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Botanical characteristics, potential uses, and cultivation possibilities of mustards in Turkey: a review

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Abstract: The mustard species [(*Brassica juncea* (brown mustard), *B. nigra* (black mustard), *B. rapa* syn. *B. campestris* (field mustard or turnip), and *Sinapis alba* (white mustard or yellow mustard)] constitute important genetic resources and sources of raw materials to large number of agrobased industries in Turkey and elsewhere. *S. alba* is usually used as a condiment in dry form. *B. nigra* is used as a condiment and as vegetable with dietary fibre, vitamin C, and other anticancer compounds. *B. juncea* is used for oil and as spice. *B. rapa* is popularly used for biofuel raw material. However, there is poor focus on their breeding and varietal development for industrial purposes like biofuel production etc. Therefore, they are rightly called neglected crops in Turkey. The aim of this study is to provide a comprehensive information about appropriate mustard species that can be evaluated in different sectors and bring innovations in laying new scientific foundations of the subject. As such, this paper has compiled information about economic importance, general characteristics, and ethnobotanical uses of the mustards found in Turkey.

Key words: *B. juncea*, *B. nigra*, *B. rapa*, energy plant, medicinal plant, oil plant, *S. alba*

1. Introduction

Mustard is among the oldest known spices, dating back to about 3000 BC (Mehra, 1968) and are cultivated for different edible and industrial uses especially in the spice and energy sector. Turkish natural flora of *Sinapis alba* syn. *Brassica alba* (white mustard or yellow mustard), *S. arvensis* syn. *B. arvensis* (wild mustard), *B. juncea* (brown mustard), *B. rapa* syn. *B. campestris* (field mustard or turnip), and *B. nigra* (black mustard) species are the most important among them (Babac, 2004; Guner et al., 2012; http://194.27.225.161/yasin/tubives/index.php?sayfa=dizin&&familya=Acanthaceae) and will be discussed in the review explicitly. These species also contain other compounds like glycosides, arachidic acid, sinabine, lignoceric acid etc. in their oils. Abundance of erucic acid in these oils make them unsuitable for culinary purposes (Kires and Hammann, 2014). Previous studies show that mustard flora of Turkey has significantly high percentage (25%–35%) of seed oil (Ozcan et al., 1998; Tonguc and Erbas, 2012; Kayacetin et al., 2018a, b; Kayacetin, 2019).

Young fresh leaves and fresh flowering shoots are used in multiple culinary recipes all over of South Asia and Far Eastern countries. Likewise, their seeds are frequently used in spice, pharmaceutical and cosmetic industries (Heenan et al., 2004; Zijll et al., 2008).

Additionaly, the plants are used in production of green manure, biofuel raw material and for soil remediation (Kayacetin et al., 2016, 2018a, b).

Furthermore, they have important role in development of beekeeping industry and animal feed industries (Basbag et al., 2010; Mao et al., 2012; Sirali et al., 2013; Singh et al., 2016; Kayacetin et al., 2018a).

B. nigra has the sharpest taste and has high potential to be used it in spice industry. *S. alba* is the lightest in taste among these species with lowest potential for its use in spice industry.

Canola production and cultivation were banned in 1979 onward in Turkey because of the presence of the compounds that are harmful to human and animal health (Tiras, 2009). Therefore, these and other plant species in the mustard reduced their importance over time and were fully or partially abandoned resulting in their under development.

This negligence has affected their breeding and varietal development practices to meet local demands. Breeding these crops will contribute towards utilization of marginalized or neglected lands (Sagar and Chandra, 2004; Kumar, 2013; Singh et al., 2016) and meet local demands that are presently met by imports from abroad. Furthermore, undertaking and focussing on breeding

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studies will help in breeding new varieties and cultivars for specific needs as mentioned earlier that in turn will save the foreign reserves and contribute to the national exchequer.

Mustard is highly resistant to various biotic and abiotic stresses. Turkey has rich mustard genetic resources. Nowadays, these species are both cultured and grown wild under natural conditions. They have centre of diversity on main lands of Mediterranean coastal regions including Turkey, from where they spread to many areas with cultivation in large areas all over the world (Yigit, 2016).

Sometimes mustard gas is confused with mustard crop. The name, mustard for a group of crop plant species and mustard gas have nothing in common. Mustard gas makes a viscous liquid (at room temperature) and an odour similar to garlic, mustard or sulphur that cause damage to skin, eyes, and respiratory system. Extensive exposures can also negatively affect the cardiac, reproductive, digestive, haematological, and nervous systems (Yamakido et al., 1985; Javadi et al., 2005; Kehe and Szinicz, 2005; Beheshti et al., 2006; Geraci, 2008; Razavi et al., 2012). Its oily drops do not evaporate quickly (Briggs, 2019). Its toxic vapours most often penetrate clothing, woods, and paints on metallic surfaces and everything in the environment (Wattana and Bey, 2009; Williams et al., 2015).

The oilseeds production in Turkey can only meet about 1/3 rd of vegetable oil requirements of Turkey. If statistics of spices and other industries from 2003 to 2017 are considered, it turns out that the import of mustard has risen to 20 thousand tons with spending US $7.6 million annually. The lack of sufficient vegetable oil production in Turkey necessitates its import in significant quantities (http://www.bysd.org.tr).

Biofuel blending has been made mandatory to all users by the Turkish Energy Regulatory Agency (EMRA) from 2013 to 2014 for bioethanol (2%) and biodiesel (1%) in the same order with intention to increase it in the following years (Bolluk and Koc, 2013). There has been no substantial improvement in selection and categorisation of the potential plants that could be used for the purpose. There is also ambiguity about the supply of biofuel raw materials in Turkey. Any kind of production, research and investment for both food and energy sector mean an important investment to reduce the deficit and meet present and future needs in many sectors including biodiesel industry (YEGM, 2018). Efforts to increase yield and quality of oilseed plants currently in production through breeding of new cultivars will contribute positively to the Turkish economy (Eryilmaz et al., 2016).

Longer vegetative period enables winter cultivars higher yields (Shavrukov et al., 2017). Studies have shown that winter-sown longer vegetative growth and shorter generative growth contributes to higher yields compared to yield from summer-sown crops. Kayacetin et al. (2018a) and Kayacetin (2019) have recommended that the *B. juncea*, *B. rapa*, and *B. nigra* mustard genotypes must be sown in winter. They emphasise that *S. alba* genotypes are sensitive to cold and are suitable for spring sowing. They have determined that both *B. nigra* and *S. alba* have low grain and oil yields. *B. juncea* surpassed *B. rapa* in yield tests and earlier maturity (Kayacetin, 2019). Kayacetin et al. (2018a) and Kayacetin (2019) further suggest that *B. juncea* and *B. rapa* should be counted as the most promising species for biodiesel industry.

B. juncea, *B. rapa*, *B. nigra* and *S. alba* species are not suitable for direct consumption as food, due to high erucic acid contents (Prakash and Hinata, 1980; Stefansson and Downey, 1995; Kayacetin et al., 2018b; Fadhil et al., 2019; Konuskan et al., 2019). There is a need to develop new summer and winter mustard varieties and cultivars to participate in local biofuel production industry besides their uses in other sectors like food, feed, and spices etc. depending on the local needs (Kayacetin, 2019). However, a limited local varieties and cultivars are available that could be used to meet any of the above mentioned activity including their uses as spices (Turkish Food Codex) and in energy (TS EN 14214) sectors (Eryilmaz, 2009; Kayacetin et al., 2016; Kayacetin et al., 2018a, b).

The main aim or purpose of this review is to compile information about mustard flora (*S. alba*, *B. rapa*, *B. juncea*, and *B. nigra*) of Turkey suitable for spice and energy industries.

2. Taxonomy, botanical description, and uses of mustards

2.1. Taxonomy

Brassicaceae comprises 338 genera and 3709 species (Franzke et al., 2010) occurring mainly in the temperate regions of the northern hemisphere (Hedge, 1976). It is represented by 571 species in the flora of Turkey (Al–Shehbaz et al., 2007). Mustard are a group of dicotyledonous plant species [mainly *S. alba* (white mustard or yellow mustard, n = 12), *S. arvensis* (wild mustard, n = 9), *B. rapa* (field mustard or turnip, n = 10), *B. juncea* (brown mustard, n = 18), and *B. nigra* (black mustard, n = 8)] (Davis, 1965; Ilisulu, 1973; Guner et al., 2012).

The genetic relationship among different *Brassica* species was established in the classical work by U (UN, 1935), which is now described as U's triangle (Figure 1). According to this relationship, the main species include *S. arvensis* (wild mustard), *B. nigra* (black mustard), *B. oleraceae* (cabbage), and *B. rapa* (field mustard or turnip). The diploid species (*B. rapa* and *B. nigra*) represent the AA and BB genomes. It is well established that *B. juncea* is an allotetraploid species and is hybrid (Figure 1). Figure 1 outlines the close relationships between *Brassica* species.

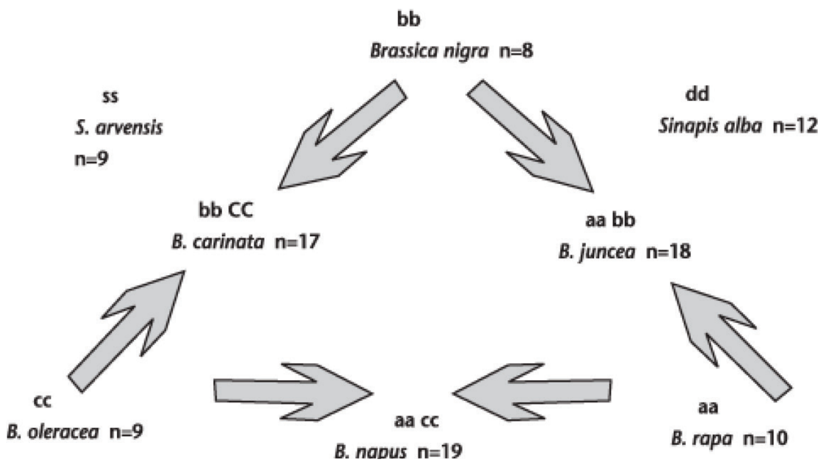

Figure 1. *Brassica* and *Sinapis* species within the triangle of U.

