



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
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NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(4): 436-447
Received: 08-02-2026
Accepted: 10-03-2026

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A review on the impact of sowing date and row spacing on the growth and yield of toria (*Brassica campestris* L.)

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i4f.5395>

Abstract

A significant oilseed crop grown in many agro-ecological zones, especially in South Asia, is toria (*Brassica campestris* L.). Agronomic techniques like row spacing and sowing date have a significant impact on its production and are essential to the crop's growth, development, and yield. With an emphasis on how these variables impact important physiological processes including germination, flowering, pod formation, and seed development, this study attempts to summarize the body of research on the effects of sowing date and row spacing on Toria growth and yield. Optimizing Toria production requires an understanding of these agronomic techniques, particularly in light of shifting climate conditions and the demand for sustainable agricultural methods.

The crop's exposure to temperature and rainfall patterns, which both have a major impact on plant growth phases and, eventually, yield, are influenced by the sowing date. Because plants can take advantage of favourable climatic conditions, early sowing frequently leads to greater plant establishment and increased output. Late seeding, however, may expose crops to reduced photoperiod and heat stress, which can stunt development and reduce yields. The relationship between the sowing date and other time-varying climatic parameters, like soil moisture and temperature, is also covered in this review.

However, another important agronomic technique that affects plant population density and resource availability is row spacing. Plant competition for light, water, and nutrients is increased by narrow row spacing, which, if improperly managed, can lower overall growth and production. Wider row spacing, on the other hand, promotes better light interception and root development, which might improve the growth of individual plants but may also reduce the density of the entire plant population, which could lower yield per unit area. This study investigates further how different environmental factors and Toria cultivars affect the ideal row spacing.

Furthermore, because these two agronomic elements don't work alone, the review assesses their combined effects. According to the majority of research, the relationship between row spacing and sowing date has a major impact on Toria growth and production. The paper emphasizes how soil characteristics, local climate, and geographic location can all affect the ideal sowing date and row spacing combination. The study also discusses the existing research gaps and makes recommendations for further research to investigate cutting-edge agronomic techniques that might raise Toria's sustainability and production.

Keywords: Toria, *Brassica campestris*, sowing date, row spacing, crop growth, yield, agronomic practices, plant population density, climatic conditions, sustainable agriculture

1. Introduction

An important oilseed crop, toria (*Brassica campestris* L.) is grown mostly in South Asia, especially in Bangladesh, Nepal, and India. The region's agricultural economy greatly benefits from toria, which is well-known for its oil-rich seeds and is essential to food security. Optimizing the growth, output, and quality of toria is increasingly important as the demand for edible oils rises globally. Agronomic techniques that affect the growth and productivity of toria include row spacing and planting date. The establishment, resource use, and reproductive success of the plant are all directly impacted by these practices, and these factors ultimately influence the plant's ultimate yield.

One of the main factors influencing crop production is the time of sowing. The length of the growing season, susceptibility to weather extremes, and the availability of water and nutrients throughout crucial growth phases are all influenced by the date of sowing. By giving the crop enough sunlight, moisture, and a suitable temperature regime during its vegetative and

Reproductive phases, timely sowing especially during favourable meteorological conditions can greatly increase seed yield and quality (Yadav & Sharma, 2018) ^[16]. On the other hand, because late sowing results in less than ideal temperature and moisture conditions during critical developmental stages, it might cause stunted growth, decreased biomass buildup, and eventually lower yields (Kumar *et al.*, 2019) ^[5]. Row spacing is another crucial agronomic aspect affecting the growth and yield of toria, in addition to the sowing date. Plant density, which in turn influences light interception, competition for water and nutrients, and root system growth, is influenced by row spacing. Wider row spacing may decrease plant density and result in lower yields, whereas narrower row spacing may promote competition between plants for resources. But it might also make more room for improved airflow, lower the chance of illness, and enable effective weed control. It is crucial to adjust this method to particular environmental conditions because the ideal row spacing changes depending on regional climate, soil fertility, and irrigation techniques (Bisht *et al.*, 2020) ^[2].

The effects of row spacing and sowing date on toria have been the subject of numerous research. According to research, early sowing typically improves crop performance, resulting in larger yields and better oil content, particularly in areas with adequate irrigation or rainfall (Khan *et al.*, 2016) ^[4]. Additionally, it has

been determined that a row spacing of 30 cm is ideal for increasing seed yield and enhancing the general performance of the crop (Sahu *et al.*, 2015) ^[12]. However, because these variables frequently interact to affect toria's productivity, the relationship between sowing date and row spacing is intricate and region-specific. The purpose of this review is to compile the body of research on how toria growth, yield, and quality are affected by row spacing and sowing date. This study offers insights into the best times to sow and how far apart to space rows in order to maximize toria output by examining research from various geographical locations and climate zones. In light of climate unpredictability and shifting agricultural conditions, it is imperative to comprehend these elements in order to ensure sustainable agricultural methods that can meet the growing demand for oilseeds while also increasing crop yields.

Rapeseed-mustard area, output, and yield were expected to be 36.59 million hectares (mha), 72.37 million tons (mt), and 1980 kg/ha, respectively, during 2018-19 (Fig.1). According to the USDA, India makes up 19.8% of global production and 9.8% of global acreage. Over the previous eight years, productivity increased dramatically, increasing from 1840 kg/ha in 2010-11 to 1980 kg/ha in 2018-19. From 61.64 m t in 2010-11 to 72.42 m t in 2018-19, production also grew.

