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Review article

Industry perspective, genetics and genomics of peanut blanchability

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ABSTRACT

Blanching is the process of removing the testa or seed coat (skin) from peanuts, and a genotype's capacity to release its testa is referred to as its blanchability. The genotype, seed quality, harvest date, level of maturity, as well as the length of time and temperature of the post-harvest storage period, all influence peanut's blanchability. This characteristic holds significant value in the production of food items made from peanuts. However, major research on this economically significant trait in breeding programmes has been limited. Blanchability is reported to be a highly heritable and genetically regulated trait, thus breeding and selection should be effective. Blanchability reports to be fixed in the early generations due to its relatively simple genetic control, hence choice of parents which have good blanchability is of utmost importance in a breeding programme. Since blanching percentage possess high genetic control with very low genotype × environment (G×E) interactions, effective selection for improved blanchability can be conducted in early generations. In peanut, blanchability is a great target trait for marker-assisted selection (MAS), but possess few factors that makes it difficult breeding target. These factors, include the high cost operations to measure blanchability and the relatively large seed size in particular, prevent testing in early generations. In this review, we emphasize genetic research on this trait, its relationship to other traits, factors influencing it, methods of measurement, its industrial significance, as well as initiatives and difficulties related to its improvement.

1. Background

Peanut (*Arachis hypogaea* L.) also known as groundnut, a seasonal herbaceous legume and a self-pollinated allotetraploid (2 n = 4x = 40) crop with a genome size of 2.7 Gb (Bertioli et al., 2019; Chen et al., 2019; Zhuang et al., 2019) belongs to the Fabaceae family (Stalker, 1997; Valls and Simpson, 2005). It is a major oilseed crop for more than 100 countries in the world. Globally, peanut is cultivated on 33.2 million hectares of area and possess annual production of 72.3 million tonnes globally with average productivity of 31.7 quintals per hectare (FAOSTAT, 2021). It ranks 13th among the most important list of the food crops and ranks 4th among the most important oilseed. It possesses several nutritional qualities that includes 44–52 % oil content, 22–32 % protein content, 8–14 % soluble sugars and rich amount of Calcium (Ca), Iron (Fe), Vitamin B and E. However, it also possesses anti-nutritional factors such as trypsin inhibitor and phytic acid that can be inactivated by boiling and roasting. Regarding the industrial importance, food products such as salted peanuts, raw or roasted nuts, oil, peanut butter, candies, peanut flour are the primary processed peanut products.

The origin and distribution of peanut is likely trace back to the valleys of Paraguay, where it was first domesticated and cultivated. Cultivated peanut originates from South America (Askew, 2001). Grown in over nearly 100 countries, major producers are China, India, Nigeria, USA, Indonesia and Sudan. Its cultivation is mostly confined to the

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tropical and sub-tropical countries ranging from 40°N to 40°S. Peanut holds an important market value and unique nutritional significance due to high monounsaturated fatty acid (MUFA) in oil content, and high level of nutrients such as minerals, proteins, and vitamins (Arya et al., 2016; Singh et al.; 2021). Globally, about 48 % of peanuts are used for food and 52 % for oil extraction, however in India, 44%, 24 % and 30 % are utilized for food, seed, and oil extraction, respectively (Singh and Singh, 1991; Parmar et al., 2022). In the processing of the peanut for the preparation of the edible products, a major step involves the removal of the testa or seed coat (skin) which is referred to as blanching. The ability of a genotype to release its testa is referred to as its blanchability. This trait is of significant economic importance in the processing of the peanut-based food products. If the peanut cultivar has poor blanchability, the product processing becomes cumbersome, leading to significant re-processing and hence increased both costs and time to produce marketable product.

The blanchability of peanut reports to be affected by factors such as genotype, seed grade, harvest date, degree of maturity, along with time and temperature of the post-harvest storage period (Farouk et al., 1977; Mozingo, 1979). Additionally, this trait is influenced by various factors which include moisture content of seed and skin, storage temperature, thermal and hygroscopic properties of seed, and skin adherence to the cotyledons (Farouk et al., 1977). A 36 kD arachin protein subunit has been reported to be associated with poor blanchability in peanut and hence was considered as a potential indicator protein for studying this trait in various peanut cultivars and breeding lines (Shokraii et al., 1985). However, an strong association has not yet been identified that would allow this protein to be used as reliable selection tool (Cruickshank et al., 2003).

Peanut skin removal is a combinatorial process involving drying, roasting, rubbing between hard and soft surfaces, and finally blowing off loose skins by air current (Janila et al., 2012) or vacuum suction in modern large-scale operations. All these steps are very crucial for maintaining the safety, quality and color of the peanut. Negligence in any of these steps will negatively affect the final products quality. The improper removal of the skin and germs from the peanut cotyledons can lead to the bitter and astringent taste (Barnes et al., 1971; Hoover, 1979; Willich et al., 1952; Wright and Mozingo, 1975).

