

Review on Breeding Potato (*Solanum tuberosum* L.) Genotypes for Processing Quality Traits

Ebrahim Seid* Lemma Tessema

Ethiopia Institute of Agricultural Research (EIAR), Holetta Agricultural Research Centre (HARC),
P. O. Box: 2003, Addis Ababa, Ethiopia

Abstract

Potato (*Solanum tuberosum* L.) is a rich source of protein, energy, vitamins and minerals. Potato is in the family Solanaceae with chromosome numbers vary from diploid ($2n = 2x = 24$) to hexaploid ($2n = 6x = 72$). In Ethiopia, the major objectives of potato breeding was targeted at selection of clones for high yield, wide adaptability and resistance for late blight, hence processing qualitative traits were not the main targets in potato breeding program still near future. Therefore, the objective of this review article is to discuss breeding potato genotypes for desirable processing quality traits. Tuber shape is a syndrome of many characters that considers the length/width ratio for describing the overall shape; it varies from compressed/round to long. The yellow pigment in potato tuber flesh is caused by various carotenoids that may protect against cancer, cardiovascular disease, and macular eye degeneration. The genetics of morphological traits are Tuber flesh color, skin color and tuber shape and eye depth. To minimize waste, varieties with long tubers are preferred for French fries and varieties with round tubers are ideal for crisps. Eye depth is an important trait of tuber quality because deep eyes affect the appearance of tubers and add to the cost of peeling in processing factories. Tuber quality traits in potato are specific gravity, dry mater content, starch content, Glycolalkaloids and tuber size uniformity. Specific gravity of potatoes is commonly used by the potato processing industry as a tool for quick estimation of dry matter content, as both are highly correlated. Tuber dry matter content and specific gravity significantly influenced by the interaction effect of growing environment and cultivars. Processing quality usually has relatively low to moderately high heritability, depending on the progenitor materials. Therefore, multiple location tests over several years are often required in order to determine whether a clone has indeed a high processing quality.

Keywords: Potato breeding; Tuber quality; Dry mater content; Specific gravity; Processing.

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1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important tuber crops, is used worldwide for human and animal consumption, and as raw material for starch and alcohol production (Storey, 2007). Potato is the third most important food crop in the world after rice and wheat in terms of human consumption. More than a billion people eat potato worldwide, and global total production exceeds 300 million metric tons (CIP, 2021). It is a nutritious vegetable containing 16% carbohydrates, 2% proteins, 1% minerals, 0.6% dietary fiber and a negligible amount of fat (Gumul *et al.*, 2011). At the highlands of Ethiopia, the potato holds great promise for improving the livelihoods of millions of smallholder farmers. The potential for high yield, early maturity and excellent food value give the potato great potential for improving food security, increasing household income and reducing poverty (Devaux *et al.*, 2014). Potatoes are either consumed directly or they are processed to give products such as chips and French fries, mashed and canned potatoes. Besides being important in human diet, potatoes are also used as animal feed and as raw material for starch production. In general, different cultivars have different uses. Red-skinned cultivars with low dry matter content are used for fresh market, whereas long types are suitable for French fries. The amount of potatoes that are used for processing is increasing. In USA and in several European countries, more than 50% of tuber yield is given to the processing industry (Carputo *et al.*, 2004).

One of the most important aspects related to this versatile crop is its quality. Quality parameters change according to the specific market utilization types, and are often referred to two major categories. The first category groups “external quality”, aspects comprising skin colour, tuber size and shape, eye depth. These traits are deemed very important for fresh consumption where external traits are most likely to influence consumer’s choice. The second category comprises “internal quality” aspects including nutritional properties, culinary value, after cooking properties or processing quality. Internal quality is given by traits such as dry matter content, flavor, sugar and protein content, starch quality, type and amount of glycoalkaloids. The potato needs a continued improvement of quality traits to meet the needs of a changing and demanding world (Carputo *et al.*, 2004).