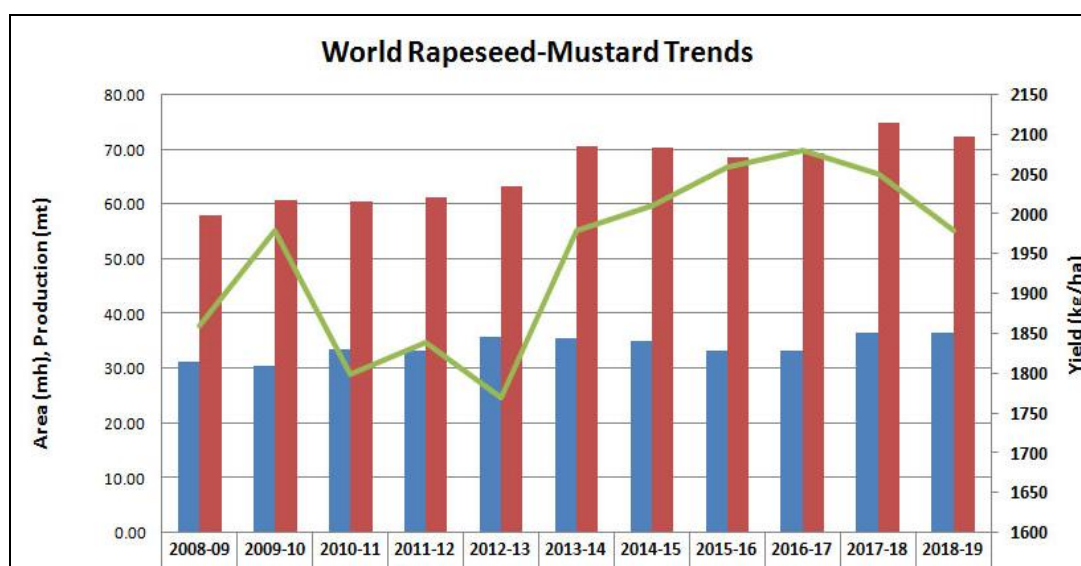
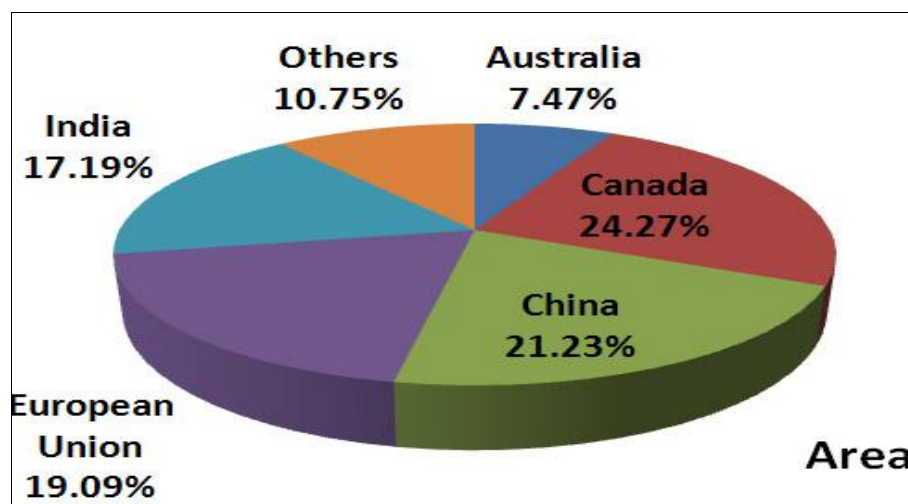
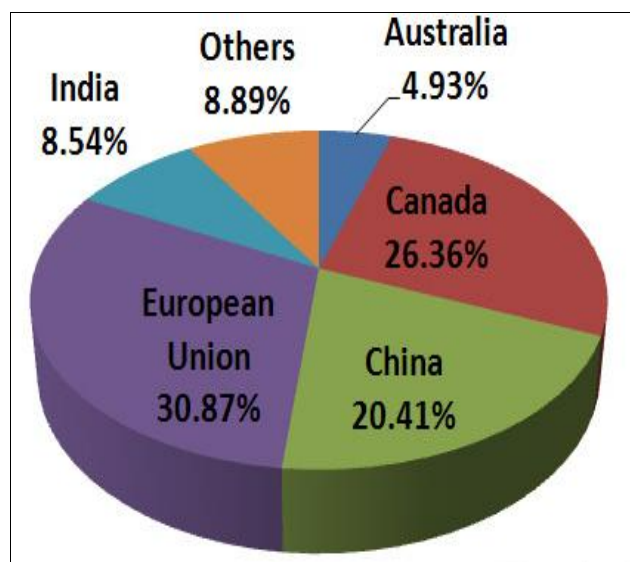


Chart 1: Rapeseed-mustard production trends in world



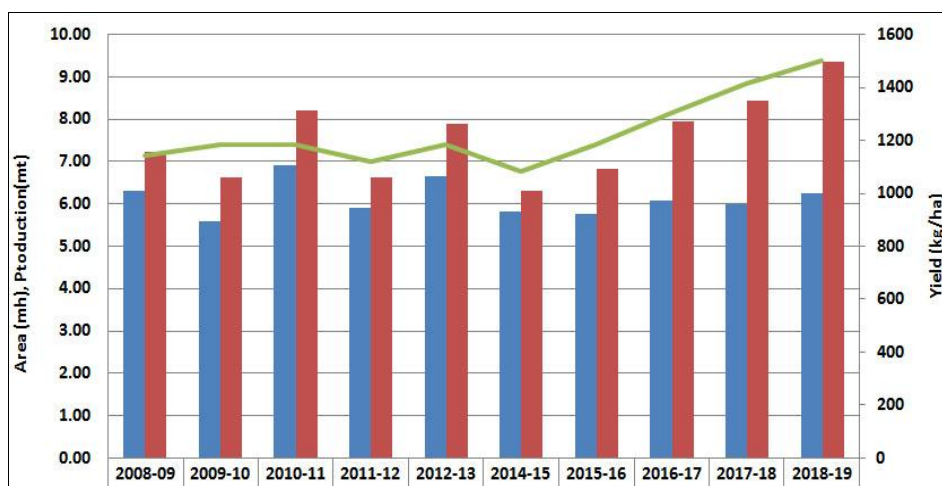
Contribution of different countries in r&m acreage average (2013-14 to 2017-18)



Contribution of different countries in r&m production average (2013-14 to 2017-18)

In India, rapeseed and mustard crops are grown in a variety of agroclimatic settings, from the hills in the northeast and northwest to the southern regions, using saline soils, early or late

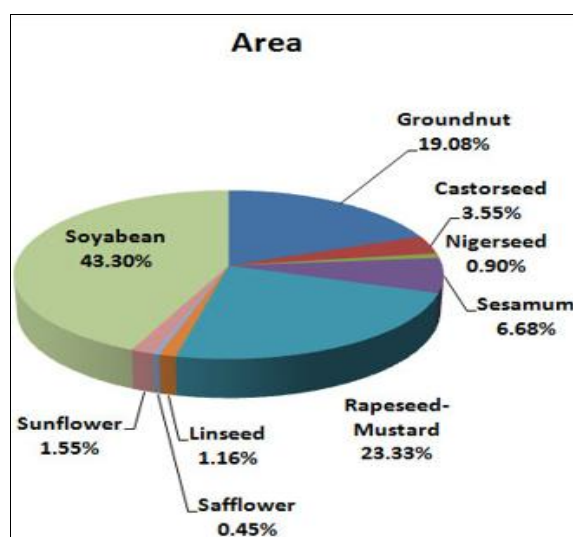
sowing, irrigation, and mixed cropping. Approximately 75-80% of the 6.23 million hectares planted to these crops in the nation during the 2018-19 planting season are Indian mustard.



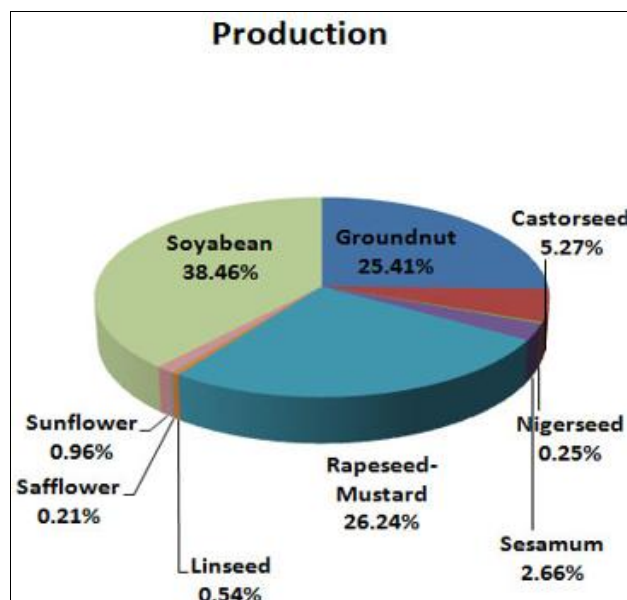
Rapeseed-mustard production trends in india

The three main oilseed crops in India are soybean, groundnut, and rapeseed-mustard, which account for around 84% and 88%

of the country's total acreage and production, respectively (Average of 2014-15 to 2018-19)

