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REVIEW ARTICLE

ORIGIN, DISTRIBUTION, TAXONOMY, BOTANICAL DESCRIPTION, AND CROP IMPROVEMENT OF CARROT (*DAUCUS CAROTA* VAR. *SATIVUS*)

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ABSTRACT

Although cultivated for over 2000 years, and originally used only as a medicinal plant, the domestic carrot *(Daucus carota* var. *sativus)* remains an important world crop with production expanding rapidly in Asia. The term carrot also applies to the long, edible, usually tapering taproot of the domesticated form. These taproots commonly are orange in color, but may be a variety of colors depending on the cultivar, including white, pink, yellow, purple and black. During its journey across centuries and continents, countless botanists managed to improve the composition, look, flavor and size of ancient carrots and produce the modern orange-colored carrot that appeared first in 17th century Netherlands. The cultivated carrots are mainly classified into eastern carrots and western carrots based on pigmentation in the carrot roots. Eastern carrots are thought to originate from Afghanistan, while the origin of western carrots is still uncertain. Carrots are versatile in several dishes and cultural cuisines. Carrots are believed to possess various health benefits due to their nutritional composition and antioxidant capacity, including the potential to prevent cardiovascular disease and certain types of cancers. Carrot has many medicinal properties. It increases quantity of urine and helps in elimination of uric acid. It has cooling effect and is beneficial for people suffering from gall stones, constipation and heat troubles. In this review, origin, distribution, taxonomy, botanical description, crop improvement, uses, nutritional value and health benefits of carrot are briefly provided.

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INTRODUCTION

Carrot is an herbaceous root vegetable, *Daucus carota* subsp. *sativus,* in the parsley family (Apiaceae or Umbelliferae), which also includes the similar parsnip. The domesticated carrot is a cultivar of the wild carrot *(Daucus carota* var. *carota),* also known as "Queen Anne's lace," which is native to temperate parts of Europe and Southwest Asia. The term carrot also applies to the long, edible, usually tapering taproot of the domesticated form. These taproots commonly are orange in color, but may be a variety of colors depending on the cultivar, including white, pink, yellow, or purple (NEW, 2022; Specialityproduce, 2022). Although cultivated for over 2000 years, and originally used only as a medicinal plant, the domestic carrot (*Daucus carota* var. *sativus*) remains an important world crop with production expanding rapidly in Asia (Stolarczyk and Janick, 2011). In Old English, carrots (typically white at the time) were not clearly distinguished from parsnips: the two were collectively called moru or more (from Proto-Indo-European *mork- "edible root", cf. German Möhre or Russian морковь/morkov). Various languages still use the same word for "carrot" as they do for "root"; e.g. Dutch wortel (WCM, 2022e). During its journey across centuries and continents, countless botanists managed to improve the composition, look, flavor and size of ancient carrots and produce the modern orange-colored carrot that appeared first in 17th century Netherlands (VF, 2022).

The cultivated carrots are mainly classified into Eastern carrots and Western carrots based on pigmentation in the carrot roots. Eastern carrots are thought to originate from Afghanistan, while the origin of Western carrots is still uncertain. The roots of most Eastern carrots are purple, and some are yellow. They have slightly dissected leaves and branched roots. The roots of most Western carrots are orange, red or white. The leaves of Western carrots are highly dissected, and the roots are unbranched. Currently, orange carrots are becoming more popular and more widely cultivated in the world (Que *et al*., 2019). Carrots are versatile in several dishes and cultural cuisines and are found in different colors such as orange, purple, white, yellow, and red (Stolarczyk and Janick, 2011; Nagraj *et al*., 2020). Carrot is a widely used root vegetable (usually orange in color) that is used all around the world as one of the most popular food ingredients (VF, 2022). Purple, red, yellow and white carrots were cultivated long before the appearance of the now popular orange carrot, which was developed and stabilized by Dutch growers in the 15th century (WCM, 2022b). Black carrot, *Daucus carota* ssp. *sativus* var. *atrorubens* (known as Kaali Gajar in India) is most commonly found and eaten in Turkey, Afghanistan, Pakistan, and India. The carrot has long been known as an orange-coloured vegetable, so this dark-colored veggie intrigues people a bit (WCM, 2022). Red coloured carrot is typical for India and also was introduced to Japan. The health benefits of carrots and their delicious taste make them an important vegetable in cultural cuisines across the globe (Stolarczyk and Janick, 2011).

Roots are used for making soups, stews, curries, pies, pickles and for salad purposes. Sweet preparation 'gajar halwa' prepared out of carrot is delicious and popular. Roots are also canned (Eagri, 2022). The swollen taproots are eaten both raw and cooked, in sweet and savoury dishes and it is known for its high beta-carotene content, which the human body converts to Vitamin A. It also forms a major ingredient in the food processing industry, a significant constituent of cosmetic products and its image has long been used to symbolize healthy eating. The leaves are also consumed in salads and the seeds made into an herbal tea (Stolarczyk and Janick, 2011). Because of their high nutrition value, presence of β-carotene, dietary fiber, antioxidants, minerals, flexibility for processing in many kinds of ways and the ability to remain edible even after months of reliable storing in both ordinary or refrigerated places, carrot instantly became embraced wherever it appeared after it was carried out from its home in Iran and Afghanistan (VF, 2022). Carrots contain an impressive selection of phytochemicals, including carotenoids, anthocyanins, and other phenolic compounds. This makes the vegetable a good source of dietary antioxidants, when included in the diet. The most abundant antioxidant compounds found in carrots are α- and β-carotene, vitamin E, and anthocyanin. Interestingly, the levels of these antioxidant pigments found in different cultivars are responsible for the coloring of the carrots (Nagraj *et al*., 2020). Carrot roots are rich sources of α and β carotenes (1890 μ g/100g) and contain sucrose 10 times that of glucose or fructose. Carrot leavesare a good source of leaf protein. It isused as fodder and for preparation of poultry feeds (Eagri, 2022). Purple and black carrots are used for preparation of a beverage called 'kanji' which is a good appetizer. In France, essential oil separated from seeds is used for flavoring liquors and all kinds of food substitutes (Eagri, 2022). Carrots are believed to possess various health benefits due to their nutritional composition and antioxidant capacity, including the potential to prevent cardiovascular disease and certain types of cancers (Nagraj *et al*., 2020). Carrot has many medicinal properties. It increases quantity of urine and helps in elimination of uric acid.It has cooling effect and is beneficial for people suffering from gall stones, constipation and heat troubles (Eagri, 2022).

ORIGIN AND DISTRIBUTION

Origin: One of the problems in unraveling the ancient history of carrot is that there is confusion between parsnip and carrot (Hedrick, 1919). The distinction between the two was finally clarified when Linnaeus published Species Plantarum in1753, creating scientific nomenclature. He called carrots *Daucus carota* (combining Greek and Latin names) and parsnips *Pastinaca sativa*. Wild carrot is indigenous to Europe, Northern Africa, and parts of Western Asia, and seeds have been found dating from Mesolithic times, approximately 10,000 years ago. Different forms of wild carrot, usually recognized as *D. carota* var. *carota*, have small spindle shaped, whitish, slender roots that are aromatic, and acrid with a disagreeable taste. In some countries it is considered a weed (Stolarczyk and Janick, 2011).

Ancient and modern literature, as far as accessible to the author, has been studied to find indications of the origin of the European cultivated carrot. Contrary to most writers on the same subject, it is concluded that there is no evidence that our type of cultivated carrot (*Daucus carota* ssp. *sativa*) was known to the Romans, or to the Europeans at the time of charlemagne or Charles the Great (±800 A.D.) or before. It is highly probable that the initial European carrot material originally came from the Arab countries, and found its way into Europe in about the 13th and 14th centuries (Banga, 1957a). It is generally assumed that the eastern, purple-rooted carrot originated in Afghanistan in the region where the Himalayan and Hindu Kush mountains meet or confluent (van der Vossen and Kahangi, 2004; Praciak, 2022). Originally wild in many parts of Europe and Asia it was first domesticated in Afghanistan, considered to be the primary center of diversity, and from there spread over Europe, the Mediterranean, and Asia, with Turkey recognised as a second center of diversity (Stolarczyk and Janick, 2011; WCM, 2022c). Areas around Afghanistan are generally agreed to be the geographic regions of the first cultivation of Eastern-type carrots.

To determine the geographic regions of the first cultivation of Western-type carrots, more genetic sequencing studies are needed (Que *et al*., 2019). The viewpoint that the Eastern-type cultivated carrot was domesticated from the wild carrots in the area around Afghanistan is generally agreed upon (Que *et al*., 2019). Accordingto Mackevic (1929) Afghanistan is the primary center of origin of carrot since a large diversity for morphological and root characters occur. Considerable variability for root also exists in India, indicating India also as a center of origin. Root color varies from absolutely colorless through light lemon, light orange, deep orange, light purple, deep purple to almost black (Eriag**,** 2022). Areas around Afghanistan are generally agreed to be the geographic regions of the first cultivation of Eastern-type carrots. To determine the geographic regions of the first cultivation of Western-type carrots, more genetic sequencing studies are needed. It is thought that orange carrots first appeared in Northern Europe, possibly Spain, Holland, Germany, Switzerland (WCM, 2022e). Cultivated carrots originated in the Afghanistan region and were at that time, yellow, purple (orange cored) and black (white cored). Red coloured carrot is typical for India and also was introduced to Japan. Black carrot (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef.) belongs to the Eastern group of the originally domesticated carrots, having its primary domestication centre today probably in the Kashmir-Afghanistan-Turkestan regions **(**WCM, 2022**).** The cultivated carrot is believed to originate from Afghanistan before the 900s, as this area is described as the primary centre of greatest carrot diversity (Mackevic, 1929*)*, Turkey being proposed as a secondary centre of origin (Banga1963). Home of carrots and its numerous cousins can be tracked to dry and hot lands of Iran and Afghanistan. Earliest evidence of its use there was dated to 3000 BC (VF, 2022).

