



## GENETIC AND PHYSIOLOGICAL ASPECTS OF SILIQUE SHATTERING IN RAPESEED AND MUSTARD

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### SUMMARY

Rapeseed (*Brassica napus* L.) and mustard (*Brassica juncea* L.) are two important oilseed crops grown worldwide for edible oil and meal production, as well as, a source of renewable energy. Silique shattering at the maturity stage is the major cause of seed yield reduction in brassica. Losses in seed yield are more in developing countries due to poor management and the non-availability of combine harvesters. Silique shattering resistance is essential for achieving good seed yield especially in *Brassica napus*. The silique on plants of rapeseed and mustard mature in different phases due to indeterminate growth habit, which is also a reason for shattering losses. Silique shattering is linked with the creation of a dehiscence zone in a brassica pod. When the siliqua wall loses its hydration, along the length of the siliqua, a few cell layers separate the replum from the pericarp tip of the two silique valves. In the dehiscence zone, it involves the collapse of cell walls and cell separation, as well as, the destruction of the middle lamella and enhanced hydrolytic enzyme activity. To avoid seed yield losses, resistance against silique shattering is essential in rapeseed and mustard cultivars. There are multiple QTLs discovered that control variance in silique shattering. Previous studies validated the shattering process in the model plant *Arabidopsis thaliana* was controlled by eight different genes. However, their role in controlling silique shattering in rapeseed and mustard is unknown. Modern tools of mutation breeding and genetic engineering, especially CRISPR/Cas9 technology, can be utilized to identify the genetic source for shattering resistance in rapeseed and mustard, which will be helpful for the development of silique-shattering resistant cultivars under changing climatic regime.

**Keywords:** *Brassica*, breeding tools, silique shattering, genetic resistance, seed yield

**Key findings:** The review summarized the literature on genetic and physiological aspects of silique shattering in rapeseed and mustard. It also identified the mechanism of silique shattering and breeding tools for the development of shattering tolerant brassica genotypes.

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## INTRODUCTION

*Brassica* is the second largest oilseed crop after soybean (*Glycine max* L.) in the production of global oilseeds (FAOSTAT, 2020). Rapeseed (*Brassica napus* L.), which produces edible oil and renewable energy, is the most important brassica specie in this regard (Zaman *et al.*, 2021). In the Brassicaceae family, there are 37 species of the genus of flowering plants, most of them are important crops. However, a number of *Brassicaceae* are considered introduced species outside of their natural range, and they have a considerable foothold in the Mediterranean region (Dobrzycka and Medina, 2020; Perrino and Wagensommer, 2022). Kale, kohlrabi, rape, rutabaga, broccoli, brown mustard, brussels sprouts, cabbage, cauliflower, and turnip are all economically important members (McAlvay *et al.*, 2017; Shankar *et al.*, 2019). *Brassica* has a diverse spectrum of amphipolyploid and diploid species that include some of the world's most significant condiment, vegetable, and oilseed crops. As members of the Brassicaceae family, *Brassicaceae* are the closest crop relatives of *Arabidopsis thaliana*, which is the model plant. The chromosomal numbers of the diploid species are *Brassica rapa*,  $2n = 20$ ; *B. nigra*,  $2n = 16$ ; and *B. oleracea*,  $2n = 18$  and amphidiploids *B. carinata*,  $2n = 34$ ; *B. napus*,  $2n = 38$ ; and *B. juncea*,  $2n = 36$  (Snowdon, 2007). *Brassica rapa*, *B. napus*, *B. carinata*, and *B. juncea* are four major crops cultivated worldwide (Raymer, 2002; Rakow, 2004).

In Asia, the mustard (*B. juncea* L.) is quite important, but the rapeseed (*B. napus* L.) is extremely useful in Canada and all of Europe (Rai *et al.*, 2007). During 2020–2021, the total cultivated area of mustard globally was 0.619 million ha and the average production was 872.4 kg/ha, whereas for rapeseed, total cultivated area was 3.55 million ha and the average production was 2,039 kg/ha (FAOSTAT, 2020). Furthermore, major contributors to this production are Europe (52.4%, 62.6%) and Asia (47.2%, 33.9%) for mustard and rapeseed, respectively (FAOSTAT, 2020). According to Aftab *et al.* (2021), the area and production of rapeseed and mustard in Pakistan were 608,000 ha and 338,000 tons, respectively. Oilseeds crops are cultivated primarily for edible oil. Oilseeds have recently gained significant attention due to increased

demand for their healthful vegetable oils, feeds, medicines, biofuels, and other oleochemical commercial uses. Over the past three decades, growing interest has resulted in an 82% rise in oilseed crop cultivation areas and a 240% increase in total world production (Wani *et al.*, 2018).