There are several factors affecting tuber quality, such as the genetic makeup of the cultivar, crop maturity, agronomic practices, environmental conditions, storage temperatures, the presence of pests and diseases. The genetic makeup is the most important factor that influences quality attributes (Carputo *et al.*, 2004). Traits that are genetically controlled can be grouped as follows: one biological traits (proteins, carbohydrates, vitamins,

minerals, reduced amounts of toxic glycoalkaloids; two sensorial traits (flavour, texture, colour); and three industrial traits (tuber shape and size, dry matter content, cold sweetening, oil absorption, starch quality). Breeding for resistance to late blight and high yield have been the main priorities of Ethiopia's potato breeding program in the past years. A lot of efforts have been made and several improved varieties have been released with these characteristics. In addition, the country has a potential in producing potatoes to supply large scale potato processing industries that might not be far from establishment (Wassu, 2016). In Ethiopia, the major objectives of potato breeding was targeted at selection of clones for high yield, wide adaptability and resistance for late blight, hence processing qualitative traits were not the main targets in potato breeding program still near future. However, the need of processing qualitative traits for potato breeders is demanding due to the ever increasing claim of post-harvest quality in potato for emerging industries in the country. Therefore, the objective of this review article is to discuss breeding potato genotypes for desirable processing quality traits.

2. Breeding Achievement in Ethiopia

Strategic potato research in Ethiopia began in 1975 with the understanding of the constraints challenging its production and productivity (Baye and Gebremedhin, 2013). In Ethiopia, more than 39 potato improved varieties (Belete, Gudanie, Dagim and Jalene...) have been released by different research centers and institutions. However, the released varieties have not satisfied the consumer for processing quality purpose. Among 39 potato varieties 37 varieties has been characterized by focusing on developing high yielding, wide adaptability and late blight resistant varieties and also the rest two varieties were developed for processing quality and Fe and Zn purpose, respectively (Figure 1).

Nevertheless, through consistent on-farm technology demonstration integrated with training of farmers and seed growers, several varieties have been disseminated to different potato growing zones of the country. From the use of these improved technologies, farmers have been able to get considerable economic benefit and impacts in their lives and livelihoods. The most important benefit from these technologies, as indicated by the farmers themselves, has been the possibility of growing the potato crop during the main rainy season, which was a key challenge to production due to late blight (Gebremedhin *et al.*, 2008).

