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# Tackling the Constraints of Cumin Cultivation and Management Practices

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## Abstract

Cumin (*Cuminum cyminum L.*) is an important seed spice crop, having good medicinal properties and grown predominately in arid and semi-arid region of the world. India is the leading country with share of 70% in the world production of cumin. Two states of India (Rajasthan and Gujarat) cover nearly 80% of the total area under cumin cultivation. The current scenario and status of area, production and productivity in India has been reviewed to identify the various factors affecting cumin production and productivity. Apart from these major constraints related to climate, soil, agronomical, crop input, extension, marketing and farm mechanization in cumin production and their management are discussed thoroughly. Due to low productivity of cumin there is need to focus on integrated approaches such as utilizing modern technologies, advance agronomic practises, farm mechanization interventions and advanced breeding tools to enhance the cumin production. The study reveals alternative solutions to overcome these problems and evidenced that there is huge scope of farm mechanization to improve the production of cumin crop and reduce drudgery of farmers.

**Keywords:** Cumin cultivation; Constraints; Farm mechanization; Scope; Integrated approaches

## Introduction

Seed spices, an important group of horticultural crops, which are largely grown in diverse region of the world under semi-arid region. In India, seed spices are extensive set of cash crop to fulfil the domestic needs as well as earning substantial foreign exchange. The International Organization for Standardization (ISO) has listed almost 109 spices that are used throughout the world. Among these, about 63 spices are grown in India, out of which 20 are categorised as seed spices [125]. The most common seed spices grown in India include fennel, cumin, coriander, anise, fenugreek, nigella, ajwain, caraway, celery and dill. Cumin crop has highest area among seed spices followed by fennel, coriander, fenugreek and other seed spices. India is the world's largest seed spice consumer, producer and exporter. It contributes approximately 51.79 and 19.06% area and production, respectively of the total spice production in the country [57]. The overall annual export of seed spice crops is Rs 19505.81 crore, out of which cumin alone accounts for Rs 2884.80 crore. India exports approximately 14% of its production and meets about 50% of the global demand [117]. There is a constantly increasing demand of seed spices in global market each year and India is the largest trustworthy supply point of these spices to other countries. India is the leading country in cumin production with a share of 70% total world production. However, the productivity of cumin in India is less in comparison to other countries due to limited adoption of improved method and new technologies in cumin cultivation. In India, Rajasthan and Gujarat are the two states that covers major area (more than 80%) of cumin production, besides these two states, it is also grown in some part of different states *viz*. Uttar Pradesh, Delhi, Uttarakhand, Madhya Pradesh, Chhattisgarh and West Bengal [85].




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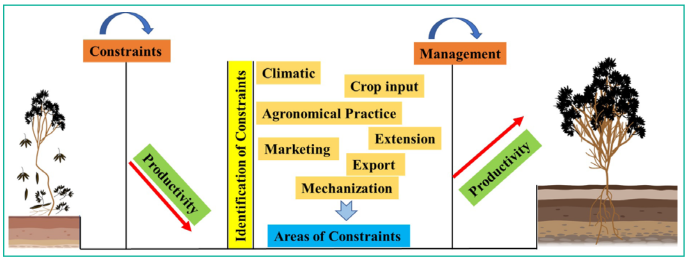


Cumin an Apiaceae (Umbelliferae) family crop, is a small annual herbaceous plant. Its seeds are valued for aroma and pharmaceutical applications [8,46,96,116] and are used for treating certain diseases as well as an additive in different foods [24,28,36,37,43,79-81,98]. Cumin is a seasonal *Rabi* crop that is cultivated extensively in rotation with food crops as well as an intercrop or mixed crop under dry or wet growing conditions. Yield of cumin crop is affected by various factors like biotic (wilt, blight, powdery mildew, aphid and mite) and abiotic (drought, frost, heat and salinity) stresses [51]. Moreover, undulating lands, conventional method of sowing (broadcasting), poor soil health, water scarcity, weed infestation and shattering losses during harvesting and threshing, are also responsible for low productivity.

