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Breeding program in Carrot (Daucus carota)

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Abstract

The carrot (Daucus carota) is an important cool season root vegetable grown & consumed globally. Most evidence points to a relatively recent domestication of carrot as a root crop around 1100 years ago in Central Asia, with the most extensive breeding effort underway the last 500 years in Europe. As an outcrossing plant unable to be clonally propagated, breeders developed open-pollinated cultivars until the discovery of cytoplasmic male sterility set the stage for hybrid cultivar development beginning in the 1950s. Color has been an important trait noted in carrots since their domestication, with yellow and purple being the colors of note before orange carrots were first observed in Europe, and with red carrots important in several Asian markets today. Flavor has also been an important trait under selection by breeders to improve consumer quality. The storage root is a rich source of carotenoids, anthocynanin, dietary fiber & vitamins, besides imparting unique flavor & health benefits to consumers. Carrot production in warmer climates has increased rapidly in recent decades, carrot cultivar development for subtropical global regions has become a major focus for breeders. With this, more attention is being paid to the abiotic threats of heat, drought and salinity. As a crop with wide genetic diversity, the prospects for continued improvement are bright.

Keywords: Introduction, Breeding Objectives & Cultivars Developed in India, Breeding Methods

Introduction

Carrot have long been an important fresh market crop around the world. During the last five decades (1967-2017), carrot production (combined with turnip) in the world has increased by 5.5 times from 7.3 to 40.3 mt. This can be attributed to an increase in area by 2.9 times from 0.39 to 1.15 mha and almost doubled productivity from 20.3 to 38.4 t/ha, respectively. Whereas in India, carrot production has increased by 5.81 times from 0.96 to 5.58 lakh tonnes owing to an area increase of 3.32 times from 0.11 to 0.36 lakh ha and a productivity increase of 1.75 times from 9.7 to 16.9 t/ha, respectively (FAOSTAT, 2023). Carrots are distinguished by their distinct root shapes namely, Imperator, Danvers, Triangular, Chantenay, Kuroda, Nantes, Paris Market

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and Ox-heart. The carrot roots are rich sources of four pigments i.e. carotene (orange carrot), lycopene (red carrot), anthocyanins (black/purple carrot), and lutein/xanthophyll (yellow carrot); while rainbow carrot possesses a blend of all these pigments and white carrot lacks the pigment (Singh et al., 2018). Among these, orange, red and black carrots are popular and of economic importance cultivated in a varied climates from temperate to tropics (Singh et al., 2021). The red carrots are used for table, juice, halwa (sweet pudding), pickling; and orange carrots for table, canning, drying and frozen purposes. Furthermore, black carrot (solid purple) is suitable for salad, halwa, fresh and fermented juice, purple tea; and pharmaceutical and nutraceutical uses as a protective food supplement, healthy food colorants and cosmetics (Singh et al., 2022).

A century ago, carrot seed production and breeding was the domain of serious carrot growers and the small regional seed companies that were the norm in North America and in many places around the world. By the mid-20th century, both seed production and breeding became more specialized, and most commercial farmers in North America no longer considered producing their own carrot seed. The commercial open-pollinated (OP) carrot varieties bred and maintained from the 1920s until well into the 1970s were successful in supplying the various needs of both the fresh market and processed vegetable trade.

Figure 1: White, Red, Black, Orange, Yellow and Rainbow tropical carrot genotypes developed at ICAR-IIVR, Varanasi UP

Breeding Objectives & Cultivars Developed in India

Yield, earliness, wider adaptability and tolerance to various stresses are the common breeding goals. In carrots, root size is an important yield factor as both undersized and oversized roots have less market value. Root shape, appearance and color also contribute significantly to marketable yield. The important breeding objectives in carrots are:

- High storage root yield

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- Higher carotenoid and anthocyanin content in roots.
- Uniformity in root color, shape and size.
- Self-colored, small and narrow core.
- Earliness and wider adaptability.
- Delayed bolting, smooth and shiny roots, flat/convex crown, and easy to uproot.
- Free from forking, cracking, root scars, and shoulder greening.