Almost five thousand years ago, carrots were firstly cultivated in the Iranian Plateau and then in Persian Empire. Western and Arabic literatures along with the studies by the US Department of Agriculture (USDA) reveal that carrots were originated in Afghanistan, Pakistan, and Iran. It should be noted, however, that there were no Afghanistan or Pakistan in those olden days and the Iranian Plateau (a term which covers Afghanistan, Pakistan, and Iran) must be considered as the land of origin for carrots (WCM, 2022e). The time frame and geographical location(s) of the earliest cultivated carrots are still uncertain. In Vavilov's opinion, Asia Minor and the inner Asiatic regions were the origin centers of cultivated carrots. In addition, regions including Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan were the basic centers of cultivated carrots in Asia. Afghanistan was thought to be the first center of carrot diversity, and Turkey was the second (Que *et al*., 2019). A study based on the transcriptome data analysis also supports the hypothesis that the Eastern-type cultivated carrot originated in Western Asia. However, there are still some different viewpoints on the origin of Western-type cultivated carrots. The Western-type cultivated carrot was thought to originate from Eastern-type carrots directly, based on the earliest molecular study about carrot domestication. In contrast, Heywood held the idea that Western-type cultivated carrots did not originate directly from the Eastern-type carrot. He summarized the hypothesis that there was a secondary domestication event in the domestication of Western-type cultivated carrot. According to a recent study, Western-type orange carrots may also originate from Eastern carrots by introgression from wild carrots (Que *et al*., 2019). With the development of sequencing technology, many molecular markers have been used in research on plant evolution. Studies on single nucleotide polymorphisms (SNPs) were adopted to analyze the structure and phylogeny of wild and cultivated carrots. A clear separation was found between wild and cultivated carrots. Based on historical documents and experimental results, central Asia was thought to be one origin of cultivated carrot (Que *et al*., 2019). The centre of diversity for the carrot is in Central Asia, and the first cultivation of carrot for its storage root is reported to be in the Afghanistan region, approximately 1,100 years ago (Mackevic, 1929). There is good genetic evidence that wild carrot is the direct progenitor of the cultivated carrot (Simon 2000). Selection for a swollen rooted type suitable for domestic consumption undoubtedly took many centuries.

Carrot domestication transformed the wild carrot with its relatively small, thin, white, heavily divided (forked or sprangled - spread in different directions) strong flavoured taproot of a plant with annual biennial flowering habit into a large, orange (eventually), smooth, good flavoured storage root of a uniformly biennial or "winter" annual crop we know today. Modern carrot breeders have further refined the carrot, improving flavour, sweetness, reducing bitterness and improving texture and colour. There have also been significant improvements in disease and pest reduction resulting in ever increasing yields. Flavour, nutritional and processing qualities are also uppermost in the minds of modern breeders (WCM, 2022e).

Despite being an important worldwide vegetable, the genetic structure and domestication of carrot is poorly understood. Sequencing data from the carrot transcriptome were used to develop 4000 single nucleotide polymorphisms (SNPs). Eighty-four genotypes, including a geographically well-distributed subset of wild and cultivated carrots, were genotyped using the KASP assay. Analysis of allelic diversity of SNP data revealed no reduction of genetic diversity in cultivated vs. wild accessions. Structure and phylogenetic analysis indicated a clear separation between wild and cultivated accessions as well as between Eastern and Western cultivated carrot. Among the wild carrots, those from Central Asia were genetically most similar to cultivated accessions. Furthermore, we found that wild carrots from North America were most closely related to European wild accessions. Comparing the genetic diversity of wild and cultivated accessions suggested the absence of a genetic bottleneck during carrot domestication. In conjunction with historical documents, our results suggest an origin of domesticated carrot in Central Asia. Wild carrots from North America were likely introduced as weeds with European colonization. These results provide answers to long-debated questions of carrot evolution and domestication and inform germplasm curators and breeders on genetic substructure of carrot genetic resources (Iorizzo *et al*., 2013).

Wild carrot and domesticated carrot continue to grow side by side in the modern world. It is a popular myth that domesticated carrot was developed directly from wild carrot, probably because of its similar odor, leaf pattern and growth characteristics. Botanists have failed to develop an edible vegetable from the wild carrot and when the garden carrot reverts to an ancestral wild type it is quite distinct from the wild form (Stolarczyk and Janick, 2011)

Overview of the Origin and Distribution of Carrots: The wild carrot is the progenitor (wild ancestor) of the domestic carrot (direct descendent) and both still co-exist in the modern world. Wild Carrot is indigenous to Europe and parts of Asia and, from archaeological evidence, seeds have been found dating since Mesolithic times, approximately 10000 years ago. One cannot imagine that the root would have been used at that time, but the seeds are known to be medicinal and it is likely the seeds were merely gathered rather than actually cultivated. Carrots originated in the Himalayas and Hindu Kush centre of the continent and moved in both directions on the Silk Road(The Silk Road was an ancient network of trade routes, formally established during the Han Dynasty of China, which linked the regions of the ancient world in commerce between 130 BCE-1453 CE. As the Silk Road was not a single thoroughfare from East to West, the term 'Silk Routes' has become increasingly favoured by historians, though 'Silk Road' is the more common and recognized name). It is generally assumed that the Eastern, purple-rooted carrot originated in Afghanistan in the region where the Himalayan and Hindu Kush mountains meet, and that it was domesticated in Afghanistan and adjacent regions of Russia, Iran, India, Pakistan and Anatolia. The cultivated carrot is believed to have originated from forms with roots coloured purple anthocyanins as well as yellow mutants lacking anthocyanins. These forms spread to the West and East reaching Asia Minor around the 10th or 11th centuries, Arab occupied Spain in the 12th century, China in 13th century, continental Northwest Europe by the 14th century. England in the early 15th century. Purple carrot, together with a yellow variant, spread to the Mediterranean region and Western Europe in the 11–14th centuries, and to China, India and Japan in the 14–17th centuries.

White colour first appeared in the 14th century (WCM, 2022e). Orange roots appeared in Spain and Germany in the 15th or 16th century (Stolarczyk and Janick, 2011), and quickly became the predominant colour. It is considered that these carrots were sweeter and did not stain cookware and cooking water, which helped make them more popular than purple carrots. Before the 16th century carrots were purple or yellow with long roots. The yellow roots were often preferred because they did not release anthocyanins during cooking. In the late 15th century it is considered that Dutch growers developed a denser orange carotene carrot from yellow varieties and this deep orange carrot was the progenitor of the modern cultivated carrot we know. Orange carrots appear to have become popular in the 16th century when Dutch and Spanish paintings began depicting orange carrots in market scenes (Banga, 1963*)*,

Summarised Timeline of Cultivated Carrot

Time Period	Location	Colour
Pre-900s	Afghanistan and vicinity	Purple and yellow
900s	Iran and northern Arabia	Purple, red and yellow
1000s	Syria and North Africa	Purple, red and yellow
1100s	Spain	Purple and yellow
1200s	Italy and China	Purple and red
1300s	France, Germany, The Netherlands	Red, Yellow & White
1400s	England	Red & white
1500's	Northern Europe	Orange, yellow & red
1600s	Japan	Purple and yellow
1600s	North America	Orange and white
1700s	Japan	Orange and red
(WCM, 2022e)		

Distribution : Color and flavor were the primary selection criteria for domestication. Root color changed significantly over the domestication period. Wild carrots are white or pale yellow, while purple or yellow were the first colors of domesticates. The domesticated types were divided into two subgroups: Eastern/Asiatic Group (var. *atrorubens*) and Western Group (var. sativus) as described by Vavilov (1926 & 1951). The Eastern/Asiatic group, the original domesticates, have anthocyanin-pigmented roots, purple, pink, or orange-yellow, that are often branched, with pubescent slightly dissected leaves that give the plant leaves a grey-green appearance. Plants are prone to early flowering. The center of diversity was the Himalayan-Hindu Kush region (Kashmir-Afghanistan) and around Turkestan (Mackevic, 1929; Heywood, 1983). The purple types have poor storage quality and erratic growth. The purple/red pigment based on anthocyanins turns brown upon cooking, and stains hands and cookware. The Western group evolved later and has un-branched, carotenoid-pigmented roots that are yellow, orange or red, and occasionally white. The strongly dissected leaves are bright yellowish green and slightly hairy. Plants require extended exposure to low temperatures before bolting. The centre of diversity for the Western carrot is the Anatolian region of Asia Minor (Turkey) and Iran (Vavilov, 1926 & 1951). The orange types displaced the purple forms in Europe and the Mediterranean by the 17th century through human preference and selection, and formed the basis of modern commercial cultivars around the world, mainly because of their superior taste, versatility, and nutritional value. Thus, the Asia Minor/Mediterranean basin (Turkey) and temperate Europe regions have been considered a secondary center of origin for carrot and the majority of modern commercial cultivars belong to this group. The yellow/orange color of Western carrots is caused by the plastid-bound pigment carotenoids, carotene, and xanthophyll. White carrots contain only traces of pigment, mainly carotene and xanthophylls (Ladizinsky,1998). The yellow and white types probably originated by mutation. Purple carrots contain anthocyanins, a powerful antioxidant, whilst red carrots contain lycopene, good for eye health (Rubatzky *et al*., 1999). The modern carrot appears to derive from a combination of mutation and selection from a complex genepool. These involve yellow rooted Eastern carrots, cultivated white-rooted derivatives of wild carrot (grown as medicinal plants since classical times), and wild unselected populations from Europe and the Mediterranean (Banga, 1957a, b, 1963a, b; Heywood, 1983).

Orange carrots probably arrived from mutations of yellow forms, and then from human selection, commonly thought to be originated in the Netherlands.

Black carrot - *Daucus carota* ssp. *sativus* var. *atrorubens*- (known as Kaali Gajar in India) is most commonly found and eaten in Turkey, Afghanistan, Pakistan, and India. The carrot has long been known as an orange-coloured vegetable, so this dark-colored veggie intrigues people a bit. The colour of Black Carrots is primarily due to a high concentration of anthocyanin. Orange and yellow carrots tend to be higher in beta-carotene. Black carrots are still grown and consumed in Eastern countries such a Turkey, Afghanistan, Pakistan India and the Far East. The Black carrot has a unique taste and has an unexpected sweetness, along with a subtle spicy aftertaste **(**WCM, 2022**).** On the basis of historical documents, the first domesticated carrot roots were purple and yellow and recorded in Central Asia, Asia Minor, then in Western Europe and finally in England between the 11th and 15th centuries (Banga, 1963a). Interestingly, orange carrots were not well documented until the 15th and 16th centuries in Europe (Banga, 1957a, b; Stolarczyk and Janick, 2011), indicating that orange carotenoid accumulation may have resulted from a secondary domestication event **(**WCM, 2022**)**. Modern research has shown that there are two distinct groups of cultivated carrots from which the modern orange carrot derives, these are distinguished by their root colours and features of the leaves and flowers (WCM, 2022e):

***Eastern/Asiatic carrot* (*anthocyanin*)**: Identified by its purple and/or yellow branched root, grey green leaves which are poorly dissected and an early flowering habit; they often have a habit to bolt easily. The greatest diversity of these carrots is found in Afghanistan, Russia, Iran and India. These are possible centers of domestication, which took place around the 10th century.It is considered that the purple carrot was brought westward as far as the Arab countries from Afghanistan (where the purple carrots of antiquity are still grown).

