The so-called ‘rat-tailed radish’, grown for its green or purple 20–60 cm long pods, is rather important in India and Eastern Asia, but only of minor importance for Asian immigrants in East Africa, where it is called ‘mogri’ (Schippers, 2004). Finally, the so-called ‘leaf radish’ is gaining importance in Europe and South Africa as forage and green manure crop but is not known to be cultivated in tropical Africa (Schippers, 2004). The radish (*Raphanus sativus*) was domesticated in Europe in pre-Roman times. They are grown and consumed throughout the world (Singh, 2018). Varieties of radish are now broadly distributed around the world, but there are almost no

archaeological records available to help determine its early history and domestication. India, Central China, and Central Asia appear to have been secondary centers where differing forms were developed. Radishes enter the historical record in 3rd century B.C. Greek and Roman agriculturalists of the 1st century A.D. gave details of small, large, round, long, mild, and sharp varieties. The radish seems to have been one of the first European crops introduced to the Americas. A German botanist, reported radishes of 45 kg and roughly one m in length in 1544, although the only variety of that size today is the Japanese Sakurajima radish. The large, mild, and white radish of East Asian form was developed in China but is mostly associated in the West with the Japanese daikon, owing to Japanese agricultural development and larger exports (Weebly, 2022).

TAXONOMY

Radish belongs to the family Brassicaceae, genus *Raphanus* and species *Raphanus sativus* (CABI, 2022). Species of *Raphanus* are derived from an ancestor that originated by hybridization between two different lineages of *Brassica*—the *B. nigra* clade and the *B. rapa* clade. Therefore, species of *Raphanus* are actually members of the genus *Brassica* (NPT, 2022). The genus *Raphanus* is classified into two sections: Raphanis DC. And Hesperidopsis Boiss. The section Raphanis DC. consists of six species, R. rostras, R. raphanistrum, R. microcarpus, R. sativus, R. maritimus and R. landra**.** The section Hesperidopsis Boiss consistsof only one species, R. aucheri (Kaneko and Matsuzawa, 1993). Species in the first group can cross reciprocally with each other. However Singh (2018) reported the following seven species in the genus.

Raphanus:

- *R. sativus* (cultivated radish)
- *R. raphanistrum* (Wild Radish, or Jointed podded Charlock), a weed among barley, in Sweden. It is bristly, and has rather large, straw- coloured flowers.
- *R. sibiricus*, or Siberian Radish, has cylindrical pods.
- *R. caudatus*, the Java, or Rat's Tail Radish, a native of China, furnishes long, edible pods, purple or violet in colour. Type: Annual. They should be used half-grown. The root of this species is not used.
- *R. maritimus* (Maritime wild radish) an indigenous, seaside variety. A large, straggling plant, often more than 1m in height, covered in a cloud of pale yellow flowers in May and June. hard pod with a beaded appearance due to constrictions between each seed. Leaves are toothed and pinnate, and covered in coarse bristles
- *R. erucoides*, of Italy, has pods with a beak of their own length, and a simple, biennial root, scarcely thicker than the stem.
- *R. tenellus*, another native of Siberia, flowers in Britain in June and July, having awl-shaped, jointed, two-celled, smooth pods. The leaves are oblanceolate to elliptic-oblong, with sinuous or coarsely-toothed leaf edges

According to Pistrick, 1987; CABI, 2019; CABI, 2022; Genebank, 2022, the cultivated radishes have several wild relatives such as R. raphanistrum and its supbspecies viz, R. raphanistrum subsp. landra (Moretti ex DC.) Bonnier & Layens, R. raphanistrum subsp maritimus (Sm.) Thell., R. raphanistrum subsp microcarpus (Lange) Thell., R. raphanistrum subsp raphanistrum**,** R. raphanistrum subsp rostratus (DC.) Thell., and R. confusus (Greuter & Burdet) Al-Shehbaz & Warwick. Sometimes these related species are considered as one species complex named *R. raphanistrum*, with the different taxa classified as subspecies. *R. sativus* crosses freely with the related wild species. *R. sativus* is also closely related to several *Brassica* species and to *Sinapisarvensis* (charlock), with which it has also been successfully crossed (CABI, 2019; CABI, 2022.).

Botanical Varieties of Radish are as given below (WIKI, 2022d) (Fig. 1):

Green radish *Raphanus sativus* var. *caudatus*
Daikon radish *Raphanus raphanistrum* subsp. *sativus* (syn. *Raphanus sativus* var. *longipinnatus*)

Green radish Daikon Black radish

Oilseed radish Wild radish Red Radish

Fig. 1. Subspecie/ Botanical Varieties of Radish

Black radish *Raphanus sativus* var. *niger*
Oilseed radish *Raphanus sativus* var. *oleiformis*
Wild radish *Raphanus sativus* var. *raphanistroides*
Red Radish *Raphanusraphanistrum* subsp. *Sativus*

Four botanical varieties are recognised within the species, *R. sativus* L., viz., *radicula*, *niger, mougri* and *oleifera*. The first two of which are grown for their tuberous roots, while oleifera is grown primarily for the oil in its seeds. Numerous cultivars have been developed within each variety. All varieties intercross freely, and also hybridise with wild *Raphanus* spp. (NRI, 1987). Kaneko and Matsuzawa (1993) classified radish cultivars into five main varieties, namely, **R.** sativus var. niger (Mill.) Pers.; R. sativus var. radicula DC; R. sativus var. raphanistroides Makino;

R. sativus var. caudatus (L.); and R. sativus var. oleifer Netz. Pistrick (1987) divided cultivated radishes **(***Raphanus sativus* L.) into the following four groups:

- Convar. oleifera **(***Raphanus sativus* var. oleiformis Pers.), also called R. sativus Leaf Radish Group (Wiersema and León 1999), oilseed and fodder radishes, which are grown in Southeast Asia and in Europe for leaf fodder, and as green manure.
- convar. Caudatus **(***Raphanus sativus* var. caudatus (L.) L. H. Bailey), also known as R. sativus Rat-Tailed Radish Group (Wiersema and León 1999) - the rat-tail radish (also known as mougri, radis serpent) grown for its edible immature green or purple seed pods and leaves. This type is grown in Southeast Asia.
- convar. sativus (*Raphanus sativus* var. sativus), also known as R. sativus Small Radish Group (Wiersema and León 1999), where all forms are with edible roots, leaves and germinated radish sprouts, with many different varieties but generally of the small type (radish, small radish, turnip radish, petit rave).
- convar. niger (*Raphanus sativus* L. var. niger J. Kern), also known as R. sativus Chinese Radish Group with the common names Chinese radish, Japanese radish, and Oriental radish are recognized as fourth cultivated group.

According to Zhu *et al***.** (2008) radishes can also be classified into four groups:

- Small-rooted (sometimes referred to as var. radicula) and large-rooted types (including names such as var. nigra, niger, sinensis, acanthiformis or longipinnatus) based on root size;
- European, Chinese, Indian and Japanese based on geography;
- spring or summer radish and winter radish, Chinese radish (var. longipinnatus Bailey) and
- all-season radish (var. radiculus Pers.) based on the adaptation to growing seasons and regions

Raphanus raphanistrum has 3 known subspecies (WIKI, 2022f):

- *Raphanus raphanistrum* subsp. *landra* (Moretti ex DC.) Bonnier & Layens ('searadish')
- *Raphanus raphanistrum* subsp. *rostratus* (DC.) Thell.
- *Raphanus raphanistrum* subsp. *sativus* (L.) Domin

The radish crop has traditionally been classified into five morphotypes (Yamagishi 2017):

- European small (*Raphanus sativus* L. var. *sativus*),
- East Asian long (*Raphanus sativus* var. *sativus*),
- black (*R. sativus* var. *sativus*), oil (*R. sativus* var. *oleiformis* Pers.) and
- rat-tail (*Raphanussativus* var. *mougri* H.W.J. Helm).

Radishes come in all sorts of colors - red, pink, purple, white, green, black, and yellow. The types of radishes are as follows (Emily. 2021):

- ***Red Radish (table radish)* -** This is the common radish sold at most grocery stores. It has bright red skin and white flesh. They are available year-round and they have a crisp, peppery flavor.
- ***Watermelon Radish* -** This radish doesn't look like much from the outside - it has white and light green skin, but the interior flesh is a vibrant pink. Cross-sections of it look like a watermelon. They are at their peak in spring and fall. Watermelon radishes have a sweeter flavor but still have a little bite.
- ***Daikon Radish* -** Daikon radishes are an Asian radish available in fall and winter. They can be white, purple, pink, green, or red. They're popular because of their milder, sweeter flavor.
- ***French Breakfast Radish* -** These radishes have ombré skin that goes from red to pink to white. They're long and thin and have a spicier flavor. They're in season in winter and spring.
- ***Green Meat Radish* -** These radishes have a dark green exterior and interior. They're usually quite crisp and subtly spicy. They're in season in spring and fall.
- ***Sparkler Radish* -** Sparkler radishes are two-toned with either a dark red or purple top and a creamy white base. They are crunchy and peppery and look great on a crudité platter. They're in season in winter and spring.
- ***Easter Radishes* -** Easter radishes are actually multiple types of small red, pink, purple, and white radishes but they are often sold in a bunch or bag together. They're beautiful and can be used just like red radishes.

