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COCCINIA ABYSSINICA (LAM.) COGN. (ANCHOTE) BIOLOGY, PRODUCTIVITY, AND PROSPECTS OF GENETIC IMPROVEMENT USING BIOTECHNOLOGICAL TOOLS

A review

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ABSTRACT

Coccinia abyssinica (Lam.) Cogn. (local name anchote) is a tuber crop that belongs to the family Cucurbitaceae and it is cultivated for food and medicinal uses. It has relatively high quality of nutrient composition compared to other tuber crops, and is considered as the leading proteinous root crop with a high calcium content. Therefore, cooked anchote tubers are highly recommended for patients with broken or fractured bones. Anchote also contains alkaloids, phenols, tannins, flavonoids, and saponins. Although anchote is principally cultivated for its tubers, farmers prefer propagation by seeds as they are easy to store. Farmers select high-quality fruits for future seeds, based on the size of fruits and tubers. Since diseases and pests rarely affect the tubers, protection is not common. However, the fruit fly can damage the fruits, which predisposes them to decay. Although anchote has very high potential as a food security crop, it is neglected and underutilized and has received very limited research attention. Research published so far covers its ethnobotany, nutritional and anti-nutritional composition, traditional methods of reproduction, *in vitro* reproduction, somatic embryogenesis, anther breeding, and morphological and molecular genetic diversity. This article includes an analysis of previous and current research achievements, presents findings in a comprehensive way, and suggests future direction in crop improvement using biotechnological tools.

Key words: anti-nutritional factors, genetic diversity, *in vitro* propagation, nutritional analysis

INTRODUCTION

Anchote (*Coccinia abyssinica* (Lam.) Cogn.) is a tuber crop that belongs to the family Cucurbitaceae. The genus *Coccinia* includes about 30 species, of which 8 occur in Ethiopia (PGRC 1995). *C. abyssinica* is the only species cultivated for its edible tuberous roots and leaves (Fekadu 2011a). In addition to its nutritional and medicinal values, anchote has economic and socio-cultural importance.

It has perennial trailing shoots. Its tubers vary in shape depending on the environmental conditions, but are generally spherical to cone shaped at maturity. The shoots have simple tendrils by which it climbs up the support (Fig. 1A & 1B). Anchote is monoecious with separate male and female flowers on the same individual plant. It has raceme-like clustered male flowers of variable number and solitary female flowers (Edwards et al. 1995). Two anchote cultivars are known locally as red and white, based on the tuber color.

In Ethiopia, anchote is commonly cultivated at an altitude that ranges from 1300 to 2800 m a.s.l. with an average rainfall of 762–1016 mm (Getahun 1973) in the western and southwestern parts of the country (Aga & Badada 1997). According to anchote germplasm collection records of Ethiopian Institute of Biodiversity, the majority of anchote accessions were collected from Oromia Regional State, mainly from Wellega, western Ethiopia, that has a long history of cultivation and diversified tradition of consumption (Getahun 1973; Hora 1995).

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The plant seems to have its center of origin and diversity in the western and southwestern parts of Ethiopia (Fekadu 2011a; Bekele et al. 2014).

Parasites of fungal, bacterial, viral, nematode, and insect pests rarely attack the plant (Yambo & Feyissa 2013). Although anchote is propagated both vegetatively and by seeds, the later one is commonly used by local farmers. Vegetative propagation is performed by either planting the whole tuber or dividing it into two or more pieces (Hora 1995). In vegetative propagation, high-quality tubers that are obtained from market or any other source can be planted and used as seed sources during the next growing season. Sometimes, tubers are left in soil for regrowth for the coming season. Moreover, anchote planting materials are a source of income for growers. Almost all activities associated with the growth of anchote are done by women (Hora 1995; Wayessa 2018).