2. Industrial importance

Blanchability, or the easy removal of the entire testa from the seed by heating and abrasion, is a very desirable peanut quality trait. For the production of a variety of confectionery items such as peanut butter, snack food, snack bars, peanut flour and others, the shellers and blanchers often blanch a large percentage of the peanut intake (>80 %) before selling to peanut processors (Sanders et al., 1999**;** Singh et al., 1996). Blanching involves considerable expenses, which are estimated to be similar to shelling and crop production costs (R. B. Hansen, Peanut Company of Australia (PCA), pers. comm., 2009) (Wright et al., 2018). This value-adding method involves cleaning and sorting the peanut seeds, which aids in aflatoxin reduction by efficiently removing damaged and discolored seeds using color sorting (Whitaker et al., 2005).

Blanchability is highly influenced by genotype (Cruickshank et al., 2003; Janila et al., 2012; Singh et al., 1996; Wright et al., 2018) as well as maturity and harvest date (Farouk et al. 1977; Mozingo, 1979), as a result, any genotypic or environmental effect that reduces seed blanchability can significantly increase costs of processing. Some genotypes with high split seeds and poor blanchability may be more suited for making candies and butter. For these applications, a high percentage of blanched splits is desired, as it facilitates easier germ removal and thereby lowers aflatoxin contamination (Diener et al., 1982).

A study by Wright et al., 2018, found that high heritability for the blanchability trait and the ability to conduct effective phenotyping on a small sample size means that future breeding and selection for this quality trait in global peanut breeding programmes should be possible. Peanut butter manufacturers in the United States blanch peanuts after roasting, rather than blanching them before roasting, as is more common in Australia. Poor blanching genotypes may have more acceptable blanching features with the more vigorous post-roasting treatment, as determined by the pre-roasting blanching procedure. This could explain why US peanut breeders aren't receiving market signals about the need to select for superior blanching genotypes. It is also important to note that some manufacturers prefer peanuts with low blanchability, where skin retention is a preferred requirement (e.g. beer nuts and seed products with various confectionary coatings).

Studies have been done on the heritability estimates for the peanut blanchability trait. Based on the consistently high heritability across environments, strong genotypic variability, and low G×E interaction, blanchability selection should be particularly successful in a limited set of environments and feasible in early generations. Based on an early-generation selection experiment, the trait was originally assumed to be under oligogenic control but now is understood to be regulated by a major gene (or genes) (Cruickshank et al., 2003).

Poor blanchability is governed by a dominant or semi-dominant gene, however, no evidence was provided in the publication to support this claim (Shokraii et al., 1985). Later, Cruickshank and co-workers discovered that seeds sampled (300 g) from bulk $F_{2:3}$ rows responded well to blanchability selection, but they made conclusion that single-plant selection in early generations or in a recurrent backcrossing programme was not possible due to the requirement of large amount of seeds for the blanchability test (Cruickshank et al., 2003). Understanding the underlying genetics of any characteristic is essential for increasing the effectiveness of the breeding program. Segregating populations should be analyzed to determine how many genes are involved and to validate whether it is under oligogenic control.

3. Phenotyping methods

There are various methods reported to use in the blanching process, including spin-blanching, water-blanching, alkali-blanching, and hydrogen peroxide-blanching, dry blanching.

3.1. *Spin-blanching*

Spin-blanching is a mechanical blanching method where raw groundnuts are rapidly rotated in a specialized spin-blanching machine while being exposed to hot water or steam. The heat softens the outer skin of the peanuts and makes it easier to remove. The centrifugal force helps in the removal of the skin or outer covering (St. Angelo et al., 1977).

3.2. *Water-blanching*

Water-blanching involves immersing peanut in boiling water or steam for a predetermined period, followed by cooling. When exposed to the hot water or steam, the heat softens the outer skin (St. Angelo et al., 1977), making it more pliable and loosens it from the inner nut. It is one of the most widely used blanching methods.

3.3. *Alkali-blanching*

Alkali-blanching is a process in which the peanuts are briefly immersed in an alkaline solution, such as sodium hydroxide. The alkali solution is heated to an appropriate temperature. The prepared peanuts are immersed in the heated alkali solution. The immersion time can vary but is generally short, usually a few minutes. After immersion, the groundnuts are quickly rinsed with water to remove any residual alkali solution. The alkali treatment effectively softens the outer skin or shell of the groundnuts (Shackelford., 1974). This softened skin can be easily removed through mechanical or manual means. The skin is separated

from the inner nut, leaving blanched peanuts.

3.4. Hydrogen-peroxide blanching

Hydrogen peroxide blanching involves treating peanuts with a hydrogen peroxide solution, followed by a rinse. It is used to remove pigments, microbial load, and off-flavors (Evranuz, 2000). Its crucial to ensure that the concentration of the hydrogen-peroxide solution and the immersion time are controlled to meet safety and quality standards. Proper rinsing is essential to remove any residual hydrogen peroxide from the blanched peanuts.