## Cumin Production Scenario in India

India leads the globe in terms of area, production, export and consumption of cumin (Figure 1a). The area under cumin cultivation in India had followed an increasing trend from 2011 to 2020 (Figure 1a). Rajasthan and Gujarat states together contribute more than 80% of the total area of cumin cultivation in India [85]. Rajasthan has the largest area under cumin cultivation i.e., 609.72 thousand ha, (Figure 1b, 1c) which is 56.09% of the total area of cumin cultivation in India (Figure 1b). After Rajasthan, Gujarat has second largest area under cumin cultivation i.e., 475.20 thousand ha, 43.71% of the total cumin cultivation area in India for the year 2020-21 (Figure 1c).

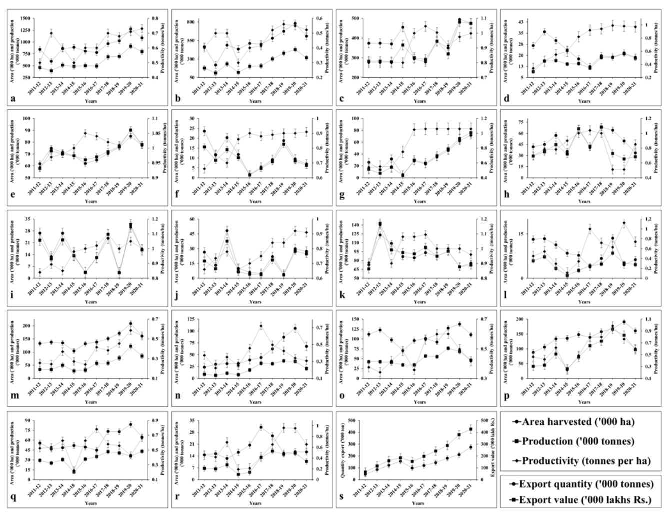


**Figure 1:** Area ('000 hectare), production ('000 tonnes), and productivity (tonnes per hectare) and export value of cumin crop from 2011 to 2020: **(a-c)** Area, production, and productivity of cumin from 2011 to 2020 in India (a), Rajasthan (b), and Gujarat (c); **(d-k)** Area, production, and productivity of cumin from 2011 to 2020 in Gujarat districts, Ahmedabad (d), Banaskantha (e), Junagadh (f), Kutch (g), Patan (h), Porbandar (i), Rajkot (j), and Surendranagar (k); **(l-r)** Area, production, and productivity of cumin from 2011 to 2020 in Rajasthan districts, Ajmer (l), Barmer (m), Jaisalmer (n), Jalore (o), Jodhpur (p), Nagaur (q), and Pali (r); **(s)** Annual export quantity ('000 tonnes) and value ('000 lakh Rs.) of cumin from 2011 to 2020. Information for the area, production and productivity and export value (from 2011 to 2020) of cumin was collected from Indiastat (https://www.indiastat.com).

Since last decade (2011-2020) cumin production followed an increasing trend from 2011 to 2019, but there was decrease of 12.83% in production of cumin in 2020-21 (Figure 1a). The decrease in the production of cumin for the year 2020-21, might be due to the effect of Covid-19 as the transportation services and movement of the labours were restricted. However, the cumin production has been raised by 40.50% from the last decade. The Production of cumin was highest in Gujarat whereas, the area under cumin cultivation was highest in Rajasthan (Figure 1b, 1c). It may be due to the low productivity of cumin in Rajasthan state because of poor soil and aberrant weather conditions. In Gujarat, the cumin production increased from 2011 to 2019, but slightly decreased in 2020-21 (Figure 1c) due to Covid-19 effect. Similar trend was observed for Rajasthan state (Figure 1b). The overall cumin production was increased by approximately 177.36% in Rajasthan and 116.47% in Gujarat from 2011 to 2020 (Figure 1b, 1c). This may be due to the increase in awareness among the farmers by Krishi Vigyan Kendras (KVKs) and the continuous efforts of ICAR Institutes towards increasing the productivity with the help of improved production technique. The productivity trend showed that the productivity of Rajasthan (0.42 tonne/ha) is almost half of Gujarat (0.89 tonne/ha). The main reason behind the lower productivity in Rajasthan is due to adverse climatic conditions during the critical growth period of crop and reproduction time. Therefore, there is need to find the constraints affecting the productivity of cumin crop and their management should be suggested to the farmers to increase the productivity and production.