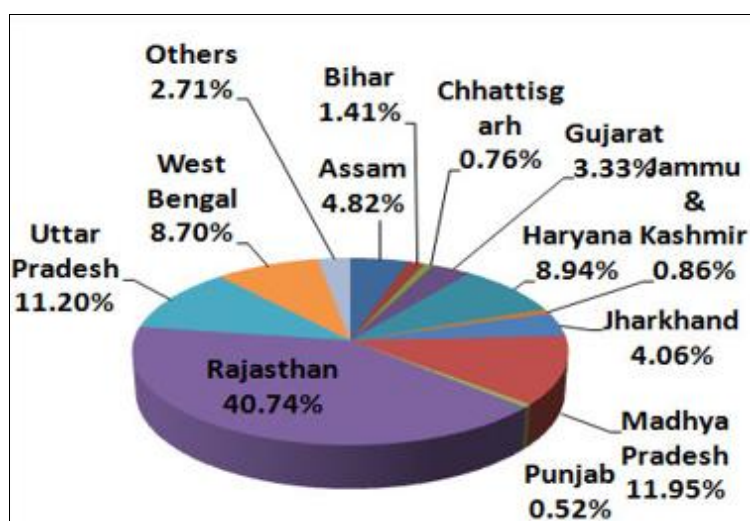
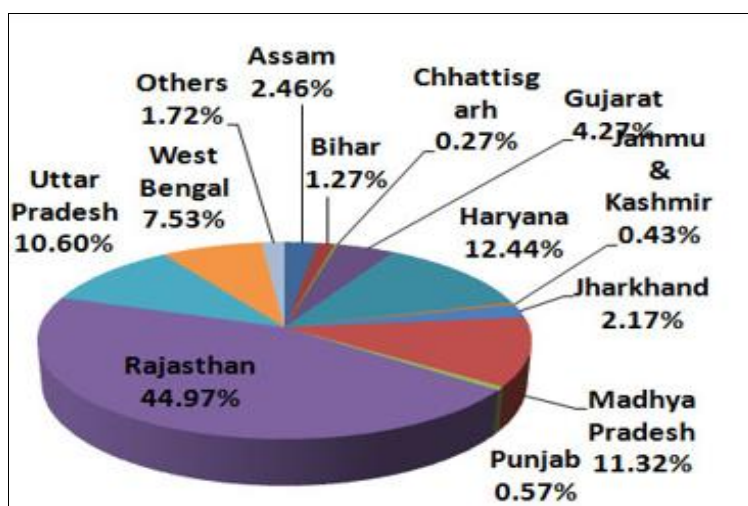


Contribution of different oilseed crops acreage Average (2014-15 to 2018-19)

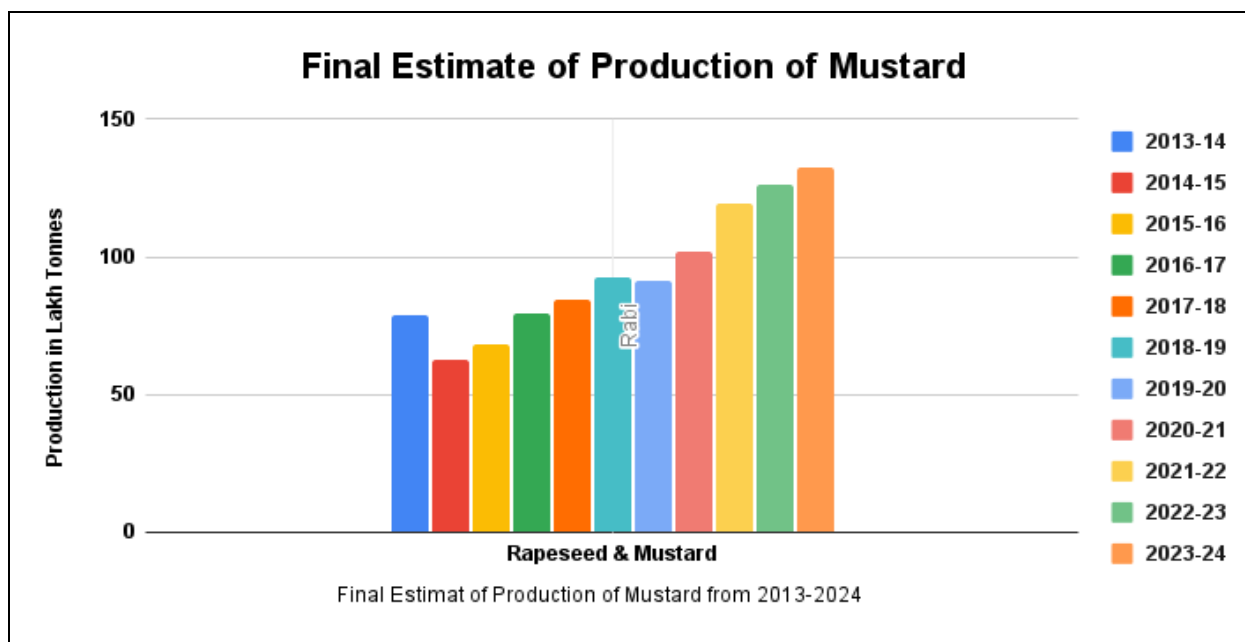


Contribution of different crops production Average (2014-15 to 2018-19)

Crop Name: Mustard	Season: Rabi											
Year	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	
Production in Lakh Tones	78.77	62.82	67.97	79.17	84.3	92.56	91.24	102.1	119.63	126.43	132.59	



Contribution of different oilseed producing states in total area
And production of rapeseed-mustard
(Average of 2014-15 to 2018-19)
(ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur)



Ministry of Agriculture & Farmers Welfare Department of Agriculture & Farmers Welfare (DA&FW)
Final Estimate of Production of Oilseeds & Commercial Crops

2. Sowing date and its impact on toria growth and yield

2.1. Importance of sowing date

The sowing date plays a critical role in the agronomic performance of toria (*Brassica campestris* L.) by directly influencing key aspects of crop growth and development. Sowing at the optimal time ensures that the crop avoids climatic extremes and maximizes resource utilization, thereby enhancing yield and quality. The timing of sowing affects multiple physiological processes, including seed germination, vegetative growth, flowering, and maturation, all of which are essential to achieving a high yield.

One of the primary factors influenced by sowing date is the crop's exposure to temperature and photoperiod conditions, which have a profound impact on its growth cycle. According to (Singh *et al.* 2012) [15], early sowing of toria in areas with moderate temperatures promotes a longer growing season, providing the crop with sufficient time to develop and mature under favorable conditions. This ensures better flowering synchronization and seed filling, leading to higher yields. Conversely, late sowing often results in reduced growth potential and early termination of the growing season due to unfavorable environmental conditions, such as high temperatures or reduced rainfall (Sharma *et al.*, 2017) [13]. In a study by (Kumar *et al.*, 2014) [6, 7, 9, 10], late sowing was associated with a shorter vegetative period and poor seed development, which ultimately led to lower yields and smaller seeds.

Furthermore, the crop's ability to withstand environmental stressors is directly impacted by the date of sowing. Toria can avoid possible climate extremes, especially frost or heat stress, which can negatively impact crop establishment and seed development, by planting early (Singh *et al.*, 2012) [15]. For example, toria may be exposed to cold if sown too early, and heat stress during flowering and pod formation if sown too late, which could reduce seed output and oil content (Chandra *et al.*, 2016) [3]. Water stress at crucial stages like blooming and pod setting can also arise from late sowing, which can cause a lack of coordination between the crop's growth stages and seasonal rainfall patterns (Kumar *et al.*, 2014) [6, 7, 9, 10].