3.5. Dry blanching

Dry blanching is the most utilized blanching method and is generally carried out at an industrial level. It involves the utilization of conveyor belts on which the peanuts are placed and then moved through large hot-air ovens in which the airflow is in the alternative direction in successive zones (Adelsberg and Sanders, 1997). In this process, the peanuts are heated in the sequential temperature zones, from 30°C to 90°C and then cooled in the last zone, with 45 minutes of total processing time. This leads to moisture removal and loosening of the peanut seed coat, and after cooling the seed coats are then mechanically removed (Sanders et al., 1999).

This method is the most prevalent method used in industry and research. The principal mechanism behind blanching is the difference in thermal expansion that leads to contraction of seed and seed coat, ultimately loosening the seed coat (Paulsen and Brusewitz, 1976). Microwave processing was proposed as an alternate to the traditional method for time, cost and energy saving. In addition, the microwave system due to shorter heating times allows better nutrient retention, improves quality characteristics such as texture and flavor, and leads to enhanced production (Giese, 1992). In the microwave system, peanut blanching occurs at the temperature over 85°C with final moisture content of 6 % or lower. It has been observed that in dry blanching, exposure to temperature above 35°C, can lead to the formation of anaerobic by-products that produce off-flavor and decrease the positive taste attributes such as roasted peanutty flavors. The study by Schirack and co-workers suggested that effective blanchability was correlated with high process temperature and corresponding low moisture content. The microwave technology provides an aid to reduce the time for producing sufficient heat to dry peanuts while minimizing the potential for off-flavors. The best blanchability was observed to be attained at the higher process temperatures with greater loss in moisture content. Unfortunately, this has impact on storage shelf life of the blanched peanuts (Schirack et al., 2007).

4. Phenotyping protocol for dry blanching: most prevalent method in industry and research

In early 2000s, the American Society of Agricultural and Biological Engineers (ASABE) published a phenotyping protocol for determining blanchability using the laboratory blancher which was designed by Wright and Mozingo in 1975. As per the protocol, a seed sample weight of about 250 gm is pre-heated at 200°C for 9 min, this pre-heating will lead to lowering of moisture content to 3.75–4.0 %. The samples are then cooled at room temperature. For extra-large and medium size seeds, the blanching duration is set to be 180 ± 25 sec and 240 ± 25 sec, respectively, with air pressure at 121 ± 0.5 kPa (17.6 ± 0.1 psi) (Fig. 1) (Janila et al., 2012). Moreover, the studies conducted by Wright and co-workers; has made modifications in the available protocol and developed a phenotyping protocol to be utilized for blanchability evaluation from seeds derived from a single plant produced in early generations after crossing (Wright et al., 2018).

The description of standardized protocol for blanching of the peanut samples is briefly mentioned here. Firstly, the standard peanut grading is performed where the seed size used ranged from 9.1 to 10.7 mm diameter based on the genotype. The main aim of grading is to minimize the variability in seed size and maturity. Next, the pre-blanching weight was recorded. Thereafter, begins the blanching process where the seeds must be placed in the trays and heated at 95°C in the oven for 1 hr. Then, the heated seeds must be cooled down at room temperature, for over next 8 hrs. The samples have been processed through blancher for ten seconds per sample. The weight of the blanched seeds and splits should be then recorded, followed by calculating the blanching percentage, using the formula below:

$$\textbf{Blanching\%} = \textbf{100} \times \frac{\textbf{Blanched weight}}{\textbf{Pre} - \textbf{blanching weight}}$$

In early generations, there is a limited seed-set, hence a phenotyping methodology that utilizes small sample size is preferred as it also provides an opportunity for good blanching phenotypes in pedigree or in single-seed-descent programs. Furthermore, the capacity to phenotype individual plants within recombinant inbred line populations allows for precise and speedy blanchability phenotyping in genetic mapping investigations intended at establishing new molecular markers for this trait and its associated regulatory genes. Furthermore, the high