There are 39 synonyms of *'Raphanus sativus'* (PWO, 2022) (Table 1). (Table 1)

Table 1. Synonyms of *'Raphanus sativus'*

1. Raphanistrum gayanum Fisch. &C.A.Mey.
2. Raphanus acanthiformis Morel ex L.Sisley
3. Raphanus caudatus L.
4. Raphanus caudatusL.f.
5. Raphanus chinensis Mill.
6. Raphanus gayanus (Fisch. &C.A.Mey.) G.Don
7. Raphanus indicusSinskaya
8. Raphanus macropodusH.Lév.
9. Raphanus niger Mill.
10. Raphanus oleiferSteud.
11. Raphanus orbicularis Mill.
12. Raphanus radicula Pers.
13. Raphanus rotundus Mill.
14. *Raphanus sativus* L.
15. *Raphanus sativus* subsp. acanthiformis (Morel ex L.Sisley) Stank.
16. *Raphanus sativus* var. aka-daikon (Kitam.) Sazonova
17. *Raphanus sativus* f. albescens (Makino) M.Hiroe
18. *Raphanus sativus* f. esculentus (Metzg.) M.Hiroe
19. *Raphanus sativus* f. exsuccus (Thell.) M.Hiroe
20. Raphanus sativusconvar. hybernus (Alef.) Sazonova
21. *Raphanus sativus* var. incarnatusSazonova
22. *Raphanus sativus* var. loboSazonova& Stank.
23. *Raphanus sativus* var. longipinnatusL.H.Bailey
24. Raphanus sativusconvar. minowase (Kitam.) Sazonova
25. Raphanus sativussubf. niger (Mill.) M.Hiroe
26. *Raphanus sativus* var. niger (Mill.) J.Kern.
27. *Raphanus sativus* var. nonpinnatusL.H.Bailey
28. Raphanus sativussubf. oleifer (DC.) M.Hiroe
29. *Raphanus sativus* var. parvipinnatusL.H.Bailey
30. Raphanus sativusconvar. radicula (Pers.) Sazonova
31. *Raphanus sativus* var. roseusSazonova
32. *Raphanus sativus* var. rubidusSazonova
33. Raphanus sativussubf. silvester (W.D.J.Koch) M.Hiroe
34. *Raphanus sativus* subsp. sinensisSazonova& Stank.
35. *Raphanus sativus* var. syrengeusSazonova
36. *Raphanus sativus* var. virensSazonova
37. Raphanus sinensisThunb. exPritz.
38. Raphanus stenocarpusKitag.
39. Raphanus taquetiiH.Lév.

According to IPKG (2022) there are 38 synonyms of *'Raphanus sativus'* (Table 2*)*.

Synonyms of *Raphanus sativus* L. (7) and *Raphanus sativus* var. sativus L.(10) has also been reported by Pavone (2022) (Table 3).

Table 2. Synonyms of *'Raphanus sativus'*

1.	Raphanussativus (Alef.) Sazon. convar. sativus(1985)
2.	Raphanussativusconvar. caudatus (L.f.) Pistrick(1987)
3.	Raphanussativusconvar. hybernus (Alef.) Sazon(1971)
4.	Raphanussativusconvar. hybernus (Alef.) Sazon(1971)
5.	*Raphanus sativus* convar. lobo Sazon.(1971)
6.	*Raphanus sativus* convar. oleifer (Stokes) Alef.(1866)
7.	*Raphanus sativus* convar. oleiferus (Stokes) Sazon. &Stankev.(1985)
8.	Raphanussativusconvar. radicula (Pers.) Sazon.(1971)
9.	Raphanussativusconvar. radicula (Pers.) Sazon.(1971)
10.	*Raphanus sativus* convar. sativus
11.	*Raphanus sativus* convar. sinensisSazon.(1971)
12.	*Raphanus sativus* 'Eiszapfen'
13.	Raphanussativusesculentus A. hybernusAlef.(1986)
14.	*Raphanus sativus* esculentus B. aestivusAlef.(1986)
15.	Raphanussativusesculentus C. radicula (Pers.) Alef.(1986)
16.	Raphanussativus f. raphanistroidesMakino(1909)
17.	*Raphanus sativus* L.(1753)
18.	*Raphanus sativus* L.(1763)
19.	Raphanussativus (Pers.) Sazon. convar. sativus(1971)
20.	*Raphanus sativus* prol. niger (Mill) O.E. Schulz
21.	Raphanussativus prol. radicula (Pers.) O.E. Schulz
22.	*Raphanus sativus* Radish Group
23.	*Raphanus sativus* Small Radish Group
24.	*Raphanus sativus* subsp. acanthiformis (M. Morel ex Sisley) Stankev.(1985)
25.	*Raphanus sativus* subsp. oleiferus (Stokes) Metzg.(1841)
26.	*Raphanus sativus* subsp. raphanistroides (Makino) Sazon.(1971)
27.	Raphanussativussubsp. sinensisSazon. &Stankev.(1985)
28.	Raphanussativus var. caudatusAlef.(1866)
29.	Raphanussativus var. caudatus (L.f.) Vilmorin(1925)
30.	Raphanussativus var. chinensis (Mill.) Alef.(1866)
31.	*Raphanus sativus* var. minor Kern.(1788)
32.	Raphanussativus var. mougriHelm(1957)
33.	*Raphanus sativus* var. nigerKern.(1789)
34.	*Raphanus sativus* var. oleiferusStokes(1812)
35.	Raphanussativus var. oleiformisPers.(1812)
36.	Raphanussativus var. radiculaPers.(1807)
37.	Raphanussativus var. raphanistroidesMakino(1917)
38.	Raphanussativus var. sylvestrisKoch(1846)

Table 3. Synonyms of *Raphanus sativus* L. and *Raphanus sativus* var. sativus L.

Synonyms of *Raphanus sativus* L.
Raphanistrumgayanum Fisch. & C.A. Mey.,
Raphanusacanthiformis Morel ex Sasaki,
Raphanuscandidus Vorosch.,
Raphanusgayanus (Fisch. & C.A. Mey.) G. Don ex Sweet,
Raphanussativus var. **longipinnatus** L.H. Bailey,
Raphanussativus var. **radicula** Pers.,
Raphanustaquetii H. Lév.
Synonyms of Raphanussativus var. sativus L.
Raphanusacanthiformis var. **gigantissimus** Nakai,
Raphanuschinensis Mill.,
Raphanus macropodus H. Lév.,
Raphanusniger Mill.,
Raphanusraphanistroides (Makino) Sinskaya,
Raphanusrotundus Mill.,
Raphanussativus f. raphanistroidesMakino,
Raphanussativus var. **hortensis** Backer,
Raphanussativus var. **niger** (Mill.) J. Kern.,

Raphanussativus var. *raphanistroides* (Makino) Makino.

BOTANICAL DESCRIPTION

Raphanus sativus is an annual or biennial herb which exists in several different forms. The main distinction is between a small, short-season type of salad radish which is a cool climate plant, and a large type which has a wide range of temperature adaptation (NRI, 1987; Piluek and Beltran, 1993; PWO, 2022)**.** It is an erect, annual, more or less densely hairy herb, 20-100 cm tall (NRI, 1987; Piluek and Beltran, 1993; PWO, 2022). The stems may be simple or branched, in the large types reaching as much as 1 m in height; stem at first short, growing out towards anthesis, hollow (NRI, 1987). Usually annual or perennial herbs. Root: Taproot system. The edible portion of radish root develops from both primary root and the hypocotyls. Radish roots vary in size, shape and other external characters as well as the length depending on cultivars. They can grow more than 60cm long, but they tend to become tough and fibrous when more than 30cm long. Stem is herbaceous, erect, branched. Leaves are simple, alternate or cauline, usually entire, sometime lobed, petiolate, exstipulate reticulate venation. Leaves are arranged in a rosette, with sizes ranging from 10–15 cm in small cultivars, to up to 45 cm in large cultivars. Inflorescence is raceme or corymbose raceme. Flowers are ebracteate, pedicellate, mostly actinomorphic, bisexual, heterochlamydeous, dimerous or tetramerous hypogynous. Flower petal colour is blue to purple, pink to red, white. Flower symmetry: there are two or more ways to evenly divide the flower (the flower is radially symmetrical). Calyx has sepals 4, polysepalous, in two whorls of two each imbricate aestivation. Corolla has petals 4, arranged in single whorl alternating with sepals, polypetalous, often with long claws and spread out to form a cross. Hence, the name cruciform corolla. Valvate aestivation. Androecium has stamen 6, polyandrous, arranged in two whorls of 4 and 2 (tetradynamous), outer two are short and inner four are long, anthers bilobed, basifixed, introse. Gynoecium is bicarpellary, syncarpous initially unilocular and later bilocular, one or more ovules on parietal placentation, style short, stigma bifid, sometimes bilobed, ovary superior. Fruit is silique or silicle. Seeds are endospermic (Fig. 2) (Singh, 2018). Radishes are usually grown as annuals and are harvested before they flower. The lobed leaves form a basal rosette that emerges from the top of the root. Flower stalks usually appear in the first season, bearing white or lilac-veined flowers with four petals; the seeds are borne in a pod called a silicle. Depending on the variety, the edible root ranges in shape from spherical to long and cylindrical or tapered, and the outside skin can be white, yellow, pink, red, purple, or black. Radishes vary in size from a few grams in the most-popular early American and European varieties up to 1 kg in the Japanese daikon radish (Britannica, 2023).