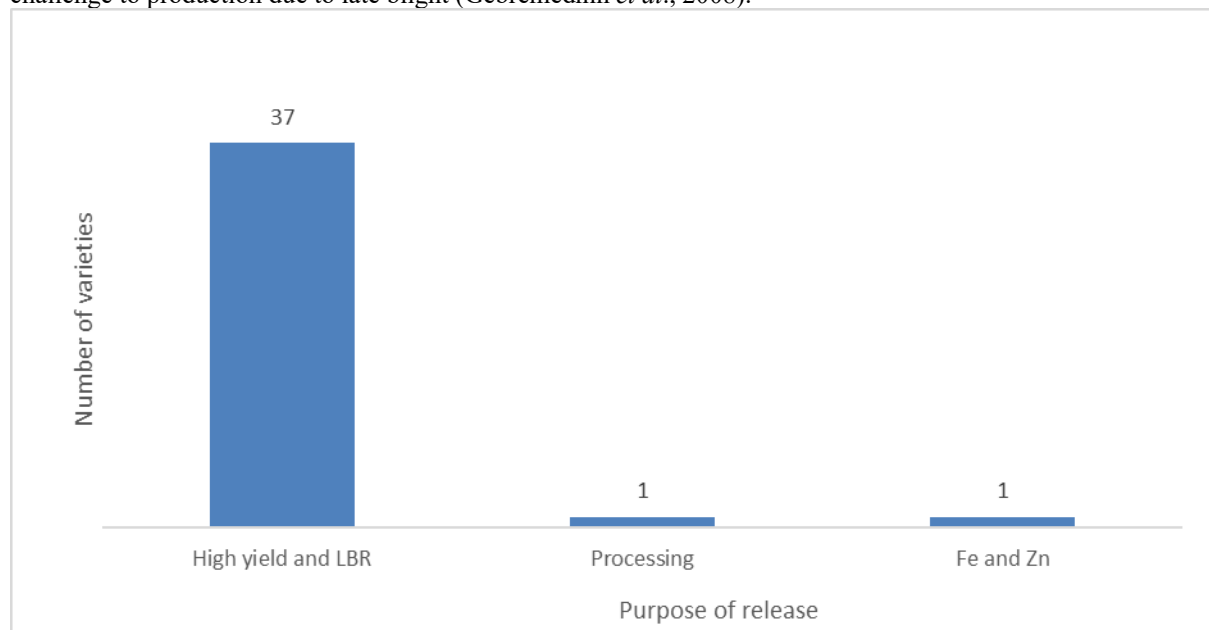


Figure 1. Varieties released achievement in Ethiopia in the past three decade

3. Breeding for quality traits

Most efforts of plant breeding in potato have been focused on increased yield and resistance to late blight (Bradshaw, 2007); breeding for quality has been a second priority (Werij, 2011). Conventional potato breeding refers to the development of new varieties from sexual crosses between pairs of parents with complementary features followed by clonal propagation and selection based on several traits (Brown, 2011). A potato breeder's most important decision is which parents to use in crosses. Based on experience, breeders choose parents and parental combinations that result in a relatively high proportion of desirable offspring (Jansky, 2009). Before making the crossing, it is necessary to measure the genetic variation available for a trait of interest, within cultivated species. For potatoes a large variation for quality traits has been reported (Monteros, 2011). This genetic variability can be exploited by breeders to improve the quality of the crop for the fresh and processing

market. In potato, genetic studies have predominantly been performed using diploid populations (Werij *et al.*, 2007; Śliwka *et al.*, 2012). Tetraploid potatoes have been used less frequently (Meyer *et al.*, 1998).

3.1. Genetic Variation in Potato

The germplasm base of potato is comprised of primitive indigenous landraces and wild *Solanum* species (Ovchinnikova *et al.*, 2011). Advances in molecular techniques have provided greater insight into the taxonomic relationships of potato and there are estimated to be 100 wild species and four cultivated species (Spooner *et al.*, 2007). Potato is a highly heterozygous out crossing species which is asexually propagated, via tubers, for food production and germplasm maintenance. Sexual propagation and the production of 'true' potato seed (TPS) allow breeders to generate genetic variation, and as a clonal crop, there are opportunities to exploit both additive and non-additive variation (Mackay, 2007).

Potato genetic variation vary in ploidy levels (diploid to pentaploid) and show a high degree of diversity in tuber size, shape, skin and flesh colour, storage ability and cooking quality (Andre *et al.*, 2007). As well as indigenous and primitive landraces, there are a number of wild species of the *Solanum* genus of various ploidy levels that can be used as new sources of genetic diversity, for a range of economically important traits, to develop new *Solanum tuberosum* potato varieties (Bradshaw and Ramsay, 2005).

3.2. The Genetics of Morphological Traits

3.2.1. Tuber flesh colour

Tuber flesh color varies from white to purple; it is due to the accumulation of two different classes of pigment anthocyanins and carotenoids (Lewis *et al.*, 1998). Anthocyanin accumulation leads to red, blue or purple flesh colors (Hung *et al.*, 1997). Red and purple-fleshed potatoes have acylated glucosides of pelargonidin while purple potatoes have, in addition, acylated glucosides of malvidin, petunidin, peonidin, and delphinidin (Brown, 2005; Lachman *et al.*, 2009). Colored potatoes may serve as a potential source of natural anthocyanin pigments, since they are low-cost crops (Jansen and Flamme, 2006), and also are a significant source of potato antioxidant micronutrients (Andre *et al.*, 2007; Nayak *et al.*, 2011). Thus, purple and red-fleshed potatoes could be used as novel sources of natural colorants and antioxidants with added value for the food industry and human health (Reyes *et al.*, 2004). Antioxidant values for red-fleshed types ranged as high as 300% of the white flesh, while for purple fleshed antioxidant values reached 250% of the white flesh (Brown, 2005). Several studies have indicated that anthocyanins have high free-radical scavenging activity, which helps to reduce the risk of chronic diseases and age-related neuronal degeneration (Teow *et al.*, 2007). Carotenoid levels determine whether the tuber flesh is white, yellow or orange it is controlled by the single dominant allele at the Y locus on potato chromosome III (Bonierbale *et al.*, 1988)