Western or carotene carrot: Identified by its yellow, orange, white or red unbranched root and yellowish green leaves more clearly dissected and slightly hairy. It is likely these carrots derived from the Eastern group by selection among hybrid progenies of yellow Eastern carrots, white carrots and wild subspecies grown in the Mediterranean. The first two originated by mutation. It is thought that Western carrots may have originated later in Asia Minor, around Turkey and could have formed from a mutant which removed the anthocyanin (purple colour).Orange carrots derived from yellow forms, and then from human selection. From Iran and Afghanistan, carrot seeds were picked, carried and sold via caravans to neigh boring Arabian, African and Asian lands, who all accepted carrots immediately and started crossbreeding and creating new types of this famous root. Even in those ancient times, many colors of carrots were present and used – black, white, red and purple. Interestingly, orange colors that we use today were not present. The most telling sign of how popular carrots were in those ancient times comes from Ancient Egypt, where numerous carrots were placed in the tombs of dead Pharaohs and the drawings of the carrot harvest and processing can be found in numerous hieroglyph paintings. The most popular color of carrots that was cultivated in Egypt was purple, and it was used not only for eating but also for medicine. By 13th century carrots traveled from Persia to Asia, reaching distant Japan. During same time, European carrot started being cultivated in gardens and fields of France and Germany. Those carrots were bitter, but they were nutritious and its popularity enabled quick spread across entire Europe. In 1609, English settlers of the New World started cultivating Carrots in their first city of James Town, Virginia (20 years later production moved to Massachusetts). Brazil was the first South American country to receive carrots in mid-17th century, and not much later carrot arrived to Australia. Modern yellow carrot appeared in Netherlands during 17th century as a tribute to the ruling House of Orange. After years of selective breeding, Dutch yellow carrot was engineered to be without bitterness, increased sweetness and minimal wooden core. This carrot type named '*Daucus carota'* quickly became popular across entire Europe (VF, 2022). There are evidences that purple carrot together with a yellow variant spread from Afghanistan to the Mediterranean region as early as the tenth or eleventh century. The white and orange carrots are probably mutations of the yellow form (Vidhi, 2022). There are orange, red, yellow, purple, white and black colored carrots (Fig. 1)

TAXONOMY: *Daucus* comprises about 20 species occurring mainly in the Mediterranean region. Wild *Daucus carota* is widespread in Europe and western Asia, and occurs also in northern Africa (Morocco, Algeria, Tunisia) and locally in tropical Africa (Eritrea, Ethiopia), at higher altitudes. Elsewhere in tropical Africa it is occasionally naturalized after escape from cultivation; this is also the case in other parts of the world, e.g. in North America, where it is now locally a common and noxious weed (van der Vossen and Kahangi, 2004). Morphological characteristics lead to a division of the cultivated carrot (*Daucus carota* subsp. *sativus*) into two botanical varieties: var. *atrorubens* and var. *sativus.* Var. *atrorubens* refers to carrots originating from the East, exhibiting yellow or purple storage roots and poorly indented, grey-green, pubescent foliage. Var. *sativus* refers to carrots originating from the West and exhibiting orange, yellow or sometimes white roots, and highly indented, non-pubescent, yellow-green foliage. Many intermediate variants exist between these two types (Que *et al*., 2019; WCM, 2022e). Wunderlin *et al*. (2022) have mentioned only two species of *Daucus*, namely*, Daucus carota* (Queen Anne's Lace) and *Daucus pusillus* (American Wild Carrot). The white carrot is a root vegetable and bona fide member of genus *Daucus* with as many as 40 species. It is an heirloom variety belonging to the *Umbelliferea* (Apiaceae) family. The botanical name of carrot is Daucus carota ssp. sativus with chromosome number: $2n = 18$ (van der Vossen and Kahangi, 2004; Praciak, 2022; NEW, 2022). Thus, save for the lack of pigmentation, white carrots are similar in almost every aspect to orange, yellow, red and purple carrots (Lawn, 2021). Simon (2008) and Vidhi (2022) have described several varietal groups based on root colour, root length, colour intensity, core colour and size, root tip shape and days to edible root maturity. Those same distinctions are still used to help categorize carrot varietal groups even today. The major root types used today include varietal groups as:

European: Nantes, Chantenay, Danvers, Paris Market, Flakkee, Berlicum, Amsterdam Forcing; *Asian*: Kuroda; *North American*: Imperator; *South American*: Brasilia. van der Vossen and Kahangi (2004), WCM (2022e) and CABI (2022) reported that wild carrot, the progenitor of the cultivated carrot, is a biennial weed native to Europe, Southwestern Asia and North Africa. Wild carrot can also negatively affect commercial carrot cultivation through genetic introgression in seed crops. *Daucus carota* is a complex, very variable species comprising wild and cultivated carrots, resulting in a confused taxonomy. The complex is subdivided into 13 subspecies, 12 for wild taxa and one for the cultivated taxon (subsp. *sativus* (Hoffm.) Arc.). However, for cultivated carrot it is better to classify directly at cultivar level below the species level. There are two main groups of cultivated carrot: the eastern (anthocyanin) and western (carotene) carrot. The eastern carrot has branched roots, is yellow, reddish-purple to purple-black, rarely yellowish-orange; leaves slightly dissected, greyish-green, pubescent; flowering in the first year. The western carrot has unbranched roots and is yellow, orange or red, occasionally white; leaves strongly dissected, bright green, sparsely hairy; normally biennial, but often annual in tropical regions. At present the western carrot is by far the most important, although the eastern carrot is still cultivated in some Asian countries. Three main groups of western (carotene) carrot cultivars arose by selection in the 19th and early 20th centuries in western Europe and the USA from the Dutch landraces 'Long Orange' and 'Horn'. Cultivated carrots cross readily with the wild carrot taxon *D. carota* subsp. *carota*, which is very common in Europe and Southwest Asia and has been introduced and naturalized elsewhere, notably to North America and Australia.

BOTANICAL DESCRIPTION

The domestic carrot is a cool season biennial plant that grows a rosette of leaves in the spring and summer while building up the stout tap-root, which stores large amounts of carbohydrates for the plant to flower in the second year.

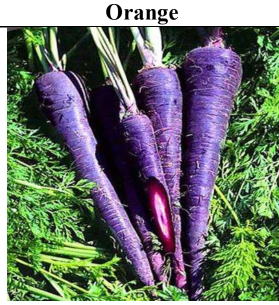
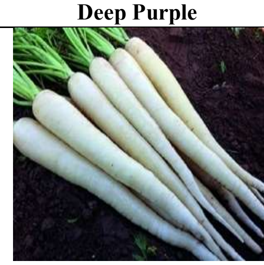
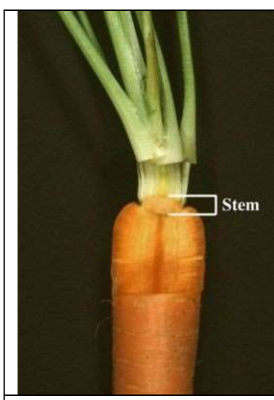
		
Orange	**Orange**	**Red**
		
Purple	**Purple**	**Deep Purple**
		
Black	**Yellow**	**White**

Fig. 1. Different colored carrot roots

		
Carrot root with stem	**Carrot field**	**Harvested carrots**
		
Carrot umbel	**Carrot umbel**	**Carrot fruits**

According to Plant List (2013a) there are 62 species in the genera Daucus (Table 1).

Table 1. Species of *Daucus*

Daucus aegyptiacus Hornem.
Daucus agrestis Raf.
Daucus aleppicus J.Thiébaut
Daucus ammoides Lojac.
Daucus arcanus F.GarcíaMart. & Silvestre
Daucus aureus Desf.
Daucus australiae Koso-Pol.
Daucus bactrianus Bunge
Daucus breviaculeatus Calest.
Daucus broteroi Ten.
Daucus capillifolius Gilli
Daucus carota L.
Daucus coadunatus Ten.
Daucus conchitae Greuter
Daucus crinitus Desf.
Daucus crinitus (Boiss.) Kuntze
Daucus crithmifolius Lojac.
Daucus cuminifolius Rouy&E.G.Camus
Daucus cuminoides Lam. exPoir.
Daucus daucorlaya (Murb.) Drude
Daucus daucorlaya Fiori
Daucus dubius E.H.L.Krause
Daucus durieua Lange
Daucus euboeus Beauverd&Topali
Daucus exarmatus Korovin
Daucus foetidus Raf.
Daucus foliosus Guss.
Daucus gaditanus Boiss. &Reut
Daucus glaberrimus Desf.
Daucus glochidiatus (Labill.) Fisch., C.A.Mey. &Avé-Lall.
Daucus gracilis Steinh.
Daucus grandiflorus Scop.
Daucus guttatus Sm.
Daucus hispanicus (Lam.) Grande
Daucus hochstetteri A.Braun ex Engl.
Daucus involucratus Sm.
Daucus jordanicus Post
Daucus leptocarpus Hochst.
Daucus littoralis Sm.
Daucus lopadusanus Tineo
Daucus martellii Gand. exCalest.
Daucus mauritianus L
Daucus microscias Bornm. &Gauba
Daucus montanus Humb. &Bonpl. exSchult.
Daucus muricatus (L.) L.
Daucus pectinaceus DC.
Daucus ponticus Velen.
Daucus prutenicus (L.) E.H.L.Krause
Daucus pusillus Michx.
Daucus pycnanthus (H.Lindb.) M.Hiroe
Daucus reboudii Coss. ex Batt.
Daucus rigidus DC.
Daucus russeus Heldr.
Daucus sahariensis Murb
Daucus sativus Roehl.
Daucus setifolius Desf.
Daucus setifolius (Boiss.) Kuntze
Daucus subglaber Prodán
Daucus subsessilis Boiss.
Daucus syrticus Murb.
Daucus tenuisectus Coss. ex Batt.
Daucus virgatus (Poir.) Maire

The flowering stem grows to about one m tall, with an umbel of white flowers. The roots are greatly enlarged and sweet with good storage ability. Predominantly a temperate climate plant, the carrot is also cultivated in tropical and subtropical regions, especially at high elevations (Stolarczyk and Janick, 2011). Eagri (2022) reported that 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 pinnate. 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. The so called carrot seed is actually a fruit, an indehiscent mericarp, which consists of a single seed.

According to Plant List (2013b) there are 48 synonyms of *Daucus carota*(Table 2).