Leaves alternate, glabrous to sparingly hispid; lower leaves in a radical rosette, petioles 3-5.5 cm long, leaf-blades oblong, oblong-ovate to lyrate-pinnatifid, 3-5-jugate with a round or ovate terminal lobe, 5-30 cm long; higher leaves much smaller, shortly petioled, lanceolate-spathulate, subdentate (Piluek and Beltran, 1993; Schippers, 2004; CABI, 2019). Leaves are lobed, with a larger, rounded, terminal lobe and smaller, paired lower segments. Irregularly toothed. The basal leaves are long, often pinnately lobed and coarsely toothed, but sometimes are not serrated, while the cauline leaves are simple and linear (NRI, 1987; PWO, 2022). Inflorescence is terminal, erect, long, many-flowered raceme (Piluek and Beltran, 1993; Schippers, 2004; CABI. 2019). Flowers bisexual, 4-merous, c. 1.5 cm in diameter, fragrant, white to lilac; pedicel up to 2.5 cm long; sepals free, oblong-linear, 6–10 mm long; petals free, spatulate, clawed, 1–2 cm long; stamens 6, 4 long and 2 short; ovary superior, style 3–4 mm long. Four white to pink or pale violet petals. Four sepals. Flowers borne on erect, many-flowered inflorescences up to 90 cm tall (Piluek and Beltran, 1993; Schippers, 2004; PWO, 2022). Fruit is cylindrical, up to 10-30 cm x 1.5 cm, consisting of 2-several superposed joints, lower joint very short and seedless, upper one(s) much larger, terete, spongy and divided into 2-12 one-seeded compartments, indehiscent, with a long, seedless beak. Fruit is a smooth, beaked, fleshy siliqua (fruit divided into two parts by a thin partition and opening by two valves to reveal seeds on central limb). The fruits are narrow, indehiscent, 2.5-7.5 cm long and about 1.25 cm in diameter, with a long tapering beak. There are usually 6-12 globose seeds, yellow to chocolate-brown in colour (NRI, 1987; Piluek and Beltran, 1993; Schippers, 2004; CABI, 2019; PWO, 2022). Seed is ovoid-globose, about 3 mm in diameter, yellowish (Piluek and Beltran, 1993; Schippers, 2004; CABI, 2019). Taproot is widely variable in colour, shape and size. Red, pink, white, yellow, purple or black externally, white to bright pink internally. Spherical, olive-,

spindle- or turnip-shaped, tapering from top or bottom, 2 cm to 1m long and 60 cm in diameter (PWO, 2022). The tap root (except in var. *mougri*) is swollen, and varies from almost globular, about 1-2 cm in diameter in the salad types to as much as 1 m long and 15 cm in diameter, cylindrical or conical in shape, in the oriental types, and weighing up to 15 kg. The flesh is normally white, though in some may be pink to red. In the salad radish the skin is usually red (occasionally white); in the Oriental radish it is normally white (NRI, 1987). The upper part of taproot and hypocotyl swollen, tuberous, globular, cylindrical or tapering, very variable in size (up to 1 m long), form and weight (from a few g to 2.5(–20) kg), red to white, sometimes grey to black, flesh white, sometimes red (Piluek and Beltran, 1993; Schippers, 2004).

Seed Production: Most radish varieties are annuals that will flower and produce seed within one growing season. They are insect-pollinated out-breeders, meaning they will cross with any and all varieties of wild and domesticated varieties. Varieties should be separated by 1.5 km or more to prevent cross-pollination. If distance or isolation is not possible in your own garden plant a single variety, and be aware if neighboring gardens have different radish varieties flowering at the same time. Because radishes require that pollen be transferred from one plant to another for successful pollination, a fairly large population size is best for good seed production.

GENETIC DIVERSITY

A wide variety of cultivars are available, producing taproots that range from 2 cm up to 1 m long, and from red to pink, white, purple or black in colour. A variety of shapes, lengths, colors, and sizes, such as red, pink, white, gray- black or yellow radishes, with round or elongated roots (Singh, 2018). Radishes are wonderfully diverse with many different colors, shapes and sizes! Spring and summer varieties can be pink, red, white, golden, or purple. They can be shaped like bulbs, be more elongated like fingers, or even taper like carrots.

Radish Field

Radish Plant

Radish Inflorescence

Radish Inflorescence

Radish immature pods

Radish immature pods

Radish Dried pods

Radish Seeds and pods

Radish Seeds

Fig. 2. Botanical Description

Seed pods will develop on the large flower stalks (up to 1 m) and tan as the seed matures and plant begins to dry. Harvest the seed stalks when all parts are fully dry. Seeds are tricky to remove from dried seed pods and may require a bit of force (SSE, 2020). A daikon is a Chinese radish (*Raphanus sativus longipinnatus*), also known as lobok and oriental radish. Daikon has large roots, and some of the biggest varieties can weigh up to 23 kg. The most common types weigh from 0.5-1 kg at maturity and can have up to 61 cm leaf spread. Most people cook daikon radishes, but they can also be used in salads. Growing daikon radishes is a nutritious and enjoyable pursuit. These tasty radishes are low in calories and full of essential vitamins and nutrients. Daikon radishes are even grown year-round in most parts of California and similar regions (Patterson, 2022). The cv. group Chinese Radish is very variable. The smaller forms (Southeast Asia) have white, cylindrical roots, 10-25 cm x 4-5 cm. Larger forms (China, Japan) can attain a weight of 20 kg, with leaves up to 60 cm long and with 8-12 pairs of pinnae. The cv. group Leaf Radish has no swollen roots. In cv. group Rat-tailed Radish, fruits can attain 30 cm or more in length. The cv. group Small Radish has globose roots, ellipsoid or cylindrical, 0.5-4 cm x 0.5-4 cm, red, white, red and white or violet (CABI, 2019).

Winter varieties are much larger, often black, and need a longer growing season to mature. Daikon radishes, an Oriental winter type, have long white roots prized for their crisp and tender flesh (SSE, 2020). Multiple types of radishes exist, with some of the more popular being red or red and white. Daikon radishes, also known as Asian or white radishes, are identified by their slender shape and coloring. They come in a range of colors from white, red, or purple to light green and tend to be larger and milder than other radishes.

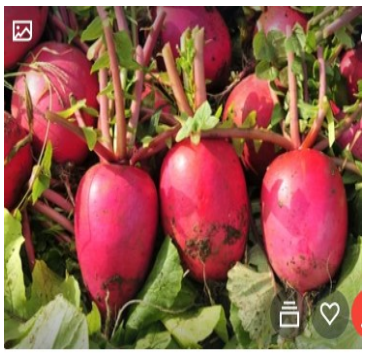
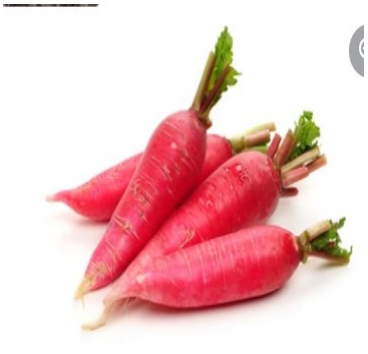
 White	 White	 White
 White	 White	 White
 Red	 Red	 Red
 Red	 Red	 Red

Fig. 3. Variable colours, shapes and sizes of radish

Pink radish

Pink radish

Pink radish

Purple color

Purple color with blue flesh

Purple color

Black

Black color with white flesh

Black

Yellow

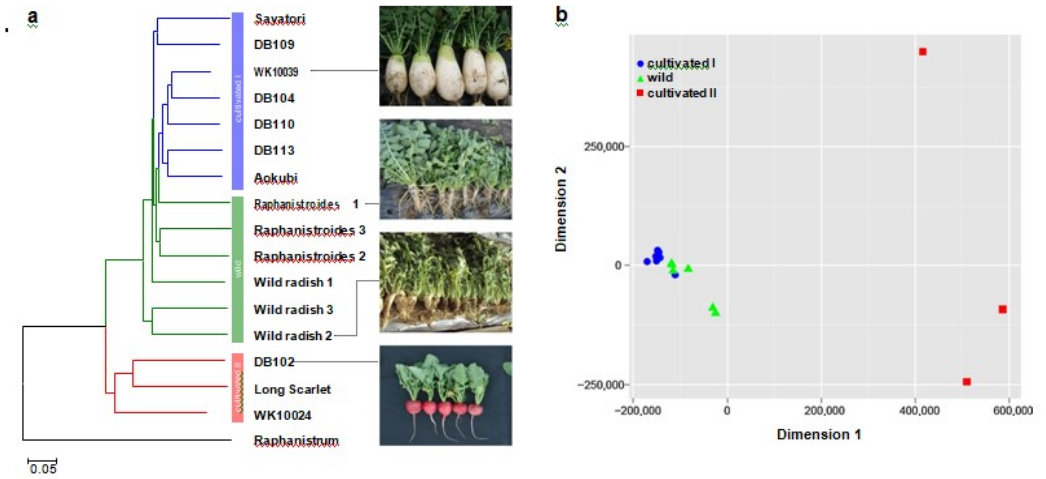
Yellow with yellow flesh

Yellow

Fig. 4. Variable colours, shapes and sizes of radish

 Green	 Green	 Green
 Green with crimson flesh	 Green with green flesh	 Green with crimson flesh
 White with red flesh	 White with Pink flesh	 White with Pink flesh
 Green with pink flesh	 Pink with white flesh	 White with pink flesh

Fig. 5. Variable colours, shapes and sizes of radish



1a. A neighbor joining tree of nuclear genomes based on high quality SNPs InDels for three tentative groups of R. sativus genotypes: cultivated I, cultivated II, and wild with R. raphanistrum serving as an outgroup. Photographs of a representative plant from each group grown in the field for 2 months are shown in the right margin .
1b. Multidimensional scaling of cultivated (blue circle symbol and red circle symbol) and wild with R. raphanistrum (green triangle symbol) genotypes.