The area, production, and productivity of cumin cultivation in Gujarat are analysed district-wise (Figure 1d-k). The largest area, production and productivity under cumin cultivation were observed in the district Surendranagar (Figure 1k), followed by Banaskantha (Figure 1e), Patan (Figure 1h), Kutch (Figure 1g), Rajkot (1j) Junagadh (Figure 1f), Porbandar (Figure 1i) and Ahmedabad (Figure d). The overall trend of area, production and productivity increased from 2011 to 2019 in Gujarat (Figure 1d-k). This may be due to continuous efforts by Gujarat government policies, KVKs of Gujarat and State agricultural universities.

The scenario of last ten years (2011-2020) for area, production and productivity of cumin cultivation in different districts of Rajasthan is represented in Figure 1 (l-r). It was observed that the largest area under the cumin cultivation was in the district of Barmer (Figure 1m), followed by Jodhpur (Figure 1p), Jalore (Figure 1o), Nagaur (Figure 1q) Jaisalmer (Figure 1n), whereas the lowest area was under Ajmer district (Figure 1l). The area under cumin cultivation in Rajasthan is increasing continuously from the year 2011 to 2020 (Figure l-r), in all the districts except Ajmer and Pali, it may be due to adoption of other crops by the farmers of these regions because of high risk in cumin cultivation. The overall production of cumin in Rajasthan, from last ten years was highest in the district Jodhpur (Figure 1p) followed by Barmer (Figure 1m), Jalore (Figure 1o), Nagaur (Figure 1q), while the lowest production was found in Ajmer district (Figure 1l) followed by Pali (Figure 1r). The area cultivated in Barmer district was more than the Jodhpur district but production in Jodhpur district was highest, might be due to soil and climatic condition of Barmer district (desert region) are more adverse compared to Jodhpur.

Interestingly, it was noticed that the highest productivity was observed in Pali (Figure 1r), followed by Jodhpur (Figure 1p) and Ajmer (Figure 1l). It might be due to the awareness among


**Figure 2:** Major constraints for cumin production including climatic constraints, soil constraint, crop input constraint, agronomic constraint, extension constraint, marketing constraint and mechanization constraint.

farmers with the efforts of ICAR institutes i.e., NRCSS, Ajmer and CAZRI (Central Arid Zone Research Institute) about the improved techniques. The KVKs and state agricultural universities also making efforts for improving the cumin production in the state. It was observed that the lowest cumin productivity found in Jaisalmer (Figure 1n) followed by Barmer (Figure 1m) and Jalore (Figure 1o), which is very low (<0.5 tonne/ha). This may be due to dessert region and more erodible soil and not proper management of soil. Therefore, there is need to improve the productivity of these cumin producing districts.

### Export Value of Cumin Crop

India accounts approximately 70.77% of overall global demand of cumin followed by Syria (13.16%), Turkey (5.15%) and UAE (2.8%) [30]. the total cumin export continuously increased from 2011 to 2020 (Figure 1s). It was observed that cumin exports had increased by 502.99 % in terms of quantity and 562.05% high in terms of value from year 2011 to 2021 (Figure 1s). This might be attributed to globalisation and free trade policies that had resulted in a high demand for cumin. As a result, farmers are encouraged for cultivation of cumin crop, because of more financial gain. Cumin cultivators were also benefited by the successful adoption of the improved varieties and production techniques.

## Major Constraints in Cumin Production

The constraints affecting the productivity of cumin crop are categorized in seven categories which are climatic constraints, soil constraint, crop input constraint, agronomic constraint, extension constraint, marketing constraint and mechanization constraint (Figure 2). These sub headings cover the problem relevant to the category for cumin crop cultivation.