Table 2. SynonymsofDaucuscarota

Carotasylvestris(Mill.) Rupr.
*Caucaliscarnosa*Roth
Caucaliscarota(L.) Crantz
*Caucalisdaucus*Crantz
*Daucusalatus*Poir.
*Daucusallionii*Link
*Daucusaustralis*Kotov [Illegitimate]
*Daucusblanchei*Reut.
*Daucusbrevicaulis*Raf.
*Daucuscarota*var.*Brachycaulos*Reduron
*Daucuscarota*var.*brachycentrus*Maire
*Daucuscarota*f.*carota*
*Daucuscarota*var.*carota*
*Daucuscarota*subsp.*Dentatus*(Bertol.) Fiori
*Daucuscarota*f.*epurpuratus*Farw.
*Daucuscarota*var.*excelsus*Maire
*Daucuscarota*f.*fischeri*Moldenke
*Daucuscarota*f.*goodmanii*Moldenke
*Daucuscarota*subsp.*Hispidus*Masclef
*Daucuscarota*var.*linearis*Reduron
*Daucuscarota*var.*Pseudocarota*(Rouy&E.G.Camus) Reduron
*Daucuscarota*f.*roseus*Millsp.
*Daucuscarota*f.*roseus*Farw.
*Daucuscommunis*Rouy&E.G.Camus
*Daucuscommunis*var.*pseudocarota*Rouy&E.G.Camus
*Daucusdentatus*Bertol.
*Daucusesculentus*Salisb.
*Daucusexiguus*Steud.
*Daucusgingidium*Georgi
*Daucusglaber*Opiz ex Čelak.
*Daucusheterophylus*Raf.
*Daucuskotovii*M.Hiroe
*Daucuslevis*Raf.
*Daucusmarcidus*Timb.-Lagr.
*Daucusmaritimus*With. [Illegitimate]
*Daucusmontanus*Schmidt ex Nyman
*Daucusneglectus*Lowe
*Daucusnudicaulis*Raf.
*Daucusofficinalis*Gueldenst. ex Ledeb.
*Daucuspolygamus*Jacq. exNyman [Invalid]
*Daucusscariosus*Raf.
*Daucussciadophylus*Raf.
*Daucusstrigosus*Raf.
*Daucussylvestris*Mill.
*Daucusvulgaris*Garsault [Invalid]
*Daucusvulgaris*Neck.
*Platyspermumalatum*Schult.
*Tirictadaucoides*Raf.

Two mericarps pair to form a single rhizocarp, the real carrot fruit which develops from a two-loculed ovary (Fig. 2). According to Que *et al*. (2019) the flower of the carrot is a flattened umbrella-shaped umbel. The umbel is a characteristic for distinguishing carrots from related taxa. The colors of the cultivated carrot flowers are usually white, and the carrot leaves are compound leaves. The fleshy taproot of the carrot develops from the hypocotyls, and the shape of the carrot root is always conical. The color of the root is varied and includes orange, yellow, purple, red, and white. Different pigment contents are responsible for the different colors. The basic chromosome number of carrots is 9–11. Most cultivated carrots are diploid ($2n = 2x = 18$). The edible part of a domesticated carrot, *Daucus carota* subsp. *sativus* is a taproot. It grows a rosette of leaves in the spring and summer, while building up the stout taproot, which stores large amounts of sugars for the plant to flower in the second year. The flowering stem grows to about one meter tall (NEW, 2022). van der Vossen and

According to Plant List (2013b) there are 14 Infraspecific taxa of *Daucus carota* (Table 3).

Table 3. Infraspecific taxa

*Daucuscarota*subsp.*Azoricus*Franco
*Daucuscarota*subsp.*Boissieri*(Schweinf.) Hosni [Unplaced]
*Daucuscarota*subsp.*Commutatus*(Paol.) Thell.
*Daucuscarota*subsp.*Drepanensis*(Arcang.) Heywood
*Daucuscarota*subsp.*Fontanesii*Thell.
*Daucuscarota*subsp.*Gadecaei*(Rouy&E.G.Camus) Heywood
*Daucuscarota*subsp.*Gummifer*(Syme) Hook.f.
*Daucuscarota*subsp.*Halophilus*(Brot.) A.Pujadas
*Daucuscarota*subsp.*Hispanicus*(Gouan) Thell.
*Daucuscarota*subsp.*Majoricus*A.Pujadas
*Daucuscarota*subsp.*Maritimus*(Lam.) Batt.
*Daucuscarota*subsp.*Maximus*(Desf.) Ball
*Daucuscarota*subsp. *Rupestris*(Guss.) Heywood
*Daucuscarota*subsp.*Sativus*(Hoffm.) Arcang.

Kahangi (2004) reported that carrot is an annual or biennial erect herb up to 50 cm tall at the mature vegetative stage and up to 150 cm tall when flowering; taproot fleshy, straight, conical to cylindrical, 5–50 cm long and 2–5 cm in diameter at top, orange (most common), reddish violet, yellow or white. Leaves in a rosette at base of plant, but alternating on flowering stems, 2–3-pinnate; stipules absent; petiole long, sheathed at base, petiole and rachis pilose; segments divided into oblong to lanceolate or linear ultimate lobes. Inflorescence a terminal, compound umbel with numerous unequal rays, strongly contracted in fruit; involucral bracts 7–13, pinnatipartite or pinnatisect, with linear lobes. Flowers mainly bisexual, but male flowers present in addition to bisexual flowers, often 1–few dark purple sterile flowers present in the centre of umbel, c. 2 mm in diameter, 5-merous; pedicel 0.5–1.5 cm long; calyx with small teeth or absent; petals free, white or pinkish, often enlarged in exterior flowers of umbel; stamens free; ovary inferior, bristly hairy, 2-celled, styles 2.Fruit an oblong-ovoid schizocarp 2–4 mm long, at maturity splitting into two 1-seeded mericarps, primary ridges ciliate, secondary ridges with hooked spines. Seedling with epigeal germination; taproot long, thin; hypocotyl 0.5–1.5 cm long, epicotyl absent; cotyledons linear, leafy; first true leaves pinnate.

Floral Biology and Pollination of Carrot: The inflorescence of carrot is a compound umbel. A primary umbel can have over 1000 flowers at maturity, whereas secondary, tertiary and quaternary umbels bear fewer flowers. Floral development is centripetal i.e. the flowers to dehisce first are on the outer edges of the outer umbellets. Carrot is protandrous. After straightening of filament, the pollen is shed and stamens quickly fall. After this, the petals open fully and the style elongates. The style is divided into two parts. The petals of petaloid plants are persistent unlike those of brown-anther, male sterile plants.

Flowers are epigynous. There are five small sepals, five petals, five stamens and two carpels. Emasculation is laborious and time consuming. As soon as the first bud in an umbel opens, the whole umbel of the female parent is bagged in a muslin/cloth bag. The flowers are removed daily until peak flowering has reached. Anthers are removed from the early opening outer flowers in the outer whorl of umbellates until sufficient flowers are emasculated. Unopened central florets in the emasculated umbellates and all late flowering umbellate are removed. Thus, only the emasculated flowers are left on the female inflorescence inside the bag. A pollen bearing umbel from previously protected male plant is inserted into the bag of the female parent along with some house-flies to ensure pollination. Daily for a few days in the morning, the male umbel is gently rubbed against the emasculated umbel to enhance artificial cross-pollination. Sometimes, 1-2 flowering umbels of both the parents are enclosed in the same cloth cage along with some house-flies. Seed from each parent is sown in adjacent rows. The hybrids and the parents could be identified (not always) and necessary roguing done to remove the selfed plants. Another alternative commonly used in Europe for inter-crossing male fertile plants. A single isolated umbel will not develop seeds even though pollen is present in the flowers as this is protanadrous. This umbel can serve as the seed parent in a cross if, one week after anthesis, the flowers of such an isolated umbel are sprinkled with water to flush out pollen. After it dries, pollen from the intended pollen parent can be introduced with a brush and the seed parent umbel again placed in isolation. Seeds thus produced are nearly always hybrids. Sometimes two parents to be crossed are covered by a plastic or cloth screen pollination cage. Flies are released in the pollination cage to move pollen or pollen is moved by hand or brush. In this system, selfed and crossed seeds are harvested together. The selfed and crossed progenies need to be identified by phenotypic or molecular markers or by hybrid vigour when inbreds are crossed (Vidhi, 2022).

GENETIC DIVERSITY

van der Vossen and Kahangi (2004) reported that the genetic basis of modern orange carrot cultivars is rather narrow, considering that they are mostly derived from a few 18th-century Dutch cultivars. Exploitation of the genetic variation existing in wild *Daucus* germplasm in the Mediterranean and South-western Asian regions started only recently. Germplasm collections of *Daucus carota* and related species, totalling some 5600 accessions, are available in Europe (United Kingdom, France, Netherlands), Russia, United States and Japan. Polymorphism of simple sequence repeat (SSR) loci was assessed in a collection of 88 carrot (*Daucus carota* L. subsp. *Sativus* Hoffm.) accessions. The collection comprised cultivars and landraces mainly from Asia, Europe, and North America. Plants were grown in the glasshouse and characterized for root color and shape. Thirty SSR loci were fully characterized using parameters derived from allele frequencies, i.e. the number of total effective and rare alleles, the observed and expected heterozygosity, and fixation index. Using a Bayesian approach, two clusters of 17 and 61 accessions were distinguished, which comprised the Asian and Western type accessions, respectively. Genetic diversity of the Asian gene pool was higher than that of the Western gene pool. The results of SSR analysis were supported by morphological characterization, and are congruent with current knowledge on the history of carrot domestication and breeding (Baranski *et al*., 2012). According to Maksylewicz and Baranski (2013) intra-population variation of 18 cultivated carrot (*Daucus carota* L. ssp. *sativus*) populations of diverse origins was evaluated using codominant microsatellite (SSR) markers. Using 27 genomic and EST-derived SSR markers, 253 alleles were identified with a mean 9.4 alleles per marker. Most of the alleles (60.5%) were rare i.e., with the frequency ≤ 0.05 while only 3.95% of alleles occurred with frequency > 0.6. EST-derived SSR markers were less polymorphic than genomic SSR markers. Differences in allele occurrence allowed 16 out of 18 populations to be assigned to either the Western or Asian carrot gene pools with high probability. Populations could be also discriminated due to the presence of private alleles (25.3% of all alleles). Most populations had excess of alleles in the homozygous state indicating their inbreeding, although heterozygous loci were common in F1 hybrids. Genetic diversity was due to allelic variation among plants with-in populations (62% of total variation) and between populations (38%). Accessions originating from continental Asia and Europe had more allelic variants and higher diversity than those from Japan and USA. Also, allelic richness and variability in landraces was higher than in F1 hybrids and open-pollinated cultivars.