Fig. 6. Genetic relationship between genotypes of *R. sativus*

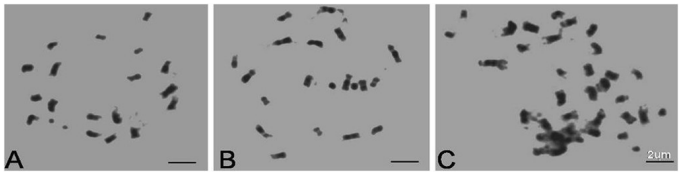


Fig. 7. Karyotypes of 'Wuqing' radish (A, 2n = 18), dual-use radish (B, 2n = 18), and potherb mustard (C, 2n = 36) (Li et al., 2018)

Within the daikon type are several varieties. A daikon heirloom, watermelon radishes (also known as Chinese radishes) have a white, round, edible root. As its name implies, it resembles a watermelon with reddish-pink flesh encircled by a white rim. Black radishes have a black or dark brown skin with white flesh when peeled. Varieties of black radishes, also known as Spanish black or Erfurter radishes (Fig. 3, 4, 5**)** (BBS, 2022). Twentyfour genotypes of radish (*Raphanus sativus* L.) were evaluated to study the genetic variability, heritability and genetic advance in radish. The analysis of variance revealed highly significant differences among genotypes for almost all the traits except total soluble solids. Both genotypic as well as phenotypic coefficients of variation were high for number of leaves, leaf weight, total plant weight, root yield/plant, acidity, and ascorbic acid. Heritability in broad sense was high for root weight, total dry matter of roots, leaf weight, root diameter, vitamin C, shoot to root ratio, total soluble solids, leaf length, root length and leaf number. Genetic advance in per cent of mean was maximum for leaf weight followed by root weight. Lowest genetic advance in percent of mean was observed for total soluble solids (Mallikarjunarao *et al.,* 2015). Biparental progenies (BIP's) of inter-varietal cross Mino Early White x PusaHimani (MEW x PH) of radish were developed in F_2 generation by utilizing North Carolina Design-I. The analysis of variance indicated significant differences among the BIP's and F_3 progenies for different horticultural and quality parameters studied indicating the presence of good quantum of variability between BIP's and F_3 progenies. Biparental progenies when compared with F_3 progenies for their overall mean values revealed that former had greater means for most of the characters except leaf weight, leaf length and nitrate content. The biparental progenies resulted in creation of more genetic variability by breakage of both coupling and repulsion phase linkages that conceal the genetic variability in F_2. The phenotypic variability as revealed by the coefficient of variation (%) was greater in BIP progenies than F_3 progenies.

The superior performance of biparental and F_3 generations revealed the breakage of undesirable linkages and plateau effect for bringing further improvement in radish (Chandel *et al*., 2015). Small radish and radish are economically important root crops that represent an integral part of a healthy human diet. The world collection of Raphanus L. root crops, maintained in the VIR genebank, includes 2810 accessions from 75 countries around the world, of which 2800 (1600 small radish, 1200 radish) belong to R. sativus species, three to R. raphanistrum, three to R. landra, and four to R. caudatus. It is necessary to systematically investigate the historical and modern gene poolof root-bearing plants of R. sativus and provide new material for breeding. The material for our research was a set of small radish and radish accessions of various ecological groups and different geographical origin, fully covering the diversity of the species. The small radish subset included 149 accessions from 37 countries, belonging to 13 types of seven varieties of European and Chinese subspecies. The radish subset included 129 accessions from 21 countries, belonging to 18 types of 11 varieties of European, Chinese, and Japanese subspecies. As a result of the evaluation of R. sativus accessions according to phenological, morphological, and biochemical analyses, a wide variation of these characteristics was revealed, which is due to the large genetic diversity of small radish and radish of various ecological and geographical origins.

The investigation of the degree of variation regarding phenotypic and biochemical traits revealed adaptive stable and highly variable characteristics of R. sativus accessions. Such insights are crucial for the establishment and further use of trait collections. Trait collections facilitate germplasm use and contribute significantly to the preservation of genetic diversity of the gene pool (Kurina *et al*., 2021). Twelve radish genotype were evaluated to estimate, Genetic Variability, Genetic Heritability and Genetic Advance to six Quantitative and two Qualitative traits. The overall values of GCV lower than the PCV for all the traits. The mean sum of square due to treatment was found significant for all the characters on the basis of analysis of variance which suggested the presence of sufficient variability in radish genotypes. The phenotypic coefficient of variance (PCV) was slightly higher in magnitude than genotypic coefficient of variance (GCV) for all the characters studied which suggests that the phenotypic expression of characters is largely influenced by the prevailing environmental conditions. The estimates of heritability were recorded high for the characters namely, number of leaves per plant, length of root, fresh weight of leaves per plant, plant spread and root yield indicating that these characters are governed by additive gene effect and are less influenced by environment and hence, selection for these characters, if found positively associated with yield will be beneficial in improvement of radish (Mashkey *et al*., 2021). The pink color of the radish roots is due to the presence of anthocyanin pigment. The characteristic pungent flavor and taste of radish roots are due to the high content of volatile alkaloid isothiocyanate (trans-4-methyl thiobutenyl isothiocyanate: MTB-ITC). For salad purposes, selection is towards low pungency (Gupta *et al.,* 2003). Radish (*Raphanus sativus* L.) is an important vegetable crop in Asia. Lack of uniformity in the crop at harvest is due to genetic variability and environmental conditions. Molecular markers associated with morphological traits of seed and seedlings were identified. Seed (100) of radish cv. Fire Ball and Long White Chinese from Australia and Mino Early, Pyuthane Red, Tokinasi, White Neck and 40 Days from Nepal.

The seed was germinated between paper (20 degrees C, 6 days) and seedlings were grown in pots under glasshouse conditions (20 degreesC, further 3 weeks). Morphological characters were measured in seed and seedlings at 6 days and 4 weeks after germination. Deoxyribonucleic acid was extracted from selected samples and Random Amplified Polymorphic DNA (RAPD) markers were identified using 10 primers. Multivariate analysis based on principle coordinates analysis was used to correlate morphological traits with molecular markers within and across cultivars. Several markers associated with high or low seed weight, germination proportion, seedling length and fresh weight were identified. This new method for identifying potential RAPD markers may be useful for marker assisted breeding and selection of improved radish varieties (Pradhan *et al.,* 2004). Chloroplast DNA sequences were investigated to further elucidate the evolution of cultivated radish. This is the first known attempt to analyse intrageneric DNA sequences of chloroplast DNA in *Raphanus*. The nucleotide sequence of the 5'-matK region (690 bp) was determined for 17 accessions including cultivated radish (*Raphanus sat*ivus), wild radish (*R.raphanistrum*), and East Asian wild radish (*Raphanus sativus* var. *hortensis* f. *raphanistroides* Makino) (Yamane *et al*., 2005). Yamane *et al.* (2009) analyzed 25 chloroplast simple sequence repeat (cpSSR) loci in 82 accessions, 59 of cultivated radish and 23 of three wild *Raphanus* species and identified 7 polymorhic loci and 20 haplotypes. The distribution of haplotypes in different species and different geographical areas was assessed. Minimum-spanning network (MSN) was used to identify phylogenetic relationships in cultivated and wild radish.

The MSN provides evidence for at least three independent domestication events, including black Spanish radish and two distinct groups of cpSSR haplotypes. One of these two haplotype groups is restricted geographically to Asia. This led Asian cultivated radish haplotypes to higher cpSSR diversity than Mediterranean cultivated radish or wild radish. These data are consistent with the diversity and distribution of agronomic traits in cultivated radish. At the same time, this implies that Asian cultivated radish is not originated from the diffused descendants of European cultivated radish, probably originated from a wild species that is distinct from the wild ancestor of European cultivated radish. Unfortunately we do not know the wild

ancestor of Asian cultivated radish. Based on recent studies using chloroplast single sequence repeats (cpSSRs), Yamane *et al.* (2009) postulate three independent domestication events which include black Spanish radish and two distinct cpSSR haplotype groups. One of the haplotype groups is geographically restricted to Asia, presenting higher cpSSR diversity than cultivated radish from the Mediterranean region or wild radish types. This implies that Asian cultivated radish cannot be traced back to European cultivated forms which spread to Asia, but might have originated from a still unknown wild species that is different from the wild ancestor of European cultivated radish. Genetic variation of forty-nine local and exotic radish genotypes including two checks was studied for morphological traits and seed storage protein electrophoresis using sodium dodecylsulphate polyacrylamide gel electrophoresis (SDS-PAGE) markers. A high variation in germplasm for root shape, root length, root colour (internal and external), flesh texture and root type were observed. Among these genotypes, the genetic variation was apparent for most of the characters like plant biomass, root weight, leaf length, root length and root diameter that indicated the potential for crop improvement in these traits through simple selection.