From a health perspective, *Brassica* oil is highly useful. It contains both linoleic acid, which is beneficial for health, and oleic acid, which is good for cooking because of its high thermostability. *Brassica* oil's nutritional and commercial value, like that of other vegetable oils, is defined by its fatty acid profile, which consists of numerous fatty acid species with different carbon chain lengths and levels of desaturation (Scarth and Tang, 2006; Verma *et al.*, 2016). Oil with a high oleic acid content tastes better and may have health benefits as well. The fatty acid's oxidative stability makes it useful for several industrial applications (Singh *et al.*, 2014, 2016; Rudzińska *et al.*, 2016). The fatty acid content in *B. napus* and *B. juncea* oil is normally 5% palmitic, 1% stearic, 15% oleic, 14% linoleic, 9% linolenic, and 45% erucic acid (Rathnakumar and Sujatha, 2022; Varghese *et al.*, 2022). Rapeseed and mustard genotypes having less than 2% erucic acid in oil and less than 30  $\mu\text{moles/g}$  glucosinolates in the meal are called double zero (00) or low erucic acid or canola. The canola quality oil from rapeseed and mustard is safe for human utilization and its meal is suitable for animal, birds, and aqua feed (Mustafa *et al.*, 2022) The beginning of the canola quality rapeseed development and the rapid rise in worldwide rapeseed productivity started with the release of "Span, Oro, and Zephyr" cultivars in 1968, followed by the canola cultivars named, "Tower and Candel" in 1974. and several others (Tofanica, 2019). Canola version cultivars mostly belong to the rapeseed group worldwide, however, Oilseeds Research Institute (ORI), Faisalabad, Pakistan has also introduced the canola version varieties not only in rapeseed, but also developed the canola variety in mustard group with the name "AARI Canola" (Mustafa *et al.*, 2018). Preference for the development of canola (00) in mustard is due to less maturity period, silique shattering resistance, and high temperature tolerance as compared with rapeseed.

However, silique shattering at the maturity stage is the primary cause of seed yield reduction in *brassica*. Seed yield losses can reach up to 50% due to unfavorable weather at the maturity stage, which also becomes the reason of contamination in subsequent crops (Singh and Singh, 2018; Zaman et al., 2021). This review summarizes literature on the genetic and physiological aspects of silique shattering, as well as explains the mechanism for developing shattering tolerant cultivars in rapeseed and mustard.

### Mechanism of silique shattering

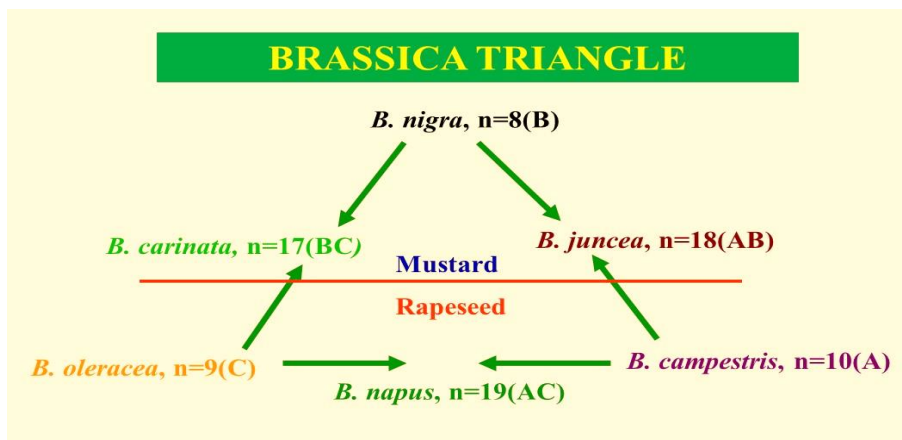
Silique shattering is a mechanism of seed release, beneficial to wild species, but it is an economically major problem with *Brassica* crops. Silique shattering is a major source of yield loss in the *Brassica napus* (Zaman et al., 2021). The fruits of the rapeseed plant ripen in different phases rather than all at once, and some silique shatter before harvesting. If harvesting is delayed by bad weather, this can result in a yield loss of up to 50%, and 'volunteers' develop from the shattered seeds, which contaminate subsequent crops (Gulden et al., 2003). Silique shattering is associated with the creation of a dehiscence zone (DZ). When the siliqua wall loses its hydration, along the length of the siliqua, a few cell layers separate the replum from the pericarp tip of the two silique valves. The process of siliqua dehiscence is similar to that of plant abscission in many ways (Meakin and Roberts, 1990a; Roberts et al., 2002). In the dehiscence zone, it involves the collapse of cell walls and cell separation, as well as, the destruction of the middle lamella and enhanced hydrolytic enzyme activity of  $\beta$ -1,4-glucanase and polygalacturonase (Meakin and Roberts, 1990b; Jenkins et al., 1996). Production of high yields from polyploid *B. napus* requires resistance against silique shattering (Zaman et al., 2019). In *Arabidopsis*, a number of genes involved in the development or control of dehiscence zone were discovered (Gu et al., 1998; Liljegren et al., 2000; Dinneny and Yanofsky, 2005; Afridi et al., 2021). Zaman et al. (2019) reported that the JAGGED (JAG) gene in *Arabidopsis* is a critical component of the fruit dehiscence. However, no relevance was found for shattering tolerance in rapeseed (Zaman et al., 2019).