B. napus, with its 19 chromosomes, is originated from a cross between *B. oleracea* and *B. rapa*. The same is true for *B. juncea*, which is originated from a cross between *B. nigra* and *B. rapa*. *S. alba* and *S. arvensis* species are more distantly related to rapeseed (Nagaharu, 1935; Gomez-Campo et al., 1999; Li et al., 2017).

B. nigra is found throughout the Mediterranean region. It shows wide distribution along the channels and irrigated fields in Turkey except for very cool regions and forms big colonies of very vigorous plants around Adana region of the Mediterranean region and in the Central Anatolia (Figure 2, Frame a). The moisture conditions of the soil regulate the development of this species. It was described as a weed of wheat fields in the Ankara region (Mizushima and Tsunoda, 1967) and in Central Anatolia (Pers. Observations). *B. rapa* and *B. juncea* are widely cultivated in South and South East Asia, particularly Japan, China, Pakistan, and India. *B. rapa* is found in at a number of places in the Mediterranean region (Ozturk et al., 2012) (Figure 2, Frame b). *S. alba* grows in Thrace and Western Anatolia largely (Figure 2, Frame c); whereas, *S. arvensis* outgrows everywhere in the Thrace, North East, West, South, Central and Eastern Anatolia (Figure 2, Frame d). *B. juncea* comes up wide spread in Antalya province (Guner et al., 2012; http://194.27.225.161/yasin/tubives/index.php?sayfa=dizin&&familya=Acanthaceae; Bizimbitkiler.org.tr) (Figure 2, Frame e).

2.2. Botanical description of mustard species

These species are tap rooted, herbaceous, growing upright, multi-branched, yellow-flowered with multiple seeds and generally grow as annual plants (Mulligan and Bailey, 1975; Kayacetin, 2019). *B. nigra* can easily mix during earlier periods of growth with *S. arvensis* of the very much same flower structure. However, they can be distinguished at later stages of growth due to their tall growth compared to *S. arvensis* genotypes. *B. nigra* flowers are smaller compared to other species. Flowering is more profuse compared to *S. arvensis*, with a more profuse branching on the plants. The distinction between *S. alba* and other mustard species is with siliqua or siliqua type fruits. The beak of the fruit in *S. alba* is flat and feathery. The beak is tapered and hairless in other mustard species (Davis, 1965; Mulligan and Bailey, 1975). The flower structures of these species are very similar, but differ in general morphological features, capsule, and seed morphology (Figures 3–8) (Davis, 1965). The flowers have cruciform (cross- or ×- shaped) petals and 6 stamens, outer 2 stamens of which are short (Cheng et al., 2014). The seed pods split open from both sides to expose a clear membrane in the centre (https://www.wildflowers–and–weeds.com/Plant_Families/ Brassicaceae.htm).

2.2.1. Wild mustard or charlock (*Sinapis arvensis*)

It is frequently seen as weed among cultivated plants in Turkey. Cultural, mechanical, and chemical control is very costly. The seeds are roundish, bright black-brown, 1–1.3 mm in size, and can remain in the soil for long periods without germination (about 10–35 years) (Figure 3a). It grows 30–80 cm tall, with large kidney-shaped cotyledons and number of branches, the lower parts of shoots usually have hard-hairs and are rarely hairless (Figures 3b,c,d). Its upper leaves are without segments with very small petioles and the lower segmented leaves. The fruit is gnarled and 25–40 × 2.5–3 mm in size. Optimum germination temperature is 7–25 °C (Uygur et al., 1986). *S. arvensis* genotypes have high self-incompatibility and self-fertilization rate is below 10% (Roy and Stanton, 1999; Groves et al., 2000; Cheng et al., 2012).

2.2.2. White mustard or yellow mustard (*Sinapis alba*)

It is an annual herbaceous plant and a rather hairy annual herb with ovate leaves. The seeds are a commercial source of mustard oil and the foliage is used as greens. They are about 1.5–3 mm, minutely pitted, seed coat is thin,

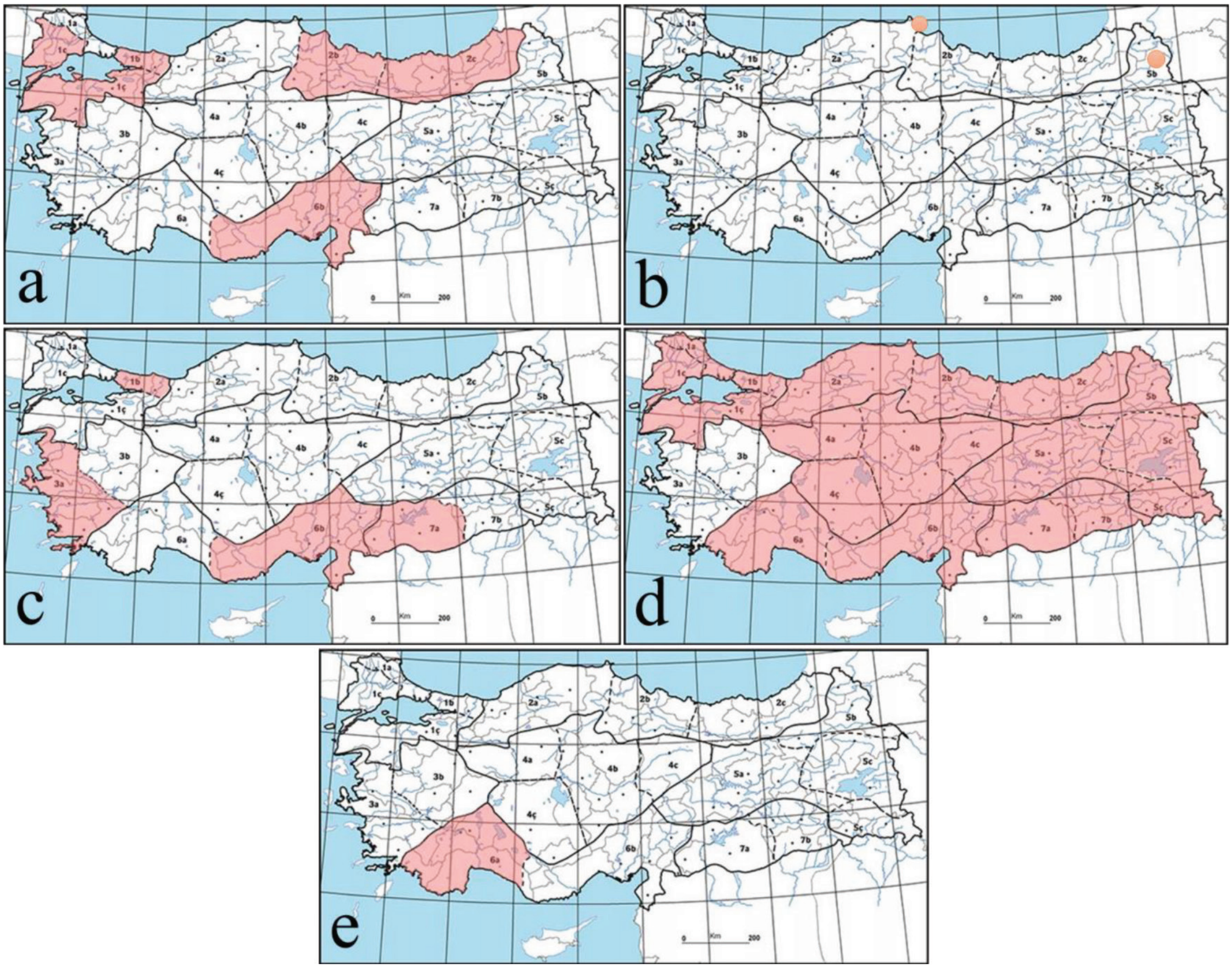

Figure 2. Distribution map of naturally growing *Brassica* and *Sinapis* species in Turkey. (Bizimbitkiler.org.tr) (a, c, d, e); (http://194.27.225.161/yasin/tubives/index.php?sayfa=dizin&&familya=Acanthaceae) (b) (Frame a) *B nigra* - (1b) Çatalca-Kocaeli, (1c) Ergene, (1ç) South Marmara, (2b) Central Black Sea, (2c) East Black Sea, (6b) Adana Divisions. (Frame b) *B. rapa* - North and North East Anatolia. (Frame c) *S. alba* - (1b) Çatalca-Kocaeli, (3a) Main Aegean, (6b) Adana, (7a) Middle Euphrates Divisions. (Frame d) *S. arvensis* growing regions of Turkey - (1a) Strandja, (1b) Catalca-Kocaeli, (1c) Ergene, (1ç) Southern Marmara, (2a) Western Black Sea, (2b) Central Black Sea, (2c) Eastern Black Sea, (4a) Upper Sakarya, (4b) Middle Kızılırmak, (4c) Upper Kızılırmak, (4ç) Konya, (5a) Upper Fırat, (5b) Erzurum-Kars, (5c) Upper Murat-Van, Hakkari, (6a) Antalya, (6b) Adana, (7a) Middle Euphrates, (7b) Tigris Divisions. (Frame e) *B. juncea* - (6a) Antalya Division

endosperm meagre and invisible to the naked eye; embryo large, yellowish, with curved hypocotyls, radicle partially surrounded by 2 folded cotyledons. They are light creamy yellow to yellow with the occasional seed being light or yellowish brown and are spherical in shape with a diameter of 2 to 3 mm. *S. alba* seed does not have any odor when crushed in water. It is sticky in water. Etheric fat content is less compared to *B. nigra*. The weight of 1000 grains is between 3 and 4 g (Figure 4a). Heart-shaped cotyledons have a few hairs on the edges and upper surface. Stems and leaf stalks are densely pubescent (hairy) (Gomez-Campo and Tortosa, 1974; Lamb, 1980). First true leaves have a dense covering of hair on both upper and lower surfaces (Figure 4b,c,d). Leaves are light-green, densely pubescent, and deeply lobed. The leaf terminates higher up on the leaf stalk and do not clasp the stem (https://saskmustard.com/production–manual/MustardProduction Manual–2017.pdf) (Figure 4e). Leaves are alternate, long, bristly branched, irregularly toothed, petiolate, hairy on both sides. It grows 60–80 cm in spring sowing and 80–100 cm in fall sowing. It is usually light pubescent and rarely naked. Flowers are small, yellow with 4 petals, cruciform; stamens tetradynamous; pistil bicarpellate. Four out of 6 anthers are long (self-pollinated), 2 are short (cross-pollinated) (Figure 4f). Petal leaves are light yellow, sepal is twice the length of the leaves. Petals are 11 × 5 mm long