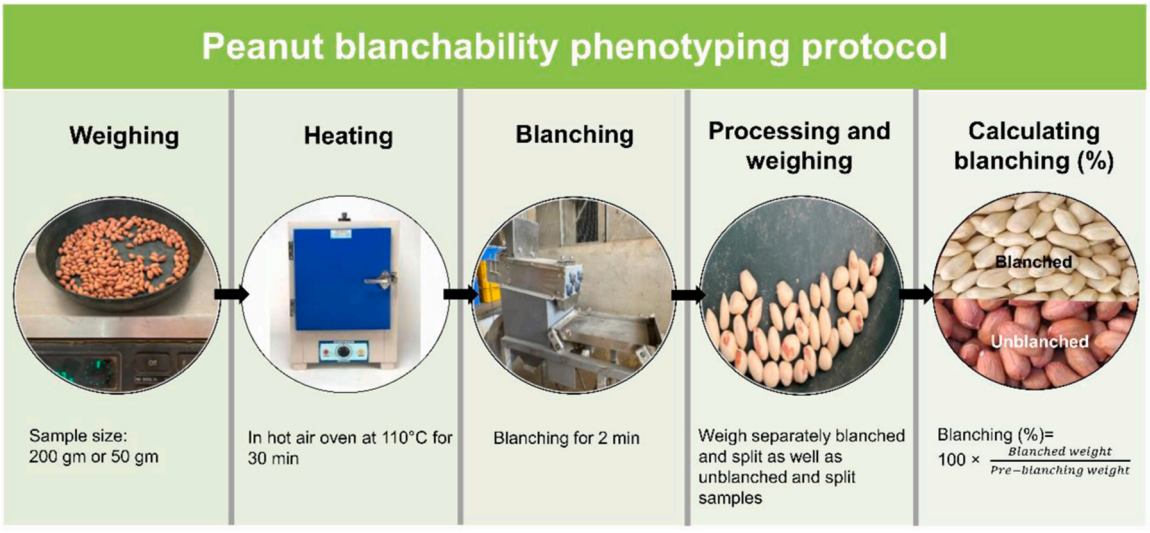

Fig. 1. Protocol for phenotyping the blanchability of peanut.

heritability and low G×E interaction effect indicate that this trait is relatively stable, which is crucial for moving new commercial varieties to different production sites.

5. Factors affecting precise blanchability phenotyping

The blanchability of a seed is reported to be affected by genotype, seed grade, and date of harvesting (Mozingo, 1979), along with pre-treatments of seeds (Farouk et al., 1977). There are various factors that must be taken into account while estimating the blanchability percentage. These include, moisture content, time-temperature, genotype, sample size, abrasion time, and replicates. When considering mechanical blanching methods, the lower relative humidity of the drying air and the faster drying rate led to increased blanchability at constant drying temperature. When other variables remain constant, decreasing seed moisture content also enhances blanching. Under constant drying air temperature and relative humidity, repeated rewetting and drying cycles for Spanish peanut seeds enhance blanchability. Skin moisture content and moisture history (i.e., cycles of humidification and dehumidification) are significant factors that influence peanut blanchability as well (Farouk et al., 1977), drier skin appears to improve blanchability.

It has been noted that skin tensile strength decreases with increasing temperature (and higher drying rates). This clearly shows that quick drying rates, low moisture content, and repetitive wetting and drying processes expose plants to stress conditions repeatedly, which ultimately reduces skin tensile strength by reducing adhesion between the seed and the seed coat and improves blanching (Farouk et al., 1977; Woodward, 1973). Lower temperature techniques are superior to high temperature processes for blanching peanuts because the low temperature blanching preserves flavor and shelf life (Woodroof, 1983).

5.1. Moisture content and time-temperature

The moisture content and time-temperature hold an important role in determining blanching efficiency. It has been reported that with increasing temperatures and moisture loss, the process of blanching becomes more efficient (Katz, 2002; Paulsen and Brusewitz, 1976). A reduction in moisture content (5.5 to <4 %) at the temperature of 87.7°C for 45 and 60 minutes, and 98°C for 30, 45 and 60 minutes resulted in blanchability above 75 % (Adelsberg and Sanders, 1997). While, if the temperature exceeded 96.7°C, with moisture content lower than 6.0 %, the blanching efficiencies are observed to be more than 84.5 %. The quality and oxidative stability of the peanuts depends on the temperature and time parameters utilized during blanching.

Due to the limited seed supplies available in the early generations of the breeding cycle, the APBP (Australian Peanut Breeding Programme) protocol sometimes becomes difficult to follow as it requires sample size of 200 gm and a 20 second exposure to abrasion in the blancher. Hence, there is a necessity to establish a new protocol which requires less seed quantity by appropriately testing factors including genotypes, sample sizes, and abrasion times. A phenotypic scale based on the blanching percentage has been defined, that categorizes the different peanut genotypes into three classes: good, average, and poor blanchers. The genotypes possessing > 85–90 blanching percentage belongs to the category of good blanchers, whereas the genotypes with 70–85 blanching percentage are the average blanchers. While, the poor blanchers are those that have < 70 % of blanching (Cruickshank et al., 2003; Schirack et al., 2007).

5.2. Plant genetic makeup, sample size and abrasion time

Blanching efficiency has been observed to be highly associated with the genetic architecture of the plant, hence precise selection of the parental genotype is critical for improved blanchability (Cruickshank et al., 2003). The blanching quality of peanut genotypes is affected by the growing season environment (Farouk et al., 1977; Mozingo, 1979). It has been observed that the effect on total blanchability was pronounced, with the post-rainy season crop yielding lower mean values. In the post-rainy season, the proportion of blanched whole seeds was only moderately impacted, while the proportion of blanched split seed decreased dramatically, that results in a higher proportion of unblanched seeds as observed in India. Parental selection could make an important contribution to breeding for improved blanchability. In a study by Wright and co-workers, it has been found that the interactions of genotype × abrasion time and genotype × sample size were highly significant ($P < 0.001$).