### Climatic constraint

The aberrant climatic condition affects the cumin crop productivity, especially during the reproductive stage. Throughout the crop growing period farmers face many challenges,

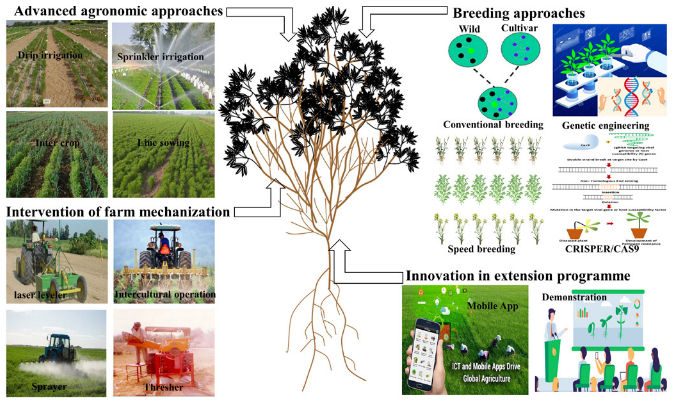


**Figure 3:** Integrated strategies to enhance the cumin production through advanced agronomic approaches, different breeding tools, intervention of farm mechanization, and new innovation the extension programme.

including drought, fluctuating temperature, high relative humidity, cloudy days and rainfall during the reproductive stage. Among the different climatic constraints, drought is one of the significant limiting factors which inhibits plant growth, productivity and also alter the biochemical properties of the seed [4,5,58,101]. Temperature is the other most critical factor for the germination of cumin seed [120]. The low temperature during the vegetative growth stage, changes the leaf colour from green to purple, while high temperature reduces the growth period of cumin crop and induce early ripening [22]. Fluctuating temperature is responsible for increase in disease and pest incidence and hampers the quality of seeds. High humidity during the flowering and fruiting stages of the cumin plant, promotes the incidence of diseases like blight and powdery mildew that drastically reduces the yield [18,22,114]. Cloudy weather during flowering and fruiting stages also increases the incidences of insect-pests and diseases that resulting into poor quality produce [124]. Frost is most limiting and dangerous factor for the cumin crop and it is highly susceptible to frost injury during flowering and early fruit setting stage [64]. There is none of the genotypes reported to be resistant against frost. In addition to this higher dew during the flowering period also affect cumin production because it is responsible for lower seed setting. Unseasonal rain during flowering and harvesting time drastically reduce the crop quality and yield potential [18].

### Soil constraint

The soil is the most important parameter for cultivating any crop. Improper soil condition may adversely affect the productivity of crop. Soil salinity is the most important constraint of cumin crop and most of the cumin growing parts (Rajasthan and Gujarat) having saline soils [66]. Cumin is a salt-sensitive plant, and increased salinity stress significantly slows down its growth [105] and its seed productivity is drastically reduced by 55% [37]. The cumin plant can tolerate upto 5 dS/m of salt in irrigation water. Salinity may cause the germination process to take longer time, which would lower the germination percentage [42,84]. Cumin cultivation is not suitable in light sandy soil because such kind of soil is susceptible to fungal disease [100]. The soil type of Rajasthan is light in texture thus, it is also a big constraint for cumin productivity.

Few other constraints related to soil such as deficiency of macro nutrient (NPK), inappropriate method of fertilizer application, excessive use of fertilizers in major growing area of cumin also reduces the productivity [35,119]. Approximately 34.83, 84.46, 41.14 and 62.81% area of the Rajasthan state suffer from the deficiency of micro nutrients Zn, Cu, Fe and Mn respectively, especially in the areas mainly located in the western plains due to light sandy soil [15]. The farmers do not focus on the availability of micro nutrient in soil which affect the crop productivity as well as its quality [35,61]. Another obstacle in cumin cultivation is non-availability of organic matter content in soil and inadequate fertility [61,97]. Further, the soil testing laboratories are far away from village due to which farmers don't test their soil before cultivation and apply excessive fertilizers [119].

**Crop Input Constraint**

The proper inputs (seeds, fertilizers, pesticides and irrigation) for cultivation of a crop are essential for its smooth growth and better yield. Lack of input supply to the crop affects the productivity and production negatively. The majority (42.5%) of cumin growers had semi-medium-sized land holdings, followed by medium (21.67%), small (16.66%), large (12.50%) and marginal (6.67%) sized land holdings respectively. Thus, majority of farmers cultivate the crop on marginal lands using poor crop management practices. The farmers (74.2%) have low investment potential and risk bearing capacity that hinders the adoption of improved crop varieties [42,77].