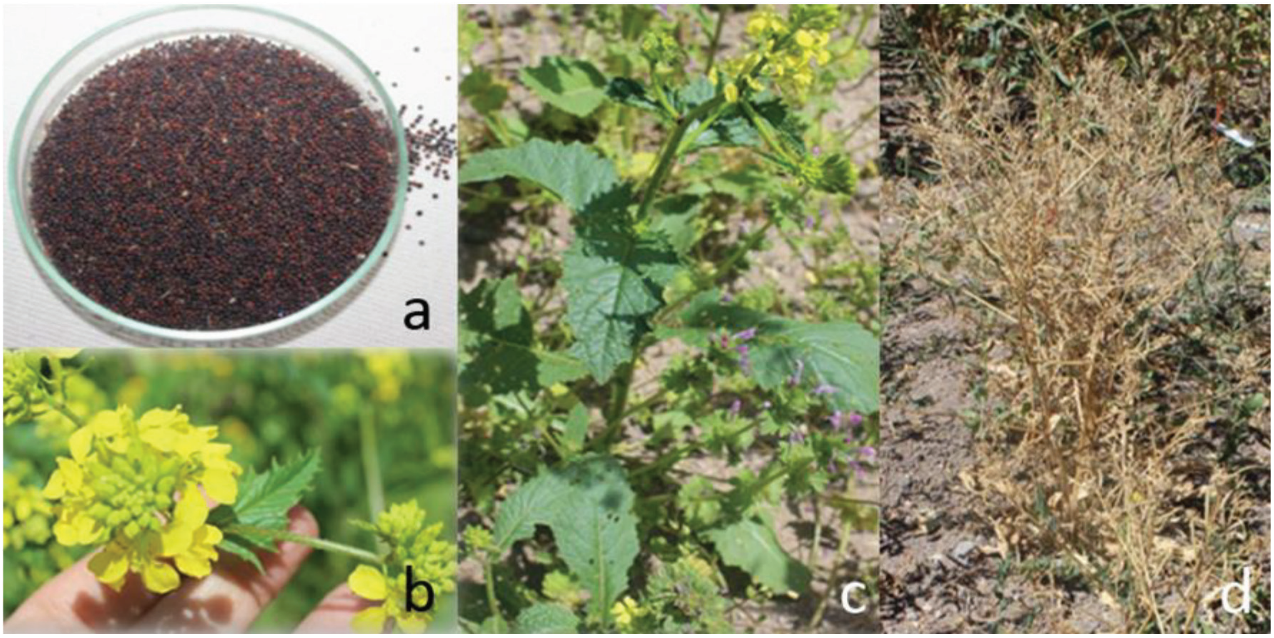

Figure 3. Growth stages of wild mustard (*Sinapis arvensis*). (a)-Seed, (b)-Booting, (c)-Plant, (d)-Grain filling

(Figure 4g,h,i). Fruit is called capsule (pod) that are long, flat, and pubescent. They are positioned at a right angle to the stem (see for details in Figure 4j,k,l). The fruit is a bristly siliqua, round, ribbed, swollen at the seeds, and with a long ensiform beak, pods spreading in the raceme. The fruit stem is 5 × 14 mm. The fruit is 20–45 × 2–4.5 mm in size and carries a beak of 15–30 mm in size. Beak has 0–1 seed; the lower part of the fruit has 1–4 seeds. It grows from sea level up to 1400 m. *S. alba* is generally mentioned as *B. hirta* in North American literature and *S. alba* or *B. alba* in European literature. *S. alba* is self-sterile (Olsson, 1960). Hypocotyl is easily distinguished from rapeseed during the early germination period due to its pubescence (Parry, 1969; Ilisulu, 1973). The yield is low compared to other cultivated mustard species (Downey et al., 1995) (Figure 4m,n).

2.2.3. Brown mustard (*Brassica juncea*)

B. juncea [AABB (n = 18)] consists of *B. nigra* (n = 8) and *B. rapa* (n = 10). *B. juncea* is presumably present in the Middle East and neighbouring regions where distributions of *B. nigra* and *B. rapa* intersects (Prakash, 1980). The seeds are round and can be yellow (oriental) or brown, spherical or oval shaped (Figure 5a). *B. juncea* seeds are reddish brown to dark brown and are 2 mm or less in diameter. First true leaves are covered with hairs on both upper and lower leaf surfaces. They have heart shaped cotyledons and hairless leaf stalks (Figure 5b,c,d). Pubescence on leaves is less dense compared to leaves on yellow mustards. The leaves are pale green pubescent on the first leaves and leaf margins. The lower leaves are deeply lobed, while the upper leaves are narrower and not lobed. The leaves terminate higher up on the petiole and do not clasp the flowering stems. *B. juncea* is a self-fertilizing plant, with report of 20%–30% cross pollination (Rakow and Woods, 1987) (Figure 5e,f,g,h). Pollen is heavy and sticky and cannot be carried by wind, so bees are the main pollen carriers. Pollination between plants is possible by physical contact of flowers (Singh, 2013). They have smooth long, conical beaked pods. The pods are usually positioned at 45° to the stems (Figure 5i,j,k) -Bebeau, 2013; https://saskmustard.com/production–manual/MustardProduction Manual–2017.pdf). Morphological features are similar to other species. *B. juncea* can be sown in spring and grows 100–150 cm tall. Fall sown cultivars grow 150–200 cm long (Figure 5l).

B. juncea is grown as a spice plant in North America, but it is also grown for vegetable oil production in South Asia. Compared to the more commonly grown canola species *B. napus* and *B. rapa*; *B. juncea* is more tolerant to heat and drought stress (Woods et al., 1991). They are low glucosinolate and low erucic acid containing varieties and cultivars. Edible (canola quality) cultivars have been developed for extraction of edible oil about 20 years ago (Potts et al., 1999).

2.2.4. Black mustard (*Brassica nigra*)

Mediterranean basin or temperate regions of West Asia are considered as the centre of diversity of this plant species. *B. nigra* is a plant that grows in Europe and Asia and is widely cultivated for about 2000 years due to its beneficial effects on health. It is a source of mustard oils and condiments. The seeds are round and dark in

Figure 4. Growth stages of white mustard (*Sinapis alba*). (a)-Seed (b,c,d)-Emergence (e)-Rozette (f)- Bud(g,h,i)- Booting (j,k,l)-Capsule (m,n)- Grain filling

colour from reddish brown to black. It is not sticky in water. The weight of 1000 grains is 1–2 g depending on variety (Figure 6a). *B. nigra* is sown during spring and grows 80–100 cm long. If sown in fall, it grows to 100–150 cm in length. The stem is round, hard, and green in colour. The leaves are oval, pointed, and usually have a burning smell, dark on top, and lighter green on the bottom (Figure 6b,c,d). It blooms in small clusters in the

Figure 5. Growth stages of brown mustard (*Brassica juncea*). (a)-Seed (b,c,d)-Emergence (e,f,g)-Bud (h)-Booting (i,j,k)-Capsule (l)-Grain filling.

mid of summer (Figure 6e,f,g,h). Capsules are flat and sword-shaped with short beaks. Capsules are steeper and smaller than other species, which are 1.5–2.5 cm in length (Figure 6i,j,k). *B. nigra* is not popular in the US and Europe due to difficulties in harvesting (Ilisulu, 1973; Uhl, 2000).

Figure 6. Growth stages of black mustard (*Brassica nigra*). (a)-seed (b)-emergence (c,d)-rozette (e,f,g,h)-booting (i)-grain filling (j,k)-capsule.

2.2.5. Field mustard or turnip (*Brassica rapa*)

It includes a variety of vegetable crops such as Chinese cabbage, Pakchoi, turnip, and broccoletto as well as oilseed crops such as turnip rape (Gomez-Campo, 1999). The seeds are nearly round, and reddish-gray to black with small yellow flowers that are hard to distinguish from the flowers (Figure 7a). The leaves are known as "turnip greens" or turnip tops (Undersander et al., 1991). It is an upright winter annual or biennial mustard with long, lobed leaves, and flat or globular roots. Plants grow 100–150 cm tall from a sometimes fleshy, enlarged taproot, with many-branched stems. *B. rapa* is most easily identified by the large rounded basal leaves and smaller clasping stem leaves. The foliage is generally hairless and sometimes covered with a whitish film (Figure 7b,c,d). Lower leaves can reach 30 cm long, have a large central lobe, and usually one to four pairs of smaller side lobes. Upper leaves are smaller, nonlobed, and have a pointed tip and widened, clasping base (Figure 7e). The bright yellow flowers are clustered at stem tops and have 4 petals that are 6–12 cm long. Plants are insect pollinated and self-incompatible (Figure 7f). The fruits are an elongated with 2-parted capsules that split open at the base to release seeds at maturity. Each half of the pod has a single prominent lengthwise vein that distinguishes it from those of other *Brassica* species that have 3 to 7 veins (Figure 7g,h,i,j). The hairless seed pods are 2 to 10 cm long, with a narrow beak at the tip, and are borne on long, 1.5 to 2.5 cm stems that point outward or upward (Downey et al., 1975; Young-Mathews, 2012).