On the basis of high yield and crispy root texture some genotypes (10076, 10362, 10429, 10658, 10662 and 10667) were identified for further testing under wide range of agro-ecological conditions (Jatoi *et al.,* 2011). Pairwise distances analysis using the neighbor joining algorithm and MDS also indicated that the Asian genotypes (cultivated I and wild) were more closely related to each other than European/American cultivars (cultivated II) (Fig. 6). Overall, this study provides evolutionary insights into domestication-related genetic selection in radish as well as identification of gene candidates with the potential to act as trait-related markers for background selection of elite lines in molecular breeding (Kim *et al.,* 2016). The development of high-throughput molecular techniques using next generation sequencers, complete genomes of cultivated and wild radish plants have been sequenced and published with annotations of predicted genes and single nucleotide polymorphism (SNP) information between radish cultivars and accessions. These, together with the construction of a high-density genetic map of radish and profiling of expression sequences in radish organs, have accelerated genetic studies, such as the identification of genes or loci associated with root development, pungent components, and plant disease resistance. Providing an overview of these advances, this article is a valuable resource for scientists involved in plant genetic research and crop breeding (Nishio and Kitashiba, 2017). Lee and Park (2017) assessed the genetic diversity of 126 F1 cultivars of radish using 29 agronomic traits and 60 SSR markers.

The 126 F1 cultivars are composed of 105 from Korea, 17 from Japan, and 4 from China. To assess the phenotypic diversity of 126 F1 cultivars, 29 agronomic traits were recorded from seedling stage to harvest, and analyzed using principal component analysis (PCA) and cluster analysis. The nine principal components (PC1-PC9) explained approximately 72% of the total variance of the 126 cultivars, and the first two PCs accounted for approximately 34%. The first PC represented "root shape to determine the harvest time", and the second PC represented "coloration of plant". Cluster analysis of 126 cultivars based on 29 agronomic traits resulted in three main groups in accordance with morphological affinity. To assess the genotypic diversity, we analyzed 126 F1 cultivars using 60 SSR markers. 226 polymorphic amplified fragments were obtained and the average of PIC value was 0.61. In UPGMA analysis, 126 cultivars were classified into seven groups at the Jaccard's coefficient of 0.47. 29 agronomic traits and 60 SSR markers successfully discriminated all the 126 cultivars, respectively. We examined the correlation between distance matrices of 29 agronomic traits and 60 SSRs using the Mantel test. The two data sets were significantly correlated (r=0.527, p=0.0001). These results would be valuable for cultivar identification and genetic diversity analysis in cultivated radishes. Chromosome and SSR Analysis was carried out in radish by Li *et al*. (2018). The results from karyotype analysis indicated that the dual-use radish has 18 chromosomes, as does the radish (Fig. 7). The number of chromosomes can determine the species attributes. Based on the number of chromosomes, the dual-use radish is still a radish.

BREEDING

Genetic Resources: Germplasm collections are maintained by NIAR (Tsukuba, Japan), IPB (Los Baños, the Philippines), Department of Agriculture (Bangkok, Thailand), USDA (Fort Collins, United States), and the Crucifer Genetics Cooperatives at the University of Wisconsin (Madison, United States) (Piluek, and Beltran, 1993). Approximately 5200 active accessions of *Raphanus* are conserved in germplasm repositories in Asia, Europe, and the USA (https://www.genesys-pgr.org). The largest collections are held in the UK and USA with 1393 and 1164 accessions, respectively (Arro and Labate, 2022). A radish panel of 152 accessions with diverse root shapes was assembled from the National Plant Germplasm System (NPGS) collection based on weighted geographical sampling. Accessions represented 35 countries and were categorized into eight geographical regions—North America, Europe, Africa, West Asia, Central Asia, South Asia, East Asia, and Southeast Asia. Multiple plants per accession were assayed using genotyping by sequencing (GBS), and 8539 high-quality polymorphisms were discovered. Average observed heterozygosity (H_o) of the markers consistently ranged from 5 to 7% in all geographical regions. Central Asia was most diverse in terms of average expected heterozygosity (H_e = 0.107), while Southeast Asia was the least diverse (H_e = 0.050). Europe and Southeast Asia were the most divergent from each other (pairwise F_{ST} = 0.199), while Europe and North America were the least divergent (pairwise F_{ST} = 0.022). The clustering of genotypes based on principal components analysis (PCA) illustrated an east/west geographical pattern. Large numbers of private alleles and a substantial proportion (3%) of markers showing signals of selection based on allele frequency differences indicate that allelic variation is available for cultivar development. European and North American gene pools could be expanded by crossing with East Asian and Southeast Asian germplasm, and vice-versa. Both could potentially benefit from South Asian sources, while the addition of West Asian germplasm could increase East Asian and Southeast Asian diversity. This resource for molecular marker development combined with an understanding of global genetic relationships will inform the continued germplasm conservation and genetic improvement of radish (Arro and Labate, 2022).

Breeding: Radish (*Raphanus sativus* L.) is a popular salad vegetable in tropical, subtropical and temperate regions grown for its root and soft leaves. Breeding work has been carried out on ecological traits, resistance to diseases, and adaptability for different kinds of consumption. The ecological traits are productive and qualitative characteristics such as high yielding ability, early maturity, late bolting, edible quality (pungency), late pore formation, cold-hardiness, drought resistance, heat tolerance, wet tolerance, soil adaptability, and so on. Virus disease, yellows, soft rot, downy mildew, grey leaf spot, and other diseases are prevalent in Japan. Radish is mainly consumed fresh, boiled, or salted or as dried strips or seedlings (Kaneko and Matsuzawa, 1993). Radish is an allogamous plant exhibiting a high level of self-incompatibility and shows inbreeding depression when self-propagation by bud pollination is repeated. It is difficult to obtain a large amount of seed mainly because of the limited seed numbers produced per pod. In this case, F_1 hybridization combined with self-incompatibility and heterosis is a helpful breeding method (Kaneko and Matsuzawa, 1993). Although radish flowers and sets seed easily in most African countries where it is grown, virtually all seed is imported. No special breeding for adaptation to African conditions has been reported. For economic reasons radish seed is normally produced in more temperate climates and imported in tropical Africa. In seed production, open-pollinated cultivars may give a seed yield of 800 kg/ha; an isolation distance of 1000 m is required. Self-incompatibility and male sterility are available for the production of F_1 hybrid seed (Schippers, 2004). Cross-pollination is high in radish due to protogyny, self-incompatibility, and open architecture and attractiveness of the flowers. The uses of sporophytic self-incompatibility (SI),

cytoplasmic male sterility (CMS) and doubled haploids (DH) are basic tools for harnessing heterotic potential. Main emphases of radish breeding are: higher and early root yield; uniformity in shape/size/color/maturity; suitability to high temperature and rainfall conditions; longer field stay and delayed bolting; robust SI, CMS and DH lines to produce F_1 hybrids; tolerance to *Alternaria* blight, *Fusarium* wilt, aphids and beetles; free from pithiness, forking and cracking; and wider adaptability. Rapidly increasing knowledge of advance biotechnological tools will provide enhanced precision and extend options in identification of cultivars and parental lines, testing genetic purity of seed, analyzing phylogenetic relationships and genetic diversity, molecular characterization of quantitative traits, and introgression of specific transgene traits (Singh, 2021). The edible portion of radish develops from the primary root and hypocotyls (Vidhi, 2022).

Selfing and Crossing: The inflorescence is a typical terminal raceme of Cruciferae. The flowers are small, usually white in colour and resemble those in cabbage and cauliflower. Sepals (four) are erect and petals (four) are clawed.Radish is cross-pollinated due to sporophytic system of self-incompatibility. It shows considerable inbreeding depression on selfing. It is entomophilous. It is pollinated mainly by wild honey bees and wild-flower flies. Stigma receptivity is maintained up to four days after anthesis. Selfing can be accomplished by bud-pollination. The flower buds are pollinated two days prior to opening by their own pollen be applying fresh pollen from previously bagged flowers of the same plant. Emasculation is not necessary in bud-pollination. After pollination, the buds are to be protected from foreign pollen by enclosing the particular branch bearing those buds in a muslin cloth bag. In crossing the same technique is used as in bud-pollination except that in the crossing, the buds of the female parent are emasculated a day prior to opening and are pollinated by pollen collected from the flowers of the male parent which were also bagged before opening. The artificial pollination is done by hand by shaking the pollen over the stigma directly from the freshly opened but previously bagged buds of male parent. When a large quantity of crossed seed is required, the roots of radish of female and male parents are planted in alternate rows, spaced 60 cm apart. Later about 3-4 days before opening of buds, the plants are covered under an insect-proof wire net or plastic cage of 22-24 mesh (Vidhi, 2022). Usually 2 plants, 1 female and 1 male are covered under small cage, or sometimes a cage is used to cover 4 plants, 2 female and 2 male plants. A small honeybee colony is placed inside the cage, 3-4 days before opening of buds.This method is followed when it is possible to rogue out the selfed or sib-mated plants in the seedling or root stage with the help of a dominant marker gene or when the male and female lines are homozygous for self-incompatibility alleles but are cross compatible (Vidhi, 2022). This procedure can also be used to produce sib-mated seeds to maintain a variety under insect proof cages. However, in this case, it will be necessary to place about 20-30 plants under a cage to avoid inbreeding depression. A wire net or plastic net cage of 3m x 3m x 2.5m (height) with a small door on one side is convenient for this purpose (Vidhi, 2022).