Table 1: Carrot cultivars developed in India

Variety	Breeding procedure, specific features	Institution
Tropical Carrot		
Pusa Kesar	Selection from Local Red × Nantes Half Long	IARI, New
Delhi Pusa Meghali	Pusa Kesar × Nantes	IARI,
New Delhi Arka Suraj	Nantes × IIHR-253, orange colored	
IIHR, New Delhi Punjab Carrot-34	Selection, Red colored root	
PAU, Ludhiana Pusa Rudhira	Red root	
IARI, New Delhi Pusa Asita	First black carrot variety	
Pusa Vasuda	First tropical hybrid using CMS system, red root	
Punjab Black Beauty	Black colored root	PAU, Ludhiana
Punjab Carrot 161	Dark red colored root	PAU, Ludhiana
Pusa Kulfi	Cream root	IARI, New Delhi
Kashi Krishna	Black colored root	IIVR, Varanasi
Kashi Arun	Selection, Red colored root	IIVR, Varanasi
Pusa Vrishti	Heat tolerant tropical variety	IARI, New Delhi
Temperate Carrot		
Early Nantes	Introduction from France, orange root	IARI, Katrain
Imperator	Introduction, orange root	
Chantenay	Introduction, orange root	
Nantes	Introduction, orange roots	
Pusa Nayanjyoti	CMS based temperate hybrid	
Pusa Yamadagini	Selection from EC 9981 × Nantes Half Long	IARI, New Delhi

Breeding in Carrot improvement

Carrot is a cross-pollinated crop (up to 95%), suffering with high inbreeding depression (18–35% for root length, 40-55% for root weight and 62–82% for root yield). The main breeding methods for carrot are population improvement (mass selection, stratified mass selection, gamete selection, family selection, line breeding, recurrent selection and mass-pedigree); backcross breeding; hybrid breeding; and marker-assisted breeding approaches. During the 19–20th centuries, population improvement was applied to accomplish higher productivity, better quality and greater uniformity. In the 21st century, the progress

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made in biochemical, molecular, genomic and biotechnological tools facilitated and diversified breeding approaches towards precise and faster breeding.

Population improvement

Mass selection has been widely used for the genetic improvement of carrots in India. Based on progeny evaluation, modifications including mass-pedigree and family selection are found better and more effective than simple mass selection. Recurrent selection is used for the improvement of quantitative characters under control of additive gene action. Further, the pedigree method of breeding has also been followed by the breeders to combine the traits of economic importance such as root size, color, etc.

Backcross breeding & isogenic line development

Backcrossing is used to transfer one or a few favorable genes of an economic trait into a desirable cultivar. In carrot, this approach has been used extensively for the transfer of CMS in elite backgrounds. ICAR-IIVR, Varanasi has developed many robust petaloid-CMS lines in various backgrounds of tropical carrot such as red root (VRCAR-211, VRCAR-212 and VRCAR-214); orange root (VRCAR-231, VRCAR-234 and VRCAR-241); yellow root (VRCAR-271 and VRCAR-272); black root (VRCAR-251 and VRCAR-252); and rainbow root (VRCAR-291 and VRCAR-292) (Singh and Karmakar, 2021). Among these, two petaloid CMS lines i.e. VRCAR-214 (INGR22160) and VRCAR-252 (INGR22088) have been registered as unique germplasm

Breeding for root quality trait

Carotenoids and anthocyanins are natural pigments abundantly found in various colored roots of carrots and are known to be beneficial for human health. The accumulation of various pigments is varied in the carrot root with different root colors and root tissues. The difference in the accumulation is due to differential expression patterns of pigment biosynthesis genes in specific tissues. Santos and Simon (2002) identified putative QTLs that are associated with the accumulation of ξ-carotene, α-carotene, β-carotene, lycopene and phytoene in carrots.

Breeding for Biotic Stress

Fungal leaf blights in carrots are caused by pathogens Alternaria dauci and Cercospora carotae and bacteria Xanthomonas campestris pv.carotae. The lesions of Alternaria blight occur on older leaves, while the lessions of Cercospora blight form on new leaves. Blight tolerant genotypes and cultivars have been reported which delay the spread rate. (Angel and Gabelman, 1968) and (Lebeda et al., 1988) reported a single dominant gene responsible for resistance to C. carotae. Whereas resistance to A. dauci was found to be under polygenic nature and 11 QTLs were identified (Le Clerc et al., 2015). Further, (Koutouan et al., 2019) observed a positive correlation between content of terpenoids and flavonoids and resistance to Alternaria leaf blight.

Conclusion

Carrot breeding progress has resulted in enhanced productivity, better quality and wider adaptation to varied climate conditions. Many studies on the domestication, germplasm resource, trait inheritance, breeding, and molecular insight of various types of carrots have been reported. For sustenance of carrot production in the tropical region, future breeding work may focus on the development of cultivars

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with smooth root surfaces and cylindrical root shape in red, black and yellow carrots; enhancing the tolerance to biotic and abiotic stresses mainly heat tolerance, water stress and salinity; and improving cultivars with medicinal, pharmaceutical and cosmetic values.

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