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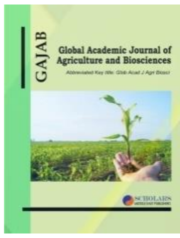

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Review Article

Overview of Genetics and Breeding of Carrot (*Daucas Carota* L.): A Review

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Abstract: Carrot is one of the most important vegetable crops consumed in the world. It is grown for its taproot which contains carbohydrate in large amount. Carrot is domesticated in ancient year and originated in Asian countries. The crop is highly diversified in color, shape, size, nutritional content and so on. Crop diversity identification was done through morphological identification and DNA markers. Carrot is well known for its beta carotene content. To increase the crop yield and quality many breeding programs have been established and achieved some objectives through conventional breeding methods and using some biotechnological tools. So there is a need to have better understanding of crop genetic characteristics and breeding methods are useful in germplasm collection, conservation and utilization, particularly in case of carrot. Since carrot is highly cross pollinated crop appropriate breeding program and method should be used to improve crop yield and quality especially in developing countries like Ethiopia.

Keywords: Genetic diversity, carrot, cultivars, breeding methods, domestication.

1. INTRODUCTION

Carrot (*Daucus carota* L.) is the most important crop of *Apiaceae* family. It is a root vegetable that has worldwide distribution. 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 taproot, which stores large amounts of carbohydrates for the plant to flower in the second year. The flowering stem grows to about 1 m tall, with an umbel of white flowers. The roots are greatly enlarged and sweet with good storage ability. Carrot is 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 recognized as a second center of diversity. During this spread across the world it introgressed with local wild types, some of which have existed since prehistoric times (Carrot, 2011).

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. Five thousand years ago, carrots were first cultivated in the Iranian Plateau (Afghanistan, Pakistan, and Iran) and then in the Persian Empire (Brothwell and Brothwell, 1969 as cited by Carrot, 2011). 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. *altorubens*) and Western Group (var. *sativus*) as described by Vavilov (1926, 1951). Recent studies have shown that Chinese carrot cultivars are genetically closer to Central Asian carrots (those of Afghanistan) than western carrots, although only a few Chinese cultivars were employed in these genetic and diversity analyses (Iorizzo *et al*.,2013; Soufflet-Freslon *et al.,* 2013; Grzebelus *et al.,* 2014; Rong *et al*., 2014).

Carrots are one of the most important vegetables grown in the world, which production has increased recently and reached about 37.2 million tons (FAO, 2013). Almost half were grown in China. Carrot roots are used as a vegetable for soups, stews, curries and pies; grated roots are used as salad, tender roots as pickles. Carrot is rich in pro-healthy antioxidants both of lipophylic (carotenoids) and hydrophilic (phenolic compounds) characters. Although carotenoid content varies considerably among carrot genotypes (Baranski *et al*., 2012) usually orange carrots contain high amounts of α- and β carotene; yellow carrots contain lutein, the red color of carrots is due to lycopene, while polyphenol substances, mostly anthocyanins are typical for purple roots. Carrots can be eaten in a variety of ways. Only 3 percent of the β-carotene in raw carrots is released during digestion: this can be improved to 39% by pulping, cooking and adding cooking oil. Alternatively they may be chopped and boiled, fried or steamed, and cooked in soups and stews, as well as baby and pet foods.

2. Domestication and Genetic Diversity

Central Asia is considered as a center of origin of cultivated carrot. Primitive purple and yellow carrots evolved to the modern edible carrot of Eastern and Western types, which differ mainly in leaf morphology, root color and shape (Simon *et al*., 2008). At present, large genetic variation is observed in cultivated carrot due to fast spread of carrot ancestors from their center of origin to distant geographical regions, and additionally due to a lack of control of random cross pollination between cultivated and wild forms.

Carrot domestication, early selection and then breeding programs resulted in creation of varieties differing in several root morphological traits, tolerance to diseases and pests, and chemical composition. Orange carrots are thus of significant importance for human beings and are commonly grown in Europe and USA, but carrots developing roots of other colors red, yellow or purple are also rich in nutrients and compounds of health promoting properties including carotenoids like lutein or lycopene, phenolics and polyacetylenes. They exhibit high antioxidant activity enabling scavenging of reactive oxygen species, and were shown to be valuable in prevention from cancer, heart diseases and age related dysfunctions (Simon *et al*., 2008).