Kasiri *et al*. (2013) have reported that Yellow carrots (*Daucus carota* var. *sativus*) have a long history of cultivation in Iran. They have desirable characters such as resistance to heat, drought, salinity, pests and diseases. The aim of this study was to evaluate morphological characters of Iranian yellow carrot accessions, a forgotten root vegetable and exposed to extinction to use in future breeding programs. Cluster analysis separated accessions into three main groups, two Asian and one European group. In this study, Iranian yellow carrots were belonging to Asian group that they had properties such as yellow roots, gray-green leaf with dense hair and slightly or intermediate dissection and celery or parsley leaf type. Heaviest (610 g) and longest (31.5 cm) root was belonging to Naein accession.

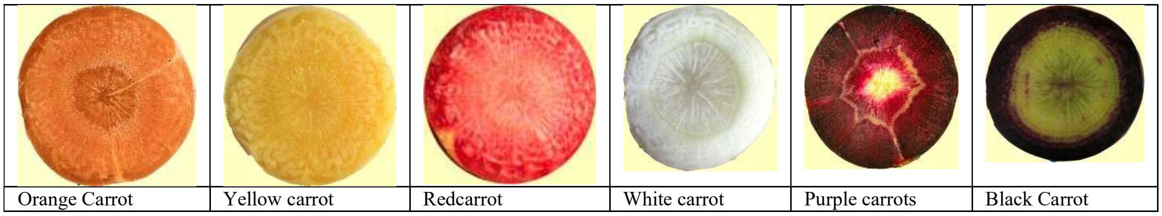


Fig. 3. Core of different colored carrots

Tabas accession had thickest root (83 mm), outer and inner core (23.2 and 45.3 mm, respectively) and lowest ratio of inner core diameter to total diameter. Factor analysis categorized the evaluated characters into 12 main factors that these factors accounted for over than 95 % of total variance. Results of simple correlation among characters showed the existence of significant, positive and negative correlations in root and leaf. The results of this study showed a high diversity among Iranian yellow carrots and that they are invaluable genetic resources for breeding programs. Iorizzo *et al*. (2016) have reported a high-quality chromosome-scale assembly and analysis of the carrot (*Daucus carota*) genome, the first sequenced genome to include a comparative evolutionary analysis among members of the euasterid II clade. We characterized two new polyploidization events, both occurring after the divergence of carrot from members of the Asterales order, clarifying the evolutionary scenario before and after radiation of the two main euasterid clades. Large- and small-scale lineage-specific duplications have contributed to the expansion of gene families, including those with roles in flowering time, defense response, flavor, and pigment accumulation. We identified a candidate gene, DCAR_032551, that conditions carotenoid accumulation (*Y*) in carrot taproot and is coexpressed with several isoprenoid biosynthetic genes. The primary mechanism regulating carotenoid accumulation in carrot taproot is not at the biosynthetic level. We hypothesize that DCAR_032551 regulates upstream photosystem development and functional processes, including photomorphogenesis and root de-etiolation.

Grzebelus *et al*. (2018) have reported that the Plant Genetic Resources Laboratory of the Research Institute of Vegetable Crops in Skierniewice currently holds 525 accessions of genus *Daucus*. Morphological characterization of these materials has been continuously performed in recent years by the Seed Company PHRO Krzeszowice. Every year a set of carrot accessions is grown in the field trials and evaluated with regard to morphology and chemical composition. Obtained RAPD markers allowed evaluation of diversity on the basis of the DNA fragments distributed through the genome. They can be very informative when a sufficient number of markers is identified. In our study some accessions were clustered closely to each other, which can certainly help in characterizing carrot genetic resources. For breeders and genebank managers it would be valuable to relate RAPD data to morphological characters to improve existing information about the accessions. The attempts for such comparison can be commenced since the method of molecular characterization has been described. At present, information on the genetic distance of carrot by means of RAPD markers can be treated only as a source of additional information in a decision-making process for more efficient management of the carrot genebank collection. Extensive genotypic and phenotypic variation occurs across diverse carrot germplasm, and the recent sequencing of the carrot genome provides an important foundation to expand the application of biotechnological tools to take advantage of that variation for future carrot improvement. Global production trends indicate that growers can expect a continuing increase in the demand from carrot consumers in all production areas. Consumers have benefitted from efforts to increase the nutritional value and flavor of carrots for use in some global carrot markets, and extensive variation in consumer quality traits occurs in diverse germplasm to better meet consumer needs. Carrot growers have benefitted from the development of a reliable system to produce hybrid cultivars with improved uniformity, market value, and disease tolerance, and given the wide variation that occurs in diverse germplasm for production traits, future opportunities exist to further improve disease and pest resistance, weed competitiveness, flowering time, and seed yield. Breeders have developed cultivars well-suited for carrot production in warmer climates, and with the prospects for future warmer, drier climatic conditions in major agricultural regions, genetic variation conferring better adaptation to abiotic stress may be a more urgent need to meet future carrot production and consumer demands. The availability of the carrot genome provides a foundation to tap into the genomic diversity of carrots, to more efficiently and effectively deliver expanded improvements in consumer quality and crop production, to better meet those future demands (Simon, 2019). Stelmach *et al*. (2021) stated that carrot is a crop with a wide range of phenotypic and molecular diversity. Within cultivated carrots, the western gene pool comprises types characterized by different storage root morphology. First western carrot cultivars originated from broad-based populations. It was followed by inter-crosses among plants representing early open-pollinated cultivars, combined with mass phenotypic selection for traits of interest. Selective breeding improved root uniformity and led to the development of a range of cultivars differing in root shape and size. Based on the root shape and the market use of cultivars, a dozen of market types has been distinguished. Despite their apparent phenotypic variability, several studies have suggested that Western cultivated carrot germplasm was genetically non-structured. Both marker systems used in the study enabled detection of substantial variation among carrot plants of different market types, therefore can be used in germplasm characterization and analysis of genome relationships. The presented results likely reveal the actual genetic diversity structure within the western carrot gene pool and point at possible discrepancies within the cultivars' passport data. According to Singh *et al*. (2022) germplasm evaluation, classification, characterization, and preservation are the initial requirements for any crop genetic improvement programs meant to promote economically important traits. Mean performance and range of different expressible traits through ANOVA showed highly significant differences within the various genotypes and helped to evaluate several promising carrot genotypes. The multivariate analysis method was used in this study, which was helpful in resolving different phenotypic and genotypic parameters/measurements of big collections into easy interpretable dimensions. The research work was carried out with eighty-one genotypes to evaluate genetic diversity in a germplasm collection through multivariate analysis. The divergence analysis grouped all eighty-one genotypes into ten clusters and cluster VI was found to be the biggest, comprised of 30 genotypes, followed by IV, which was comprised of 16 genotypes. Cluster X exhibited a high mean value for root weight and anthocyanin content; cluster III showed high value for days to 1^{st} root harvest and root girth, and cluster V for dry matter content, total sugar content, and carotene content; respectively. The maximum distance between clusters was recorded among II and X cluster (43,678.5) follow by I and X (43,199.7), and it indicated that genotypes from these far away clusters could be used efficiently in breeding programs to obtain superior hybrids. Total sugar content (36.14%) contributed most to genetic divergence, followed by anthocyanin content (35.74%). Out off our principal components, PC1 largely contributed towards total variation, followed by PC2. The partial variances (%) from the first to fourth PC-axes were 36.77, 25.50, 12.67, and 10.17, respectively. Genotypes like PC-161, PC-173, PAU-J-15, PC-103, and PC-43 were considered superior with respect to marketable yield and its associated traits such as root length and root weight, and hence can be released directly as a variety. According to Vidhi (2022) carrot genetic resources are in the form of open-pollinated cultivars. The U.S. and European databases are on

Centres on carrot germplasm accessions are as follows:

- USDA – ARS = 723 accessions of *Daucus carota*.
- European cooperative programme for Crop Genetic Resources – ECP/GR = 5037 accessions of D. carota.
- National Centre for Vegetable Crops Research- Carrot Breeding Collection (CNPH), *Empresa Brasileira dePesquisa Agropecuária* (Embrapa) -Brazil = 200 accessions.
- BAZ – Inst, of Horticultural Crops, Germany = 5 species, 25 subspecies, 30 wild relatives.
- National Gene Bank – Rural Development Administration, Korea = 695 accessions.

CROP IMPROVEMENT

Breeding Goals of Carrot

Recent progress in carrot breeding has primarily focused on breeding for resistance and improved quality. Size is only one factor in carrot yield because both undersized and sometimes oversized roots are less valuable to the grower. Root shape, appearance, color, and uniformity also contribute significantly to marketable yield; because of this, hybrid carrot cultivars have become popular as heterosis can increase growth rate to provide marketable size earlier and uniformity is greater. Progress in genetically improving carrot yield has focused on reducing the incidence of root defects through selection for increased uniformity and desired shape (Simon, 1993). Primary carrot breeding emphasis is placed on uniformity, appearance, disease resistance, and quality (Simon, 1993). van der Vossen and Kahangi (2004) stated that the main breeding objectives of carrot are improvements in total yield of fresh roots but also seed (F_1-hybrids in particular), growth rate and earliness, uniformity of root size and shape, lightly shouldered tops without greening, small core and no internal greening, dark orange external and internal colour, smooth skin and absence of large laterals, resistance to cracking and breaking of the root during harvesting and post-harvest handling, taste, flavour, texture, carotene content, strong foliage, non-bolting, resistance to diseases and pests and heat tolerance for warm climates. The most popular cultivars are somewhat conical, as these break less easily during harvesting. According to Vidhi (2022) the breeding goals of carrot are 1) High root yield, 2) Good eating quality, 3) Scarlet/orange colour roots, 4) High carotene content in roots, 5) Uniformity in root shape and size, 6) Thick flesh roots, 7) Thin and self-coloured core in roots, 8) Broad shouldered, cylindrical, uniformly tapering or stump rooted carrot with non- branching habit, 9) Early rooting, 10) Cracking free roots (major gene Ck known for root cracking), 11) Smooth, shiny root, 12) High sugar and dry matter in roots, 13) Slow bolting habit, 14) Heat tolerance, 15) Crown or upper surface (shoulder) free from green colour, flat or slightly up-lifted rather than concave or shrunken, and 16) Resistance to: Alternaria blight (*Alternaria dauci*), Cercospora leaf blight (*Cercospora carotae*).

Selection Criteria of Carrot (Vidhi, 2022)

***Colour and Quality*:** Visual examination of roots, cross section of roots and longitudinal section of roots is effective. Same colour should extend from crown to down tap root. The colour of xylem, phloem and vascular cambium should match as far as possible.