The crop's resistance to pest and disease stresses is another

important element associated with the date of sowing. Aphids and flea beetles are among the many pests that are more common at particular times of the year. Toria may be able to avoid periods of high insect activity by rescheduling the sowing date, which could greatly minimize damage and boost output. By enabling the crop to finish its growth cycle before pest population's peak, early sowing has been demonstrated to limit exposure to several insect pests (Chandra *et al.*, 2016) [3]. Additionally, the date of sowing affects the availability of soil moisture, which is crucial in areas where irrigation is dependent on rainfall. Better germination and establishment are the results of early sowing, which enables the crop to benefit from the best moisture availability throughout the growth season. The crop may be exposed to drought stress if it is sown late, especially in areas with little rainfall, especially during the crucial reproductive phases (Sharma *et al.*, 2017) [13]. In areas with irregular rainfall patterns (Kumar *et al.*, 2014) [6, 7, 9, 10] found that this can result in decreased seed filling and a lower total yield.

2.2. Impact on germination and early growth

The germination and early growth stages of toria (*Brassica campestris* L.) are greatly influenced by the date of sowing. Establishing a robust and fruitful crop requires both of these phases. When toria seedlings are sown at the right time, they will grow strongly in the early stages and have better crop establishment because they will emerge in ideal environmental conditions. On the other hand, planting at less-than-ideal periods may result in weak seedlings, poor germination, and slower early growth, all of which may have detrimental long-term consequences on yield and quality.

Temperature and moisture availability, which change based on when seeds are sown, have an impact on the link between the date of sowing and germination. For successful germination, toria need soil that is at least 10 °C, with ideal temperatures falling between 15 °C and 20 °C (Singh *et al.*, 2014). Early sowing, when soil temperatures are still low, might cause poor seedling establishment or postpone germination. However, planting too late in hot weather can result in decreased soil moisture, increased evaporation, and possible heat stress, all of

which can harm seedling growth (Kumar *et al.*, 2015) ^[8]. According to studies, early seeding, especially in temperate climates, improves germination because of more hospitable temperature conditions, which lays a solid basis for later growth (Sharma *et al.*, 2017) ^[13].

A crucial element affecting germination and early growth, in addition to temperature, is moisture. The ability of the seed to absorb water and start germination is improved when it is sown during times when there is sufficient soil moisture availability. Toria seedlings are more likely to establish rapidly and thrive strongly if they are sown when there is enough rainfall or irrigation available. However, water stress from delayed sowing, especially in areas with seasonal or unpredictable rainfall, can cause poor seedling establishment and reduced early growth. Late sowing in dry conditions frequently results in lower emergence and early growth because of insufficient moisture, which impedes seedling development and postpones the establishment of the crop (Kumar *et al.*, 2014) ^[6, 7, 9, 10].

The crop's capacity to withstand environmental stressors during the early stages of growth is also influenced by the date of sowing. While late sowing exposes the crop to possible high temperatures that may impact seedling growth and development, early sowing guarantees that toria plants can develop prior to the commencement of heat stress during the height of the growing season (Chandra *et al.*, 2016) ^[3]. This stress can further impair early growth by causing poor root development and lowering the plant's capacity to absorb water and nutrients from the soil.

Because plants can obtain sunlight and nutrients during the ideal growing time, early seeding typically results in higher canopy development during the early vegetative phase. For toria, this is especially critical because a strong early vegetative phase is essential for producing the energy needed for later flowering and seed filling. But planting too late cuts into the amount of time the plant has to grow its canopy and generate adequate biomass for seed development and flowering (Kumar *et al.*, 2015) ^[8]. The plant's total photosynthetic capacity is diminished by this delayed growth, which eventually limits the plant's potential production.

In conclusion, toria germination and early growth are directly influenced by the time of seeding. Under ideal temperature and moisture circumstances, early seeding improves germination and encourages robust early growth, which improves crop establishment and increases potential output. On the other hand, delayed sowing may lead to weak early growth, water stress, and poor germination, all of which may lower the crop's overall performance. In order to maximize germination and early growth in toria, it is crucial to carefully examine the local environment and soil moisture availability while choosing the best time to sow.

2.3. Effects on flowering and maturation

The flowering and maturity phases of toria (*Brassica campestris* L.), which are essential for seed growth, yield, and oil content, are significantly impacted by the timing of sowing. The timing of planting impacts the crop's exposure to climatic conditions, particularly temperature and photoperiod, which have an impact on flowering and maturation. While poor sowing dates can result in asynchrony in flowering and maturity, which lowers overall yield and quality, appropriate sowing times can synchronize flowering with favorable environmental conditions, enhancing seed growth and increasing oil content.

Flowering time and synchronization

The timing of sowing has a significant impact on the flowering

stage in toria because it directly impacts the crop's exposure to temperature and light, both of which are essential for the start and growth of blooms. Early planting usually causes plants to flower during the optimal window of the climate, when light and temperature are favourable for the development of flowers and the setting of pods (Singh *et al.*, 2012) ^[15]. According to research, toria planted early tend to flower at a more opportune time, minimizing drought stress and high temperatures that might delay flowering and adversely affect seed set (Kumar *et al.*, 2014) ^[6, 7, 9, 10]. On the other hand, late sowing, particularly in hot climates, can result in faster flowering, which frequently causes a lack of flowering and pod formation synchronization, which leads to smaller seeds and less pod set (Chandra *et al.*, 2016) ^[3].

Late sowing might result in poor synchronization between blooming and the environmental conditions required for optimal seed set in areas with irregular temperature and photoperiod conditions. Extreme temperatures or decreased water availability frequently accompany late flowering, which hinders pod formation and lowers the potential yield (Sharma *et al.*, 2017) ^[13]. Therefore, early seeding gives more time for flower development and seed filling in addition to improving flowering synchronization.

Maturation and seed development

Sowing period is also directly related to the maturation stage of toria, which involves seed growth and oil accumulation. The length of the vegetative growth phase and the environmental factors during the seed-filling phase have a significant impact on toria's capacity to amass enough biomass and oil during maturation. Better seed size and more oil content result from early seeding because it allows the crop enough time to grow and fill pods under ideal circumstances (Singh *et al.*, 2014). However, a shorter growing period brought on by late sowing may result in smaller, less oily seeds and inadequate pod filling. Toria sown later in the season displayed a decrease in seed size and oil content, according to a study by (Kumar *et al.* 2015) ^[8]. This is probably because the plant was unable to finish maturing before adverse environmental conditions started.

Delays in sowing can also expose toria to heat stress during the maturity phase, which has been demonstrated to decrease oil synthesis and hinder seed filling (Chandra *et al.*, 2016) ^[3]. The plant's capacity to produce oils is diminished by heat stress during seed filling, which lowers oil output and quality. According to studies, toria that is sown too late frequently accumulates heat units quickly at the end of the growing season, shortening the maturation time and impeding healthy seed development (Sharma *et al.*, 2017) ^[13].

Impact of Photoperiod Sensitivity

being a short-day plant, toria's flowering and maturation are influenced by the amount of daylight it receives. The plant will be exposed to the proper photoperiod for the best flowering and pod filling if the seeds are sown at the right time. In general, early sowing improves seed establishment and oil production by timing blooming with the ideal photoperiod. Late sowing, on the other hand, may provide an uneven photoperiod, which could result in either delayed maturation or early flowering, both of which would impact seed quality and production (Singh *et al.*, 2012) ^[15].

2.4. Optimal sowing dates for maximizing yield

To maximize yield potential, the best time to sow toria (*Brassica campestris* L.) must be determined. Because toria is climate-

sensitive, when it is sown has a direct impact on its growth, flowering, maturation, and, eventually, seed output. Numerous variables, including as the duration of the growing season, rainfall patterns, soil temperature, and regional climate, influence the best time to sow. According to research, choosing the right planting date maximizes flowering and maturity times, reduces stress exposure, and improves resource utilization all of which are essential for producing large yields.