With advanced research in the general field of biotechnology, including plant tissue culture, molecular breeding, genetic engineering, and genome editing, much have been done resulting in achievements that were thought impossible some years ago. Orphan and underutilized crops attract very little research attention and they are improved rarely by using advanced biotechnology research. Most of these underutilized crops have very interesting traits of importance that need to be promoted.

Despite the importance of anchote, generally few studies have been conducted and almost nothing has been done with regard to improving the species through biotechnological applications before our first report on *in vitro* propagation (Yambo & Feyissa 2013) and molecular genetic diversity study using markers generated by Inter Simple Sequence Repeat (ISSR) techniques (Bekele et al. 2014), which has been followed by others (Bekele et al. 2013; Guma et al. 2015; Kahia et al. 2016; Abate et al. 2019; Mekbib et al. 2018). The objective of this article is to review research on anchote, present it in a comprehensive way, and suggest future directions of its improvement using biotechnological tools.

Uses of anchote

Anchote is grown mainly for its tuberous roots and young leaves that are also used as a vegetable. It has higher-quality nutrient composition because it contains more vitamins and minerals than other tuber crops, and is regarded as a leading proteinous root crop with high calcium content (Aga & Badada 1997). Thus, it has a high potential to fight protein deficiency in developing countries such as Ethiopia (Hora 1995). Also, the tender leaves are cooked and served with other foods (Bekele et al. 2014; Wayessa 2018). Moreover, anchote is used by the local inhabitants to prepare a variety of food items for traditional ceremonies, special food for guests, and for animal fattening (Hora 1995; Bekele 2007). In the western part of the country, especially Wellega, anchote tubers are cooked and mixed with local butter for "Meskel" holiday celebration in September. A finely prepared anchote dish called "lanqaxaa" is commonly served during weddings, birthdays, circumcisions, betrothals, religious celebrations, New Year, and Thanksgiving Day for the harvest celebrations, as well as on other occasions (Olika 2006). Anchote can be peeled off before or after cooking. For tuber and root crops, Walingo (2009) recommended the importance of proper processing before consumption in order to reduce the effect of anti-nutritional factors and to improve nutrient availability. Fekadu et al. (2013) reported that peeling before cooking is more effective for availability of some nutrient and mineral contents. Currently, anchote meals are often found in hotels in the cities and towns of Oromo, which spreads the knowledge about this plant (Wayessa 2018).

Medicinal uses

Anchote is consumed to treat bone fractures and displaced joints among traditional communities in western Ethiopia due to its high protein and calcium contents (Hora 1995; Aga & Badada 1997). It is also believed that anchote consumption makes lactating mothers healthier and stronger. Abebe and Hagos (1991) reported that juice prepared from anchote is used to treat gonorrhea, tuberculosis, and tumor cancer because it contains saponins as active substances. Anchote plants' tuber extract was used in the green synthesis of zinc oxide nanoparticles (ZnO Nps), which is being tested for its antibacterial and antioxidant activity (Safawo et al. 2018). The antimicrobial activities of the synthesized ZnO Nps were evaluated against several pathogenic bacteria, including *Staphylococcus aureus* and *Salmonella typhimurium*. Moreover, ZnO Nps showed free radical scavenging activity.

Nutritional and anti-nutritional composition of anchote

Fekadu et al. (2013) reported that raw anchote contains substantial amounts of carbohydrates, crude proteins, crude fibers (Table 1), calcium, magnesium, iron (Table 2), and low levels of anti-nutrients (oxalate, tannin, and cyanide), except phytate (Table 3), as compared to other previously reported raw root and tuber plants. According to Fekadu et al. (2013), traditional processing increases the crude fiber content and improves the bioavailability of zinc, but decreases the crude protein, total ash, calcium, zinc, and iron content of the tubers and also reduces anti nutritional compounds, except phytate that may hinder iron bioavailability. The authors also reported that consumers prefer the taste of anchote cooked before peeling.