3.2.2. Tuber skin color

One of the most easily noticeable traits of potato tubers is the skin color. This character ranges from white-cream to blackish. The tuber skin color is controlled by different genetic systems that control the presence and absence of red and blue pigments. The potato R locus is required for the production of red anthocyanins, which have been shown to be derivatives of pelargonidin, while P is required for the synthesis of purple pigments, which are typically derived from petunidin (Dodds and Long, 1955; Lewis *et al.*, 1998). A third locus, I, is required for the synthesis of red or purple anthocyanins in tuber skin (Dodds and Long, 1955). All three of these loci have been mapped in the potato genome (van Eck *et al.*, 1994).

3.2.3. Tuber shape and eye depth

Tuber shape is a syndrome of many characters, that considers the length/width ratio for describing the overall shape, it varies from compressed/round to long (Van Eck, 2007; Werij, 2011). The shape of the tuber is one of the most eye-catching traits of the potato crop (Van Eck *et al.*, 1994). The tuber shape which is most favoured depends on the actor in the potato food chain. To minimize waste, varieties with long tubers are preferred for French fries and varieties with round tubers are ideal for crisps (Van Eck *et al.*, 1994, Kirkman, 2007). Eye depth is also an important component of tuber quality as it adds to the cost of peeling and affects the general appearance (Li *et al.*, 2005).

Tuber shape and eye depth showed a large variation, from compressed to elongate and from shallow to very deep, respectively. These distributions suggest a polygenic inheritance. However, at the diploid level some studies have concluded that the inheritance is monogenic and regulated by the *Ro* locus for tuber shape (Van Eck *et al.*, 1994) and *Eyd* locus for eye depth (Li *et al.*, 2005). To analyze if tuber shape follows a Mendelian model of segregation, the eight classes identified were reduced to three (round, oval and long) as was done in other populations studied (De Jong and Burns, 1993; Li *et al.*, 2005).

3.3. Tuber Quality Traits in Potato

Quality is one of the most important characteristics of potato and its quality is dependent on external and internal aspects of the tuber. However, various workers have pointed out that the true quality of potato is directly linked

with its dry matter content (Dale and Mackay, 1994); an important attribute to both the food and nonfood potato industries determining both the quality and yield of the processed product (Haase, 2004). Consequently, potato varieties with a dry matter content of 20% or higher, a starch content of 13% and above and/ or a specific gravity of 1.08 or higher are the most preferred for processed products (Kirkman, 2007).

3.3.1. Specific gravity

Tuber specific gravity, which is a measure of dry matter content, is a critical processing quality trait. Cultivars with high dry matter are required for the production of fries, chips, and starch. The genotype-environment interaction for specific gravity is generally low, so rankings of cultivars do not change across years and production environments (Killick and Simmonds, 1974). On the contrary, Elfnes *et al.* (2011) and Tesfaye *et al.* (2013) reported that dry matter content and specific gravity of tubers significantly influenced by the interaction effect of growing environment and cultivars. High specific gravity is often noted in tetraploid clones derived from sexual polyploidization in which the diploid parent contains wild or cultivated potato relatives (Buso *et al.*, 2000).

3.3.2. Dry matter content

For the processing industry dry matter content (DMC) is also a critical component. It is a measure of the tuber internal quality, starch is the principal compound, which is a polygenic trait and the effects are located on all chromosomes (Werij *et al.*, 2012). Kirkman (2007) established that a DMC below 19.5% for French fries and 20% for chips potatoes is not acceptable. Similarly, a DMC of more than 25% for French fries manufacturing are not adequate. The DMC and distribution has implications for bruise susceptibility during harvest and effects on cooking type, e.g. a waxy or mealy texture when boiled, organoleptic characteristics and in processed potatoes the final product texture (Taylor *et al.*, 2007). Dry matter content is affected by environmental factors during growth of the crop, such as solar radiation, soil temperatures, soil moisture, fertilizers and haulm killing (Haverkort, 2007). In general, cold climate and short growing seasons reduce DMC, whereas the contrary occurs in warm, sunny locations with long growing seasons and an adequate water supply.