### Evolutionary relation of silique shattering in *Brassica napus* and *Brassica juncea*

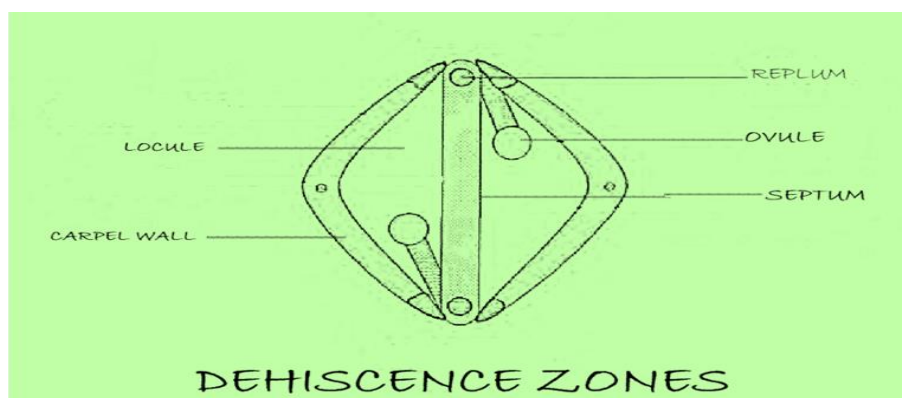
*Brassica napus* was originated by natural hybridization between two diploid progenitors, *B. rapa* (AA,  $2n = 20$ ) and *B. oleracea* (CC,  $2n = 18$ ). Similarly, *B. juncea* and *B. carinata* were originated by natural hybridization between two diploid progenitors, *B. rapa* (AA,  $2n = 20$ ) and *B. oleracea* (CC,  $2n = 18$ ) with *B. nigra* (BB,  $2n = 16$ ), respectively. This natural hybridization process broadened the genetic vigor in *B. napus*, *B. juncea*, and *B. carinata* by the introgression of genes from two diploid progenitors (Song et al., 2020). *Brassica juncea* and *B. carinata* are more resistant to silique shattering and grow more consistently than *B. napus*, resulting in reduced seed loss at harvesting (Mackie, 2021). This showed that *B. nigra* has some shattering tolerant genetic source. Thirty-two shattering genes were identified by complete genome analysis of *B. napus* and *B. juncea* and categorized on protein motif structure, exon-intron organization, and phylogeny bases. The phylogenetic study revealed that these shattering genes contain little duplications and have distinct chromosome number. Reverse transcription polymerase chain reaction (RT-PCR) based expressions profile showed higher expression of shattering genes in *B. juncea* as compared with *B. napus*. FUL gene was expressed more in the mature silique. ALC gene was not expressed in the fresh silique of *B. napus*, but highly expressed in the mature silique (Afridi et al., 2021). The evolutionary relationship among different *brassica* species is described by the U triangle of *brassica* as shown in Figure 1.