Table 1. Proximate composition of raw anchote tubers on a dry weight basis (in g per 100 g)

Sample type	Moisture content	Crude protein	Total ash	Crude fiber	Crude fat	Carbohydrate	Gross energy	Reference
Whole	74.93	3.25	2.19	2.58	0.19	16.86	82.12	Fekadu et al. 2013
BAP[a]	81.74	2.67	1.33	3.71	0.13	10.42	53.48	Fekadu et al. 2013
BBP[b]	76.73	3.14	1.99	2.77	0.14	15.23	75.26	Fekadu et al. 2013
WA[c]	71.47	2.77	1.1	1.26	0.41	24.25	111.77	Parmar et al. 2017
RA[d]	78.76	3.58	1.12	0.95	0.26	16.27	81.78	Parmar et al. 2017
Peeled	68.8	3.9	1.7	1.5	0.12	25.5	117.5	Aga & Badada 1997
Whole	73	3.0	2.0	1.6	0.17	22.5	103.5	Aga & Badada 1997
Leaf	78.6	4.5	2.8	4.4	1.2	8.03	-	Guma 2014
Tuber	75.3	2.7	1.8	4.04	0.2	15.68	-	Guma 2014
Stem	84.3	2.2	2.42	5.15	0.69	5.24	-	Guma 2014

BAP[a]: boiled after peeling; BBP[b]: boiled before peeling; WA[c]: white anchote; RA[d]: red anchote

Table 2. Mineral content of anchote (in mg per 100 g)

Sample	Na	K	Ca	Fe	Mg	Zn	P	Reference
Whole	-		119.50	5.49	79.73	2.23	34.61	Fekadu et al. 2013
Whole	67.38	51.46	223.18	-	28.77		29.50	Ayalew 2016
WA[a]	5.763	315.83	81.16	0.98	50.30	0.58	80.41	Parmar et al. 2017
RA[b]	5.87	313.01	59.13	0.90	50.33	0.58	98.72	Parmar et al. 2017
Peeled	16.3	610.4	327	4.6	124	1.8	103.5	Aga & Badada 1997
Whole	16.0	663.46	344	5.5	80	1.8	123	Aga & Badada 1997
Leaf	17.2	283.3	303.8	6.7	328.1	106.1	71.5	Guma 2014
Tuber	13.9	192.1	117.1	3.5	157.8	106.3	54.1	Guma 2014
Stem	23.2	323	313.5	8.6	336	148.4	76.9	Guma 2014

WA[a]: white anchote; RA[b]: red anchote

Table 3. Anti-nutritional content of tubers of anchote on a dry weight basis (in mg per 100 g)

Sample	Phytate	Oxalate	Tannin	Cyanide	Reference
Whole	389.30	8.23	173.55	12.67	Fekadu et al. 2013
Whole	126.64	-	116.31	13.08	Ayalew 2016
Peeled	199.8	7.1	445.4	-	Aga & Badada 1997
Whole	249.6	9.0	632.5	-	Aga & Badada 1997

Guma (2014) reported a higher protein content in anchote leaves and a lower content in tubers. The highest magnesium (336 mg·100 g^{-1}), potassium (323 mg·100 g^{-1}), and calcium (313 mg·100 g^{-1}) contents were obtained from the stem (Table 1). Similarly, Ayalew (2016) reported significant variability of nutrient composition and anti-nutrient content among 44 accessions of anchote and different parts of the plant. The leaves were found to be richer in crude protein than tubers. In contrast, tubers were found to be superior to leaves in utilizable carbohydrates and gross energy. The levels of anti-nutrients were found to be higher in leaves than in tubers. High total phenol and flavonoid contents in anchote leaves followed by the fruit and the lowest in the tubers were reported. Leaves were found to contain the highest content of saponins compared to other parts. The β-carotene content of the leaves ranged from 25.9 to 35.2 μg per g. Regasa et al. (2018) reported the presence of reducing sugar, alkaloids, terpenoids, steroids, saponins, tannins, coumarins, and phlobatannins in anchote.