3.3.3. Starch content

Starch is the major component of potato tubers, accounting for 75–80% of the tuber dry weight (Burton 1989). Its grains are small and of uniform size in young tubers. Towards tuber maturity the filling of starch into granules results in increased size and larger size distribution of granules (Burton 1989; Viola, 2000). In growing potato tubers, starch concentration increases towards maturity, and thus, mature tubers have high starch and protein concentrations, but are low in sugar (Burton, 1989). Therefore, the length of growing period of tubers has an important effect on the starch concentration of harvested tubers (Turakainen, 2007). The concentration depends on cultivar, growth conditions and cultivation practices (Burton, 1989).

3.3.4. Glycoalkaloids

Another important attribute that affect the taste of the tubers is glycoalkaloid content. Glycoalkaloids are naturally occurring components in all parts of the potato plant; they are secondary plant metabolites that at appropriate levels may be toxic to bacteria, fungi, viruses, insects, animals, and humans (Friedman, 1997). The glycoalkaloid content can increase during storage and transportation and under the influence of light, heat, cutting, slicing, sprouting, and exposure to phytopathogens. Their presence at low concentrations may contribute to the flavor characteristics of processed potato, but at levels above 15 mg per 100 g fresh weight a bitter taste may be detected (Sinden and Webb, 1972). The consumption of large amounts of glycoalkaloids by humans could produce toxication symptoms ranging in severity from nausea to, in extreme cases, death (Friedman and Levin, 2009; Friedman *et al.*, 1997). The majorities of glycoalkaloids in the potato tuber are located within the first 1 mm from the outside surface and decrease toward the center of the tuber (Friedman, 2006).

3.3.5. Tuber size uniformity

Uniformity of tuber size is of great economic importance, because it directly affects the marketable yield, as well as costs involved in size grading. Most studies focus on the processes of stolon initiation, elongation, swelling, tuber growth and resorption within a given genotype, across a wide range of environmental factors (Ewing and Struik, 1992). Genetic variation in size distribution across a wide range of diploid genotypes was studied by Celis Gamboa *et al.* (2003). Their results suggest that the final marketable yield and size distribution of potato tubers are defined by the degree of stolon branching, the duration of the stolon tip swelling period, the ability of the small growing tubers to reach a marketable size and tuber resorption. Therefore, understanding of the inheritance of tuber size uniformity might not be feasible without first understanding the inheritance of all underlying factors, which are known to be highly genotype-dependent.

3.3.6. Greening and tuber dormancy

Other obvious quality traits are greening and tuber dormancy. Greening is a process that involves the transformation of amyloplasts in the outer layers of the tuber to chloroplasts (Lebecka and Zimnoch-Guzowska, 2004). Greened tubers are associated with an accumulation of glycoalkaloids, which are poisonous for humans and animals. However, there is no direct metabolic link between chlorophyll biosynthesis and total glycoalkaloids content (Percival, 1999). Many factors can influence tuber greening, such as light (Griffiths and

Dale, 2001), maturity of tubers (Buck and Akeley, 1967), time and temperature of storage (Griffiths *et al.*, 1998), production treatments (Lewis and Rowberry, 1973) or tuber size (Parfitt and Peloquin, 1981). Although tuber greening is affected by environmental factors, variability among varieties has been reported by (Reeves, 1988). Tuber dormancy (resting period) of potato tubers is the physiological state after harvest, during which tubers do not sprout (Wiltshire and Cobb, 1996) even when stored under conditions favorable for sprouting. Two molecular mapping studies detected a number of QTLs for tuber dormancy and demonstrated the complex character of this trait (van den Berg *et al.*, 1996). According to Werij (2011) in potato the genes involved in breaking dormancy and the following sprouting action, can be divided in several categories. A first group concerns the genes coding for homeotic proteins and transcription factors (Faivre-Rampant *et al.*, 2004). A second class of genes regulates hormone metabolism and hormone response. Abscisic acid and ethylene are mentioned as requirement for dormancy induction, while abscisic acid maintains dormancy and cytokinins are involved in loss of dormancy (Suttle, 2004). The third group of genes is involved in metabolism of reserve storage molecules (Agrimonti *et al.*, 2007).