### Morpho-physiological aspects of silique shattering

The siliqua of *B. napus* is made up of two carpels separated by a false septum (Picart and Morgan, 1984). The carpel margins close to the septum generate dehiscence zones that run through the middle of the siliqua (as shown in Figure 2). The dehiscence zone's cells ultimately deteriorate, weakening the contact between the carpel walls, or valves, and the septum. The loss of cellular cohesion is restricted to the cells in the dehiscence zone and is caused by the breakdown of the middle lamella (Meakin and Roberts, 1990b; Spence



**Figure 1.** U-Triangle; Evolutionary relationship among different *Brassica* species.



**Figure 2.** Structure of *Brassica napus* silique.

*et al.*, 1996). Spence *et al.* (1996) also said this process starts at the time of post-fertilization development of fruit walls. Li *et al.* (2021) cloned BnaA07g12590D (BnMAN7A07), an AtMAN7 homolog from rapeseed, and found its role in the dehiscence of rapeseed silique. They found that BnMAN7A07 was expressed in both vegetative and reproductive organs and significantly expressed in leaves, flowers, and silique.

Phenotypic studies of RNA interference (RNAi) lines revealed that down-regulation of BnMAN7A07 in rapeseed could significantly enhance silique dehiscence-resistance. They concluded that expression of hemicellulase gene, BnMAN7A07, can be used for dehiscence-resistance, which could be helpful for breeding shattering tolerant rapeseed. The exocarp, mesocarp, and endocarp cell expands, and make non-lignified thick layers. In endocarp the endocarp a (ena) cells expand to develop thin whereas, endocarp b (enb) cells

expand to develop thick lignified walls elongating in the longitudinal axis of silique. The lignified layer of cells surrounding repla joins exocarp as a single-celled band. At maturity and desiccation stage, lignified layers around repla and non-lignified layers of repla separate and dehiscence/shattering occurs. However, *B. juncea*, which is resistant to shattering, have same structure and development of carpel.

The ena in endocarp in both species is same, but enb is different in *B. juncea*. In *B. juncea* enb is not entirely lignified. The lignification of the secondary walls does not extend to the primary walls or the middle lamella regions between the cells. Pectin remains abundant in these areas, due to which carpel wall remains flexible even in desiccation and do not create same type of tension reducing shattering. Elongation in Brassicaceae fruits takes place within the development of specialized tissues, such as, valve margins at the replum borders (which are involved in the

fruit dehiscence), valves (silique walls), and a central replum (Stephenson *et al.*, 2019). Silique shattering resistance may relate more to tissue-specific anatomy and physiology of dehiscence zone and its surrounding area. Silique shattering is highly influenced by the silique structure, such as, short or thick-walled silique reduces stress on dehiscence zone which means no silique opening (Wang *et al.*, 2007). Non-lignification of secondary endocarp layer in *B. juncea* contributes to shattering resistance by decreasing stress on replum on desiccation (Spence *et al.*, 1996). Meanwhile, Hu *et al.* (2015) reported an association between large replum-valve joint with high silique shattering.

In silique shattering mainly three factors are involved: first, the weakening of cell walls in specified regions of dehiscence zone, second, the external surrounding tissues force, and third, the silique is exposed to the environment, which lead to shattering on desiccation stage (Meakin and Roberts, 1990a; Spence *et al.*, 1996). The valve margins are composed of a separation layer and a lignified layer of distinct cell types (Stephenson *et al.*, 2019). During fruit maturity, cells in the valve margins facilitate fruit opening by secreting polygalacturonase enzymes that degrade the rich-pectin separating layer (Petersen *et al.*, 1996; Spence *et al.*, 1996; Degan *et al.*, 2001; Ogawa *et al.*, 2009). It is also reported that especially homogalacturonan rich in pectin found in middle lamella is necessary to be degraded for dehiscence (Ridley *et al.*, 2001; Dong and Wang, 2015). *Brassica* shows enhanced  $\beta$ -glucanase activity in the cells of the dehiscence zone, as well as, cell wall breakdown at the site of fruit dehiscence (Kemmerer and Tucker, 1994).