Seed is the primary input for the crop production. Seed related constraints in cumin production are such as non-availability of quality seed, lack of suitable and high yielding variety, lack of information about seed treatment related to wilt and blight resistance, limited adoption of seed treatment by farmers and lack of organic input [41,61].

The imbalanced application of fertilizers, particularly in the arid and semi-arid regions of India, has a direct impact on crop growth. The untimely application of nutrients, following inappropriate method of application are some other constraints related to fertilizer input, which leads to severe loss of nutrients by leaching and fixation [35]. Farmers use uneven or high dose of pesticides, causing harmful impact on human health, increased cost of cultivation and also affect the quality of seeds [26]. Among the crop input constraint, irrigation also play an important role in crop productivity especially for the arid and semi-arid cumin growing areas due to high water scarcity and low annual rainfall. Morwal et al. [77] reported that 85.8% farmers did not have irrigation facilities. The limited amount of water available for irrigation requires an urgent need for water-saving technology to improve cumin productivity in low-water areas [74]. The leaching of salts and poor underground water quality, contamination of various pollutants & heavy metals and low water table are some other prominent constraints related to Irrigation [42].

**Agronomical Constraint**

The agronomical constraints may result in partial or total loss to crop. The proper management of these constraints can increase the productivity and production tremendously [42]. Major agronomical constraints for cumin cultivation include the constraints in land preparation, sowing method, intercultural operations and incidence of pest and disease. The major growing areas of cumin are semi-arid and arid regions which have extensively degraded lands and undulating topography [63]. Thus, farmer facing challenges in field operations performed for the cultivation of crop. The sowing operation is the most crucial operation on which the whole crop productivity depends. The major constraint in this operation is method of sowing, farmers sow cumin seeds by broad casting method that causes uneven plant population. As the cumin seeds are small in size the broadcasting method of sowing require more number of seeds [83]. After germination plant compete with weed for water, light and space. Weed also invites various harmful disease and insects [112]. Yadav and Dahama, [129] reported that weed infestation causes a loss of 80–90% in the seed production of cumin. The amount of loss caused by weeds is the highest compared to other loss-causing factors like disease and pest insects [71]. Due to slow initial growth and short height (25-50cm) of cumin crop it trigger off heavy infestation of wide spectrum weeds, that lead to the severe reduction in crop productivity. Farmers frequently believe that weed control at any point in the growing season can be advantageous for the crop. However, Zimdail, [130] found that time of weed removal is also much important factor. Thus, there is a need to develop effective schedule of weed control in cumin [71]. The conventional weeding of cumin is done manually, that is tedious, labour consuming and expensive. Moreover, the shortage of manpower during early growth stage is also a major constraint in weeding.

The cumin crop is more susceptible to diseases, which significantly affects its productivity. The loss of yield in cumin crop due to the disease is estimated to vary between 7-45% in Gujarat and up to 35% in Rajasthan [27,127]. A key aspect to improve the cumin production is the reduction of disease incidence [6,12,76]. The productivity of cumin crop is mainly affected by three prominent diseases *viz.,* wilt (*Fusarium oxysporum f.* sp. *cumini*), powdery mildew (*Erysiphe polygoni*) and alternaria blight (*Alternaria burnsii*) [20]. Among the major diseases of cumin, alternaria blight is most devastating disease [47,60]. Fusarium wilt and blight, which are caused by the soil-borne pathogen, can have a significant negative impact on cumin production [6,59]. Kafi et al. [44] revealed that more than 27% of the damage in Gujarat and Rajasthan is caused by fusarium wilt. Cumin cannot be planted again in the infested land for at least ten years [6]. Due to the absence of an adequate control measures over time the attack of insects and pests are more severe that leads to damage the crop at large extent resulting in a significant loss of yield and quality [69]. The two main sucking insects that seriously damage the cumin crop are thrips (*Thrips tabaci*) and aphids (*Myzus persicae and Aphis gossypii*) [21]. Seed bug, *Nysius sp*. whitefly, *Bemisia tabaci* (Gen.), seed borer, Jassids, Empoasca sp *Hellula undalis* (F.) and other minor insects that feed on crop and cause damage at different levels [70]. The cumin aphid severely damages the crop during the flowering stage by initially yellowing and curling the leaves [21,69]. Thrips infestations begin during the early vegetative development of crop and continue through the flowering stages. It sucks plant leaves, causing leaf yellowing and dryness [56].