Schematic representation of different branch types of mustard species are shown in Figure 8a,b,c,d.

2.3. Economic importance and uses of mustards

Total mustard sowing area in the world is 616,000 ha with production of 564,000 tons and yield of 915 kg ha^{-1} (http://www.fao.org/faostat/en/#data/QC). About half of this is produced by Canada and Nepal. The other important mustard growing countries in the world include China, Czech Republic, France, Germany, Myanmar, Pakistan, Russia, Ukraine, and USA (Yigit, 2016). The leaves, seeds, and oil are useful for different ethnobotanical purposes. Whereas, total rapeseed sowing area in the world is 34,740,000 ha with a production of 76,238,000 tons and yield of 2194 kg ha^{-1} (http://www.fao.org/faostat/en/#data/QC).

2.3.1. Food

Notification of breeding suitable varieties and cultivars of spices is very important in meeting local demands in Turkey. List of plant species used as spices according Turkish Food Codex Spice Communique, is given in Table 1 (https://www.resmigazete.gov.tr/eskiler/2013/04/20130410-19.htm). Physical and chemical properties of whole and ground mustard used as spices are given in Table 2 (https://www.resmigazete.gov.tr/eskiler/2013/04/20130410-19.htm).

Young and fresh leaves of mustard, flowering shoots and unopened flower buds are harvested and are evaluated as a vegetable variably (Duke, 1983; Pruthi, 1992). Some ethnobotanical studies conducted in different parts of Turkey and elsewhere show that *S arvensis*, *S. alba*, *B. juncea*, *B. rapa*, and *B. nigra* species are the most consumed herbs. Generally, they are roasted and/or eaten with boiled eggs. They have frequent use in salad, pastry, or vegetable soup making (Dogan et al., 2004; Ertug, 2004; Kargioglu et al., 2010; Yucel et al., 2010; Ahiskali et al., 2012). Yucel et al. (2010) conducted a study by selecting randomly the families at Mihalıççık county of Eskisehir province. They found that about 66% of the people in the region used local plants belonging to 18 families and 25 plant taxa in their culinary (cooking, salads, and making of pies). They also noted high consumption of mustard plants in local culinary.

Genotypes of low-fat species are suitable for use as spices. High fat content, especially in oils rich in unsaturated fatty acids, causes rancidity due to oxidation and may cause storage problems (Ozcan et al., 1998). Uses of different mustard species in Turkish folk medicine and ethnobotany are given in detail in Table 3.

Most of these plants contain glucosinolates. It could be said in nutshell that *B. rapa* with glucoraphanin, *B. nigra* with sinigrin, *S. alba* with sinalbin, *B. juncea* with myrosinase are primarily consumed as a part of the human diet (Bridges et al., 2002; Bartnik and Facey, 2017).

Essential oil obtained from seeds of these species are rich in allyl isothiocyanate and aroma and can be used as food preservatives (Ozcan et al., 1998). There is a viscous liquid found in the seeds of *B. nigra* that contains 25%–30% fat, sinapine and sinigrin called glycoside and myrosin. The seeds of *B. nigra* are mixed with other types of mustard seeds crushed and powdered, followed by addition of water with preservative juice, wine or vinegar, salt, sugar, and some spices for garnishing meat cuisine (Mandal et al., 2002).

Sharpness of the bitter aroma varies according to different mustard species. Palle-Reisch et al. (2013) mention that *B. juncea*, *B. nigra* and *S. alba* species can be used variably as spice. Among these 3 types of mustard, *B. nigra* has the sharpest taste and *S. alba* has the lightest taste. It is reported that *B. juncea* is also used to produce Dijon mustard. All mustard seeds do not have a pungent taste at start but provide a pungent taste after chewing. The bitter taste in *S. alba* is felt on tongue, whereas the bitter taste in *B. juncea* and *B. nigra* is felt in nose and eyes. In addition to use ground seeds of mustard as a strong food preservative in condiments and bakery products, soft drinks, and pickles (in South Asian pickles), young leaves of mustard plant are also used in salads and as vegetables.

Figure 7. Growth stages of field mustard (*Brassica rapa*). (a)-seed (b,c,d)-emergence (e)-rosette (f)-booting (g)-ripening (h,i)-capsule (j)-grain filling.

S. alba powder is used after crushing and *B. nigra* powder is used as additive in meat industry, sausage and salami industries (Akgul, 1993).

Aroma is not preserved in ground mustard. However, when the enzymatic effect is triggered in the presence of water it releases the taste or sharpness of mustard flavor. Glycosides are formed by various isothiocyanate compounds found in mustard tissues. The main sharp compound of *B. nigra* and *B. juncea* is allyl isothiocyanate. Particularly in *B. juncea* and *B. nigra*, the release of the sensation is delayed

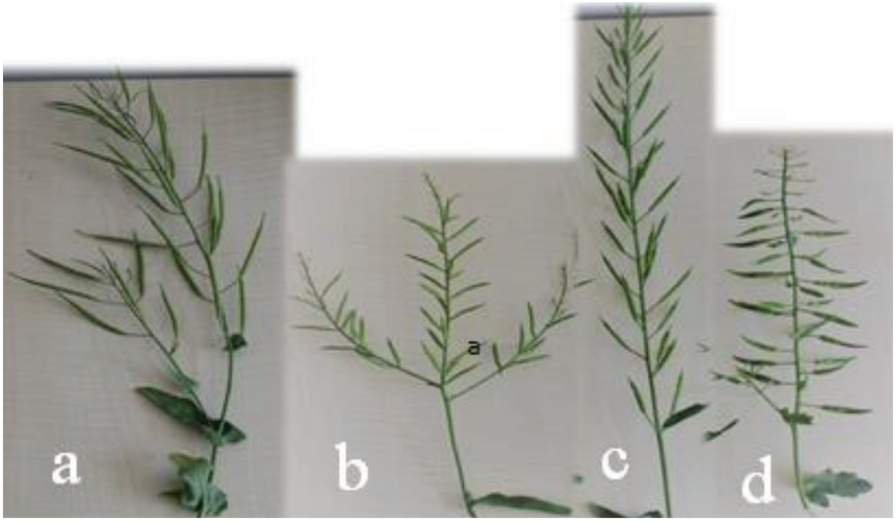

Figure 8. Schematic representation of different branch types of mustard species (a)-*B. rapa*, (b)-*B. nigra*, (c)-*B. juncea*, and (d)-*S. alba*.

Table 1. List of plant species used as spices.

No	Botanical names of the plant	Family	Common name	Name of plant part used as spice
1	*Brassica juncea*	Brassicaceae	Brown mustard	Seed
2	*Brassica nigra*	Brassicaceae	Black mustard	Seed
3	*Sinapis alba*	Brassicaceae	White mustard	Seed

Turkish Food Codex Spice Communique (https://www.resmigazete.gov.tr/eskiler/2013/04/20130410-19.htm).

Table 2. Physical and chemical properties of mustard whole and ground as spices.

Spice	Acid insoluble ash w/w% Max.		Moisture w/w% max.		Ash w/w% max.		Acid insoluble ash, percent by mass w/w% max.		Nonvolatile ether extract, percent by mass w/w% min.		Volatile (essential) oil w/w% min.	
	Whole	Ground	Whole	Ground	Whole	Ground	Whole	Ground	Whole	Ground	Whole	Ground
Turkish Food Codex	1.0	1.0	10	6	6.0	6.0	1.5	1.5	28	25	0.5	0.35

Turkish Food Codex Spice Communique (https://www.resmigazete.gov.tr/eskiler/2013/04/20130410-19.htm).

and an enzyme begins behind the mouth, giving a sense of attraction to the sinuses through activation of myrosinase. In the presence of water, the enzyme myrosinase breaks down in *S. alba*, *B. nigra* or *B. juncea* or the glycoside (sinalbin) in the sinigrin, para-hydroxybenzyl isothiocyanate, which is responsible for the characteristic sharp aroma. Fragrances last until enzyme activity stops (Durkeet and Harborne, 1973; Thomas et al., 2012).

The aroma and sharpness of *S. alba*, such as *B. juncea* or *B. nigra*, can only be fully experienced by triggering the enzyme myrosinase that releases them. The most effective enzymatic trigger is in the presence of water at room temperature, but other low-acid liquids such as milk and beer also work. Water, acidic liquids such as wine, vinegar, and lemon juice are weak triggers of the general flavour of mustard, but are good subsequent preservatives of flavour and prolong the penetrating odour. A very pungent and warm taste is produced with water, while vinegar produces a softer flavour. Milk with a lighter pleasant and tangy flavour and beer produces a very hot flavour (Uhl, 2000).

Table 3. Uses of different mustard species in Turkish folk medicine and ethnobotany.