4. Tuber Quality Traits for Table Purpose

Quality characteristics are broadly defined as those traits that determine the degree to which tubers are fit-for-purpose for their intended end-use (Simmonds, 1979). Consumers requirements for the fresh market are often associated with the morphological features (shape, depth of eyes, skin and flesh color), together with greening, dormancy and taste. Furthermore these traits are also important for farmers and traders as we demonstrate. These characters determine the acceptability of the tuber. However, for farmer's agronomic traits as late blight resistance and yield are important to consider in the definition of the ideotype of potato for the fresh market. High tuber yield is one of the most important selection criteria of the breeding scheme for the development of new potato varieties and is also an important selection criterion for farmers in Ethiopia.

In the case of potato several traits influence the preference of the farmers, traders and consumers. These characters are mainly agronomic, tuber quality and tuber processing related characteristics. Consumers' requirements regarding tuber quality for fresh market potatoes are often associated with the visual characteristics of the product; in the case of potato the shape, tuber size, skin and flesh color and appearance of the tuber were the preferred characteristics by consumers (Storey, 2007). An important character that affects the taste and safe consumption of potato for the fresh market is total glycoalkaloid content in tubers, which is an important criterion of selection in the potato-breeding scheme, since glycoalkaloids can be passed to progenies during breeding (Kozukue *et al.*, 2008).

Most of the consumers prefer a variety suitable for several types of food preparation (mashed potato, soups, fries, salad or cooked). However, to get a variety with all these characteristics is a difficult task because each food preparation has specific requirements regarding tuber quality. For example for fried potatoes a variety with high dry matter content (DMC) and low reducing sugar content is necessary (Storey, 2007), while, potatoes for soups or stews should maintain their consistence after cooking then a low dry matter content potato is required (Taylor *et al.*, 2007). Culinary uses of potato varieties are related to their texture (Jansky, 2010).

Flavor is due to the combination of taste, aroma, and texture. Raw potatoes are bland, but become more flavorful when heated, as a result of chemical changes (Maga, 1994). Although potatoes are not considered to have a strong flavor, the components of flavor are complex (Coleman *et al.*, 1981). Pyrazines are considered to be among the most important and characteristic components of baked potato flavor (Buttery *et al.*, 1973). They are produced by the non-enzymatic maillard reaction, in which sugars interact with amino acids at high temperatures. There is a strong positive relationship between pyrazines and organoleptic quality in both baked potatoes (Maga and Holm, 1992) and potato chips (Maga and Sizer, 1973).

5. Quality traits for the processing market

For the processing market, tuber shape, eye depth, dry matter content, Enzymatic discoloration (ED) and reduce sugar content (RSC), are crucial traits that affect the product-manufacturing efficiency (Storey, 2007). Round tuber shape is preferred for crisps and long shape is ideal for French fries potatoes. Furthermore, shallow eyes are preferred in both cases (Van Eck, 2007).

Dry matter content (DMC) and the level of sugar content in potato tubers are important factors that affect quality in potatoes (Storey, 2007). Despite dry matter content is strongly influenced by the environment (Laboski and Kelling, 2007), it is genetically controlled and selection of suitable varieties offers the best means of producing high DMC potatoes (Hughes, 1974). The concentration of reduce sugar content (RSC) is genetically determined (Menendez *et al.*, 2002), and selection for low RSC germplasm is possible through breeding evaluation. Tuber maturity, fertilization, temperature and soil moisture are some of the factors that affect the resulting sugar accumulation in newly harvested tubers (Sowokinos, 2007). Enzymatic discoloration, which is a significant problem in the food industry, is one of the main causes of quality loss during postharvest handling (Coetzer *et al.*, 2001). This discoloration results in considerable economic losses for the food processing and

retail industry (Werij *et al.*, 2007).