Cumin crop matures in 90-120 days for harvesting [56]. The harvesting losses have a substantial impact on the amount of production [42]. Delays in harvesting (full plant drying) had detrimental effects on all quality indices. Lal et al. [56] reported that long-term sun drying of harvested cumin plant before threshing is not beneficial for cumin quality. Due to delayed harvesting and sun-drying of the crop, the volatile oil content of cumin seeds is lost, which lowers the quality of the seeds and revenue returns. Traditional method of cumin threshing i.e., beating the plants on mud floors or plastered with cow dung exposes seeds to few undesirable microorganisms and aflatoxin [56], which hampers the quality of seed. The traditional practice of threshing cumin requires lots of labours. There is also mixing of stone and dust takes place while the threshing operation these needed to be removed manually by hand sieving or mechanical processing machines which leads to reduction in the quality and cost of cultivation.

**Extension Constraint**

Lack of knowledge and awareness among the farmers about recommended technology interventions is due to limited access of extension programmes. KVKs play an important role in extension programmes. The total number of KVKs in Gujarat and Rajasthan are 30 and 44, respectively [38] that are very less in numbers causing limited outreach to the famers. Chandawat and Singh, [14] reported that there was knowledge gap of 7.33 to 43.50% among farmers (sample size of 100 farmers) regarding recommended technology intervention in cumin cultivation. This gap indicates that there is a strong need to play an active role by extension workers and KVKs in transfer of latest technology and improved cultivation practices in cumin production. The number of demonstration organized by the KVK's are not adequate [14]. Desai et al. [26] confirmed that there was huge gap in technology intervention recommended by KVK in case of sowing method, variety, seed, fertilizer dose, treatment and weed management in comparison to the farmer practice. Further, Subject Matter Specialists (SMS) were found to be least used source of information [14]. Farmers are in less contact with the SMS and are unaware of the services that can be provided by the SMS. The number of training programmes organized by KVK, DEE (Directorate of Extension Education) or SAU (State Agricultural Universities) were not effective due to unorganized and inadequate way of conducting [14].

Desai et al. [26] reported that there was large gap in adoption of the recommended technologies such as use of high yielding verities, line sowing method, recommended seed rate, recommended fertilizer dose, effective weed control methods and suggested plant protection measures. Chandawat and Singh, [14] reported that out of 100 selected farmers the knowledge gap in adopting improved practices in seed treatment, use of high yielding varieties, sowing practices, fertilizer application, weed control and plant protection measures were 43.5, 12.6, 30.6, 29.75, 26.16 and 8.75%, respectively. Similar results were also reported by [77,103]. Thus, very few farmers aware about improved methods of cumin cultivation. The major reason for unawareness and lack of knowledge about improved methods was low literacy of the farmers maximum in the age group of 31-50 years [109]. It was revealed that 67.5% farmers were illiterate and out of them 91.7 % farmers were completely dependent on the agricultural income. Morwal et al. [77] reported that 45% of the cumin farmers had only completed their elementary education, 27.5% being illiterate, 17.5% completed their upper secondary education and only 10% had completed their higher secondary education. Tavethiya, [119] reported that the high cost of crop input such as seeds, weedicides, pesticides, fertilizer and high wages of labour were main constraint for the farmers to adopt recommended technology by KVK,s.

**Marketing Constraint**

The cumin industry is continuously facing marketing challenges. The economic returns are drastically affected by these marketing constraints [83]. According to agricultural statistical data from 2018, the majority of farmers have poor economic conditions. In India, 86% of farmers are small (17.69%) and marginal farmers (68.52 percent). Thus, they have limited resources to cultivate the farms using their own money. As a result, approximately 40% of farmers rely on non-institutional financial sources, which have higher interest rates. Lack of awareness about institutional sources of farm financing, they opt to borrow money from non-institutional sources. Other reasons for preferring non institutional loan is complex bank formalities and inadequacy of loan amount [68]. Because of the debt taken by non-institutional financial sources (dealers) farmers are forced to sell their produce to a specific dealer at a lesser price. Farmers are bound to sell their product immediately after the harvest to local sellers for payment of wages, meeting daily requirements and loans of the cooperatives [83]. Instead of selling in local markets, more than half of the overall supply is sold in Gujarat's Krishi Upaj Mandis, such as Unjha, Mehsana and Deesa. The brokers of Unjha and Deesa mandi purchase produce that has not been processed, such as sieving or grading, and fix the prices of crops standing in farm so farmer get less profit to his produce. While, brokers after processing sell the crop produce at higher prices [53,83].