Climatic considerations and temperature sensitivity

Similar to other Brassica species, toria is extremely sensitive to temperature, which has an impact on all growth phases. Temperatures between 10 °C and 20 °C are ideal for toria germination and early growth; temperatures over 30 °C are harmful during the flowering and pod-filling phases (Singh *et al.*, 2012) ^[15]. Therefore, in order to prevent high temperatures during crucial developmental stages, the date of planting must coincide with the current temperature patterns. Early seeding, usually in late winter or early spring, guarantees that toria matures before the arrival of high summer temperatures, which can negatively impact flowering and seed set in temperate and subtropical regions (Sharma *et al.*, 2017) ^[13]. Likewise, in subtropical and semi-arid areas, planting in the fall or late winter coincides with ideal cooler temperatures for early development and steers clear of the peak of heat stress during the flowering stage.

Effect of photoperiod and flowering synchronization

Toria is a short-day plant, which means that the amount of daylight has a big influence on when it flowers. By planting at the right time, the crop will be exposed to the ideal photoperiod for flower induction, which will improve the timing of blooming and pod development. Early or late sowing might provide an imbalanced photoperiod, which can affect yield potential by causing either delayed maturation or premature flowering (Singh *et al.*, 2012) ^[15]. Selecting the right time to sow helps guarantee that the plant blooms in early spring or late summer, when photoperiod is at its best in regions with erratic day lengths. Coordinating flowering with ideal climatic factors, like appropriate moisture and temperate temperatures, which are essential for optimizing seed set and yield.

Moisture availability and water stress

The availability of soil moisture is a crucial consideration when choosing the best time to plant. Throughout the stages of germination, early development, flowering, and seed filling, toria need enough moisture. In order to ensure adequate water during the crucial stages of growth, early sowing typically makes use of the soil moisture that was available from the previous rainy season or spring showers (Kumar *et al.*, 2015) ^[8]. However, in areas where the rainy season is short or unpredictable, late sowing may expose the crop to water stress during the blooming and seed-filling stages.

The best time to sow is usually during the early rainy season, when there is plenty of moisture for germination and early growth, in regions with clearly defined monsoon or rainfall patterns (Chandra *et al.*, 2016) ^[3]. To ensure that the crop is established before the start of dry periods, which might diminish yield potential due to drought stress during flowering and maturity, sowing should be planned to coincide with forecast rainfall events in areas with irregular rainfall.

Research on optimal sowing dates for yield maximization

Numerous studies have looked into how the date of sowing

affects the potential yield of toria. In northern India, for example, (Singh *et al.*, 2014) discovered that planting toria in early October produced the best growth, flowering, and maturation, which in turn produced the maximum oil content and seed production. In a similar vein, (Chandra *et al.*, 2016) found that in India's semi-arid locations, planting toria in mid-October produced the longest growth season with ideal moisture and temperature conditions, leading to a higher yield.

However, it has been demonstrated that late seeding (such as in December or January) lowers production because the crop goes through shorter vegetative and reproductive periods, which results in smaller seeds, worse pod development, and less oil. Additionally, late sowing (December) in areas with early spring heat resulted in smaller seed sizes and less seed filling, which decreased overall yields, according to (Kumar *et al.*, 2015) ^[8].

3. Row spacing and its effect on toria agronomics

3.1. Role of row spacing in crop competition

An important agronomic aspect affecting the growth, development, and yield of toria (*Brassica campestris* L.) is row spacing. In order to control competition for vital resources like light, water, and nutrients both inside and between plants, the distance between rows is crucial. The general plant architecture, canopy development, and eventually the toria seed quantity and quality are all impacted by this. Plants can grow with less competition when rows are spaced properly, which maximizes resource use efficiency and enhances crop agronomic performance.

Light competition and canopy development

For crops with relatively modest canopy heights, such as toria, adequate row spacing is essential to optimizing light interception throughout the growing season. Shade is a common occurrence for plants cultivated in close quarters in thin rows, which inhibits photosynthesis, delays growth, and eventually limits potential production. The plants' growth is inhibited as they compete for light, which results in poor seed filling and a decline in biomass accumulation (Chandra *et al.*, 2016). Wider row spacing, however, gives plants greater access to sunlight, which improves photosynthetic activity, the leaf area index (LAI), and canopy formation. Better development, larger seeds, and eventually bigger harvests are the outcomes of this.

Wider row spacing (30 cm to 40 cm) in toria improved the plants' capacity to absorb sunlight more effectively, resulting in higher biomass production and seed yield, according to a study by (Singh *et al.*, 2012) ^[15]. Narrower row spacing (20 cm), on the other hand, caused poor crop development, overcrowding, and decreased light penetration, all of which decreased yield.

Water and nutrient competition

Row spacing has an impact on water and nutrient availability and uptake in addition to light. Plants that are too close to one another may compete for nutrients and water, particularly during the crucial stages of germination, early development, and flowering. Plant growth and production are ultimately impacted by this competition, which results in poor root development, decreased water uptake, and nutritional deficiencies (Kumar *et al.*, 2015) ^[8]. By increasing soil evaporation and reducing the amount of moisture available to each plant, narrow row spacing can worsen water stress, especially in areas that are prone to drought (Chandra *et al.*, 2016) ^[3]. Better root development and availability to soil moisture and nutrients are made possible by wider row spacing, which lessens intra-plant competition for water and nutrients. When toria need enough water and nutrients

for seed filling and oil accumulation during the reproductive period, this becomes especially crucial. According to research, the root-to-shoot ratio is increased by ideal row spacing, which also facilitates better nutrient and water uptake, resulting in healthier plants and higher yields (Kumar *et al.*, 2014) ^[6, 7, 9, 10].

Plant density and yield

Row spacing also determines the density of plants in the field, which influences both vegetative and reproductive growth. While a higher plant density in narrower rows may result in increased competition and lower yield, a moderate plant density in rows that are properly spaced apart promotes balanced growth and improved reproductive outcomes. Research by (Sharma *et al.*, 2017) ^[13] shown that row spacing of 30 cm allowed for optimal plant density and reduced competition for resources, resulting in higher seed yields compared to more closely placed rows. This was attributed to increased canopy development, reduced competition, and improved seed filling. However, too broad of a row spacing can also result in underutilization of the land, which lowers the number of plants per unit area and lowers the total yield of toria. Thus, a balance must be achieved between maintaining the ideal plant density for effective land use and reducing intra-plant competition.

Weed control

In toria crops, row spacing also affects weed competition. Increased weed infestation and competition for light, water, and nutrients may result from wider row spacing, which can also provide weeds a chance to develop in between rows. However, this problem can be lessened by using suitable weed control methods, like mulching or inter-row weeding. Narrower row spacing, on the other hand, can assist naturally regulate weed growth by reducing the amount of space available for weeds to establish (Singh *et al.*, 2014) ^[15].

3.2. Impact on plant architecture and yield

Crop growth and yield are significantly impacted by the way row spacing affects the plant architecture of toria (*Brassica campestris* L.). The spatial arrangement of plants in the field affects plant architecture, which includes characteristics like plant height, leaf area, branching patterns, and root system development. Particularly important in deciding how resources are distributed across plants, row spacing has a direct effect on yield, seed production, and overall growth.