***Sugar and Flavour*:** A thin cross-sectional slice could be cut and tested. The roots with harsh flavour are eliminated. Total sugars which contribute to sweetness and are an important component of general preference can be estimated by a refractometer. Selection for high soluble solids and dry matter is also possible by specific gravity. High dry matter is useful for processors. Percentage dry weight is easily determined by weighing a fresh sample, drying and reweighing.

***Non-bolting*:** Bolting may cause serious losses in yield and quality, hence it is important to apply selection pressure for non-bolting.

***Disease Resistance*:** Susceptible cultivars are generally planted between rows of breeding lines and the spreader row plants are inoculated to ensure the spread of disease. This practice is applicable for both alternaria leaf blight and cercospora leaf spot.

Methods of Carrot Breeding

Open-pollinated Varieties: Carrot is an out crossing species subject to inbreeding depression although numerous inbreds self-pollinated to S_4 or S_5 have been developed. The biennial reproductive habit and difficulty of floral manipulations for controlled hand pollinations complicate breeding and genetic studies (Simon, 1993). In the recent past, mass selection and pedigree selection within the different populations have been the most important breeding methods. Open-pollinated varieties are adapted to different situations. Nevertheless, all efforts to breed varieties with high level of uniformity have been limited by genetic factors originating from breeding methods used for open-pollinated varieties. One reason for this is the heterozygosity of the open- pollinated varieties, while another is the inbreeding depression resulting from radomselfing of plants within the populations. All open-pollinated varieties suffer from inbreeding depression and a limited degree of uniformity. As an out crossing diploid with significant inbreeding depression, adequate population size is vital to maintain population vigor in development of open-pollinated cultivars. The development of most open-pollinated carrot cultivars begins with a pre-existing open-pollinated cultivar and selection is exercised for one or more traits. Population improvement for carrot typically starts with inter crosses among plants of open-pollinated varieties followed by phenotypic mass selection for root shape, smoothness, length and desirable root colour in a particular local production area. Where facilities are available, selection should also be done for disease resistance (Alternaria leaf blight), root quality, cavity spot, nematodes, flavour, carotene content and processing quality. Plants with premature bolting, excessive root cracking and poor plant vigour are always removed. Several of the more successful open-pollinated carrot cultivars of North America began with an inter-cross between two cultivars, like the breeding of 'Imperator'. Other examples include 'Waltham Hicolor' from 'Hutchinson' x 'Turkey Red Carrot' and 'Gold Pak' from 'Long Imperator' x 'Nantes' (Vidhi, 2022). Mass selection: The most promising roots of a given variety or breeding progeny are selected and then planted to gether in the open to cross-pollinate at random. Superb uniformity for given characteristics can hardly be expected from this method. Yet, as exemplified by such varietal types as Red Cored Chantenay and Nantes, important gross characteristics can be maintained with reasonable attention to selection; and, certainly, some improvement is possible (Frazier and Varseveld, 1965). Before 1960 breeding methods were based on mass selection in open-pollinated populations (van der Vossen and Kahangi, 2004).

Hybrids: Generally, with vegetable crops, these first-generation hybrids are made between two inbred lines. The inbred are obtained via continued self-pollination (inbreeding); the major horticultural characters should be uniform, or the F_1 hybrid cannot be maintained as a dependable type year after year. An F_1 hybrid, in reality, can also be considered as any first-generation cross involving two established varieties (or strains), or two breeding stocks of any type. In carrot, and other cross-pollinated vegetable crops, the potential value of F_1 hybrids arising from inbred combinations lies in vastly improved uniformity of various characteristics. Since the search is for improved uniformity for root color, shape, resistance to cracking, smoothness, size and texture, and for freedom from rotting, bolting, branching, internal browning, bitterness or off taste, hollow heart, sloughing when processed, core separation (from cortex), then the ideal theoretical approach is via use of characteristic might to matched by uniformity for an undesirable characteristic. It is the total combination of characters which is important (Frazier and Varseveld, 1965).

There are distinct problems involved in development of the hybrid carrot. It is a biennial and, in cold climates, short cuts are necessary via greenhouses or shipment to warm production areas after induction of potential flowering by cold storage. Loss of high quality roots by various organisms causing decay is serious; and inbreeding generally results in weak vigor and low seed yields (some inbreds are better than others). Maintenance of inbred lines is costly –two lines must be maintained for the male sterile (female) parent, from which seed is obtained; a third line, the pollen-producing inbred, must also be maintained as one of the F_1 parents. These are costly, time-consuming operations for breeders as well as seeds men. As a means of improving the potential of carrot hybrid seed yields, the three-way hybrid is being given considerable thought and some combinations are being made. The male sterile (female) seed parent line, for example, would be a hybrid of two lines, say A x B, which preferably should be uniform in their major horticultural characteristics, yet when hybridized would show hybrid vigor for good seed yield. This A x B male sterile hybrid, with good seed-yielding potential, is planted alongside male fertile (pollen-producing) line C; seed harvested from the A x B plants is, then, a three-way hybrid, (A x B) x C. A great deal of work is required to develop and test such combinations, as well as to maintain them for seed production purposes (Frazier and Varseveld, 1965). Sterile cytoplasms have been identified that condition either petaloid or brown anther male sterility. The maintenance of male sterility is controlled by several genes. Most new carrot cultivars are three-way or single-cross hybrids using one of these male sterility systems (Simon, 1993).

F_1-hybrids with greater uniformity are now increasingly replacing the older cultivars, particularly in Europe, the United States and Japan. Seed production of F_1-hybrid cultivars is based on cytoplasmic male sterility of one of the parent inbred lines. Two types are used: the brown anther type, in which the anthers degenerate before anthesis, based on S-cytoplasm and at least two recessive genes with complementary action, and the petaloid type, in which the anthers are replaced by 5 additional petals, based on S-cytoplasm and at least two dominant genes with complementary action. The development and maintenance of inbred lines is complicated by severe loss of plant vigour after a few generations of inbreeding (van der Vossen and Kahangi, 2004). According to Vidhi (2022) hybrid breeding in carrot is generally based on two systems of cytoplasmic male sterility (CMS) with different genetic backgrounds and origin. These are brown anther type and the petaloid type. The brown anther type (ba) is present in all cultivated orange coloured open pollinated varieties. The phenotype is characterized by deformed, brown coloured anthers without functional pollen caused by a genetic block in meiosis. The type ba results from an interaction of the Sa cytoplasm with two independent nuclear genes (homozygous aa or dominant B).The two complementary genes E and D operate with their dominant alleles as restorer genes. Due to this complex inheritance, many test crosses are necessary for the development of a suitable maintainer. The cytoplasm of the petaloid type (pt) is derived from a wild form of *Daucus carota* L. and has been introduced into many open-pollinated varieties of cultivated carrot. The 'pt' type is characterized by a transformation of the anthers into petals or petal like structures which are unable to produce functional pollen. For the inheritance of this type, an interaction between Sp-cytoplasm and two independent dominant genes (M_1; M_2) was postulated. Backcrosses should be performed by use of the male-fertile genotype (Sp) m1m1, m2m2 as a tester in order to find dominant alleles. Petaloid male sterility was discovered in North American wild carrot. Petaloidy is a homeostatic mutation where a second whorl of petals exists in place of anthers. Petaloid CMS is the most widely used form of male sterility for production of commercial carrot hybrids in North America today. It is stable over a wide range of environments throughout flowering and seed production, although in some genetic backgrounds petaloidy breaks down and late season umbels can be fertile.The incorporation of CMS into carrot inbreds for production of hybrid cultivars is similar to that for other crops. Generally this process begins at the F_2 or F_3 generation with the inter-crossing of individual selected fertile plants to a male sterile plant. In the next generation progeny from the male sterile are examined for male fertility in the process of backcrossing for sterile line development. Presence of male fertile plants indicates the presence of restorer alleles from the original fertile parent. It has been easy to identify and select male sterility maintaining carrot in breds from a wide range of germplasm backgrounds but the incidence of restorers varies widely. The two CMS systems 'ba' and 'pt' generally suffer from instability of male sterility under specific conditions. The instability is mainly influenced by high temperature. Nevertheless, observations over many years have revealed that other factors such as dry conditions, growing time or long day conditions operate provocatively. A strict selection scheme is therefore necessary because carrot is partially andromonoecial, i.e. in umbels of higher order, male flowers can be produced. Umbels of the 5—7th order must be examined carefully. The development of the ms and maintainer lines is very laborious process due to the dominant state of male sterility. Crossing, backcrossing, selfing and testing of the progenies in the following two generations, including isolation of the positive progenies, are characteristic steps in breeding processes. Recently, exchange maintainer lines for the most important ms lines have become available and can be used for seed production of new lines. Pollinator lines which are necessary for hybrid seed production are derived from op-varieties or special breeding lines by using a top-cross system for the testing of general combining ability.

Synthetics: So-called synthetic varieties represent a third method for improving cross pollinated crops. They arise from carefully selected breeding lines, somewhat similar in desired characteristics; when crossed together, these lines result in a superior open-pollinated stock. Some undesirable character which might present if random, mass selection were practiced, can be eliminated by this method. Once selected lines are combined, the synthetic is then maintained by open pollination. It may be that such types will play an interim role in carrot production while hybrids are evolving (Frazier and Varseveld, 1965). In case where extreme uniformity seems to be unnecessary, e.g. for juice or pulp production or for regions with weakly developed agriculture, breeding of synthetics would also be worthwhile (Vidhi, 2022).

Recurrent Selection: This simply represents an extension of the method described in development of the synthetic. For example, after combining several good lines for a synthetic in open pollination, if we select and develop another round of selfed lines from the synthetic superior (after testing) to those originally used, we practice recurrent (repeated) rounds of selection. Time must be taken to determine whether the new round of lines, when again inter-crossed in all directions, are in fact superior to the prior rounds. This process may be repeated indefinitely, as long as progress can be demonstrated (Frazier and Varseveld, 1965). Simple phenotypic recurrent selection has usually been used in carrot inbred development (Simon, 1993).

Backcross Breeding: **C**arrot which is normally cross-pollinated. A desirable parent (for many characters), such as Nantes, is chosen for the recurring parent (continued crossing back to Nantes) with the object of growing the F_2 progeny of each cross, selecting for desired Nantes characters, plus a desired character or characters introduced from the other (nonrecurring) parent. For example, the other parent may have resistance to cracking. The idea is to select crack-resistant roots near Nantes in type, then to hybridize them again to Nantes so that we continue to add genes from Nantes, selecting for resistance to cracking in each backcross generation. In general, at least three or four rounds of backcrosses are necessary for mass transfer of the desired parent (Nantes) genes. More may be required, depending upon complications of the interties of crack resistance with desirable or undesirable inheritance units (genes). This is a very valuable "Intertie" complications are not serious(Frazier and Varseveld, 1965).