This shows that genotypes typically have varied effects on sample size and abrasion time. Additionally, the interaction between sample size and abrasion duration was found to be significant ($p = 0.043$), showing that the two factors significantly altered the percentage of samples that blanched compared to the control group. Thus, when inferior blanching genotypes are considered, sample size and abrasion time can also differentially affect a genotype's blanchability score. Notably, due to a higher incidence of seed abrasion time, blanchability might rise significantly when using fewer sample sets. It has been discovered that a modest sample size (50 g) with an abrasion duration of 10 sec can also be used to accurately test the phenotypic characteristics of blanchability on single segregating plants (Wright et al., 2018). Having check lines with known poor and good blanchability values grown under the same conditions is also recommended when testing new genotypes.

5.3. Air pressure

The air pressure in the blancher has an important impact on the quality of peanut blanching. With a rise in atmospheric pressure, the proportion of unblanched seed reduced, but the proportion of blanched split seed increased. With increased air pressure up to 15 psi, the blanching percentage of whole seed increased as well, before declining, owing to a higher percentage of blanched split seed. Blanchability is also influenced by blanching time and temperature. The percentage of unblanched seed reduced as the preheating temperature was raised, however, after 190°C, the drop is rapid. Throughout the temperature range investigated, the blanching percentage of whole seeds remained relatively constant. After 190°C, the blanching percentage of split seed increased swiftly. These findings were similar to those of previous researchers, who discovered that good laboratory blanching tests could be achieved by operating the blanching apparatus for 120 seconds at 17.6 psi (Barnes et al., 1971; Singh et al., 1996).

6. Genetic variability

Most of the research for the blanchability trait has been conducted on the runner type peanut and several laboratory-scale blanchers made to assist breeding programs to identify the genotypes with high blanchability (Barnes et al., 1971; Hoover, 1979; Singh et al., 1996; Wright and Mozingo, 1975). Additionally, several methods and protocols have also been established for the estimation of blanchability using the laboratory blanchers (American Society of Agricultural and Biological Engineers, 2006).

The blanchability trait has been identified to be fixed in the early generations (Cruickshank et al., 2003; Mozingo, 1979). Therefore, the selection of the parental genotypes with high blanchability must be made carefully. This will ensure a high probability of success in confectionary peanut breeding programs with the resultant high performing progenies exhibiting high blanchability. Also, there has been research conducted for developing a cost-efficient and rapid phenotyping method along with consideration of G×E interaction for establishing optimal selection protocol (Wright et al., 2018). However, enough attention has not been given to this economically important trait in breeding programs.

Genomics-assisted breeding (GAB) has been an emerging technology for improving several important traits in peanut. With the rapid development of the next-generation sequencing (NGS) technology, various peanut genomic resources have become progressively available (Pandey et al., 2020, 2016; Varshney et al., 2009). The high quality of reference peanut genomes for cultivated tetraploid (Bertioli et al., 2019; Chen et al., 2019; Zhuang et al., 2019) are now available, along with genome assemblies of diploid progenitors (Bertioli et al., 2016; Chen et al., 2016). In addition, the gene expression atlases are also available to verify the functions of discovered candidate genes at various stages in subspp. *hypogaea* (Clevenger et al., 2016) and *fastigiata* (Sinha et al., 2020). This development has opened many ways for high density genetic mapping, the discovery of candidate genes, and development of functional markers (Fig. 2). The identification of the closely or tightly linked markers is a prerequisite for the deployment of GAB to perform the marker based early generation selection (MEGS) (Parmar et al., 2021). Among all the trait mapping approaches available, sequencing-based genetic mapping has been the most suitable method for performing high resolution mapping for candidate gene discovery and marker development (Pandey et al. 2020). Advanced sequencing technologies can generate thousands of data points for conducting high resolution trait mapping using NGS technologies like genotyping-by-sequencing (GBS), whole genome re-sequencing (WGRS) or SNP array-based genotyping (Pandey et al., 2020, 2017).

In the recent study, two strong QTLs for blanchability have been identified and validated in an independent population by performing QTL-seq analysis. Further, the Kompetitive Allele Specific PCR (KASP) markers were designed from the most significant SNPs from the QTLs on B01 (Arahy.11_15,264,657 Arahy.11_16,329,544, Arahy.11_18,994,278) and A06 (Arahy.06_108,665,514, Arahy.06_108,812,907) (Korani et al., 2021). The linkage drag associated with two prominent *A. cardenasii* introgressions have been discovered, confer disease resistance and increased blanching resistance, hence it provides an opportunity for developing the disease resistant and blanching resistant cultivars that are uniquely suitable for confectionery (Korani et al., 2021). Although, blanchability has been neglected so far, however there have been efforts made to identify the marker-trait associations (MTAs) linked with high blanchability among the diverse panel for variety of traits, including blanchability in peanut to develop parental peanut varieties with higher blanchability to be utilized as donors in peanut breeding programs (Fig. 3). The cultivated agronomic type of peanut includes, 'Spanish Bunch', 'Valencia Bunch', 'Virginia Runner', and 'Virginia Bunch'. These botanical types possess distinct phenotypic characters, such as branching habit, seed, and pod size as per the suitability to the specific cultivable environments.