6. Selection Methods for Tuber Quality Traits

Once genetic variability has been produced, it is necessary to identify selection procedures that reduce time and costs. This is particularly important when breeding programs based on inter specific hybridization are pursued. Indeed, one main constrain in the use of wild species is that, together with useful traits, they can transfer characteristics that are undesired from the commercial standpoint. In the case of *Solanum* species, traits such as long stolons, deep eyes, and negative quality traits can be transmitted. As reported by Pavék and Corsini (2001), transmission of undesired traits has very much limited the use of potato genetic resources. Therefore, after inter specific crosses, time-consuming evaluation and selection are necessary to eliminate unwanted wild-type genes and restore the cultivated improved phenotypes.

Progress in molecular genetics and associated technologies have paved the way for the development of new and powerful tools in aid of potato breeders. Marker-assisted selection is perhaps the most powerful approach that uses DNA markers efficiently. Tagging chromosome segments bearing desired alleles with these markers could be particularly useful in the selection of inter specific hybridization because it efficiently reduces the linkage drag in terms of time and space. The use of DNA markers can be ascribed not only to the use of markers tightly linked to target genes (positive assisted selection), but also in the use of markers specific for the wild donor parent to perform selection against the wild genome negative assisted selection (Barone, 2004).

Negative assisted selection approach to transfer useful traits from *Solanum Commersonii* to *Solanum tuberosum* gene pool within our breeding program. *S. commersonii* is a diploid wild species with several useful traits, such as frost resistance, acclimation capacity, high dry matter content of tubers, resistance to *Ralstonia solanacearum*. However, due to the presence of demissine, tomatine and commersonine, glycoalkaloid content in the tubers of this species is too high. It is well known that potato glycoalkaloids are extremely toxic to humans and animals, and that the glycoalkaloid content of newly developed genotypes should be carefully determined (Korpan *et al.*, 2004).

7. Challenges for Improving Processing Quality Traits

Processing quality usually has relatively low to moderately high heritability, depending on the progenitor materials (Tarn *et al.* 2006). Despite clear differences among cultivars indicating genetic variation, environmental conditions can often give rise to phenotypic variation within cultivars that are almost as great as inter cultivar differences. Therefore, multiple location tests over several years are often required in order to determine whether a clone has indeed a high processing quality (Dale and Mackay, 1994; Love *et al.* 1998). This seasonal or environmentally induced variation creates difficulties for conventional selection and breeding of processing quality traits. Consequently, high expectations have been placed in biotechnological solutions for rapid and effective improvements to the processing quality of potato.

Summary and Conclusion

Breeding potato for quality traits requires a continuous flow of new genes and allelic diversity into the *S. tuberosum* gene pool. The quality in potato is defined as the sum of favorable characteristics of the tuber. A complex set of external and internal quality traits are required for fresh and processing potatoes. External quality traits include tuber shape, eye depth, skin and flesh color but also dormancy and greening are important. Internal quality traits include the content of dry matter (DMC), reducing sugars (RSC), glycoalkaloids, enzymatic discoloration (ED) and nutritional quality. The true quality of potato is directly linked with its dry matter content. For making chips of uniform size, the tubers should be round to oval in shape having a diameter of 45–80 mm. For French fries, oblong to long tubers having >75 mm length are preferred. potato varieties with a dry matter content of 20% or higher, a starch content of 13% and above and/ or a specific gravity of 1.08 or higher are the most preferred for processed products Consumers requirements for the fresh market are often associated with the morphological features (shape, depth of eyes, skin and flesh color), together with greening, dormancy and taste. Furthermore these traits are also important for farmers and traders as we demonstrate.

There are several factors affecting tuber quality. They include the genetic makeup of the cultivar, crop maturity, agronomic practices, environmental conditions, storage temperatures, the presence of pests and diseases. The genetic makeup is the most important factor that influences quality attributes. Tuber dry matter content and specific gravity significantly influenced by the interaction effect of growing environment and cultivars. It is a measure of the tuber internal quality, starch is the principal compound, which is a polygenic trait and the effects are located on all chromosomes.

Conflict of interest

The authors declare no conflict of interest.

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