According to Aga and Badada (1997), the protein, starch, total sugars, reducing sugars, and vitamin A and B contents were higher in peeled than in whole tubers. Mitiku (2016) pointed out that blending of anchote flour with wheat flour resulted in increased ash, fat, and fiber contents. Mineral nutrient content of different anchote accessions are significantly different, so it is important to investigate and select accessions with better mineral nutrient content (Desalegn et al. 2015). Mossa et al. (2018) reported that removal of flower buds had pronounced effect on root mineral nutrient content of anchote. According to Parmar et al. (2017), red anchote tubers contained significantly higher protein content (16.85 mg·100 g^{-1} dry matter basis) than the white ones. The white variant was found to be a more important source of calcium. However, on dry matter basis, the content was similar in both (Table 2).

Propagation of anchote

Farmers select quality fruits for seeds source, based on the size of fruits and tubers (Fig. 1C & 1D). Anchote plants with larger fruits produce smaller tubers, and therefore, smaller fruits are the source of planting material. The seeds are extracted from mature fruit flesh, which is followed by mixing with wood ash (Duresso 2018). The seeds are then dried in the sun to the desired level of moisture to store for the next growing season (Fig. 1E), and then, they are kept in clay or wooden pots or wrapped in a piece of cloth (Olika 2006). Mother plants, known as *guboo*, are planted in the home gardens and used as the source of seeds for further planting.

The seeds are sown at the beginning of summer by broadcasting followed by covering with soil at spacing of about 20 cm. Abera and Gudeta (2007) reported that spacing in the rows highly affects the root yield, whereas spacing between the rows affects the root yield and the average root weight per plant. When spacing within the rows was reduced from 30 to 10 cm, total tuberous root yield increased by 137%.

The rate and percent of germination of anchote seeds were evaluated under different *in vivo* and *in vitro* conditions (Table 4) and wide variations were reported (Yambo & Feyissa 2013; Bekele et al. 2013). This implies that environmental factors can influence both the rate and percent of seed germination. It is well known that duration of seed storage affects not only germination efficiency, but also further growth and development of plants (Negash 1993). Therefore, using fresh seeds from ripe fruits may be advantageous to the yield.

Anchote yield strongly responds to soil fertility, especially to wood ash (Wayessa 2018). Although slash and burn is commonly practiced, farmers also use cattle manure. Gradual reduction in the availability of cattle manure forces using chemical fertilizers (Ta'a 2002; Wayessa 2018). Although chemical fertilizers were found to improve tuber crop productivity, they adversely affect the taste of food. The increase in the price of chemical fertilizers is forcing some farmers to shift to cultivating other tuber crops such as sweet potato and taro, which are non-native species, and this may put anchote cultivation at high risk of genetic erosion.

Anchote is also planted in other areas where other wastes such as wood ash and green manure are available in addition to cow dung (Getahun 1973). Abera and Gudeta (2007) recommended 5–8 tons per ha of farm yard manure or 46/20 kg per ha N/P to obtain high yield of anchote and to enhance soil structure and its nutrient content.

Figure 1. Anchote plant: (A) young plant, (B) maturing plant, (C) unripe fruit, (D) ripe fruit, (E) seeds, (F) tubers; scale bars = 3.0 cm for A, B, C, D and F, and 1.0 cm for E

Table 4. Germination percentage of anchote seeds under different conditions

Sterilant	Seed type	Growth medium	Germination percentage	Reference
-	With coat	Filter paper on Petri dish and maintained in a laboratory	49	Yambo & Feyissa 2013
-	With coat	Soil : compost : sand in 2 : 1 : 1 ratio and maintained in greenhouse	33	
0.15% $HgCl_2$	With coat	Filter paper on Petri dish and maintained in laboratory	66.7	
1% Clorox	With coat	Filter paper on Petri dish and maintained in laboratory	50	
1% Clorox	With coat	Growth-regulator-free MS medium and maintained in a growth room	22.2	
	Without coat	Growth-regulator-free MS medium and maintained in a growth room	42.1	
-	With coat	Sand : loam soil : coffee husk in 2:1:1 ratio	24.5	Bekele et al. 2013
-	Without coat	Sand : loam soil : coffee husk in 2:1:1 ratio	97.3	