Endopoly-galacturonase (endo-PG), which is expressed particularly in the dehiscence zone, catalyzes the hydrolysis of -1,4-glycosidic linkages in poly-galacturonic acid in the main chain of the homogalacturonan region of pectin. This hydrolysis process was thought to be involved in the degradation of the middle lamella (Christiansen *et al.*, 2002). According to Kalaitzis *et al.* (1997), increased PG activity was associated with cell separation during fruit shedding. Increased endo-1,4 glucanase and endo-PG activity, but a considerable reduction in protein content in the DZ during maturation and senescence, were also discovered (Christiansen *et al.*, 2002). Endo-1,4-glucanases and endo-PG were shown to dissolve the middle lamella in the separation layer, resulting in reduced cell-to-cell adhesion.

### Genetics behind silique shattering

Molecular mechanism regarding silique shattering resistance in rapeseed is still not well understood. However, the pod shatter resistance at quantitative trait locus qSRI.A9.1 is controlled by one of the *B. napus* *SHATTERPROOF1* homologs, BnSHP1.A9, in a doubled haploid rapeseed population generated from parents R1 and R2. A copia-like retrotransposon-based marker, BnSHP1.A9R2, can be used for marker-assisted breeding targeting the pod shatter resistance trait in rapeseed (Liu *et al.*, 2020). *SHATTERPROOF1* (*SHP1*), *SHATTERPROOF2* (*SHP2*), NAC secondary wall thickening promoting factors (NST1, NST2, and NST3), INDEHISCENT (*IND*), and *ALCATRAZ* (*ALC*) are known regulatory genes that govern silique shattering (Liljegren *et al.*, 2000; Rajani and Sundaresan, 2001; Liljegren *et al.*, 2004; Østergaard *et al.*, 2006; Mitsuda *et al.*, 2007; Ogawa *et al.*, 2009; Liljegren *et al.*, 2009; Sorefan *et al.*, 2009; Girin *et al.*, 2010). These are known as valve margin identity genes or dehiscence zone identity genes (Rajani and Sundaresan, 2001; Liljegren *et al.*, 2004; Dinneny and Yanofsky, 2005). The transcription factors, REPLUMLESS (*RPL*) and FRUITFULL (*FUL*), control the expression of valve-margin identity genes. REPLUMLESS (*RPL*) and FRUITFULL (*FUL*) function in the replum and valves, respectively, by limiting the dehiscence zone within the valve margin and protecting replum and valve development (Gu *et al.*, 1998; Ferrándiz *et al.*, 2000; Roeder *et al.*, 2003; Ferrándiz and Fourquin, 2014).

Other factors were identified to have a role in the silique shattering regulation network. NAC secondary wall thickening promoting factor1 (NST1) and NST3 are lignification associated factors that govern secondary wall development in the endocarp b and lignified layer (Mitsuda and Ohme-Takagi, 2008). This regulatory network also contains genes involved in leaf development, the creation of dorsoventral axes of lateral organs (e.g., Filamentous flower, *YABBY3*, Asymmetric leaves1/2), and the maintenance of meristematic potential (*BREVIPEDICELLUS*) (Hay *et al.*, 2006; Cantabrana *et al.*, 2007). In *B. oleracea*, *B. napus*, and *B. juncea*, *IND*, *PG* (poly-galacturonase), and *FUL* play essential roles in modulating silique shattering resistance. In *B. napus* (Jenkins *et al.*, 1999; Mitsuda *et al.*, 2007; Sorefan *et al.*, 2009), there is multiple QTLs discovered which controls variance in silique shattering (Raman *et al.*, 2014).

This network of transcription factors known as 'dehiscence zone identification genes' in *Arabidopsis* has been systematically investigated at the molecular level (Zhai *et al.*, 2019). The bHLH genes *INDEHISCENT (IND)*, *ALCATRAZ (ALC)*, and *SPATULA* are all induced by SHP proteins (SPT) (Ferrández *et al.*, 2000; Liljegren *et al.*, 2000). Mutants who are missing one or more of these valve margin identity genes do not develop valve margins and produce indehiscent fruits with seeds trapped inside (Rajani and Sundaresan, 2001; Liljegren *et al.*, 2004). Expression of the *Arabidopsis FUL* gene has been found to cause silique shatter resistance by suppressing SHP expression in *B. juncea* (Østergaard *et al.*, 2006). Given that *Arabidopsis* and *B. napus* have comparable silique development and structure, the *SHP*, *IND*, and *ALC* genes have been recommended as potential candidates for modification in creating silique shatter-resistant cultivars of rapeseed (Spence *et al.*, 1996).