In the study conducted at ICRISAT, the genotypes ICGV 03136, ICGV 05168 (post-rainy season) and ICGV 01395, ICGV 03137 (rainy season) showed the highest percentage of blanched splits, hence these genotypes will be best suited for candies and peanut butter preparation (Janila et al., 2012). There has also been a reported significant influence of growing season on the blanching quality of peanut genotypes (Farouk et al., 1977; Singh et al., 1996). A study was conducted at ICAR-IIGR, Junagadh among the genotypes that possess high blanchability and high sugar content. In this study, during 2020 rainy season (Kharif) and summer 2021, altogether 102 released Spanish peanut varieties were evaluated for blanching and sugar content. It has been identified that six varieties that include VRI2, Tirupathi 3, Kadiri 6, TG 26, ICGS 1 and GJG 31 possess > 90 % blanchability. Hence, these varieties can be further exploited in breeding programs as donor parents for the development of good confectionery varieties with high percentage of blanchability (Praveen et al., 2021).

Additionally, in the US mini core (USMC) trials evaluation conducted in Australia, it was found that PI 268696 had highest blanching percentage (94.4 %) followed by PI 504614 (92.8 %) while in the commercial varieties the overall highest blanching percentage is reported in Florida 07 (93.1 %) followed by Tamnut OL 06 (92.0 %). The lowest blanching percentage was observed to be 45.2 % in USMC (PI 476025), and in commercial varieties it is 53.4 % in Tifguard. In the Australian commercial check varieties, Kairi has the highest blanching percentage (92.9 %), while in the APBP (Australian Peanut Breeding Program) early-maturity series trials, the genotype P52-p199–80 has been reported to be the highest, 94.6 % blanching. Moreover, Holt and Middleton are Australian commercial varieties that are considered as good blanchers (>85–90 % blanching), while D48–4-p4–1 with 70–85 % blanching is considered to be an average blancher, and P13-p07–219

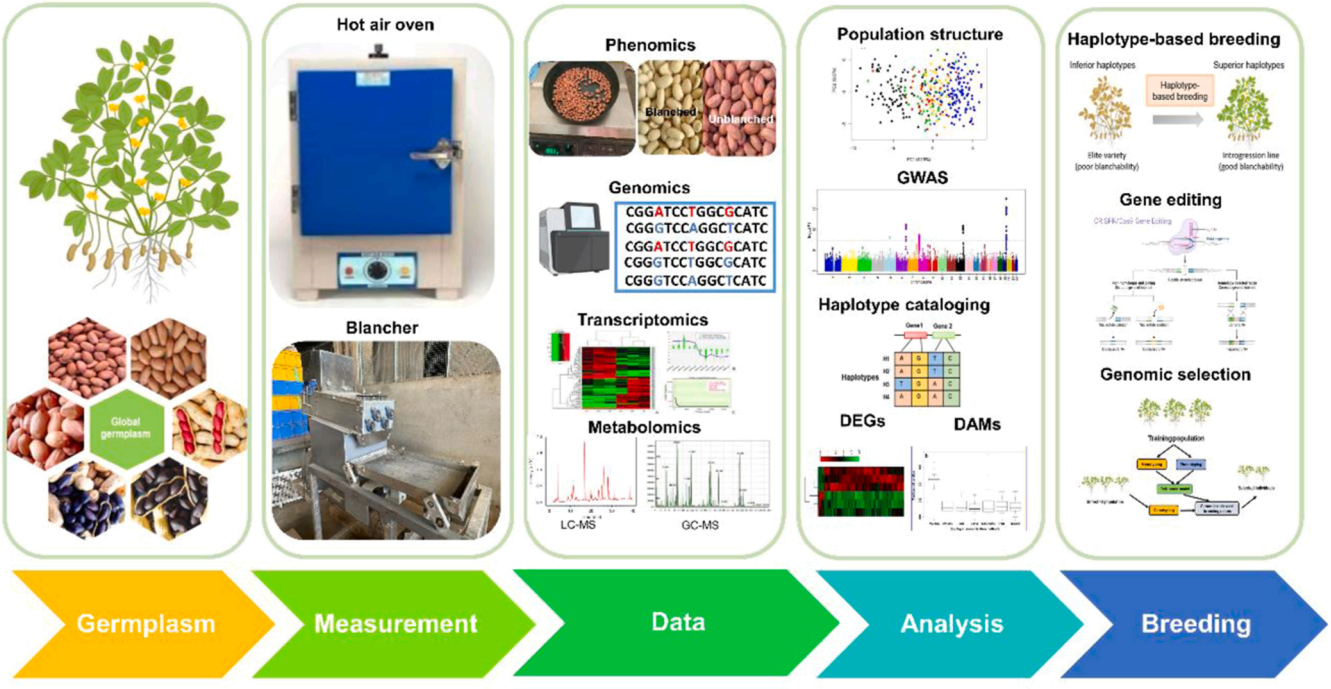

Fig. 2. Peanut germplasm and breeding approaches for the development of diagnostic markers for blanchability to enable effective marker-assisted selection.