Table 5. *In vitro* culture initiation, shoot multiplication, and rooting of anchote on MS medium

	Sterilant	Exposure time (min)	Explant type	Growth regulators	Shoot induction percentage	Number of shoots per explant	References
Culture initiation	2.0% NaOCl	5	Node	3.0 μM BAP	80	-	Bekele et al. 2013
	2.0% NaOCl	5	Shoot	3.0 μM BAP	70	-	
	5% JIK	15	Node	0.025 μM TDZ	84	-	Kahia et al. 2016
	5% JIK	10	Leaf	5 μM BAP + 5 μM 2,4-D	82.5	-	Guma et al. 2014
Shoot multiplication	-	-	Shoot	1.1 μM BAP + 0.5 μM IBA	100	13.1	Yambo & Feyissa 2013
	-	-	Node	3.0 μM BAP + 0.5 μM IAA	100	13.4	Bekele et al. 2013
	-	-	Shoot	3.0 μM BAP + 0.5 μM IAA	100	11.0	
Rooting	-	-	Shoot	0.12 μM IBA	100	7.0	Yambo & Feyissa 2013
	-	-	Shoot*	0.5 μM IBA	91	3.3	Bekele et al. 2013
	-	-	Shoot*	0.5 μM NAA	86	4.6	Kahia et al. 2016

*Shoots are cultured on half-strength MS medium for rooting; NaOCl – sodium hypochlorite

Ecological requirements

Anchote is mainly cultivated at an altitudinal range between 1300 and 2800 m a.s.l. (Getahun 1973). The western Ethiopian highland is mainly characterized by alfisols soil type and located at an altitude of 1800 m a.s.l. This highland receives annual rainfall of 950–1500 mm. The southwestern parts of the highlands are characterized by oxisols, ultisols, and vertisols as the major soil types, located at 1500–2400 m a.s.l., and receive annual rainfall of about 1500 mm to over 2000 mm.

Prospects of biotechnology for anchote improvement

Application of biotechnology tools has been advancing very fast since the invention of recombinant DNA technology in 1970s. New developments in this field together with development of genomics have been advancing research in plant science. Although these advanced tools are first applied to model plants followed by globally cultivated plants, these experiences can also be used to improve neglected and underutilized plants that have high food security potential, like anchote. It appears that anchote is recently attracting attention of researchers to improve it by using biotechnology tools soon after we published our first reports of *in vitro* propagation (Yambo & Feyissa 2013) and molecular genetic diversity study (Bekele et al. 2014).

Plant tissue culture of anchote

In addition to paving the way to biotechnological research, *in vitro* propagation is the method of choice to produce large number of disease-free, high-quality planting materials of horticultural, ornamental, and tree plants. True-to-type plants of sustained tuber quality (Fig. 1F) cannot be produced through seeds. Yambo & Feyissa (2013), Bekele et al. (2013), and Guma et al. (2015) developed *in vitro* propagation protocol for this crop. Further research developed methods of plant regeneration from anther culture (Mekbib et al. 2018) and somatic embryogenesis and plant regeneration (Abate et al. 2019).

***In vitro* propagation of anchote**

There are reports of culture initiation, shoot multiplication, and rooting using nodal and shoot tip explants of anchote on Murashige and Skoog (1962) medium (MS) (Table 5). Yambo and Feyissa (2013) and Bekele et al. (2013) reported the highest mean shoot number (13 and 11 per shoot and nodal explants, respectively). The percentage of shoot induction, shoot multiplication, rooting, and acclimatization was found to be variable depending on culture conditions (Bekele et al. 2013; Yambo and Feyissa 2013; Guma 2014; Kahia et al. 2016). Acclimatization of microplants in a mixture of red soil, compost, and sand in a 2:1:1 ratio gave survival of 68.8% (Yambo & Feyissa 2013).