Plant height and canopy development

The distance between rows significantly influences the toria's vertical development. Plants typically have more room to grow vertically when row spacing is wider, which results in taller plants with larger canopy volumes. Plants may be better able to absorb light and maximize photosynthesis as a result. Wider row spacing (30 cm and above) encouraged higher plant height in toria, according to a study by (Chandra *et al.*, 2016) ^[3]. This led to a higher Leaf Area Index (LAI) and more effective light interception during the growing season. In order to drive biomass accumulation and seed filling and ultimately increase yields, this improved canopy growth aids in optimizing photosynthetic activity. Conversely, a smaller row spacing reduces the amount of room for vertical development. Because of the greater competition for light, plants in closely spaced rows typically have shorter canopies. According to (Singh *et al.*, 2012) ^[15], this frequently results in less effective light absorption, decreased photosynthesis, and ultimately, decreased biomass buildup and seed output.

Branching and pod formation

Row spacing also affects the quantity of pods per plant and the branching style. Toria plants typically have more branches when the row spacing is larger because there is less competition for space, which frees up more resources for branching and reproductive development. A larger yield is often the result of this increased branching, which produces more pods per plant. When toria plants were cultivated with wider row spacing (30-40 cm), they generated more secondary branches and more pods than when they were grown in short rows, according to research by (Kumar *et al.*, 2015) ^[8]. Overall, the seed output increased as a result of the extra branches and pods. Narrow row spacing, on the other hand, increases plant competition for resources, which may restrict pod production and branching. The plant's capacity to reproduce is diminished since there is less room for the growth of roots and shoots, which leads to fewer branches and pods. This frequently results in less seed set and a reduced yield in the end.

Root system and nutrient uptake

Another important factor that is impacted by row spacing is the toria root system. Better root development is made possible by adequate row spacing, which gives the plant greater room to spread its roots both vertically and horizontally. During the reproductive phases of growth, when nutrient and water needs are high, this enhances the uptake of water and nutrients, which is very crucial. Wider row spacing (30 cm) improved root extension and deeper soil penetration, improving the plant's ability to obtain water and nutrients, according to a study by (Kumar *et al.*, 2014) ^[6, 7, 9, 10]. Larger seeds and more oil were thus produced by plants cultivated with wider row spacing. Conversely, a smaller row spacing restricts root development and leads to less efficient water and nutrient uptake. Under such conditions, plants may have nutrient deficiencies, particularly during the blooming and seed-filling stages, which negatively impact seed production and growth.

Seed size and oil content

Row spacing has a direct effect on toria's overall seed size and oil content. Wider rows give plants better access to nutrients, light, and water, which promotes more vigorous seed growth and a longer time for seed filling. Larger seeds and more oil are the results of this. According to a study by (Sharma *et al.*, 2017) ^[13], toria plants planted with a 30-cm row spacing produced larger and more oil-rich seeds than plants cultivated in narrower rows, which resulted in less seed filling because of resource competition. However, because the plant's capacity to produce high-quality seeds is limited by competition for resources, smaller seeds and lesser oil content are frequently the outcome of shorter row spacing. According to (Singh *et al.*, 2012), ^[15] when row spacing was lowered to 20 cm, the plants' incapacity to mature fully under the restricted circumstances resulted in significantly smaller seeds and lower oil yield.

Yield potential

The potential yield of toria is ultimately determined by the combined impacts of plant height, branching, root development, and seed generation. These elements are maximized by appropriate row spacing, which results in increased seed output and better quality. In contrast to toria sown with narrower row spacing, toria sown with wider row spacing (usually between 30 and 40 cm) yields a larger total yield, according to numerous studies. According to a study by (Chandra *et al.*, 2016) ^[3], toria cultivated in rows 35 cm apart produced the most seeds, which

was explained by better plant architecture and less rivalry for resources. On the other hand, because of inadequate canopy development, decreased root growth, and restricted pod formation, a 20 cm row spacing led to a lower yield.

However, because fewer plants are cultivated in the same field, an overly wide row spacing might also result in a lower yield per unit area. To optimize yield potential, the ideal ratio of plant density to row spacing must be achieved. In the majority of agroclimatic areas, the ideal row spacing for toria is between 30 and 40 cm, according to (Kumar *et al.*, 2014) [6, 7, 9, 10]. This strikes a good compromise between optimizing plant architecture and guaranteeing an adequate plant population density for maximum output.

3.3. Effects of row spacing on seed quality

Row spacing is one of several agronomic techniques that affect the quality of toria (*Brassica campestris* L.) seeds, including characteristics like seed size, germination rate, oil content, and seed vigor. Individual plant growth and the general quality of seeds can be impacted by row spacing, which also impacts plant density and competition for resources like light, water, and nutrients. Rows that are properly spaced can promote the best possible plant growth and help produce high-quality seeds with superior size, oil content, and general vitality.

Seed size and uniformity

Two important elements that govern the marketability and quality of toria seeds are seed size and uniformity, both of which are directly impacted by row spacing. When plants are spaced appropriately, they can grow to their full potential, producing larger and more consistent seeds. Conversely, undersized, uneven seeds may result from overcrowding and competition for light, nutrients, and water caused by narrow row spacing (Kumar *et al.*, 2015) [8]. According to studies, toria plants can grow more vigorously and produce fewer plants per unit area when the row spacing is widened, usually between 30 and 40 cm. Better seed filling, higher seed size, and improved seed uniformity are the results of their increased access to nutrients. According to (Chandra *et al.*, 2016) [3], toria plants cultivated in rows 35 cm apart yielded noticeably bigger seeds than those cultivated in rows that were closer together. The plants were able to fully develop because to the greater spacing, which produced the best possible seed formation. Narrow row spacing, on the other hand, like 20 cm, may inhibit the growth of individual plants, producing smaller seeds and a less consistent batch of seeds. The plants' capacity to yield big, superior seeds is hampered by competition for light and nutrients caused by overcrowding (Sharma *et al.*, 2017) [13].

Oil content

For toria seeds, oil content is a crucial quality factor that is impacted by agronomic techniques such as row spacing. According to research, by promoting improved plant growth and larger seeds, ideal row spacing can raise the oil content of toria seeds. Wider rows give plants better access to nutrients, light, and water, which improves seed filling and increases oil buildup. According to a study by (Kumar *et al.*, 2014) [6, 7, 9, 10], toria plants with a 30 cm row spacing showed more oil than those with narrower rows. Wider rows made resources more readily available, which for more effective photosynthesis and nutrient uptake, producing seeds with higher oil content. Conversely, a drop in seed size and oil content may result from tight row spacing, which limits plant development and lowers resource availability. Because plants compete for nutrients, especially

during the crucial seed-filling stage, (Singh *et al.*, 2012) [15] found that when toria was planted with row spacing of 20 cm, the oil content of the seeds was reduced.

Germination and seed vigor

Vigor and seed germination rate are crucial markers of seed quality. By influencing uniformity, seed maturity, and plant health, row spacing can have an impact on these factors. Stronger seed vigor and higher germination rates result from seeds that mature consistently in rows that are appropriately spaced. Narrow row spacing, on the other hand, may produce smaller seeds with poorer seed vigor and lower germination rates. According to (Chandra *et al.*, 2016) [3], toria plants cultivated in rows 35 cm apart produced seeds with better vigor and higher germination rates than plants grown with closer spacing. Stronger, healthier seeds were produced as a result of the plants' increased ability to thrive. Better germination was also facilitated by the better consistency of size, shape, and quality of the seeds produced by plants cultivated in wider rows. Because of congestion caused by narrow row spacing, plants grow less quickly and may produce smaller, less robust seeds. These seeds can be less suited for sowing the following season because of their lower germination rates and decreased overall seedling vigor. According to (Kumar *et al.*, 2015) [8], toria plant seeds cultivated in tighter rows were less vigorous and had a lower germination rate, most likely as a result of the stressful growing conditions brought on by resource competition.