Species	Part used	Ethnobotanical uses	Potential Benefit	Use	References
S. arvensis	above ground	foodstuff		roasted with eggs	Dogan et al., 2004
	flowers, stems	medicinal	headache, toothache, rheumatism	decoction, dried and make powder for lesions	Gunes ve Ozhatay, 2011
	fresh leaves and shoots	medicinal	improves digestion and aids in the metabolism of fat; applied externally, helpful for chest congestion, inflammation, injuries, and joint pains	oral	Esiyok et al., 2004
	leaves	foodstuff		roasted	Akaydin et al., 2013
	seeds, leaves	medicinal	cough, rheumatism	crushed, decoction external, wrapping drink one tea cup 2 times a day for 6 days	Kultur, 2007
	above ground	foodstuff, fodder	relieving blood accumulation in the lungs, bronchitis, rheumatic pain, vocal development, paralysis	consumed as food and fodder	Nacakci, 2015
	above ground	foodstuff		cooked with rice, tomato paste and onion	Yesilyurt et al., 2017; Ozgen et al., 2004
	leaves	foodstuff			Akan et al., 2013
	whole plant	foodstuff		eaten fresh	Ozudogru et al., 2011
	flowering branches	medicinal	Diabetes	taken one tea cup 2 times a day for 2–3 weeks	Polat and Satil, 2012
	leaves	foodstuff	headache, rheumatism	Infusion	Yapici ve ark., 2009
	above ground	foodstuff, medicinal	constipation problems and digestive system health	consumed vegetables in salads and beside meals and by boiling the leaves	Fidan, 2018
	leaves	foodstuff		fresh body and leaves are consumed raw as well, fried with tomato paste and onion in oil and eaten. Pancakes are also made.	Oymak, 2018
	above ground	foodstuff		roasted with eggs, or boiled and made into salad. Also consumed as vegetable soup	Doğan, 2012
	seed	medicinal	mustard oil has a caustic effect on the skin, so it is important in the production of some patches.	Mush	Zeybek and Zeybek, 1994
	young leaves	foodstuff		young leaves eaten with or without bread	Senkardes and Tuzlaci, 2016
	young leaves	medicinal	for bronchial trouble, dermatological disorders, urinary system disorders, as carminative, sedative		Gunbatan et al., 2016
	whole	foodstuff, medicinal	appetizer	young leaves are eaten or added in meals to taste	Simsek et al., 2004

Table 3. (Continued).

S. arvensis	above ground	foodstuff		roasted and then cooked with rice and eaten with garlic and yogurt	Sarper et al., 2009
	branchs, leaves	foodstuff, fodder-medicinal		salad, roasted- the leaf is heated on fire and put on an inflamed wound	Metin, 2009
	branches seeds	medicinal	rheumatism cough rheumatism stomach-ache	hopped up, externally wrapped in a cloth decoction, internal decoction, internal	Ecevit ve Ozhatay, 2006
	leaves	foodstuff, medicinal		salad, fresh	Senkardes, 2014
S. alba	aboveground	foodstuff		roasted with eggs	Dogan et al., 2004
	aboveground	foodstuff		roasted with eggs or boiled and made into salad.	Doğan, 2012
	leaves	foodstuff		Vegetables	Kizil and Ertekin, 2003
	branches, leaves	foodstuff		fresh body and leaves are consumed raw as well, fried with tomato paste and onion in oil and eaten. Pancakes are also made.	Oymak, 2018
	flowering branches	medicinal	diabetes	infusion, drink one teacup 2 times a day for 2–3 weeks	Polat and Satil, 2012
	above ground	foodstuff, medicinal	constipation problem and digestive system health	consumed raw in salads besides meals. İt is consumed by boiling the leaves	Fidan, 2018
	leaves	medicinal	sinigrin	Pain killer	Akgunlu, 2012
	above ground	foodstuff		roasted and then cooked with rice and eaten with garlic and yogurt	Sarper et al., 2009
B. nigra	leaves	medicinal	digestive, ligament, rheumatism	eating in powdered form	Ahmed, 2017
	leaves	medicinal	to rheumatism	foodstuff	Darwesh, 2017
	leaves	foodstuff			Ertug, 2004
	seed	foodstuff, medicinal	indigestion, antidepressant, stimulant, warning	by eating directly, vegetable, decoction	Darwesh, 2017
	flower and seed	foodstuff, medicinal		Rheumatism	Oguz, 2017
	seed	medicinal	vascular obstruction, pulmonary tuberculosis and pneumonia	1 kg honey 70–80 g mustard seeds are mixed - one spoon is eaten.	Akan and Bakir, 2015
	young shoot and leaf	foodstuff		consumed as salad	Dogan, 2012
	seeds	medicinal	to heal kidney stone	dried, decoction	Pieroni et al., 2005
	above ground	medicinal	to cough	infusion, internal use	Guler et al., 2015
	seeds	foodstuff, medicinal (Mesir Paste)	painful, stomach sedative -rheumatism, bronchitis and neuralgia as moxibustion, mush or bath- appetite, awakens digestion and has a positive effect on blood circulation	Crushed	Oksel et al., 1997; Cekin and Sertoglu, 2007;-Asil and Sar, 1984;-Giritlioglu et al., 2010

Table 3. (Continued).

B. juncea	seed	biodiesel	no ethnobotanic use or their use in pharmacology have been reported in Turkey	Kayacetin et al., 2016; Kayacetin et al., 2018b-Kayacetin, 2019
	above ground	green manure		Ficici, 2018
B. rapa	seed	biodiesel	no ethnobotanic use or their use in pharmacology have been reported in Turkey	Kayacetin et al., 2018b; Kayacetin, 2019

Mustard powder provides flavour, colour, and has protective and antioxidant properties (Ammar, 2012). In salad dressings, the most important feature of the seasoning is its emulsifying function, which provides the viscosity as well as bind water and oil phases. Cold press method is used to obtain 30%–35% (v/w) of the mustard fixed oil. Oil is used for cooking in South Asian countries, China, Japan, and Pakistan (Thomas et al., 2012).

The seeds, which are milled into powder, are mixed with vinegar or lemon juice to make a pungent paste. The paste is used to season grilled meats, fish, chicken and vegetable dishes, and make mustard sauces. These mustard sauces are mostly used in making of hamburgers and hot dogs. Whole mustard seeds can be used in cooking meat, seafoods and South Asian pickle etc. (Thomas et al., 2012). In South Asian cuisines, the seeds are fried and exploded in ghee (purified butter oil) for garnishing or as a condiment for meals with their pleasant aroma. Mustard is very rarely used as spice in Turkey. Fresh leaves are popularly used as salad in local Turkish restaurants and at homes (Yigit, 2016).

Mustard oil is extracted from *B. nigra* seeds treated with steam or warm water distillation. The crude oil is dark brown and is fatty acids free. Refined oil is soft and light brown. The characteristic smell of mustard oil is due to the sulphur-containing essential oils produced by the hydrolysis of glucosides in the seeds. The quality of mustard oil depends on the content and percentage of fatty acids. Mustard oil is dangerous as it contains high amounts of allyl isothiocyanate (Thomas et al., 2004; Thomas et al., 2012).

The volatile oil is obtained by steam distillation of the pressed pulp obtained after removal of mustard (brown) oil that is obtained after hydrolysing by the enzyme myrosinase to release allyl isothiocyanate from glycoside. Since the essential oil of *S. alba* contains little or no essential oil, it is extracted from the pressed pulp solvent. Also, the pressed pulp must be hydrolysed first to release the final products formed by the action of the enzymes. In both cases, hydrolysis is achieved by mixing the pressed pulp with hot warm water (Sharma, 2012, Thomas et al., 2012).

In a study, among the various spices, condiments and medicinal plants, the effects of mustard powder on meat fermentation in wine is effective and even stronger than the chemical preservatives like benzoic acid and sulphur dioxide (Pruthi, 1992).

Various parts of *Brassica juncea* Czern. and Coss. are used in folk medicines and spices. Mustard seeds are used to treat inflammatory neuralgic affections, rheumatism and vomiting, jaundice diuretics, and stimulate liver-bile (Desai, 2005; Mishra et al., 2012).

The cytotoxicity of mustard seeds on human dermal fibroblast cells was assessed by (3-(4.5-dimethylthiazolyl-2)-2.5-diphenyltetrazolium bromide test for evaluating antioxidant potency. It was reported that mustard seeds feeding to rats in equal doses to human intake have no adverse influence and affects parameters related to histopathology (Khan et al., 1995).

Raw, cooked, and boiled extracts of mustard, possess highest anti-TPO potency in raw extracts. Goitrin is an active goitrogen present in Brassica seeds that is destroyed during cooking that negates its anti-thyroidal potency (Greer, 1957).

2.3.2. Oil production

It has been determined that domestic mustard seeds contain approximately 20%–30% oil (Kayacetin, 2019). Although the oil obtained from wild mustard seeds is not suitable for nutritional purposes due to high erucic acid percentage in terms of fatty acids, the oil is used as a spice for different purposes in pharmaceutical and cosmetic industries (Ilisulu, 1973, Baytop, 1984, Akgul, 1993, Ozcan et al., 1998, Kayacetin et al., 2018b).

Mandal et al. (2002) have reported some species in the family of Brassicaceae with their total fat contents and fatty acid compositions. The results showed fat and erucic acid contents ranging from 23.5% to 25.1%, and from 35.9 to 40.1%, respectively. The total fat contents of *B. nigra* changed between 21.5% and 33.9% and the amount of erucic acid changed between 39.1%–47.2%.

Ozcan et al. (1998), noted thousand seeds of *S. arvensis* seed, seed diameter, water, crude ash, crude protein, crude oil, crude cellulose, and volatile oil amounts, relative density, refractive index, free fatty acids, peroxide number, iodine number, saponification number and nonsaponification amount in seed oil. Gas chromatography study determined 95.40% allyl isothiocyanate in 0.25% volatile oil, 22.52% fixed oil, 29.62% oleic, 24.18% linoleic, 20.65% erucic and 16.52% linolenic acids as the main compounds.

It is the combination of mono unsaturated fatty acids in the mustard species that helps in biodiesel production. Fatty acid compositions of all mustard species grown in Turkey confirm EN 14214 standards by the European Committee for Standardization that describes the requirements for FAME - the most common type of biodiesel (Altuntas, 2006; Schmidt, 2007; Eryilmaz, 2009; Blackshow et al., 2011; Eryilmaz and Ogut, 2011; Kayacetin et al., 2016).

Kayacetin et al. (2018b) determined the fatty acid components of 57 mustard genotypes belonging to different domestic and exotic mustard species. They found significant differences among genotypes in terms of fatty acid components. The researchers reported that oleic acid (7.4% to 41.6%), linoleic acid (9.6% to 25.1%), and erucic acid (20.6 to 44.1%) were detected as major fatty acids and belonged to 3 species (Table 4). The result of this study showed that *Brassica* species have significant potential for use in future breeding programs due to significantly different fatty acid compositions in industrial applications. The fatty acid components in the seed oil depend on genetic, ecological, morphological, physiological, and cultural factors (Turhan et al., 2011; Zhang et al., 2014). The knowledge about oil components of mustard makes it possible to produce oil from the respective genotypes of the species suitable for any specific use.