Bekele et al. (2013) obtained 82.2% survival rate on acclimatization of microplants in a sterile soil mix of top forest soil : coffee husk : sand in 2 : 1 : 1 ratio. In the study of Kahia et al. (2016), microplants survived in 83% in top soil : cattle manure substrate in 1:1 ratio.

Callus induction and *in vitro* regeneration from leaf and nodal explants

Guma et al. (2014) cultured leaf and nodal explants on MS medium containing different concentrations of 6-benzylaminopurine (BAP), thidiazuron (TDZ), and kinetin in combination with 2,4-dichlorophenoxy acetic acid (2,4-D) and α-naphthalene acetic acid (NAA) for callus induction. The highest percentage of callus induction (80%) from leaf explants and 78% from nodal explants was obtained on a medium containing 5 μM BAP in combination with 5 μM 2,4-D. The highest shoot regeneration percentage from callus explants (75%) was obtained on the MS medium supplemented with 2.5 μM BAP, with the mean shoot number per explant being 3.2 ± 0.5. The highest mean shoot number per explant (4.2 ± 0.1) was reported from the MS medium containing 0.025 μM TDZ in combination with 2.5 μM BAP.

Somatic embryogenesis and plantlet regeneration

Abate et al. (2019) obtained highly embryogenic callus on the MS medium containing 36 μM 2,4-D in combination with 4.4 μM BAP in two genotypes. The highest mean numbers of somatic embryos per explant, 36 and 34, were obtained on half-salt-strength MS medium supplemented with 8.9 μM BAP and on full-strength MS medium containing 2.2 μM BAP depending on the genotype. The highest mean shoot number per explant in both genotypes and the highest mean shoot number that simultaneously developed roots (4.0 and 3.75) were obtained on full-salt-strength MS medium containing activated charcoal and 8.9 μM BAP or on full-salt-strength MS medium containing activated charcoal and 4.4 μM BAP depending on the genotype.

Haploid plants regeneration in anther culture

In vitro haploid production has made a remarkable contribution for crop improvement as it significantly reduces the time required to produce homozygous plants through conventional breeding. Mekbib et al. (2018) reported the highest percentage of callus induction on the MS medium containing 4.5 μM each of 2,4-D and BAP and on the medium containing 4.5 μM 2,4-D in combination with 8.9 μM BAP (84.37% and 62.5%, respectively), depending on the genotype. When 2,4-D concentration was reduced, massive greenish-white, loose to friable callus was induced earlier than at a higher concentration of 2,4-D. The medium containing only 2,4-D or BAP did not induce callus. Highest mean shoot number (4.25) was obtained on the medium containing 8.9 μM BAP. Among 10 plants of each genotype examined for ploidy level, 5 or 3 were found to be haploids.

Genetic diversity of anchote

A strong genetic similarity among anchote populations in different parts of Ethiopia, the presence of diverse oral traditions of the origin of anchote in Wellega, and the occurrence of diverse anchote tuber-processing technologies in this region show that most likely, anchote was domesticated in Wellega (Fekadu 2011b; Bekele et al. 2014). It was then distributed to other parts of Ethiopia through Oromo population movement (Fekadu 2011b; Fekadu et al. 2013; Bekele et al. 2014). To improve any plant species either by classical and molecular breeding based on marker selection, the presence of variation is important. Morphological, biochemical, and molecular tools have been used to study the genetic variation. A few studies have been conducted on the morphological diversity of anchote (Mengesha et al. 2012; Wondimu et al. 2014; Duresso 2018), and we reported the first molecular genetic diversity study (Bekele et al. 2014). Mengesha et al. (2012) studied the growth and yield performance of this plant under contrasting environments.