Lack of facilities for determining moisture content is a significant issue since it has a negative impact on product price [41]. Farmer does not get the actual price of his product because of fluctuation in weight due to moisture content. Lack of suitable storage facilities, and appropriate roadways are also major marketing constraints. India loses approximately $10 billion (one-third of its annual output worth) due to spoilage [50,68]. The shortage of warehouse, inadequate cold storage, weighing facilities, absence of generator and electricity [41] forces the farmers to sell their product immediately at lower prices as quality of product get reduced due to lack of facilities and prolong duration. Inappropriate infrastructure facility in market such as non-availability of cafeteria, toilets, internet and stalls for merchants in market yards make farmers suffer in marketing their product [68,93].

The biggest marketing challenge for cumin is post-harvest constraints such as lack of grading and sorting facility, inadequate transportation facilities and infrastructure for linking communities to the central market [53,68,93]. Further, as evidenced by the large number of farmers, the primary limitation of government was failure to declare the MSP (Minimum Support Price) [83]. Market price fluctuation due to absence of fix MSP in cumin crop leads to a high price fluctuation of this crop [119]. Farmers do not receive timely information about the market and price swings despite of available technology (e-marketing) because they are not trained to use web services [68]. Mary, [67] reported that farmers have no access to market understanding or the newest trends in the spice industry because 74.2% of Indian farmers are illiterate. The Unjha APMC in Gujarat's Mehsana district is Asia's largest cumin trade market. Unjha APMC had declined to enter the online portal due to lack of capability to manage the influx of commodity arrivals and place them on the internet. More than one lakh bags of cumin arrive on regular basis in season. Therefore, sampling, grading and testing of such large quantity was difficult. Another reason for the decision by Unjha APMC not to enter e-NAM is concern amongst traders that they might lose their profit [53].

**Export Constraint**

The major constraints in cumin exports varies with country, due to standards for maximum limits of residue for chemical, pesticides and other contaminants [31]. The absence of standardization is one of the biggest barriers to export of cumin. The Indian exporters face difficulties due to noncompliance with food safety and health standards [16,17,23,40,73]. Contamination with pest and presence of food bacteria, disease inoculums, prohibited chemicals are the major reasons for rejection of export consignment. The participation of multiple agencies such as Spice board, Export Inspection Council (EIC), Agricultural and Processed Food Products, Export Development Authority (APEDA), Directorate of Plant Protection, Quarantine and Storage, National Accreditation Board for Testing and Calibration Laboratories (NABL), Bureau of Indian Standards (BIS), Food Safety and Standards Authority of India (FSSAI) are the main complexities in export of cumin seeds.

**Mechanization Constraints**

The unit operations performed in cumin crop are similar to other crops [3]. Due to lack of mechanization level in this crop the productivity and quality of the crop is affected drastically. Land preparation is great challenge for cumin farmers, because it is generally grown on sandy to sandy loam soils with an uneven topography. Limited availability of suitable machineries for land preparation, farmers sow their crop on undulated fields causing non uniform seed germination [42]. The unavailability of efficient seed drill (specifically design for cumin) forces farmers to adopt broadcasting method for sowing of cumin seeds [83,123]. Broadcasting method also limits the use of modern intercultural equipment [41]. The facilities for irrigation and drainage are also a big challenge throughout the crop growth period. The availability of ground water resources in both the state Rajasthan and Gujarat is also at quite alarming stage. Situation has been worsened from the last two decades. Cumin crop need favourable moisture regime for best performance requiring proper irrigation and drainage. The pumps used by farmers are less efficient which cause more cost and high electricity consumption [106]. Farmers purchase these pumps due to its cheaper cost but in long term use it is loss to the farmer. Limited availability of electricity and higher cost of electricity is also a big concern for farmers [119].