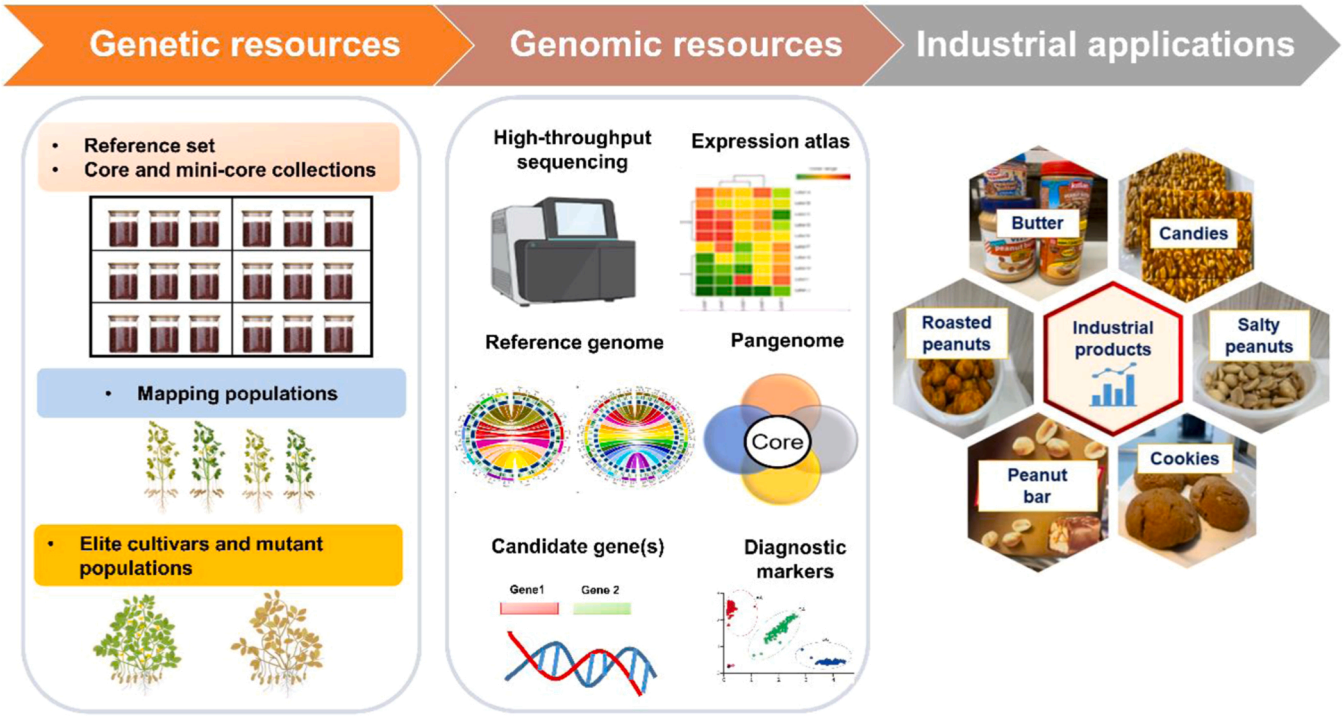

Fig. 3. Peanut genetics, genomics resources and industrial applications of the blanchability.

and P13-p07–218 with < 70 % blanching, are reported to be poor blanchers. Blanchability trait possess very low G×E and possess very high genotypic correlations (~0.60–0.96) between various environments considered under study with heritability of 0.74–0.97 that is reported to be very high. Hence, it has been established that early generations and a limited number of different environmental conditions can be used to successfully select for enhanced blanchability, ensuring consistency of outcomes (Wright et al., 2018).

7. Blanchability linkages with other traits

Blanchability has been related with both nutrients and anti-nutritional factors (Nkafamiya et al., 2010). Blanching results in the removal of tannins, that are generally reported to contribute to off-flavors and off-color of roasted peanuts. The blanching process has been found to result in reduced enzyme activity and moisture content, which in turn affects the stability and flavor quality (Adelsberg and Sanders, 1997; Katz, 2002). The lipoxygenase activity is found to be less with increasing blanching temperature and heating time. One of the major benefits associated with blanching is consumer safety from removal of damaged or discolored seeds removal which are associated with the aflatoxin contamination (Sanders et al., 1999). In the study on non-conventional leafy vegetables, an evident effect of blanching on the vitamins and nutrient contents has been reported that blanching causes the reduction of anti-nutrients (Nkafamiya et al., 2010).