Description of *Daucus* diversity has been done initially based on morphological characteristics and then supported by a deep insight in composition of the genera specific compounds, recently extended to more health oriented screening (Baranski *et al*., 2012a; Leja *et al*., 2013). Several DNA marker systems like RAPD, AFLP and ISSR allowed distinction between *Daucus carota* accessions represented by wild and edible carrots, thus enabled genetic analysis of biodiversity. Polymorphism of simple sequence repeats (SSR) is a marker system extensively used in the assessment of genetic diversity in many plant species (Kalia *et al*., 2011). Recently, new SSR were identified in carrot (Cavagnaro *et al*., 2011) and were used for the evaluation of carrot genetic resources (Baranski *et al*., 2012b) extending earlier assessment by (Clotault *et al*., 2010). Their use enabled diversity evaluation in genetic resources of edible carrot and lead to identification of two separate carrot gene pools. The first gene pool, being more diverse, comprised a group of varieties of Eastern type and originating mainly from Asia, and the second gene pool included accessions originated from Europe, USA and Japan of Western type. This division was even more clearly evidenced after genotyping using DArT (Diversity Array Technology) markers, that additionally allowed separation of cultivated and wild carrots (Grzebelus *et al*., 2013), and independently depicted by (Iorizzo *et al*., 2013) by SNP (Single Nucleotide Polymorphism) analysis.

2.2 Cultivars of Carrot

Carrot cultivars can be grouped into two broad classes, eastern carrots and western carrots. A number of novelty cultivars have been bred for particular characteristics. Eastern (a European and American continent reference) carrots were domesticated in Persia (probably in the lands of modern-day Iran and Afghanistan within West Asia) during the 10th century, or possibly earlier. Specimens of the "eastern" carrot that survive to the present day are commonly purple or yellow, and often have branched roots. The purple colour common in these carrots comes from anthocyanin pigments (Tiwari, *et al,* 2012). The western carrot emerged in the Netherlands in the 17th century. There is a popular belief that its orange colour making it popular in those countries as an emblem of the house of orange and the struggle for Dutch independence, although there is little evidence for this (Greene, 2012). The orange colour results from abundant carotenes in these cultivars.

2.2.1 Nantes Carrot Varieties

These have sparse foliage, are cylindrical, short with a more blunt tip than Imperator types, and attain high yields in a range of conditions. The skin is easily damaged and the core is deeply pigmented. They are brittle, high in sugar and store less well than other types. Varieties include Nelson Hybrid, Scarlet Nantes and Sweetness Hybrid

2.2.2 Imperator Carrot Varieties

This cultivar has vigorous foliage, is of high sugar content, and has long and slender roots, tapering to a pointed tip. Imperator types are the most widely cultivated by commercial grower. Varieties include Imperator 58 and Sugarsnax Hybrid.

2.2.3 Chantenay Carrot Varieties

Although the roots are shorter than other cultivars, they have vigorous foliage and greater girth, being broad in the shoulders and tapering towards a blunt, rounded tip. They store well, have a pale-coloured core and are mostly used for processing. Varieties include Carson Hybrid and Red Cored Chantenay.

2.2.4 Danvers Carrot Varieties

These have strong foliage and the roots are longer than Chantaney types, and they have a conical shape with a well-defined shoulder, tapering to a point. They are somewhat shorter than Imperator cultivars, but more tolerant of heavy soil conditions. Danvers cultivars store well and are used both fresh and for processing. Varieties include Danvers Half Long and Danvers 126.

2.3 Cytogenetic of Carrot

Carrots belongs to the genus *Daucus*, including species ranging from x=7 to 11. The cultivated species is *D. carota* 2n=2x=18.The nine carrot chromosomes are small and uniform in length. The DNA content in this species is 0.98 pg DNA per 1C nucleus or (473 Mbp), 40% of the DNA is highly repeated. Three chromosomes have satellites. Aneuploids have been reported only in tissue culture cell lines. Inheritance of root color is complex and at least five of interacting genes are involved resulting in colors that range from white to purple. . Most of this work was initiated by (Imam and Gabelman, 1968) and the most recent work on the subject can be found in the papers of (Just *et al*, 2007, 2009). This includes the isolation and mapping of 24 candidate genes in the carrot carotene pathway in 8 of the 9 linkage groups.

3. Breeding of Carrot

There are basically two ways that carrot varieties are produced, either as open-pollinated varieties or as F1 hybrids. Producing open-pollinated varieties is relatively easy to do if the grower is in a climate suited to the reproductive phase of carrots, and (Colley and Myers, 2007) willing to put in the time to learn the intricacies of working with a biennial seed crop and learn the discipline of selecting for a set of traits in an OP without overly narrowing the genetic base of the population.

3.1 Mass Selection

The most promising roots of a given variety or breeding progeny are selected and then planted together in the open to cross-pollinate at random. Superb uniformity for given characteristics, such as color, shape, and taste can hardly be expected from this method.