Seed disease resistance

Disease resistance is yet another crucial component of seed quality. The plant's health and susceptibility to disease can be indirectly impacted by row spacing, even if it may not directly affect disease resistance. Resource rivalry causes higher stress on plants grown in thinner rows, which might weaken the plants and increase their susceptibility to diseases. This can therefore result in lower seed quality and increased seed mortality.

Greater plant growth and stress tolerance, as well as increased disease resistance, are made possible by wider row spacing. Because they were healthier overall, toria plants cultivated in wider rows were more resistant to specific seed-borne illnesses, according to research by (Sharma *et al.*, 2017) [13]. The plants were able to devote more resources to defense mechanisms and disease resistance as a result of improved nutrient uptake, decreased competition, and less environmental stress.

3.4. Optimal row spacing for toria production

A crucial element affecting plant development, yield, and overall crop performance is the ideal row spacing for the cultivation of toria (*Brassica campestris* L.). Plant density, light interception, resource allocation, and competition among plants for light, water, and nutrients are all influenced by row spacing. Research has indicated that specific row spacings can optimize growth and yield for toria, while the optimal row spacing varies depending on environmental factors, soil fertility, and other agronomic techniques.

Factors influencing optimal row spacing

1. Plant density and yield

The number of plants per unit area is directly impacted by the row spacing, which in turn influences the total crop output. Although increasing plant density in narrow rows may seem like a good way to maximize land use efficiency, too much competition for resources like light, water, and nutrients can lead to stunted plant development, smaller seeds, and a poorer yield

overall. On the other hand, because there is less rivalry, wider row spacing promotes greater plant development; however, too much spacing might result in underuse of the land area and lower output per hectare. The ideal row spacing for toria to attain good yields is between 30 and 40 cm, according to a study by (Singh *et al.* 2012) ^[15]. This range of row spacing promotes healthy plant growth and increased seed yields by allowing for adequate plant density while reducing resource rivalry. According to the study, a row spacing of 35 cm offered a compromise between increasing light interception, decreasing overcrowding, and guaranteeing an adequate number of plants per unit area.

2. Soil fertility and water availability

The ideal row spacing for toria depends on a number of important elements, including soil quality and water availability. Even with smaller row spacing, toria plants can thrive in regions with rich soil and sufficient water supply. Wider row spacing, however, can be required in areas with poorer soil quality or scarcer water supplies to guarantee that every plant has access to enough moisture and nutrients. Row spacing of 30 to 40 cm is advised for improved water and nutrient usage in areas with moderate to poor soil fertility, according (Kumar *et al.* 2015) ^[8]. This spacing guarantees that plants can effectively access soil moisture and have adequate room to grow strong root systems. Additionally, by promoting improved air circulation and lowering soil evaporation, wider row spacing lowers the danger of water stress, particularly during dry times.

3. Light interception and canopy development

Optimizing light interception, which has a direct impact on photosynthesis and biomass buildup, requires proper row spacing. Narrower rows may cause plants to be shaded by nearby plants, which could result in a poorly developed canopy and less light absorption. This may lead to decreased seed output, decreased biomass, and stunted development.

Toriia plants cultivated in rows 35 cm apart had a more established canopy, enabling improved light interception and photosynthetic efficiency, according to research by (Chandra *et al.*, 2016) ^[3]. Each plant can receive more sunshine with a wider row spacing (30 to 40 cm), which improves growth and the leaf area index (LAI). Larger biomass output and, eventually, larger yields are the results of this enhanced canopy development.

4. Weed competition

Weeds can compete with toria plants for resources like light, water, and nutrients, therefore row spacing also affects their growth. Because the plants are planted closer together in narrower rows, there may be less room for weeds to grow. Tighter plant spacing, however, may also result in more intra-plant competition, which could make plants weaker and more vulnerable to weed pressure. More space between plants is made possible by wider row spacing, which could present a weed-growing opportunity. Nevertheless, this can be controlled by using efficient weed-control techniques such mulching, herbicide treatment, and interrow cultivation. While greater row spacing may make weed competition more likely, (Sharma *et al.*, 2017) ^[13] claim that it also improves overall plant growth, which can assist toria plants outcompete weeds by improving root development and canopy cover.

5. Environmental conditions and regional variations

Depending on the local temperature, soil properties, and

agricultural methods, there are differences in the ideal row spacing for toria. Narrow row spacing may be more successful in areas with shorter growing seasons and milder temperatures in order to maximize plant density and achieve early canopy closure, which lessens weed competition and provides protection from temperature extremes. On the other hand, larger row spacing may be advantageous in warmer climates with longer growing seasons in order to support more extensive plant growth. In order to maximize plant density and yield, toria grown in areas with a longer growing season fared best with row spacings of 30 to 35 cm, while regions with a shorter growing season needed narrower row spacings, according to a study by (Kumar *et al.*, 2014) ^[6, 7, 9, 10] conducted in various agro-climatic zones of India.

Recommended row spacing for toria

The ideal row spacing for toria production usually ranges between 30 and 40 cm, depending on the previously mentioned parameters. This spacing ensures adequate light interception and canopy development while minimizing competition for resources and optimizing plant density. The ideal range for optimizing light interception, photosynthetic efficiency, and plant growth is between 30 and 35 cm. additionally, it balances resource availability and plant density, which increases the potential production. 35 to 40 cm: Greater root development and resource consumption are made possible by wider row spacing in this range, which is advantageous in areas with little water or low soil fertility. Higher seed quality, greater branching, and improved disease resistance are all made possible by this spacing. Although high-density cropping systems occasionally employ row spacing of 20 cm or less, this is generally less advantageous for toria production because of the increased competition for resources, which can restrict development, decrease seed size, and adversely affect output.

4. Combined effect of sowing date and row spacing

The total agronomic performance of toria (*Brassica campestris* L.) can be greatly impacted by the interplay between row spacing and sowing date. Although row spacing and sowing date have separate effects on crop development, yield, and quality, when combined, they can either lessen or increase the constraints imposed by either element alone. To maximize toria's growth potential, resource use, and final production, it is essential to comprehend the best possible combination of these two aspects.

Interaction between sowing date and row spacing

1. Early sowing with optimal row spacing

It has been discovered that toria production benefits from early sowing in conjunction with ideal row spacing, which is usually between 30 and 40 cm. Early sowing improves plant growth and yield by allowing the crop to form robust roots before inclement weather (such as frost or excessive heat) strikes. Early sowing can improve the crop's access to sunlight, water, and nutrients when combined with the ideal row spacing. Increased yield and improved seed quality result from this combination's reduction of intra-plant competition and optimization of resource usage efficiency.

Research evidence: According to a study by (Kumar *et al.*, 2015) ^[8], compared to later sowing dates combined with narrower row spacing, early sowing (mid-October) with row spacing of 35 cm produced noticeably larger yields and better seed quality. Wider row spacing boosted light interception,

decreased competition, and improved total crop development, while early sowing allowed the plants to finish their growth cycle before the arrival of adverse weather conditions. In a similar vein, (Chandra *et al.*, 2016) ^[3] discovered that early-planted toria with a 35 cm row spacing produced better seed output and ideal plant growth. While the ideal row spacing minimized congestion and promoted improved plant architecture, the early seeding allowed the plants to take use of the full potential of the soil moisture and sunlight.