8. Improving seed genetics for desired blanchability in modern varieties

Previous research has shown that speed breeding technology, developed for wheat and barley, can be successfully translated to cultivated peanut, providing peanut breeders with a new tool to generate improved cultivars more quickly. It has been clearly demonstrated that by employing a speed breeding / SSD method, generation time may be significantly decreased, and new varieties can be generated up to two years faster than using traditional field-based pedigree breeding strategies. Speed breeding has been implemented to shorten generation times (O'Connor et al., 2013). It includes a controlled environment along with constant exposure to 24 hours high-intensity photosynthetically active radition (PAR) light (Hickey et al., 2009). In the peanut breeding system, speed breeding program enabled the advancement of two generations of full season maturity genotype in 202 days, whereas a traditional field-based pedigree system would have taken roughly 290 days and two full summer cropping seasons. Speed breeding technology comprises controlled environment conditions, continuous light with appropriate temperature (28–32°C), and a single seed descent breeding strategy in a greenhouse environment. This has led to reduction in the generation period of full-season maturity cultivars from 145 to 89 days. In less than a year, speed breeding can progress the inbreeding of F_2, F_3, and F_4 generations, potentially accelerating the development of the initial cross to commercial release in six to seven years. The greenhouse based speed breeding system has provided an alternate approach for intensive monitoring of stresses, with very limited land, machinery and labor resources (O'Connor et al., 2013).

With broad-sense heritability ranging from 0.74 to 0.97, blanchability is substantially influenced by genetics (Cruickshank et al., 2003; Shokraii et al., 1985). The blanchability trait has been reported to get fixed in the early generations (Cruickshank et al., 2003; Mozingo, 1979), hence the speed breeding technology could be a highly useful technique to effectively select for blanchability in early generations of peanut. By utilizing this strategy of speed breeding/ SSD system, the inbreeding development time of the F_2 to F_5 generation is made around 17 months which earlier used to be 42 months with conventional pedigree breeding approach (Wright et al., 2011). However, the cost-effectiveness of using speed breeding techniques with continuous light conditions, when compared to the traditional breeding systems is also a major consideration. When compared to the traditional field-based pedigree breeding procedures, the aforementioned research clearly shows that generation time can be cut significantly in a speed breeding / SSD system, and thus new cultivars can be generated up to two years faster. Increased expenditures connected with a speed breeding / SSD system may thus be a

minimal price to pay if more fast variety commercialization is able to recover these relatively low upfront costs. The speed breeding techniques developed for peanut could be adopted to fast tracking varieties with high yield, value-added and blanchability traits (O'Connor et al., 2013).

From the above information, there is clarity on blanchability trait genetics but there have been no efforts in developing genomic tools and candidate gene discovery for this important trait. Hence, there is an important need for focused and dedicated efforts for generating multi-season and multilocation phenotypic data for GWAS. This should be followed by haplotype and candidate genes discovery, and development of diagnostic markers. Once the candidate genes are identified, various biotechnological approaches, such as gene editing and RNAi can be applied. This will further help to accelerate the trait improvement and the development of superior genotypes.

9. Challenges

Blanchability is a trait with a significant impact on processing of peanut. Blanching can result in loss of seeds during processing and sorting, removing seed testa from poor blanching varieties necessitates a large amount of energy and additional expenditures, especially re-processing. Some processing application necessitates the utilization of skin-on peanuts, it is preferable to use cultivars that are resistant to blanching. Blanchability is a difficult breeding target since it is labor intensive and requires a high seed input, which prevents testing at early generations. For these reasons, blanchability has been targeted for marker-assisted selection. However, in a larger cultivated peanut germplasm collection, the data that have been published on the genetic variability for the blanching trait are sparse. Furthermore, there is minimal information about the blanchability trait stability across multiple environments. Due to the large labor investment required to test for the trait, most of the breeding programs for peanut, do not select for blanchability. Furthermore, testing for blanching percentage requires a significant number of seeds, which prohibits early generation selection. It has been noted that the current uniform peanut performance trials (UPPT) in the United States do not test for percentage of blanching (https://www.ars.usda.gov/southeast-area/dawson-ga/national-peanut-research laboratory/docs/uniform-peanut-performance-tests-uppt/, retrieved on 28 October 2021). There is a considerable expense to peanut processers linked to poor blanchability. Unblanched seeds are dumped as waste, sold as low-value products, or crushed for oil after blanching. Hence, due to its high genetic control and minimal G×E effect, blanching is an excellent target for marker assisted selection (MAS) in peanut.

10. Opportunities

There is a cost-effective opportunity for blanchability available for the trait improvement, such as the optimization of the phenotyping protocol with small sample size. This improved protocol can be utilized purely for routine research and breeding. With regards to nutritional traits, such as high oleic acid content in peanut, there have been studies carried out such as GWAS and MAS. Likewise, for this industrial important trait, GWAS studies should be carried out and transformational cost-effective diagnostic markers should be developed. For the successful study and improvement of this trait, there is an significant need to develop a functional and strong link between the industry and researchers.

Conflict statement

The authors declare there is no conflict of interest.

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CRediT authorship contribution statement

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Declaration of Competing Interest

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Data availability

No data was used for the research described in the article.

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