In eastern part of Ethiopia Haramaya I variety was released by Haramaya University which performs better than commercial Nante variety and farmers variety. The variety was developed through mass selection from 64 genotypes collected from Haramaya district. The genotypes were maintained by farmers for a long period of time through an open-pollinated seed production system. The released carrot variety was found to be superior in marketable and total root yields and other desirable traits to the commercial Nantes variety, which was used as the standard check, and fame's open pollinated cultivar, which was used as a local check. Furthermore, this variety was superior to the Nantes variety and the farmer open-pollinated cultivar in terms of producing lower proportions of small-sized, cracked, forked, and hairy roots (Mohammed *et al*, 2014).

3.2 Hybridization

Most carrot hybrids are usually 3-way crosses, (AxB) xC. This is because the hybrid vigor in a single-cross F1 female seed parent produces much more seed than an inbred male-sterile parent. Single-cross hybrids, AxB, which are more uniform, are used when seed productivity is adequate, depending on the inbred used (Carlos, 2010).

Generally, with vegetable crops, these first-generation hybrids are made between two inbred lines. The inbreds are obtained via continued self-pollination (inbreeding); the major horticultural characters should be uniform, or the F1 hybrid cannot be maintained as a dependable type year after year. An F1 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, onion, sweet corn, and other cross-pollinated vegetable crops the potential value of F1 hybrids arising from inbred combinations lies in vastly improved uniformity of various characteristics. Producing hybrid carrot varieties, on the other hand, requires maintaining a series of parental inbred lines. These include both sterile and fertile male lines for each female parent, as well as a fertile male parental line for each hybrid. To produce hybrid seed, you must first produce seed of each of the parent lines in separate isolated fields at least a year before hybrid production. Then, when the hybrid seed crop is produced, the hybrid seed is harvested only from the female parent, as all of the male parent rows are destroyed.

Today, hybrids have replaced open-pollinated cultivars. Jagosz (2011) documented carrot hybrid breeding based on inbred lines, in which crossing resulted in a heterosis effect, mainly in the case of root yield. On the other hand, heterosis is very rare in the case of root quality traits, which was confirmed by (Chira *et al*., 2008 and Jagosz, 2011). Cultivated and wild carrots can easily hybridize and a considerable amount of genetic variation is exhibited both among and within subspecies, with no apparent signature of domestication bottleneck (Iorizzo *et al, 2013).*Hybrids derived from cross-pollination of cultivated and wild carrot are characterized by woody, mostly white-colored root with low content of reducing sugars, resulting in bad taste and strong tendency for bolting (Rong *et al.,* 2013).

3.3 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 characters which might be 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.

3.4 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.

3.5 Backcross

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 F2 progeny of each cross, selecting for desired Nantes characters, plus a desired character or characters introduced from the other (nonrecurring) parent. 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 approach in plant breeding, providing a highly desirable recurrent parent is available and the "Inter-tie" complications are not serious.

4. Biotechnology of Carrot

Making use of modern biotechnology, including GM, is one way to reduce pressure on agricultural resources, by improving food quality, increasing the productivity of current crops and helping crops adapt to environmental stresses such as drought. The biotechnological modification of plants to increase their nutritional benefits in the food supply is a rapidly expanding field of nutritional investigation. Bio-tech use in plant breeding has evolved quickly over the past decade, incorporating new techniques for targeted mutagenesis, using epigenetics, reverse breeding and other applications in which transgenesis is only used in an intermediate step of the breeding process(Lusser *et al.,* 2012).Scientists Genetically Engineer “Super Carrot” Rich in Calcium.

5. Achievements in Carrot Breeding

Genetic diversity of carrot has been studied using different technologies which will help for breeding programs. Different varieties of carrot have been developed for different desired character such as disease resistance, high yielding, quality, morphological characteristics etc. Also genetically modified carrot has been developed to improve nutritional quality. In Ethiopia some varieties like Haramaya I have been developed through mass selection.

6. SUMMARY AND CONCLUSION

Carrot is produced in most of the world because of its most important function which china is produced half of world production. Carrot is rich in pro-healthy antioxidants both of lipophylic (carotenoids) and hydrophilic (phenolic compounds) characters. Carrot is a biennial cross-pollinated species that rely on insect pollination. Much of this cross-pollination is due to the fact that carrots are protandrous, the anthers on any particular flower shed pollen before the stigma of that same flower is receptive to fertilization. Five avenues are open to the plant breeder in improving a cross-pollinated crop such as the carrot. These are by mass selection, hybridization, synthetics, recurrent selection and back cross methods are breeding methods used for carrot improvement. Also by using biotechnology it is possible to improve nutritional content and quality, resistant to stresses and disease. Future carrot breeders may farther enhance carrot production and profitability by directing their efforts toward cultivar development for different environments. The genetic basis in stored carrots has not been studded well need further research. There has been some indication of genetic variation for bitter flavor development in stored carrot however no selection has to be initiated. Also hybrid varieties should be more developed especially for developing countries.

Conflict of Interest: The author declare there is no any conflict of interest

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