Late sowing with suboptimal row spacing

However, toria performance may suffer if early seeding is coupled with insufficient row spacing. Reduced growing periods, vulnerability to high temperature stress, and inefficient use of resources are the outcomes of late sowing, particularly in less than ideal circumstances. The plants will compete more fiercely for light, nutrients, and water if they are planted too close to one another. This will result in stunted growth, smaller seeds, less oil, and eventually a lower yield.

Research evidence: According to (Kumar *et al.*, 2014), ^[6, 7, 9, 10] toria planted late in November with a 20 cm row spacing produced poorer seed quality and a lower seed production. While the narrow row spacing increased competition among plants, restricting their growth potential and lowering the overall yield, the delayed seeding shortened the vegetative period. Under such circumstances, late sowing further exacerbated yield loss by making the plants more vulnerable to pest and disease impact.

In contrast, because of the shorter growing period and increased exposure to environmental stress, late sowing usually results in lower overall productivity than early sowing with optimal row spacing, even though it can still produce satisfactory yields when combined with appropriate row spacing (30 cm to 40 cm).

2. Sowing date and row spacing in different climatic zones

The climatic zone in which toria is grown can affect the combined effect of row spacing and planting date. Wider row spacing and earlier sowing are often the best ways to maximize toria yield in areas with a longer growth season and moderate temperatures. On the other hand, late sowing might be more appropriate for the available growing window in areas with shorter growing seasons or unpredictable rainfall; nonetheless, in order to minimize competition and guarantee that the plants can grow as much as possible in the short amount of time, ideal row spacing is even more important.

Research evidence: In areas with more rainfall and moderate temperatures, toria plants planted in late October with row spacing of 30 to 35 cm yielded the maximum yields, according to a study by (Sharma *et al.*, 2017) ^[13] carried out in several agroclimatic zones of India. On the other hand, early sowing with a wider row spacing (35 cm) in drier areas improved crop production by enabling the crop to better utilize the sunlight and soil moisture that were available. Wider row spacing and early seeding were essential for overcoming water stress and guaranteeing ideal growth in these areas.

Optimal timing and spacing for yield maximization

By enhancing plant growth and guaranteeing the prompt use of available resources, the combination of sowing date and row spacing is essential for maximizing production. The crop gets a head start from early seeding, enabling it to develop before unfavourable circumstances arise. In the meantime, adequate

row spacing guarantees that plants have enough room to develop without facing undue competition for water, light, and nutrients.

Research evidence: A study by (Singh *et al.*, 2012) ^[15] found that toria plants sown early in the season (mid-October) with a row spacing of 35 cm produced the maximum output since there was less competition for resources and the plants had more time to grow to their full potential. Because of this combination, the plants were guaranteed adequate access to nutrients and sunlight, which increased biomass production and, in turn, seed yield.

5. Conclusion

Both the sowing date and row spacing have a major impact on the agronomic performance of toria (*Brassica campestris* L.), which is crucial for determining seed quality, growth, and yield. The analysis of the research highlights that both of these parameters can significantly improve crop production when they are maximized; however, how effective they are depending heavily on the particular agro-climatic circumstances of the growing location.

By minimizing the chance of exposure to temperature extremes and guaranteeing optimal resource usage, timely seeding guarantees that toria plants finish their growth cycle under ideal climatic circumstances. When combined with the ideal row spacing, which is usually between 30 and 40 cm, the plants have less competition for water, nutrients, and light, which results in healthier plants and larger harvests. When paired with ideal row spacing, early sowing in particular gives the plants a longer growing season, which is especially beneficial in areas with a favourable growing season.

However, depending on regional environmental parameters such as soil fertility, water availability, and local climate, the ideal sowing date and row spacing might vary greatly. Because of the local climate or soil type, late sowing with wider row spacing may be more advantageous in some places. To find the best combinations of row spacing and sowing date for their particular farming conditions, farmers and researchers must therefore carry out localized trials.

Furthermore, although the impacts of row spacing and sowing date have been the main emphasis of this research, it is crucial to remember that these agronomic parameters do not work alone. To create more thorough and region-specific instructions for the best toria cultivation, it is necessary to take into account the interplay between planting date, row spacing, and other factors including irrigation techniques, insect control, and fertilizer applications. To enhance agricultural methods and boost toria yield in a variety of settings, future research should delve deeper into these connections.

In conclusion, increasing toria yield necessitates optimizing the sowing date and row spacing; yet, effective management of these variables necessitates a deep comprehension of the local climatic circumstances. To maintain sustainable and high-yielding toria production, more research into the integrated management of agronomic practices is required.

References

1. Bhatt R, Singh A, Kumar S. Impact of sowing date and row spacing on growth and yield of toria in northern India. *Int J Agric Sci.* 2021;13(2):45-50.
2. Bisht BS, Pandey VP, Singh R. Effect of row spacing and fertility levels on the yield and economics of toria (*Brassica campestris* L.). *J Oilseed Brassica.* 2020;11(1):23-29.
3. Chandra R, Kumar A, Singh S. Effect of sowing dates on growth, yield, and quality of toria (*Brassica campestris* L.).

- J Oilseed Brassica. 2016;7(1):45-53.
4. Khan MA, Yousaf M, Ali H. Influence of sowing date on growth and yield of toria under rainfed conditions. *J Agric Res.* 2016;54(3):275-283.
 5. Kumar A, Sharma S, Verma MK. Agronomic management of toria: effect of sowing time and row spacing on seed yield and quality. *Indian J Agron.* 2019;64(4):467-472.
 6. Kumar R, Singh N, Sharma M. Effect of row spacing on growth, yield, and water use efficiency of toria (*Brassica campestris* L.). *Agric Water Manag.* 2014;14(2):255-263.
 7. Kumar R, Singh N, Sharma M. Effect of sowing date and row spacing on growth and yield of toria (*Brassica campestris* L.). *Indian J Agric Sci.* 2014;84(6):850-854.
 8. Kumar R, Singh N, Sharma M. Effect of sowing date on germination, early growth, and yield of toria under semi-arid conditions. *J Agron.* 2015;7(3):102-110.
 9. Kumar S, Patel S, Thakur P. Effect of row spacing on growth, yield, and oil content of toria (*Brassica campestris* L.). *Indian J Agric Sci.* 2014;84(6):850-854.
 10. Kumar S, Patel S, Thakur P. Influence of sowing date on growth and productivity of toria (*Brassica campestris* L.). *Indian J Agric Sci.* 2014;84(4):432-439.
 11. Raza A, Saeed M, Ali S. Effect of row spacing and sowing time on growth and yield of toria. *Pak J Agric Sci.* 2017;54(2):375-380.
 12. Sahu RK, Verma RS, Singh RK. Agronomic factors influencing yield and quality of toria: a review. *Agric Rev.* 2015;36(1):22-28.
 13. Sharma P, Yadav S, Sharma R. Impact of row spacing on the growth and yield of toria (*Brassica campestris* L.) under varying climatic conditions. *Agric Res.* 2017;6(2):153-160.
 14. Singh H, Yadav RK, Pal S. Effect of sowing time on the growth and yield of toria in semi-arid conditions. *Indian J Agron.* 2017;62(2):169-172.
 15. Singh R, Verma A, Gupta M. Agronomic management of toria (*Brassica campestris* L.): effect of sowing date and other agronomic practices on growth and yield. *Indian J Agron.* 2012;57(1):33-39.
 16. Yadav K, Sharma S. Influence of sowing date and row spacing on yield of toria (*Brassica campestris* L.). *Indian J Agric Sci.* 2018;88(3):456-460.