Breeding Objectives: The breeding objectives of radish are i) Early rooting, ii) High yield, iii) White, long/stump roots with thin tap root and non-branching habit, iv) Non-pithy roots, v) Pungency of roots as per consumers' preference, vi) Slow bolting habit, low bolting habit, vii) Heat tolerance, viii) Drought resistance, ix) Wet tolerance, x) Resistance to alternaria blight, white rust, radish mosaic virus, and xi) Tolerance to aphids (Vidhi, 2022).

Breeding Methods

Mass Selection: This is practiced in landraces/cultivars collected from the farmers' field. Roots are allowed to reach an over-mature stage. They are dug-up and leaves (but not growing points) removed.Bare roots after discarding the undesirable types are immersed in a container of water. Roots which float being pithy and full of air spaces are discarded and only the large sinking roots are retained for seed production in isolation en masse. Small sinkers are also rejected (Vidhi, 2022).

***Hybrid Breeding*:** This has been a common breeding approach in Japan. Inbred lines which are self-incompatible are produced by 5-6 generations of selfing through bud-pollination, while selfing, only the plants with desirable root shape, size, colour, and other quality considerations are advanced to the next generation. The F_1 hybrids could be(i) Single crosses, (ii) Three-way crosses, and (iii) Double crosses. In a practical breeding programme, the recommended isolation distance is 500-1000 m to avoid outcrossing. Usually planting ratio of male and female lines is 1: 1 ratio (Vidhi, 2022).

***Recurrent Selection*:** The uses of coloured radishes in the salads and their anthocyanins as colourants are gaining popularity because of the colour characteristics, health benefits as well as antioxidant activities. However, information on the genetic variability, heritability and interrelationship of total phenolics, anthocyanins and antioxidant activities in pigmented radish is very limited, but prerequisite to initiate breeding programme; and therefore investigated in the present study. Radish genotypes were significantly diverse for all the antioxidants; differed by 4.98-fold for total phenolics, 36.16-fold for anthocyanins content, 4.96-fold for FRAP activity and 4.03-fold for CUPRAC activity; and the genotypes accounted for >97% of total variations. The meager differences between phenotypic and genotypic coefficient of variation reveals the greater role of genotypes and lesser influence of the environment on the biosynthesis and accumulation of antioxidants. Significantly positive correlations along with higher magnitude for anthocyanins content, total phenolics, FRAP activity and CUPRAC activity (r= 0.823 to 0.964) could be used as indirect selection criteria for improving levels of antioxidant compounds. The estimates of heritability and genetic advance indicate the role of additive and non-additive genes for biosynthesis of antioxidants and root development, respectively; therefore, recurrent selection would be the best breeding approach to improve both the traits simultaneously in coloured radish (Fig.8) (Singh *et al.,* 2017).

Fig. 8. Colored radishes

Varieties (Vidhi, 2022):

***Pusa Desi*:** It is the first variety of radish released by IARI, New Delhi in 1965. It is an Asiatic type suitable for sowing from middle of August to October in northern plains. Its roots are pure white, 30-35 cm long, tapering with green stem end. It matures in 50-55 days.

***Pusa Reshmi*:** It is also an Asiatic variety with roots 30-45 cm long, white with green tinge on top. It is suitable for sowing in September. It takes 50-60 days for maturity.

Pusa Chetki: This variety was developed at IARI, New Delhi from seeds collected from Denmark in 1966 by selfing and massing to get desired type of roots with good tolerance to high temperature and humid weather conditions. Roots are white, smooth, medium long (12.5 cm in summer and 20.5 cm in rainy season) and almost stumpy.It is an early maturing tropical type which takes 40-45 days for attaining harvest maturity. Period of growing of this variety is fairly long from April to early September, the best season being from July to early September. It yields 200-350 q/ha depending on the season.

***Japanese White*:** It is an introduction from Japan and recommended by IARI Regional Station, Katrain. Roots are 25-30 cm long, 5 cm in diameter, cylindrical and blunt at the tip, skin is pure white, smooth. Flesh is snow-white, smooth, crisp, solid and mildly pungent. Top is medium large with deeply cut leaves. It is suitable for October to December sowing.

***Kalyanpur No 1*:** It is selection from local material released in 1982 in Uttar Pradesh. Stem and foliage are green. Top is heavy, leaves are long, broad and less lobed. Roots are 22-23 cm long, smooth, crispy, white with green shoulder, thick and tapering.

***Pusa Himani*:** It is temperate variety developed by hybridization between Black and Japanese White at IARI Regional Station, Katrain. It is suitable for December to February sowing in the plains when no other variety can form such good roots.It is the only variety which can be grown throughout the year in the hills barring three winter months (November to January). Roots are 30-35 cm long, semi-stumpy, pure white with whitish green shoulder, mildly pungent, crispy and sweet flavoured. Tops are short with green cut semi-erect leaves.

***Mino Early*:** This is an introduction from Japan and large quantity of imported seed is marketed in India by Pvt. sector seed companies. The roots are long, oblong, white, medium pungent, white flesh is crispy and tender. It is leading OP radish for summer and fall cultivation in Japan.It has good tolerance to heat. Roots are 30-50 cm long. Roots are slightly tapered, foliage is dark green.

***Palam Hridaya*:** Developed through selection from exotic material at HPKV, Palampur. Plant top is small. Leaves are dark green and hairy with entire lamina, Roots are oblong with stump end. Top half of the root is green and lower half is creamy. Tail and flesh are pinkish. Most farmers in South-East Asia use their own local cultivars of cv. group Chinese Radish. Breeding work of seed companies aims primarily for attractive root shape, colour and mild flavour. Numerous cultivars have been bred by Japanese, Chinese and western seed companies. These modern cultivars have early maturity, resistance to bolting ('Minowase'), attractive root texture (crisp, firm, high solids content), tolerance to diseases such as black rot, *Fusarium* yellows ('Scarlet Knight') and club root ('Saxafire', 'Novitas') (Piluek and Beltran, 1993). In seed production, open-pollinated cultivars may give a seed yield of 800 kg/ha; an isolation distance of 1000 m is required. Self-incompatibility and male sterility are available for the production of F_1 hybrid seed (Piluek and Beltran, 1993).

USES

Depending on the cultivar, it may be grown for its edible roots, leaves, seeds, or seed pods (Singh, 2018). Radish roots are low in calories and are usually eaten raw; the young leaves can be cooked like spinach. The young fruits are also edible and are often eaten raw or sautéed. The small quick-growing spring varieties have a mild, crisp, moderately firm flesh, whereas the large, slow-growing summer and winter types have pungent firm flesh. Winter varieties can be stored through the winter (Britannica, 2023). The small early-maturing radishes (Raphanus sativus) are usually eaten raw in salads. The large winter radishes and oriental radishes are an important article of diet in many tropical and subtropical (and some temperate) countries, particularly in eastern Asia; the characteristic, somewhat pungent flavour is especially liked in Japan, the Philippines and Hawaii. They may be eaten raw in salads but are more often cooked and eaten as a vegetable (NRI, 1987). The leaves and seed pods of some cultivars are boiled and eaten as a vegetable. It has also been suggested that the leaves could be utilised as a commercial source of leaf protein. In some countries the roots are used medicinally for the treatment of liver and gall-bladder complaints. The seeds contain a non-drying oil which is commercially extracted and is suitable for soap making and edible purposes, and is reported to be used in the manufacture of crayons in Japan. The seed cake remaining after oil extraction can be used as a fertiliser or, after the removal of isothio cyanates, as a feeding stuff (NRI, 1987). Radish is grown mainly for its thickened fleshy root. The western radish (cv. group Small Radish) is pungent and is prized as a relish or appetizer and for adding colour to dishes. The Oriental radish (cv. group Chinese Radish), being crisp with mild flavour, plays a much wider role in Southeast Asia. The roots are thinly peeled, sliced or diced and put into soups and sauces or cooked with meat. They can be preserved in salt. Sometimes, as in the Philippines, they are eaten fresh, mixed with other vegetables like tomato. Tops (leaves) are eaten as salad or spinach. Seedlings known as radish sprouts are used as greens for appetizers or cooked as spinach. The rat-tailed radish (cv. group Rat-tailed Radish) is grown for the immature seed pods, consumed raw, cooked or pickled. Leaf radish (cv. group Leaf Radish) is mainly grown as green manure and forage (central and western Europe). In South-East Asia (Indonesia) it is sometimes cultivated for the leaves that are used as vegetable (Piluek and Beltran, 1993). Radish roots are eaten raw as salad and as a side item and cooked as vegetables.

The very characteristic flavor is popular in Japan, the Philippines, and Hawaii, and roots are used to prepare food products such as takuwan and cabaizuku. It increases appetite, produces cooling effects, and prevents constipation (Gupta *et al*., 2003). Radish is grown mainly for its thickened fleshy root. Small radishes are pungent and used as appetizer when eaten fresh and for adding colour to dishes. Oriental radish (to which Chinese radish, Japanese radish and mooli belong) is crisp with a mild flavour. The roots are thinly peeled, sliced or diced and put into soups and sauces or cooked with meat. They can be preserved in salt. Oriental radish can also be eaten fresh, mixed with other vegetables such as tomato. Also the leaves are eaten as salad or spinach. Seedlings known as radish sprouts are used as greens for appetizers or cooked. Rat-tailed radish is grown for the immature crisp, fleshy fruits, consumed raw, cooked or pickled, but the roots are not edible. Leaf radish is mainly grown as green manure and forage in central and Western Europe and is also grown as fodder for cattle in South Africa. There are forms of radish that are used as an oil-seed crop but these are not known to be grown in Africa. In traditional medicine, radish is used to treat hepatic disorders, bronchitis and coughs (Schippers, 2004). Radish (Raphanus sativus) is an important root and leafy vegetable throughout the world. The small-rooted and short-season type of radish is cultivated for salads and as fresh vegetable. The large-rooted type of radish is usually cooked, canned or pickled besides being eaten raw. The leaves and sprouts are used as salad or are cooked, too.