### **Seed yield losses in *Brassica* due to shattering**

Silique shattering is a highly unfavorable feature in *Brassica* crops for commercial seed production, resulting in severe yield losses of up to 70% in canola. (Raman *et al.*, 2017). Oilseed *Brassicaceae* are usually 'windowed' to decrease seed loss due to shattering, however, this method is not always effective (Mongkolporn *et al.*, 2000). Losses are of two types: long-term and short-term. Yield loss can be described as a short-term loss, but the volunteer seeds which can act as weeds in the next crops is a long-term loss. As they are difficult to control or eradicate in a standing crop, it definitely leads to an extra labor cost and one more yield loss in the prospective crop (Morgan *et al.*, 2000). When dry weather, combined with wind movement under the crop canopy between physiological maturity and straight combining, silique broke or split up to open, leading to fast seed loss. In such condition the yield loss due to seed shatter usually accounts for about 5%–10% of total production; and under relatively harsh climatic conditions, it can reach up to 50% (Kadkol *et al.*, 1984; Price *et al.*, 1996).

### **Agronomic management**

The identification of several structural features is required for the development of an ideotype that represents rapeseed as being increasingly resistant to seed misfortune at harvest and

remaining exceptional agronomically (Thurling, 1991). Rasheed *et al.* (2021) said that the morphological properties of the entire plant and raceme, and also the morphology of individual silique and the interaction of various factors, will be addressed. A significant amount of unit shattering happens inside the crop canopy before and during harvesting as a result of the canopy's character development, resulting in silique thumping against one another or stems and branches tumbling against one another. Mechanical damage is likely to be influenced by other plant properties, such as, the number of unit points, case length, and breadth (Jonsson and Bengtsson, 1970). Rapeseed is grown traditionally in Pakistan, where rapeseed production requires around 140–160 labors ha<sup>-1</sup>. However, in other countries (Europe and Canada) 15 labors ha<sup>-1</sup> could fulfil the requirements (Rasheed, *et al.*, 2021).

Rapeseed productivity is reduced by inadequate mechanical harvesting processes, which is the reason why farmers choose other crops like wheat and rice, throughout the growing season (Zhang *et al.*, 2012). Delaying harvesting is a beneficial strategy, and adequate land and seedbed preparation minimize shattering-related yield losses (Zhang *et al.*, 2012). Rapeseed seedbeds should be uniform, solid, and humid to provide optimal seed-to-soil contact (Hussain *et al.*, 2018). The irrigation is also an important factor related to silique shattering for rapeseed. It usually requires three irrigations: firstly, during the first month of sowing; secondly, during flowering, and thirdly, during seed production. Increased water availability will boost the water potential of leaves and silique, resulting in reduced shattering (Rasheed *et al.*, 2021).

There are two harvesting methods, namely, swathing and direct harvesting (Rasheed *et al.*, 2021). The implementation of efficient harvest management techniques can also help to reduce the impact of unfavorable weather conditions causing silique shattering (Gan *et al.*, 2008). Recently, the Oilseeds Research Institute, Faisalabad (Pakistan), has started mechanical harvesting through a wheat combine harvester, by changing its sieve calibrated to *Brassica* seed size and minimum seed losses were observed as compared with manual harvesting.

### **Breeding for silique shattering resistance**

Braatz *et al.* (2018) studied the increase of shatter resistance in indehiscent double knock-down mutants obtained by TILLING with a

systematic approach comparing three independent phenotyping methods. They observed a positive correlation of silique length and shatter resistance. Microscopic studies ruled out the influence of different lignification patterns. The study explained the influence of indehiscent mutations on rapeseed silique shattering resistance, as well as. phenotype with enlarged replum-valve joint area and altered cell dimensions in the dehiscence zone. Raman *et al.* (2017) studied the pod shattering resistance level in Ethiopian mustard (*B. carinata*) and identified quantitative trait loci (QTL) for targeted introgression of this trait in Ethiopian mustard.