Gupta (2016) noted that the oils of these species have potential industrial markets (realized or future) as paint and printing ink additives, lubricants, greases, heating oils, polymers and resins, plastics, and in the production of cosmetics and pharmaceuticals.

2.3.3. Medicinal and pharmaceutical uses

Mustard is used as an antidote for scorpion and snake bites in some parts of the world (Kadel and Jain, 2008). It is also used to stimulate blood circulation and warm

Table 4. Fatty acid compositions of mustard genotypes that belong to *Brassica* species.

	Palmitic asit (C16:0)	Stearic asit (C18:0)	Arachidic asit (C20:0)	Behenic acid (C22:0)	Lignoceric acid (C24:0)	ΣSFA	Palmitoleic acid (C16:1)	Oleic asit (C18:1n9c)	Eicosenoic asit (C20:1) E	Erusic asit (C22:1n9t)	Nervonic asit (C24:1)	ΣMUFA	Linoleic acid (C18:2n6c)	Linolenic acid (C18:3n6)	Cis-11,14-eicosadienoic acid (C20:2)	Cis-11,14,17-eicosatrienoic acid (C20:3n3)	Cis-13,16-docosadienoic acid (C22:2)	ΣPUFA
Brassica juncea																		
Max	4.1	2.2	1.0	1.3	0.9	8.3	0.3	24.5	12.2	44.1	2.4	73.6	25.1	14.7	1.1	1.0	1.9	41.6
Min	2.5	1.2	0.9	0.4	0.3	5.9	0.1	7.4	5.3	21.2	1.2	50.9	9.6	9.6	0.3	0.0	0.4	20.5
Mean	3.2	1.7	1.0	0.8	0.5	7.1	0.2	16.7	9.6	31.5	1.6	59.6	19.2	11.8	0.9	0.5	0.8	33.2
Brassica rapa																		
Max	3.1	2.1	1.0	1.3	0.8	7.2	0.2	21.8	11.5	47.5	2.0	70.2	21.3	13.7	0.9	1.3	1.4	36.7
Min	2.1	1.2	0.8	0.6	0.3	5.3	0.1	11.1	6.0	21.6	1.1	56.2	13.2	9.8	0.7	0.0	0.4	24.6
Mean	2.6	1.4	0.9	0.9	0.5	6.4	0.2	15.1	8.8	37.6	1.6	63.2	16.9	11.3	0.8	0.6	0.9	30.5
Brassica nigra																		
Max	3.4	2.0	1.5	1.7	1.0	8.8	0.2	21.0	12.1	37.9	1.9	62.5	25.0	14.4	1.2	0.8	0.9	39.3
Min	3.0	1.4	0.6	0.5	0.3	6.8	0.1	10.4	9.0	21.1	1.1	54.0	12.8	12.2	0.7	0.0	0.3	29.8
Mean	3.1	1.6	1.2	1.2	0.8	8.0	0.2	14.0	10.2	33.7	1.6	59.6	17.1	13.1	0.9	0.4	0.7	32.3
Sinapis alba																		
Max	3.5	2.0	1.0	0.5	0.4	6.9	0.2	41.6	12.0	21.8	1.3	69.0	21.3	12.2	0.9	0.0	0.4	34.8
Min	3.2	1.7	0.5	0.0	0.3	6.2	0.2	23.2	5.3	20.6	1.2	58.3	12.9	12.0	0.0	0.0	0.0	24.9
Mean	3.3	1.8	0.7	0.3	0.3	6.6	0.2	32.4	8.6	21.2	1.2	63.6	17.1	12.1	0.4	0.0	0.2	29.8

Kayacetin et al., 2018b

the cold feet, relax hard muscles, treat arthritis, and rheumatism (Thomas et al., 2012). Furthermore, mustard oil also stimulates flow of saliva, gastric juices, and stimulates appetite (Raghavan, 2006). It has been used for treatment for asthma, as a laxative, and induce vomiting or relieve coughs in Greek and Ayurvedic systems (Indian Pharmacopia) of medicine (Agricultural Corporation 1980, Raghavan, 2006, Thomas et al., 2012). The massage with mustard oil is also considered very effective in treatment of paralysis (Krishnamurthy, 1993). Mustard oil stimulates and improves digestion. Excessive use of fat causes impotence in men. Mustard is also considered diuretic, emetic, and stimulating (Skrypnik et al., 2014). Mustard removes congestion by pulling the blood to the surface as in the case of head disorders, neuralgia, and spasms (Agricultural Corporation, 1980; Raghavan, 2006; Thomas et al., 2012; Skrypnik et al., 2014). Mustard plaster is used to treat arthritis and rheumatism (Yabanoglu et al., 2012).

Aslan (2013) has reported and identified 41 mustard plant lines at Şanlıurfa, Turkey, of which 27 were wild and 14 were cultivated. *B. nigra* is also among these wild plants. Local people use branches of mustard plants as spice and analgesic. Polat and Satil (2012) have reported tea of flowering branches of *S. arvensis* and *S. alba* by the people of Balıkesir (Aegean region of Turkey) by drinking a teacup twice a day for 2–3 weeks for treatment of diabetes. Similarly, Kokcu et al. (2015) has identified the use of wild mustard seeds and leaves, for the treatment of external moxibustion, mush, bronchitis and rheumatism diseases at Çanakkale (Marmara region of Turkey).

Esiyok et al. (2004) have reported a brief overview of important herbs in the Turkish flora, including fennel, mallow, chicory, nettle, wild radish, and wild mustard as important food plants for promoting human health and their potential anticancer characteristics.

It is believed that mustard stimulates brain activity and facilitates digestion of fatty foods. The powder obtained from mustard seed is of low-caliber and soothing. It is externally used as a muscle relaxant. The oil and bitterness in the mustard stimulate the gastric juice to facilitate digestion of fat containing foods. Mustard is low in calories, fat and cholesterol and contains plenty of vitamin C (Fahey and Talalay, 1995; MEB, 2013).

B. nigra, *B. juncea*, and *S. alba* seeds have been used in traditional folk medicines as stimulants, diuretics, and cleansers for the treatment of various diseases such as peritonitis and neuralgia. It is also used in mustard plasters to treat rheumatism, arthritis, chest congestion, back pain, and muscle pain. Prolonged use of mustard plasters can result in skin burning and nerve damage (Chan et al., 2014).

2.3.4. Importance of mustards in beekeeping

Most Brassica species are insects pollinated and are grown in large range of areas across Turkey. They are popularly evaluated for obtaining high quality honey. Expert beekeepers could manage to get about 10–50 kg honey per hive during the season. Many of the plant species of this family act as good source of nutrients for honey bees and other pollinating insect species (Teper, 2003).

The bright yellow petals of these plant species attract bees. The morphological structure of flowers with large amount of nectar and high sugar contents are very suitable for nectar and pollen accessibly to honey bees and other pollinating insect species (McGregor, 1976; Jablonski and Szklanowska, 1997; Kapeluszny, 2003; Singh, 2013; Gupta, 2016). Honey bees, solitary bees, bumble bees, flies etc. extensively visit the flowers of the species to collect nectar and pollen, and serve as a source of cross pollination (McGregor, 1976, Lauffer, 1987, Jablonski and Szklanowska, 1997; Zengin, 1997; Baydar and Gurel, 1998; Fakir and Babalik, 2012; Sirali et al., 2013). Sugar in nectar is an important source of carbohydrate for vital activities of honey bees and pollen is the main source of protein, fat, vitamins, and minerals (Lauffer, 1987; Teper, 2003).

2.3.5. Importance of mustards in phytoremediation

Phytoremediation is a developing low-cost alternative to physico-chemical methods to clean contaminated soils. The technology of removing pollutants from the air, soil and water, with the help of living plants with or without associated microorganisms and make environment harmless is generally called phytoremediation (Reichenauer and Germida, 2008; Das, 2018). The main advantages of phytoremediation over other breeding methods include cheapness and not requiring any special equipment. The disadvantages include slow and variable remediation efficiency depending on the plant species used (Paz-Alberto and Sigua, 2013; Ozbek et al., 2014).

Growing plants for phytoremediation are a well-known concept. First known studies were carried out on the use of plants in treatment of waste water about 300 years ago (Garg and Kataria, 2010). The increasing industrialization and the use of mechanised agriculture techniques has constrained natural resources making it important to use different approaches to clean environment and integrating plant species in cleaning ecosystems contaminated with heavy metals (Raskin et al., 1994; Ebbs and Kochian, 1997; Epstein et al., 1999; Lim et al., 2004; Wu et al., 2004). Therefore, there is a need to understand how plants metabolize, absorb, and translocate heavy metals (Zhang and Schmidt, 2000, Evangelou and Marsi, 2001, Zhang et al., 2003). Turan and Esringu (2007) have indicated that application of EDTA could increase heavy metals (like Cu, Cd, Pb and Zn) uptake by *B. napus* and *B. juncea* through roots. They also noted that root heavy metal uptake of both species was higher compared to shoot heavy metal uptake.

To date, around 400 plant species from approximately 45 plant families have been identified as metal exploiters. Most of these plants can biologically phytoremediate nickel, about 30 of them can absorb cobalt, copper and/ or zinc, and a very few can accumulate manganese and cadmium (Thompson, 1997). Phytoremediation studies conducted with the Brassicaceae family have shown that these plants can remediate soils by accumulating about 30 to 1000 times the heavy metal concentration in the soil (Turan and Esringu, 2007; Garg and Kataria, 2010). The amount of heavy metals accumulation in plants can be up to 5% (w/w) w of the dry plant (Ilya et al., 1994).