The seed pods are cooked for soups in southwest China and Southeast Asia. People press seeds of *Raphanus sativus* to extract oil. Wild radish seeds contain up to 48 percent oil, which is not suitable for human consumption but has promise as a source of biofuel. Farmers also grow oil radishes to improve and fertilize the soil and as fodder (Adams 2008). There are also several ways to process radish roots. They can be eaten raw or cooked, and preserved by pickling, canning, or drying. Radish is not only a vegetable crop but also an important source of medicinal compounds for diseases such as gall bladder trouble, diabetes, hepatitis, and gastrointestinal disorders (Li *et al.,* 2018). Radish is grown mainly for its thickened fleshy root. Small or western radishes are pungent and prized as a relish or appetizer and for adding colour to dishes. The Oriental radish (cv. group Chinese Radish), being crisp with mild flavour, plays a much wider role in Southeast Asia. The roots are thinly peeled, sliced or diced and put into soups and sauces or cooked with meat. They can be preserved in salt. Sometimes, as in the Philippines, they are eaten fresh, mixed with other vegetables like tomato. Tops (leaves) are eaten as salad or spinach. Seedlings known as radish sprouts are used as greens for appetizers or cooked as spinach. Cv. group Rat-tailed Radish is grown for the immature seed pods, consumed raw, cooked or pickled. Leaf radish is mainly grown as green manure, forage or as a catch crop (Central and Western Europe) (CABI, 2019). Radish is cultivated as an annual for its enlarged, succulent taproot, which has been used for food since prehistoric times. The taproot is eaten raw in salads, relishes and appetizers, and slices are included in stir-fries. Black radishes are favoured in many Eastern European cuisines. Young radish leaves are edible and are cooked in the same manner as spinach. Sprouted radish seedlings (jaba) are also consumed. Young radish fruits have a spicy flavour and are sometimes pickled. Radish

was grown for its seed oil in Ancient Egypt. Oriental radish (*Raphanus sativus* '*longipinnatus*'), known as daikon or mooli, can produce a long-lasting taproot over 45 cm long and weighing up to 50 kg. This mild-flavoured taproot is widely used in oriental cuisines, for example in soups, sauces and meat dishes. In Japan it is grated to produce a garnish for sashimi. Pickled daikon is popular in Japan and Korea. Daikon is used to make 'turnip cake', which is eaten at Chinese New Year. Daikon is fed to stock in the East. *Raphanus sativus* '*caudatus*', known as rat's tail, is cultivated in Asia for its fruits which grow up to 30 cm long. The young fruits are consumed raw, cooked or pickled. Some radish cultivars are grown for their leaves, which are used as fodder *(*PWO. 2022). The most commonly eaten portion is the napiform or fusiformtaproot, although the entire plant is edible and the tops can be used as a leaf vegetable. The seed can also be sprouted and eaten raw. The root of the radish is usually eaten raw, although tougher specimens can be steamed. The raw flesh has a crisp texture and a pungent, peppery flavor, caused by glucosinolates and the enzyme myrosinase, which combine when chewed to form allyl isothiocyanates. Radishes are mostly used in salads, but also appear in many European dishes. In Mexican cuisine, sliced radishes are used in combination with shredded lettuce as garnish for traditional dishes such as tostadas, sopes, enchiladas and posole stew. Radish greens are usually discarded, but are edible and nutritious, and can be prepared in a variety of ways. The leaves are sometimes used in recipes, like potato soup or as a sauteed side dish. They are also found blended with fruit juices in some recipes. In Indian cuisine the seed pods are called "moongra" or "mogri" and can be used in many dishes. The seeds of radishes can be pressed to extract radish seed oil. Wild radish seeds contain up to 48% oil, and while not suitable for human consumption, this oil is a potential source of biofuel. The daikon grows well in cool climates and, apart from its industrial use, can be used as a cover crop, grown to increase soil fertility, to scavenge nutrients, suppress weeds, help alleviate soil compaction, and prevent winter erosion of the soil (WIKI, 2022c).

NUTRITIONAL VALUE

Although radish is consumed worldwide, it contributes little to nutrition. Radish is low in calories and is a good source of vitamin C (15– 40 mg 100 g^{-1} fresh wt). One serving size of 85 g has only 15 cal and this will provide 30% of the RDA of vitamin C and 20% of the RDA for calcium. Radish contains glucose as the major sugar and smaller quantities of sucrose and fructose. Pectin and pentosans are also reported to be present. Pink-skinned radishes are generally richer in ascorbic acid than white-skinned ones. Radish leaves are a good source of extraction of protein on a commercial scale. The seeds are a potential source of non-drying fatty oil suitable for soap maturing (Gupta *et al.,* 2003). The composition of the raw root of white radish per 100 g edible portion (87% of the product as purchased) is: water 93.0 g, energy 64 kJ (15 kcal), protein 0.8 g, fat 0.1 g, carbohydrate 2.9 g, fibre 1.5 g, Ca 30 mg, P 25 mg, Fe 0.4 mg, carotene 0 µg, thiamin 0.03 mg, riboflavin 0.02 mg, niacin 0.5 mg, ascorbic acid 24 mg. The composition of the raw leaves per 100 g edible portion (90%) is: water 89.7 g, energy 137 kJ (33 kcal), protein 3.5 g, fat 0.5 g, carbohydrate 3.5 g, Ca 200 mg, P 44 mg, Fe 3.8 mg, carotene 3670 µg, thiamin 0.13 mg, riboflavin 0.35 mg, niacin 0.8 mg, ascorbic acid 63 mg (Schippers, 2004). Per 100 g edible portion, the root contains: water 93.5 g, protein 0.6 g, fat 0.1 g, carbohydrates 5.3 g, Ca 32 mg, P 21 mg, Fe 0.6 mg.

It contains vitamin A in small quantity, vitamin B_1 0.02 mg, vitamin B_2 0.03 mg, and fair amounts of vitamin C (25 mg) and niacin (0.30 mg). The energy value is 90 kJ/100 g. The 1000-seed weight is about 10 g (Piluek, and Beltran, 1993). Average composition of the edible portion (roots) has been reported as: energy 86.7 kJ/100 g; water 93.5 per cent; protein 1.05 per cent; fat 0.15 per cent; carbohydrate 3.85 per cent; fibre 0.7 per cent; ash 0.75 per cent; boron 2.08 mg/100 g; calcium 33 mg/100 g; chlorine 19 mg/100g; copper 0.13 mg/100 g; iodine 8 mg/100 g; iron 0.8 mg/100 g; magnesium 15 mg/100 g; manganese 0.05 mg/100 g; phosphorus 29 mg/100 g; potassium 322 mg/100 g; sodium 18 mg/100 g; carotene 0.006 mg/100 g; thiamine 0.03 mg/100 g; riboflavin 0.03 mg/100 g; niacin 0.4 mg/100 g; pantothenic acid 0.8 mg/100 g; ascorbic acid 0.029 mg/100 g; glucose 640 mg/100 g; fructose 390 mg/100 g; campesterol 5 mg/100 g; sistosterol 6 mg/100 g (NRI, 1987). In a 100-gram (3+½-ounce) reference serving, raw radishes provide 66 kilojoules (16 kilocalories) of food energy and have a moderate amount of vitamin C (18% of Daily Value), with other essential nutrients in low content. A raw radish is 95% water, 3% carbohydrates, 1% protein, and has negligible fat (WIKI, 2022c). In a 100 g reference serving, raw radishes provide 66 kJ of food energy and have a moderate amount of vitamin C (18% of Daily Value), with other essential nutrients in low content. A raw radish is 95% water, 3% carbohydrates, 1% protein, and has negligible fat (WIKI, 2022d). Radishes are low in calories and high in vitamin C, folate, and potassium. Radishes contain sulfurous compounds, such as sulforaphane, which have anti-cancer properties, and are expectorant (Genebank, 2022).

The leaves of Oriental radishes are also nutritious; an analysis gives their approximate percentage composition as: water 87.4 per cent; protein 2.2 per cent; fat 0.4 per cent; carbohydrate 6.1 per cent; fibre 1.5 per cent; ash 2.4 per cent; calcium 400 mg/100 g; phosphorus 300 mg/100 g; ascorbic acid 17 mg/100 g; vitamin A 18 660 IU/100 g (NRI, 1987). Radish seeds contain 30-50 per cent of oil with the following characteristics: SG (30°C) 0.9773; ND (30°C) 1.4704; acid val. 0.9; acet. val. 2.8; sap. val. 178.9; iod. val. 103.1. The fatty acid composition is: palmitic 1.3 per cent; stearic 1.4 per cent; arachidic 3 per cent; behenic 3.4 per cent; erucic 22 per cent; oleic 60.8 per cent; linoleic 4.5 per cent; linolenic 3.6 per cent (NRI, 1987). The characteristic pungent flavour of the roots is due to the presence of isothiocyanates, while the coloured cultivars contain anthocyanins which are reported to occur as naturally acylated, either with ferulic or p-coumaric acids. Catechol has been reported in the red cultivars and flavanols have been detected in minute quantities. A growth inhibitor, raphanusanol, has been isolated from radish seedlings (NRI, 1987). The pungency of radishes depends on the content of isothiocyanates, which varies with cultivar and environmental conditions. The main compound is 4-methylthio-3-trans-butenyl isothiocyanate. Glucosinolates, which are the precursors of isothiocyanates, are also present. These compounds have long been known for their fungicidal, bactericidal, nematicidal and allelopathic properties, and have recently attracted attention because of their chemoprotective attributes against cancer (Schippers, 2004).