***Gene Editing*:** The storage root is widely utilized due to its richness in carotenoids, anthocyanins, dietary fiber, vitamins and other nutrients. Carrot extracts, which serve as sources of antioxidants, have important functions in preventing many diseases. The biosynthesis, metabolism, and medicinal properties of carotenoids in carrots have been widely studied. Recently, with the development of high-throughput sequencing technology, many efficient tools have been adopted in carrot research. A large amount of sequence data has been produced and applied to improve carrot breeding. A genome editing system based on CRISPR/Cas9 was also constructed for carrot research. (Que *et al*., 2019)

Cultivars/Varieties

According to Eagri (2022) and Vidhi (2022) varieties with long, orange colored and smooth roots are preferred in India. Many varieties, both indigenous and exotic, differing in temperature requirement, length, size, shape and color of roots and duration of crop are grown in India. Varieties are also classified into temperate and tropical types. 1) Temperate or European or biennial types require a low temperature of 4-8^{o}C for flowering. They do not produce seeds in plains of India, e.g., Nantes, Half long, Early Nantes, Pusa Yamadagni and Ooty 1 & 2. Tropical or Asiatic or oriental or annual types which do not require low temperature for flowering and they produce seeds in plains of North India. e.g., Pusa Kesar, Pusa Meghali. A brief description of important varieties is given below:

Temperate /European varieties

Nantes Half Long: The variety commonly known as Nantes is evolved at IARI Regional Station, Katrain; roots are small, slim, rough, sweet, cylindrical and stumpy with abrupt tail; the core is small and self colored; yield is 15-20 t/ha in 90-110 days.

Early Nantes: Roots almost cylindrical terminating abruptly in small thin tail,12-15 cm long, orange flesh with self colored core; duration 90-100 days.

Chantenay: Suitable for canning and storage; roots are reddish orange with a length of 11.5–15.0 cm.

Chaman: Developed at SKUA&T, Srinagar; roots long, cylindrical and semi blunt; tolerant to cracking; yields 25-27 t/ha.

Pusa Yamadagni: Developed at IARI Regional Station, Katrain; roots15-16 cm long ,orange with self colored core, slightly tapering and semi-stumpy with medium top; 9-10 t/ha in 90-100 days.

Ooty-1: Developed at Horticultural Research Station (TNAU), Udhagamandalam**:** roots are 25 cm long with deep orange color; yield 45-50 t/ha in 100-110 days. 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.

Tropical /Asiatic varieties

Pusa Kesar: Evolved at IARI, New Delhi by selection from a cross between Local Red and Nantes Half Long. Roots are scarlet in color sufficiently red colored central core compared to yellow or white core in Local; roots stay one month more than the Local red without bolting; contains high carotene (38 mg/100 g).

Pusa Meghali: Selection made at IARI, New Delhi by crossing Pusa Kesar and Nantes. It has
Long orange colored tapering roots with self coloredroots.

Hisar Gairic: Roots long (18.5 cm), tapering, light brick red in color, less fibrous with thin self colored core. Yield 25-30 t/ha.

USES

The swollen taproot of *Daucus carota* is an important market vegetable. The roots are consumed raw or cooked, alone or in combination with other vegetables, as an ingredient of soups, dishes, sauces, juices and in dietary compositions. Large coarse roots are also used as fodder. Young leaves are sometimes eaten raw or used as fodder. In Ethiopia fruits are used against tapeworm. Essential oil extracted from the seed is used for flavouring. Carotene is extracted from the root and used to colour margarines and is added to hen feed to modify egg-yolk colour (van der Vossen and Kahangi, 2004). Carrots can be eaten raw, whole, chopped, grated, or added to salads for color or texture. They are also often chopped and boiled, fried or steamed, and cooked in soups and stews, as well as fine baby foods and select pet foods. Grated carrots are used in carrot cakes, as well as carrot puddings, an old English dish thought to have originated in the early 1800s. The greens are edible as a leaf vegetable, but are rarely eaten by humans.Since the late 1980s, baby carrots or mini-carrots (carrots that have been peeled and cut into uniform cylinders) have been a popular ready-to-eat snack food available in many supermarkets. Carrot juice is also widely marketed. Baby carrots tend to be very tender, but not as flavorful as full grown carrots (NEW, 2022).

NUTRITIVE VALUE AND HEALTH BENEFITS

Nutritive Value: Carrots (orange, young, raw, ends trimmed, edible part 87%) contain per 100 g edible portion: water 88.8 g, energy 126 kJ (30 kcal), protein 0.7 g, fat 0.5 g, carbohydrate 6.0 g, dietary fibre 2.4 g, Ca 34 mg, Mg 9 mg, P 25 mg, Fe 0.4 mg, Zn 0.2 mg, carotene 5.33 mg, thiamin 0.04 mg, riboflavin 0.02 mg, niacin 0.2 mg, folate 28 µg, ascorbic acid 4 mg (Holland, B., Unwin, I.D. & Buss, D.H., 1991). Orange carrot is a rich source of carotenoids (pro-vitamin A)(van der Vossen and Kahangi, 2004). Carrots are a good source of several vitamins and minerals, especially biotin, potassium, and vitamins A (from beta carotene), K1 (phylloquinone), and B6. Carrots offer many plant compounds, including carotenoids. These are substances with powerful antioxidant activity that have been linked to improved immune function and reduced risk of many illnesses, including heart disease, various degenerative ailments, and certain types of cancer. Beta carotene, the main carotene in carrots, can be converted into vitamin A in your body. However, this conversion process may vary by individual. Eating fat with carrots can help you absorb more of the beta carotene. The main plant compounds in carrots are:

- **Beta carotene:** Orange carrots are very high in beta carotene. The absorption is better (up to 6.5-fold) if the carrots are cooked.
- **Alpha-carotene:** An antioxidant that, like beta carotene, is partly converted into vitamin A in your body.
- **Lutein:** One of the most common antioxidants in carrots, lutein is predominantly found in yellow and orange carrots and is important for eye health.
- **Lycopene:** A bright red antioxidant found in many red fruits and vegetables, including red and purple carrots, lycopene may decrease your risk of cancer and heart disease.
- **Polyacetylenes:** Recent research has identified bioactive compounds in carrots that may help protect against leukemia and other cancers (Bjarnadottir, 2019).

The carrot (*Daucus carota*) is a root vegetable often claimed to be the perfect health food. It is crunchy, tasty, and highly nutritious. Carrots are a particularly good source of beta carotene, fiber, vitamin K1, potassium, and antioxidants (Bjarnadottir, 2019). Most of the benefits of carrots can be attributed to their beta-carotene and fiber content. According to the USDA Nutrient Data, these root vegetables are also a good source of antioxidants, potassium, vitamin K, vitamin C, niacin, and vitamin B6 (Nagdeve, 2020). Lawn (2021) reported that white carrot's health benefits are minimal in comparison to the other carrot pigmented varieties. The lack of pigmentation is the main reason. The fiber available in white carrots, while beneficial to health, can easily be found in other fruits and vegetables without need for white carrot consumption. However, perhaps the more outstanding benefit is the usefulness of white carrot as a carotene-free alternative to the common carotene-rich orange carrot. This is a convincing health benefit for individuals with carotene related allergies. The carrot gets its characteristic orange color fromβ-carotene, which on consumption by humans is metabolized intovitamin A. Carrots are a rich source of vitamin A, with a 100 g portion having about five to ten milligrams of carotene. Carrots are also rich in dietary fiber, antioxidants, and minerals. For best nutrition, the carrot greenery should be removed as soon as possible as it takes moisture and vitamins from the roots (NEW, 2022). Carrot is rich in pro-healthy antioxidants both of lipophylic (carotenoids) and hydrophilic (phenolic compounds) characters. Although carotenoid content varies considerably among carrot genotypes, usually orange carrots contain high amounts of α- and β- carotene; yellow carrots contain lutein, the red colour of carrots is due to lycopene, while polyphenol substances, mostly anthocyanins are typical for purple roots WCM, 2022**)**. Each pigment has been carefully developed to obtain more attractive vegetables. At the same time, it resulted in an increased nutritional value. More exactly, while the vitamins and minerals content (with the exception of vitamin A), dietary fiber, carbohydrate, protein, fats, sugars profile and energetic value are more or less the same in all varieties, antioxidant profiles differ. different varieties of carrots are a great source of different types of antioxidants (WCM, 2022a) (Fig.3).

***Orange Carrots**:* They are highest in beta-carotene, contain smaller amounts of alpha-carotene, gamma-carotene, lutein, zeaxanthin. The carotenes are both orange pigments. High in Vitamin A essential for well-being, healthy eyes. Like all carrots these are a good source of fibre, which is vital for healthy gastrointestinal tracts and is linked to reducing cholesterol. Their pre-dominant pigment is beta-carotene; the orange pigment which is converted by the liver to vitamin A which is important for healthy vision. It forms rhodopsin, which the eye needs to see in dim light. This is accomplished by raising the effectiveness of the light sensitive area of the retina. Vitamin A also maintains the surface linings of the respiratory, urinary, and intestinal tracts, and regulates the immune system by helping white blood cells fight infections.

***Yellow carrots**:* They contain xanthophylls and lutein, pigments similar to beta carotene, which help develop healthy eyes aid in the fight against macular degeneration and may prevent lung and other cancers and reduce the risk of astherosclerosis (hardening of the arteries). The major pigment found in the yellow carrots is xanthophyll which helps develop healthy eyes. Studies have shown that intake of xanthophyll-rich foods are associated with a significant reduction in the risk for cataract (up to 20%) and for age-related macular degeneration (up to 40%).

Redcarrots: They are highest in lycopene(another form of carotene), they also contain smaller amounts of lutein, beta-carotene, alpha-carotene. are tinted by lycopene; lycopene is associated with the reduced risk of macular degeneration, serum lipid oxidation, helps prevent heart disease and a wide variety of cancers including prostate cancer. Red carrots contain the pigment known as lycopene which has been associated with a lowered risk of prostate cancer in men and heart disease. It also helps maintain healthy skin.

White carrots: They lack any pigmentation, but do contain other health-promoting substances called phytochemicals, natural bioactive compounds found in plant foods that work with nutrients and dietary fibre to protect against disease. One might say these are the least healthy of carrots. These chemicals may be important in reducing the risk of atherosclerosis, which is the buildup of fatty deposits in artery walls. White carrots are preferably used in baby foods to prevent them from forming orange skin.