Brassica species are well known as metal accumulators and some of them are being used for phytoremediation in contaminated soils. Approximately, 25% of the documented metal hyper accumulating species are members of the Brassicaceae because of their slow growth and low biomass, other fast-growing and high biomass *Brassica* crop plants, for example *B. juncea* and *B. nigra* are frequently evaluated for their ability to hyper accumulate metals from contaminated soils (Memon et al., 2008; Ozturk et al., 2012).

It is commonly believed that *B. juncea* can play a dominant role to decontaminate heavy metal polluted soils (Salt et al., 1995). Advanced root system of *B. juncea* is capable of accumulating heavy metals such as Pb, Cd, and Zn (Minglin et al., 2005; John et al., 2009). It is well established that the plant can accumulate (at least 10 times more metal accumulation compared to other hyperaccumulators (plants that can grow rapidly even in the contaminated soils).

Memon et al. (2009) has mentioned Cu accumulation capacity of Diyarbakir genotype and compared it with other *B. nigra* ecotypes No. 6619, 6620, and 6630 obtained from different sites of Western Europe. In these comparative studies *B. nigra* Diyarbakir ecotype was found a super accumulator of Cu compared to the other ecotypes.

Copper is an essential trace element for plants, but it can be toxic in case of high levels of accumulation. Low concentrations (25 and 50 µM CuSO4) of Cu were applied to different ecotypes for 72 h. *B. nigra* collected from Diyarbakır, Turkey survive at high level Cu concentrations, and 2 other ecotypes (CGN06625 and CGN06626, Ethiopian origin) were compared for Cu tolerance. Heavy metal accumulation in root, shoot and leaves of these ecotypes were detected using ICP-OES (Inductively coupled plasma optical emission spectroscopy). It was shown that Diyarbakır ecotype had higher Cu tolerance compared to other ecotypes. Twenty-three genes related to heavy metal mechanism and metal homeostasis were defined from *B. nigra* microarray data that were performed with root tissues under Cu stress. Among these genes, 8 genes were selected for the validation with more robust technique of quantitative RT-PCR (Reverse transcription polymerase chain reaction). Detailed mRNA expression profiles of these genes were evaluated in roots, shoots, and leaves of 3 tolerant and nontolerant *B. nigra* ecotypes exposed to different concentrations of Cu. The idea was that the genes shown to be differentially expressed will provide important contributions to understand the pathways related to Cu metabolism and transgenic studies for phytoremediation applications (Yildizhan, 2015).

2.3.6. Hardaliye production from mustards

Hardaliye is a non-alcoholic traditional Turkish beverage. It is produced from ripe fresh dark and fragrant grapes, sour cherry, quince leaf, and cracked *B. nigra* seeds after lactic acid fermentation in the Thrace Region extending from Turkey to Greece and Bulgaria. If black mustard seeds are used, they improve taste, aroma and also significantly reduce number of yeasts and moulds in the hardaliye beverage in comparison to the use of *S. alba* seeds in preparations (Coskun and Arici 2006). They also noted the ratio of grape juice polyphenols and type of mustards can be used to determine and improve the characteristics of hardaliye (Askin and Atik, 2016).

2.3.7. Green hay, green manure

Mustards are easy to grow and have abundant vegetative growth. Therefore, they are also evaluated as green feed and green manure (Tariman, 1965).

Nitrogen is one of the most significant nutrients required for crop growth and development. Crops from the legume family can take nitrogen from atmosphere and fix it, and hence it becomes available for other crops. This is done through ‘nodules’ (home to nitrogen-fixing bacteria) on the roots. The exploitation of legumes can help farmers make dramatic reductions in nitrogen fertilizer costs. Nonlegumes can be used to ‘hold’ nitrogen. They mop it up from the soil and store for future crops. Nitrogen release is slower with more mature plants. This is particularly noticeable with short term annuals such as mustards (Rosenfeld and Rayns, 2011) (Table 5).

2.3.8. Other uses

Mustard oil has potential mosquito repellent formulations (Bowers et al., 1995). *Brassica* spp. has high potential to be used as fumigant due to the presence of isothiocyanates and nitriles for controlling fungi, bacteria and nematodes (Mojtahedi et al., 1991; Kirkegaard et al., 1997). Mustard and its component allyl isocyanate are bacteriostatic (inhibiting bacterial growth) and bactericidal (bactericidal) in properties (Charalambous, 1994). Mustard bio-disinfection can be integrated to provide environment friendly products and could be used as repellent of cats and dogs (Thomas et al., 2012).

They are agriculturally used as a cover crop and can provide affordable control of soil-borne pests and diseases under integrated pest management systems (Haramoto and Gallandt, 2004; Rehman et al., 2019; Thomas et al., 2012).

When livestock take large quantities of seed or are confined to pastures composed primarily of mustards, they may get ill. The roots, leaves, and especially seeds of mustard species contain sulfur compounds (glucosinolates) that can irritate the digestive tracts; toxicity in livestock especially horses. It may also create symptoms such as colic, diarrhoea, anorexia, excessive salivation, thyroid enlargement and thyroid problems, if consumed in large quantities (DiTomaso and Healy, 2007; Ahmann Hanson, 2008). Nitrate nitrogen toxicity can also be a problem for ruminants if *B. rapa* is grazed when immature or if soil N levels are high (Undersander et al., 1991). Therefore, mustard meal is not recommended as animal feed. However, it can be added to feeds in very small proportions (Tariman, 1965).

All mustard species in general and *S. arvensis* in particular have allelopathic properties (Rehman et al., 2019).

Unay et al. (2019) determined the usability of *B. juncea* meal in ruminants. Therefore, dry matter, crude ash, organic matter, crude oil, crude protein, crude fiber in cold pressed pulp samples of mustard plants are cultivated as spring and fall mustard in different regions. Neutral detergent insoluble fibre (NDF), acid detergent insoluble fibre (ADF), and acid detergent insoluble lignin (ADL) analyses were performed and energy value was calculated. The results of the analysis showed nonsignificant difference in terms of sowing periods ($P > 0.05$) and terms of raw nutrient contents of mustard sown as summer and winter crops. When the data obtained from the study were evaluated, it was concluded that mustard meal can be used as an alternative protein and energy source in ruminant nutrition selectively.

Mesir Macunu (Mesir Paste) is a popular traditional high antioxidant, traditional aphrodisiac stomach sedative, astringent, and skin softener of the Aegean region of Turkey (Aggarwal et al., 2001; Aqil et al., 2006; Guven, 2010) and is used in many parts of Anatolia since 16th century. It is prepared using 41 different spices including *B. nigra*, sugar, and honey (Baylav, 1968; Oksel et al., 1997; Cekin and Sertoglu, 2007, Simsek, 2012; Tufan et al., 2018). It is also effective in porous bronchitis and rheumatism. It is also known for treatment of rheumatism, bronchitis, and neuralgia as moxibustion, mush, or bath (Asil and Sar, 1984). Additionally, it is used to improve appetite, digestion, and blood circulation (Giritlioglu et al., 2010).

3. Vegetable oil production and trade of Turkey

There was 2.9 million tonnes oilseeds production and 786 thousand tonnes of crude vegetable oil production during 2017 in Turkey (http://www.bysd.org.tr) that could meet about 1/3rd of the local requirements. The lack of sufficient vegetable oil production in Turkey and the inability to meet local demands necessitate imports. Present consumption of mustard as spice in the USA is next to pepper; but the condiment manufacturing is concentrated mainly to the USA, France, Germany, Japan, Canada, and UK. A mean of 2014, 2015, and 2016 shows that *Brassica* is grown on 35 million hectares of land in the world that amounts to 72 million tonnes of Oil Seed *Brassica* (Jat et al., 2019).

It is very clear from Table 6 that the government paid up to 7.6 million dollars between 2003 and 2017 to import mustard needed in the spice and other industries increased by

Table 5. Features of mustard for producing green manure.

Green Manure	Plant type	N potential	Duration	N release rate	Fix or hold
Mustard	Brassica	Large	2-4 months	Slow	Hold

Rosenfeld and Rayns, 2011

Table 6. Imports of mustard and paid foreign exchange.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Imports amount (tonnes)	1.128	6.495	12.660	8.627	17.509	18.436	**20.323**	832	556	597	672	913	1.016	902	1.171
Imports (thousand US dollar)	635	1.362	3.221	1.748	3.598	**7.561**	5.188	1.152	1.030	1.199	1.448	1.899	1.643	1.352	1.676

http://www.tuik.gov.tr

20,000 tonnes thereafter (http://www.tuik.gov.tr). Therefore, Turkish national needs as mustard spice and other uses are met by imports paying a huge amount of foreign exchange.

4. Possibilities of mustard cultivation in Turkey

Mustard is a cool season crop, well suited to a short growing season. Mustard is grown in drier regions because of the better seed quality obtained under these conditions (Rosengarten, 1973). The seedbeds should be firm, moist, and uniform for a successful crop. Early sowing should be preferred by preparing a good seed bed in fall to obtain optimum emergence and yield. Mustard plants that enter winter in the period of weak cotyledon (2–3 leaves) growth are damaged at freezing temperatures below 0 °C in winter. Hence, the plants must enter winter at 8–10 leaves rosette stage. Therefore, fall sowing should be completed earlier in Central Anatolia (Kayacetin et al., 2018). A firm seed bed provides good seed-to-soil contact, even sowing depth and quick moisture absorption by the seeds resulting in uniform germination. Mustards are drought tolerant and prefer well-aerated soils that do not become waterlogged. Poor aeration in the root zone permanently stunts their growth. Mustard performs best in soils close to neutral pH, with tolerance in alkaline and slightly acidic soils. It is important to irrigate fields that provide enough moisture for seed to germinate in the absence or delay of rainfall (Arif et al., 2012; Hassan and Arif, 2012; https://saskmustard.com/production–manual/MustardProduction Manual–2017.pdf).

Crop rotation is a very important part of any crop production system. Mustard crops following a cereal crop makes an ideal rotation. Moreover, to prevent biotic stress (attack of fungal, bacterial, viral diseases etc.) based grain contaminations and down grading, usually a break of several years between canola/mustards, is important.