Among the 55 metabolites detected in radish roots, the levels of most amino acids and phenolic acids, vital to nutrition and health, were higher in green radish roots, while slightly higher levels of glucosinolates were observed in white radish roots—information which can be used to develop an effective strategy to promote vegetable consumption. Furthermore, glutamic acid, as a metabolic precursor of amino acids and chlorophylls, was positively correlated with other amino acids (cysteine, tryptophan, asparagine, alanine, serine, phenylalanine, valine, isoleucine, proline, leucine, beta-alanine, lysine, and GABA), and chlorophylls (chlorophyll a and chlorophyll b) detected in radish roots and phenylalanine, a metabolic precursor of phenolic compounds, were positively correlated with kaempferol, 4-hydroxybenzoate, and catechin. In addition, strong positive correlations between carbohydrates (sucrose and glucose) and phenolics were observed in this study, indicating that sucrose and glucose function as energy sources for phenolic compounds. In conclusion, this is the first study to profile metabolites in the roots of white- and green-colored radishes and investigate the metabolic relationship between diverse metabolites detected in both cultivars. Among the 55 metabolites detected in green- and white-coloured radishes, the levels of most amino acids, organic acids, phenolic compounds, and chlorophylls, which are important for nutrition and health, were higher in green radishes. In contrast, the white radish contained slightly higher levels of glucosinolates. Furthermore, metabolic precursors (glutamic acid and phenylalanine) were positively correlated with the levels of other amino acids, chlorophylls, and phenolics, and carbohydrates (sucrose and glucose), acting as energy sources, were positively correlated with phenolics. The metabolic profiles of Korean white- and green-colored radish roots associated with primary metabolites (amino acids,

carbohydrates, and organic acids) and secondary metabolites (chlorophyll, desulfoglucosinolate, and phenolics) will provide valuable information and help to lay the groundwork for human health (Fig.9) (Park *et al.,* 2022).

Fig. 9. Photograph of (A) green-colored radishes; and (B) white-colored radishes

HEALTH BENEFIT

Radish roots are considered to be good for patients suffering from liver trouble, gallbladder ailments, hemorrhoids (piles), jaundice, and enlarged spleen. The seeds are said to be carminative, diuretic, expectorant, and peptic. The seed oil is used to make soap (Gupta *et al.,* 2003). In traditional medicine, radishes are used as one of non-poisonous materials to treat coughs, cancer, whooping cough, gastric discomfort, liver disorders, constipation, dyspepsia, gallbladder disorders, arthritis, gallstones, and kidney stones (Adams 2008). Radishes have long been known for their medicinal purposes. All parts of the radish are useful for medicinal purposes including the pods, flowers, and seeds. They are as juicy as they are pungent or sweet depending on the type you choose. Radishes contain the following components: Fiber, Vitamin C, Folate, Potassium, Magnesium, Copper, Calcium, Manganese, and B Vitamins. The health benefits of radish are as follows (Neil, 2018):

Hydration and Standard Skin: Radishes contain high levels of water. Vitamin C, phosphorus, zinc, and some components of the B-12 complex. These ingredients are vital to maintaining proper hydration and standard skin conditioning. They are also beneficial to relieving constipation, improving your digestion system, and maintaining an adequate intake of the nutrients from the food you eat.

Improves Immunity: One of the most significant benefits of radishes is the improvement to your immune system. One half a cup is equal to 15% of your daily intake of Vitamin C. Ensuring that you eat your allowance daily will ensure that your immune system is refreshed. Many of the white blood cell and antioxidants that combat colds and diseases are then replaced. Vitamin C and thus Radishes are immune system boosters. It also adjusts your metabolism and then changes your fat into energy. The vitamin C that is derived from the radishes is also responsible for the creation of collagen and reducing of heart disease.

Treatment for Jaundice*:* Radish leaves are an effective treatment for jaundice. While radishes, in general, are beneficial, the leaves are the most effective. If you choose to eat the radishes over the leaves, the black radishes make the best choice. They help to remove the bilirubin and to check its production in the blood. Radishes will monitor the destruction of red blood cells by increasing the oxygen in the blood. Building the oxygen within the blood will assist in removing the yellowing of the skin and eyes. You should drink one cup of the juice from the radish leaves per day for ten days to recover quickly.

Treatments for Respiratory Problems*:* Radishes have a robust natural spice and a pungent odor that is good for preventing illnesses. The pungent smell acts as an anti-congestion by clearing the sinuses. It is beneficial in decreasing the overall congestion in the lungs. Radishes have a volatile compound that is called ether. It is responsible for reducing the phlegm and subsequently as an additional aid in the congestion. The juice of radishes and carrots can assist in the cleansing and healing of respiratory organs. It is rich in vitamins and provides the disinfectant properties that decrease the irritation to allergies, infections, colds and more.

Prevents Piles: Radishes are a known remedy for piles otherwise known as hemorrhoids. Radishes have been a proven way to cleanse the system. This helps in relieving the inflammation and pain associated with piles. Radishes can be used in one of several ways as a juice, with honey or as a paste

Weight Loss: Radishes are at the top of the weight reducing food chain. The overall water and fiber content are high and ensure that radishes remain at the top of this "diet list." They are both filling and satisfying. The fiber naturally regulates the bowel movements to flush out toxins and prevent constipation. Radishes can be eaten raw or cooked.

Improves Cardiovascular System*:* Radishes assist in reducing cardiovascular diseases through the anthocyanins that contain anti-inflammatory properties. These properties reduce cardiovascular disease and the effects such as heart failure and peripheral artery disease. Radishes aid in cleansing and purifying the blood. They also assist in circulating the metabolites that protect against other heart problems.

Treats Cancer*:* Holistically speaking, radishes induce apoptosis or cancer-killing properties. There are several types of cancer that it is believed to have been effective in fighting. Some of these cancers include colon, stomach, and oral cancer. The compounds isothiocyanates and anthocyanins fight cancer. The fiber in radishes is helpful in preventing and battling colorectal cancer. Radishes appear to decrease the risk of many cancers by inhibiting the growth of carcinogens in the body or by blocking the interaction with soft body tissue.

Aides in Digestion*:* The juice of the radish and carrots assists in cleaning and healing the mucous membrane of the digestive system. Radishes stimulate the production of bile and regulate the output of bilirubin production and flush the excess from the blood. The fiber content in the radishes assists in moving the bowels and aides in prevents constipation.

Lowers Blood Pressure*:* The most important purpose of radishes for medicinal purposes is for its ability to lower an individual's blood pressure. Radishes are a natural and high source of potassium. They and are known for their ability to assist in reducing high blood pressure. The leaves of the radish are its most significant source of nutrients as well as the compound ethyl acetate that is an antihypertensive action that reduces the blood pressure. The arterial contractions are safely and consistently eased. A good tip to always keep in mind with your blood pressure is that sodium raises it and that potassium is a diuretic and lowers it. Eat both the leaves and the roots of the radishes for the best antihypertensive results.

CULTURAL SIGNIFICANCE

On 23 December in Oaxaca (Mexico) thousands of people gather to celebrate Noche de rábanos (Night of the radishes). The focus of this festival, celebrated since 1897, is the creation of intricate sculptures carved from giant radishes, many depicting nativity scenes or saints (PWO, 2022). The daikon varieties of radish are important parts of East, Southeast, and South Asian cuisine. In Japan and Korea, radish dolls are sometimes made as children's toys. Daikon is also one of the plants that make up the Japanese Festival of Seven Herbs (*Nanakusa no sekku*) on the seventh day after the New Year. Citizens of Oaxaca, Mexico, celebrate the Night of the Radishes (*Noche de los rábanos*) on December 23 as a part of Christmas celebrations. This folk art competition uses a large type of radish up to 50 cm long and weighing up to 3 kg. Great skill and ingenuity are used to carve these into religious and popular figures, buildings, and other objects, and they are displayed in the town square

(WIKI, 2022c). Every December 23, crowds gather in Oaxaca's main square to celebrate the Night of the Radishes, or La Noche de Rábanos. It's a competition between artists who use the purple produce to make sculptures and, hopefully, win the big prize of the night. The competition's origins date back to when holiday market vendors tried to make their vegetables more enticing by making sculptures with them. It was such a hit that the governor, Francisco Vasconcelos, decided to create an official contest in 1897. It's been a tradition in Oaxaca ever since. All kinds of sculptures can be seen—saints, musicians, buildings, even a tiny cemetery where little radish people are celebrating the Day of the Dead. As Mexico is a heavily Catholic country, religious themes are common. Radish replicas of Michelangelo's La Pietà and da Vinci's The Last Supper have made appearances. To ensure fair competition, everyone uses vegetables grown by the government for the festival. And these radishes are big: Some grow 45 cm long and can weigh almost 3 kg. The festival starts in the morning, when everyone can see the artists working on their sculptures, but wait until night if you want to see the finished masterpieces. The festival also features concerts around the city, fireworks, and light shows (WIKI. 2022b).

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