Genetic analysis of the F2 and F2:3 derived lines revealed five statistically significant QTL (LOD  $\geq$  3) that are linked with pod shatter resistance on chromosomes B1, B3, B8, and C5. They concluded that molecular markers can be utilized in marker-assisted selection for tracing the resistant alleles. Qing *et al.* (2021) proposed a 2-degree-of-freedom collision method (2-DFCM) for evaluating pod resistance in rapeseed, which was helpful for screening suitable varieties for mechanized harvesting. Statistical results showed that the pericarp thickness, thousand seed weight, pod thickness, pod volume, and primary branch height are the significant factors for pod resistance. Identification of highly shattering tolerant genetic source is prerequisite for the development of shattering tolerant rapeseed cultivars. Chu *et al.* (2021) identified an elite line OR88 with a strong shatter resistance and a lignified-layer bridge (LLB) structure. The LLB structure is controlled by a single recessive gene and differentiated at stage 12 of gynoecium development. Silique shattering-resistant line may be used in rapeseed breeding programs by direct transfer of the gene with the assistance of the DNA markers.

Modern technologies like embryo rescue, marker-assisted breeding, and mutation may make it much easier to introduce new rapeseed varieties. We might be able to minimize the negative effects of dehydration if we modify the thickness of the siliqua wall. The use of such enzymes, which prevents the dehiscence layer from dissolving, can improve the shatter resistance (Jenkins *et al.*, 1996). CRISPR/Cas9 has already proven to be an effective tool for modifying a wide range of plant characteristics, with the potential to increase variability in existing organisms (Breed *et al.*, 2019). Already Rodríguez-Leal *et al.* (2017) have used CRISPR/Cas9 to develop a rich allelic diversity in tomato.

Conventional plant breeding strategies that have been used in the past and can be used involve evaluating and selecting silique shattering resistant parental plant traits with the objective of combining those traits to increase performance (Gocal, 2021). Many literatures on the successful application of CRISPR/Cas9 technology in rapeseed breeding have been published as of 2022, indicating that this technology's application in rapeseed is becoming more mature, and it has been widely used in the creation of germplasm resources and genetic improvement of rapeseed. In *B. napus*, CRISPR/Cas9 technology has become a key tool for studying gene function and molecular mechanisms (Ali *et al.*, 2014; Bortesia and Fischer, 2015; Brookes and Barfoot, 2018; Cabral *et al.*, 2018; Bernabé-Orts *et al.*, 2019; Gocal, 2021).

### **Achievements in breeding silique shattering**

Maity *et al.* (2021) reported that seed shattering is a genetically controlled trait, which is significantly influenced by environmental factors, as well as, management practices and their interactions. Conventional and molecular breeding approaches are being used to minimize shattering in domesticated crops. Shattering resistance is a desired trait for global rapeseed (*B. napus* L.) development efforts to prevent grain loss in mature standing crops, windrowing, and mechanized harvest (Raman *et al.*, 2014). Previous research has found a strong link between genotype and shatter resistance in oilseed rape silique.

Multiple genes control shatter resistance, according to a genomic study. In addition to additive factors dominating the shatter resistant characteristic, non-additive effects play a role (Morgan *et al.*, 2000). Mongkolporn *et al.* (2003) discovered a *Brassica campestris* variant that was resistant to shattering and determined that this characteristic was regulated by two primary recessive genes. Many genes that influence the shatter resistance characteristic were discovered to be limited in the natural growth process of *B. napus* (Raman *et al.*, 2014); consequently, breeders must introduce corresponding alleles from other related species to improve shatter resistance.

Tan *et al.* (2006) discovered that silique shattering forces varied widely, implying that shatter resistant cultivars might be used as parents to develop types appropriate for mechanized harvesting. Liu *et al.* (2020) conducted in-depth basic research on genetic

regulation in conjunction with the identification and screening of shatter resistance resources, and discovered the unique gene BnSHP1. A9, which is linked to shatter resistance. This demonstrates that selecting shatter-resistant types not only reduces harvest loss and promotes the development of oilseed rape mechanization, but also provides parents for genetic breeding. As many genes related to dehiscence and silique shattering have been identified, use of latest biotechnological techniques and breeding methods can bring new silique shatter resistant varieties.

## CONCLUSIONS

It is concluded that development of silique shattering resistant cultivar of rapeseed and mustard is the need of time to reduce yield losses for food security under the scenario of climate change. Modern technologies like mutation breeding, embryo rescue, marker-assisted breeding, especially CRISPR/Cas9 technology, will be helpful for identification silique shattering resistant genes for the development of shattering resistant rapeseed and mustard varieties.

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