Moisture is often limiting factor in germination and in the growth of mustard. Ground water charging during excess rainy seasons both naturally and through anthropogenic processes helps in maintaining soil water moisture level and water harvesting subsequently for irrigation (Russell et al., 2010). Crop rotation also influences the maintain of soil moisture by good selection and rotating deep and shallow rooted crops. A list of the common crops used during rotations and their rooting depths in Turkey is found below (https://saskmustard.com/production–manual/MustardProduction Manual–2017.pdf).

Deep rooted plants: Alfalfa- Sunflower -Chickpea

Moderate rooted plants: Barley -Canola -Mustard -Wheat

Shallow rooted: Field pea -Flax -Lentil

Growing about 9 months is required for fall cultivars, and the cultivars sown in spring ripen in 90–100 days. *S. alba* is comparatively earlier, compared to other oilseed plants meant for spring sowing. *S. alba* varieties and cultivars mature in 80-85 days while brown types require about 90–100 days in spring sowing. In sowing fall, the earliest maturity is obtained in *B. rapa* that are adapted to short season growing areas (Kayacetin, 2019).

Usually sowing of 6 kg ha^{-1} seed is recommended for *B. juncea* and 10–12 kg ha^{-1} seed is recommended for *S. alba* types. Mustard seeds are small and should be sown in moist, hard, and shallow seedbeds to ensure rapid germination and emergence. A good source of moisture provides a long blossoming period, resulting in a longer flowering time and better yield. Good moisture supply favours a long blossoming period and a longer flowering period that ensure better yields (Ag-NDSU, 2019; https://hort.purdue.edu/newcrop/afcm/mustard.html). Grain cultivation tools and equipment suitable for mustard farming are shown in Figure 9a,b.

Both summer and winter genotypes of mustard are sown in Turkey. Winter cultivars are needed to obtain higher yields by cultivating these species. Kayacetin et al. (2018a) and Kayacetin (2019) have shown that longer vegetative growth and shorter generative growth due to winter sowing contributes to higher yields compared to yield from summer sown crops. It has been determined that the *B. juncea*, *B. rapa* and *B. nigra* genotypes must be grown in winter (Figure 10 - Kayacetin, 2019). *S. alba* genotypes are less resistant to cold and are suitable for spring sowing as confirmed by studies carried out at the Central Field Crops Research Institute, Yenimahalle, Ankara, Turkey. *S. alba* possesses many beneficial characteristics such as pest resistance and a short growing season (Bodnaryk and Lamb, 1991). *S. alba* is grown as a spring annual crop in cold climates; thus, it may fit well in winter under various geographical regions of Turkey with hot, dry growing conditions. Heat and drought tolerance of *S. alba* is superior compared to *B. rapa* and *B. napus*. *S. alba* has extensive root system that penetrates deep into the soil profile. More than 50% of all moisture uptake is from below 150 cm in the soil profile; therefore, it can utilize nitrates leached down previously (Brown et al., 2005). Also, yield tests have shown that *B. juncea* surpassed the yield of *B. rapa*. Earlier maturity of *B. rapa* makes it better adapted to short season growing areas (Kayacetin, 2019). As both *B. nigra* and *S. alba* do not have high grain and oil yields *B. juncea* and *B. rapa* could be counted as the most promising species in terms of providing raw material to biodiesel industry.

Kayaçetin et al. (2019) also determined the adaptation of *B. juncea* in spring and fall sowing at Ankara, Aydın, Erzurum, Eskişehir, Isparta, Tekirdağ, Tokat, and Şanlıurfa to measure emergence, 50% inflorescence, physiological maturity, and total cultivation days. These locations as classified by Köppen-Geiger ecological conditions lied

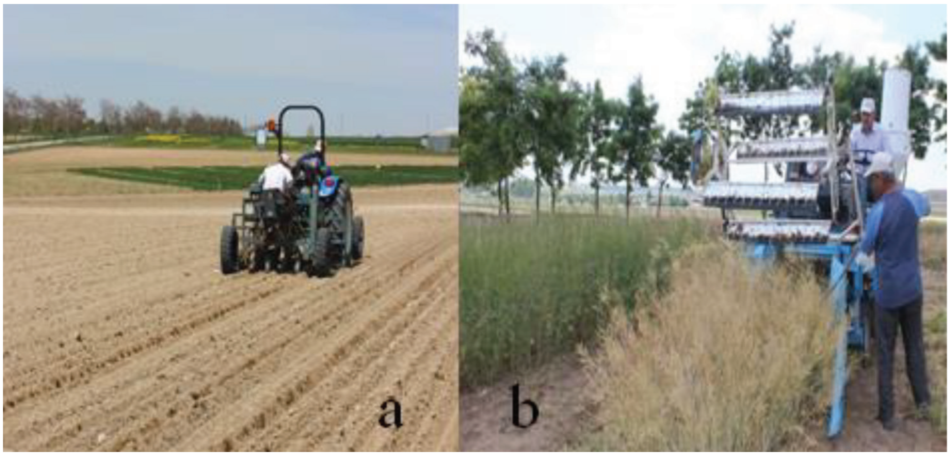

Figure 9. Mustard sowing (a) and harvesting (b).

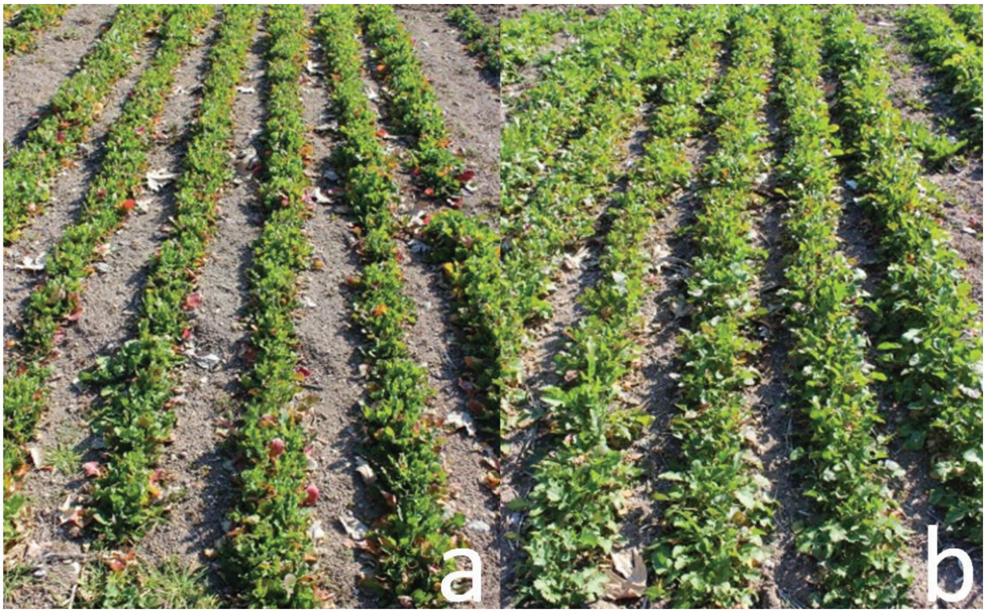

Figure 10. (a)-*B. rapa* and (b)-*B. juncea* fields after winter (March 2019)

under different climatic conditions. Their results showed that, growing degree-days (GDD) about sowing seasons and locations significantly affected the seed yield. The maximum seed yield of 3754.9 kg ha^{-1} was obtained from Tokat (warm humid) during fall sowing with total accumulated GDD of 1512.1 °C for mustard. Sum of growing degree-days accumulated in different sowing seasons and locations ranged from 1132.0 °C to 2285.1 °C depending on the related ecological conditions. Fall season crop in Aydın location had the maximum growing degree-days. Overall, fall season accumulated more growing degree-days due to longer period of sunshine in comparison to spring season with less sunshine days and longer vegetation period (Kayacetin et al., 2019). The seeds of these species could be harvested upon achieving ~8.5% moisture content at maturity (CFIA, 1999).

Diseases and pests: Mustard is not known to suffer from major diseases, but it attracts a variety of insect pests including flea beetles (*Phyllotreta* spp.) and aphids (e.g. *Brevicoryne brassicae*). Effective insect pest control can be achieved by using resistant cultivars, appropriate agronomy, crop rotation, and disinfection of seeds (https://uses.plantnet–project.org/en/Sinapis_alba_(PROSEA)). Flea beetle has become the dominant pest of mustard in Turkey. Adult flea beetles emerge in spring and feed on the cotyledons and true leaves especially under spring sowing conditions. When emerging in huge numbers, they can quickly damage seedling mustard fields. Minimal feeding damage is noted at maturity. Therefore, a timely detection and management of this pest is important (Knodel and Olsen, 2002; Olsen and Knodel, 2002; Rosenfeld and Rayns, 2011).

5. Conclusions

Flora of Turkey has large variation in mustard genetic resources. Based on national and international research findings, mustard can be counted as an important plant in terms of application areas and Turkey can act as an important place for the growth of mustard species.

A knowledge about plant characteristics, application areas, and evaluation of some basic information about the plant species will affect the commercial exploitation of the mustard plants positively. A focus on breeding and development of new varieties and cultivars must be the new target.

Turkey has appropriate geographical location for growth and cultivation of mustard species. There is a need to exploit local genetic resources for breeding new cultivars based on their characteristics to meet demands of specific industries. There is a need to further exploit Turkish genetic resources that have potential to meet the consumer's needs for the economic benefits. Adaptability to high losses due to biotic and abiotic stresses, high yield potential, development of good marketing could serve positively and help in creation of an option for cultivation on marginal areas. Different cultivars could be developed for each agro climatic region of Turkey for food, energy, or any other desired purposes based on the type of demand.

The formation of seed banks, improvement of institutional infrastructures and training of manpower and international cooperation would serve the purpose. Last but not the least, there is need to review the legislation about Mustard cultivation and research to exploit full potential of local flora.

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