Morphological diversity

Wondimu et al. (2014) evaluated 17 phenomorphic and agronomic traits of yield and the yield-related traits of 49 anchote landrace populations collected from western and southwestern parts of Ethiopia. These populations were grouped into five clusters with highly significant inter-cluster distance. The clustering pattern showed individuals of the populations collected from the same location distributed across the five clusters, which could have resulted from the transferring of anchote seeds from area to area by people.

Duresso (2018) studied flower width and length and showed 61% and 52% heritability, respectively, which indicates that such traits are least affected by environmental changes; so, selection based on phenotypic performance would be reliable. According to this report, genetic advance as percentage of the mean ranged from 2.5% for leaf length to 77% for flower width. However, a relatively high genetic advance as percent of the mean was observed for flower length (58%) and flower width (77%). These high values of heritability and genetic advance of the characters provide information on the existence of wider genetic diversity among anchote landraces, which offers high chances for improving several traits of the crop through simple selection.

Qualitative trait studies showed that anchote has epigeal type of germination, spreading runner vine, yellow flowers, and green sepals, with five sepals and petals. Most plants form tubers of ovate shape, although others may have round, long irregular, or curved shape. The tubers have predominantly cream, cream white, cream purple, or purple red color (Duresso 2018). Reports on the quantitative traits of anchote showed significant variation among flower length, flower width, and root length, whereas root diameter and total root yield per plot did not show significant variation. High phenotypic and genotypic variances were reported for total root yield, whereas low phenotypic and genotypic variances were recorded for all other traits (Duresso 2018).

Flower length and width exhibited higher than 20% genotypic and phenotypic coefficient of variation. When genetic advance is considered in association with high genotypic coefficient of variation, it becomes a strong selection tool (Johnson et al. 1955). Traits of high heritability and low genetic advance may be affected by high genotype and environmental interaction. Some accessions collected from the same location were grouped in the same cluster. In addition to such phenotypic characterization, it is strongly recommended to use molecular markers for characterization of these accessions to get more reliable information about the genetic diversity of this species (Negash 2001). Mengesha et al. (2012) reported significantly high total biomass, days to maturity, and storage root yield variations of anchote between two locations, Jimma and Ebantu, in Ethiopia.

Molecular genetic diversity

Bekele et al. (2014) analyzed the molecular genetic diversity within and among 12 populations of this crop using ISSR-PCR-generated markers. Among 87 scorable bands, 74 were polymorphic. Based on polymorphic bands, they reported within-population diversity ranging from 13.8% to 43.5%. Shannon information index was 0.07–0.23, and Nei's genetic diversity was 0.04–0.156. Analysis of molecular variation (AMOVA) of 51.4% was detected. Based on all diversity parameters, three populations showed the highest diversity, whereas one showed the lowest diversity.

CONCLUSION

The purpose of this review was to comprehensively present the past and current research activities on anchote. It is obvious that very little research had been done on this crop, although recently, it is gaining promising research attention. This is encouraging and paves the way for further advanced future research for the propagation, management, conservation, and improvement of this crop. Low yield and presence of anti-nutritional factors are the main constraints of this crop; so, the different traits that influence these properties need to be focused. Cooking quality and fiber content traits should also be targeted for lower fiber content. So far, there has been no breeding program of anchote, but there is a plan to start it in the near future.

With advances in plant research, especially in the area of plant biotechnology, particularly plant tissue culture, genetic engineering, genome editing, and plant molecular breeding, there might be future hope for improvement of this crop, although the international funding opportunities for such crops are highly limited. *In vitro* propagation and regeneration from different explants and somatic embryogenesis protocols have already been developed, and these protocols can be used for genetic engineering and genome editing of this crop. In addition, the morphological and molecular genetic diversity results reported so far could be used as a starting point for more research in the improvement of this crop using genomic tools including marker-assisted breeding. Integrating both new and traditional technologies for the improvement of this crop is crucial.

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