Purple carrots: They are highest in anthocyanins, also contain beta-carotene and alpha-carotene and small amounts of lutein and zeaxanthin. They get their pigment from an entirely different class, the anthocyanins, these pigments act as powerful antioxidants that protect key cell components, grabbing and holding on to harmful free radicals in the body. Anthocyanins also help prevent heart disease by slowing blood clotting and are good anti-inflammatory agents. Purple carrots neutralize the damaging effects of free radicals which disrupt the structure of other molecules leading to cellular damage, aging, and various health problems. Anti-inflammatory properties of anthocyanins have also been observed. They neutralize enzymes that destroy connective tissue and they repair damaged proteins in blood vessel walls. Finally, anthocyanins may prevent heart disease by slowing blood clotting and inhibiting the absorption of LDL, "the bad cholesterol."

***Black Carrots**:* They contain anthocyanins, part of the flavonoid family with antioxidant properties. Flavonoids are currently under investigation as anticancer compounds, as free radical scavengers in living systems, as well as inhibitors of LDL (the bad) cholesterol and the black carrot anthocyanins are especially active. The Black variety has anti-bacterial and anti-fungicidal properties and oil made from its seed can help control scalp itchiness and provides essential nutrients for hair growth. The ancient black carrot has been making a comeback, not so much for culinary purposes but as a source of natural food colorants. Carrot is rich in pro-healthy antioxidants both of lipophylic (carotenoids) and hydrophilic (phenolic compounds) characters. Although carotenoid content varies considerably among carrot genotypes, usually orange carrots contain high amounts of α- and β- carotene; yellow carrots contain lutein, the red colour of carrots is due to lycopene, while polyphenol substances, mostly anthocyanins are typical for purple roots. Carrots of Asian origin belonging to Eastern gene pool are more often purple or red and richer in phenolics and have higher antiradical activity than those from the Western gene pool which now have mainly orange roots. One study found that, compared to orange carrots, purple carrots contain twice the amount of alpha and beta carotene, which the body converts into vitamin A, this is in conflict with most other, more recent studies which show purple varieties tend to to have the same or less beta carotene, than orange varieties. It is difficult to be definitive when there are many different variants in the core colour of purple carrots (WCM, 2022c).

Health Benefits of Carrots

Much of the research on carrots has focused on carotenoids. Diets rich in carotenoids may help protect against several types of cancer. This includes prostate, colon, and stomach cancers. Women with high circulating levels of carotenoids may also have a reduced risk of breast cancer. High blood cholesterol is a well-known risk factor for heart disease. Intake of carrots has been linked to lower cholesterol levels. As a low-calorie food, carrots can increase fullness and decrease calorie intake in subsequent meals. For this reason, they may be a useful addition to an effective weight loss diet. Individuals with low vitamin A levels are more likely to experience night blindness, a condition that may diminish by eating carrots or other foods rich in vitamin A or carotenoids. Carotenoids may also cut your risk of age-related macular degeneration. Purple carrots possess an entirely different class of pigments from the other carrot colours - anthocyanins - which act as powerful antioxidants. Red carrots derive their colour mainly from lycopene, a type of carotene believed to guard against heart disease and some cancers. Yellow carrots accumulate xanthophylls, pigments similar to beta-carotene that support good eye health. They also have a number of health benefits. They're a weight-loss-friendly food and have been linked to lower cholesterol levels and improved eye health. What is more, their carotene antioxidants have been linked to a reduced risk of cancer. Carrots are found in many colors, including yellow, white, orange, red, and purple. Orange carrots get their bright color from beta carotene, an antioxidant that your body converts into vitamin A (Bjarnadottir, 2019). The health benefits of carrots include the following (Nagdeve, 2020):

Regulate Blood Cholesterol: High cholesterol is a major factor causing heart diseases, and regular consumption of carrots reduces cholesterol levels. Hence it is a good idea to consume a healthy dose of carrots a few times per week, to prevent heart-related problems. Researchers during a study on the therapeutic value of carrots found that cholesterol levels drop by an average of 11 percent if consumed for three weeks.

Improve Eye Health: Dr. Lindeboom found in his research that a deficiency of vitamin A can cause some difficulty seeing in dim light, leading to night blindness. Since they are rich in vitamin A, a study to determine the antioxidant capacity of seven-colored carrots also suggests they are good for improving eye health and preventing conditions like night blindness from developing as we age.

Manage Diabetes: Carrots are good for blood sugar regulation due to the presence of carotenoids, as per a study published in the journal of *Preventive Nutrition and Food Science* in 2018. Carotenoids inversely affect insulin resistance and lower blood sugar, thereby helping people with diabetes live a normal, healthy life. Carrots also regulate the amount of insulin and glucose being used and metabolized by the body, providing a healthy fluctuation in those with diabetes.

Lower Blood Pressure: Scientific research indicates that coumarin found in carrots is linked to reducing hypertension and protecting your heart. They are rich sources of potassium, which is a vasodilator and relaxes the tension in your blood vessels and arteries, thereby increasing blood flow and circulation. Furthermore, it aids in boosting organ function throughout the body and reducing the stress on the cardiovascular system.

Boost Immunity: Carrots contain many antiseptic and antibacterial properties that make them ideal for boosting the immune system. Not only that, they are a rich source of vitamin C, stimulating the activity of white blood cells, and are an important core of the human body system.

Help in Digestion: Carrots have significant amounts of dietary fiber in their roots. Fiber is one of the most important elements in maintaining good digestive health. Fiber adds bulk to stool, which helps it pass smoothly through the digestive tract, and stimulates peristaltic motion and the secretion of gastric juices. Altogether, this reduces the severity of conditions like constipation and protects your colon and stomach from various serious illnesses. Fiber also boosts heart health by helping to eliminate excess LDL cholesterol from the walls of arteries and blood vessels.

Reduce Macular Degeneration: This is a common eye disease of the elderly that impairs the function of the macula. Research has found that people who ate a high amount of beta-carotene had a forty percent lower risk of macular degeneration. Therefore, carrots are an all-around vision booster.

Improve Oral Health: The organic compounds in carrots are good mineral antioxidants and they also stimulate the gums and induce excess saliva.

Reduce the Risk of Stroke: Eating a carrot every day reduces the risk of stroke by 68 percent. Many studies have a concrete belief in the "carrot effect" on the brain. Lutein, a carotenoid present in carrots, has been positively linked to improved brain health, according to a study conducted by the researchers at The University of Illinois. Studies conducted on stroke patients revealed that those with high levels of beta-carotene also had a good survival rate. Black carrots are loaded with nutrients that offer numerous health benefits. Rich in nutrients, black carrots get their colour from anthocyanins. These carrots help in providing relief from inflammatory disease, treating digestive issues like constipation, boost cognition, bloating, cough, weakness in joints and cramps. The following are the health benefits of black carrots (WCM, 2022):

Provide anti-inflammatory benefits: Anti-inflammatory foods such as the black carrot can help combat inflammation in the body and thus, prevent the risk of several diseases and illnesses. Some studies have shown that foods such as black/purple carrots may help in preventing urinary tract infections.

Rich in antioxidants: Antioxidant anthocyanins work to protect the cells from damage caused by oxidants. They help the body by neutralizing and removing these oxidants from your bloodstream. This provides other benefits like slowing down the signs of aging, making your skin look youthful, and lowering the risk of heart disease. A diet rich in antioxidants is also known to keep your brain active and your gut healthy.

Full of nutrients: They are low in calories and rich in dietary fiber, vitamin K, vitamin C, potassium, and manganese. They are also good sources of carotids that boost eye and skin health. It is important to load up on vitamin C-rich foods during the winter season as it helps in boosting your immunity and protects you against bouts of cold and flu.

Good for your eyes: Anthocyanin-rich foods such as the black carrot may help improve your eye health. Anthocyanins can benefit your vision in many ways – they enhance your vision, improve circulation and also help in fighting macular degeneration.

Aids digestion: The black carrot is full of fibre which helps in regulating digestion. The fermented Kaanji drink that is made using black carrots and mustard seeds is known to boost your digestion during the winter season which tends to become a bit sluggish. Most of the fibre found in black carrots is soluble which absorbs water in the digestive tract and turns into a gel-like substance. This keeps you full for longer and can also help lower blood cholesterol and stabilize blood sugar levels. Black carrots are extremely high in dietary fibre which can help to stimulate peristaltic motion, improves the nutrient absorption in the gut and helps smoothen the bowel movements. Its helps as fibre can help in quick weight loss and lower cholesterol levels. Dietary fibre also regulates the release of insulin and glucose in the body, which makes it an excellent choice for diabetics.

Reducing the risk of neurological diseases: Evidence from new research suggests that eating black carrots on a regular basis could have positive benefits in reducing the risk of neurological diseases such as Alzheimer's. A number of components in black carrots including its anti-inflammatory properties and anthocyanin can play an important role in treating these conditions. The research is not yet conclusive but it's a big step towards understanding Alzheimer's as well as its potential natural treatments **(**WCM, 2022**)**. Eating a purple carrot a day has the potential to protect against cardiovascular disease, inhibit cancer cells and reverse negative effects of a high-fat diet, among other benefits. It comes after a number of research projects indicated this, including last year's University of Southern Queensland study into the ancient carrot variety that found purple carrots were high in anti-inflammatory properties and antioxidants. Results of the pre-clinical trial on rats when fed a high-fat diet got fat, developed high blood pressure, became glucose intolerant and had liver and heart damage but after being fed purple carrot juice for several weeks everything was back to normal. Purple carrots contained up to five times more phenolics and falcarinol than orange carrots and both compounds are being investigated for their potential to protect against cardiovascular disease, inhibit the development of cancer cells in the body and reverse the negative effects of high-fat diets. Purple carrots are best eaten raw to get the maximum benefit but can still be steamed, boiled, roasted and juiced. Purple carrots contain high doses of Vitamin A, which helps to prevent clogging of the arteries and thus helps to prevent strokes. Along with that, they also contain vitamin B, C and E as well as calcium pectate, which is a very good source of fibre, and they help to lower cholesterol levels. They are also very useful in the prevention of macular degeneration. Studies into the health qualities of purple carrots have shown that they give us extra protection against various forms of cancer and heart disease. They contain purple pigments called anthocyanins, and act as anti-oxidants that protect the body (WCM, 2022c). Ethnomedically, the roots are used to treat digestive problems, intestinal parasites, and tonsilitis. Falcarinol, a seventeen-carbon diyne fatty alcohol was isolated from carrot. It was shown to have potent anticancer properties on primary mammary epithelial cells (breast cancer) (NEW, 2022).

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