Manual weeding is time consuming, tedious, labour intensive and costly. Due to this, herbicides are frequently used by farmers in cumin-growing areas as pre- and post-emergence weed control measures [89]. Therefore, there is a need of weeding equipment that can easily remove the weeds with less labour and time. Lack of mechanical spraying equipment farmers use excess dose of pesticides to control the attack of disease and insects [26]. The sprayers used by the farmers are less efficient and they spray excessive pesticides which cause more cost to the farmer and it also affects the quality of the cumin seed. Therefore, there is a need of sprayers which can effectively spray and save labour and cost of the farmers. The harvesting of cumin crop is done by sickle. Manual method of harvesting causes higher losses, more labour and cost [42]. Currently no machine is available for harvesting of the cumin crop so there is huge scope to develop such machinery. The manual method of harvesting reduces the level of production and the quality of the seed [56]. However, in last few years attempts were made to modify harvesters for the cumin crop. But no efficient technology could be developed [95]. The traditional method of threshing is beating the crop on mud pasted floor that cause infections and reduces the quality of seeds. The method is labourious, time consuming and inefficient [42]. It requires lots of labour for dust and stone removal during the threshing operation by hand sieves or cleaning machine and it also reduces the quality of seeds. There is no such packing technology available for storage of seeds for long duration without hampering its quality [62,65]. Further, the available grinding machines affect the quality of oil and have less recovery [102].

## Management of Constraints in Cumin Production

Due to the various constraints in cumin cultivation there is a large gap between attainable and actual productivity. Proper management of these constraints using new and better technologies might raise current productivity levels by 30 to 40 percent in around 5-6 years [42]. The potential solutions for major constraints affecting the production and productivity of cumin crop are discussed thoroughly in following section.

**Management of Climatic Constraint**

The management of climatic constraints is alternate solution for improving cumin productivity. In order to overcome the constraints related to the drought, seed priming is a possible solution for the improvement in seed germination up to 26% [4,61]. Draught tolerant varieties can also help in increasing yield potential under drought conditions [57]. Selecting sowing period according to weather forecast, is also a good way to overcome the drought period. Trivedi et al. [120] reported that at the temperature of 20°C cumin seed showed higher germination and other quality parameters were also good. Whereas, Dar et al. [22] reported that cumin seeds can sprout in between temperature range of 2 to 5°C, however, temperature between 20 to 30°C is ideal for better germination. The management of temperature constraint can be achieved by applying mulch practice and timely irrigation of the crop. Relative humidity indirectly affects the photosynthesis process, leaf growth, occurrence of diseases, pollination and yield [114]. The factor of humidity can be managed by adopting improved varieties like GC-3 and GC-4 [64]. These cultivars have resistance to wilt and blight, so the chance of disease attack gets reduced. Cloudy days during any crop growth stage, enhance the incidence of disease and pest. The alternate solution for this may be adoption of disease and pest resistant varieties along with proper monitoring of the crop [18]. In order to manage the frost, if the weather is clear, it is preferable to water the crop to mitigate the damage. Additionally, a smoke arrangement needs to be built in the field to protect the crop from frost. The crop can be effectively protected against the occurrence of frost by using 0.1 percent commercial $H_2SO_4$ spray [114]. There is no management for dew is available but irrigation of the crop and arrangement of smoke can be a probable solution to this problem. Drought, fluctuating temperature and frost effect on any stage of crop growth, utilizing the advance and integrate breeding tools is a good way to cope up with these constraints [110,111].

**Management of Soil Constraint**

Cumin crop can be cultivated on soils having Exchangeable Sodium Percentage (ESP) less than 10.0 and electrical conductivity of less than 4.0dS/m. Moreover, optimal value of EC and ESP are less than 2.0dS/m and 5.0, respectively [104]. The desirable range of pH is between 4.5 to 8.2 [100]. The saline soils may be reclaimed through the use of amendments such as mulching, green mannuring, crop rotation and application of lime [42]. Sandy loam and sandy soils having adequate aeration, well drainage and appropriate oxygen availability with good fertility level are preferred for cumin cultivation [22,124]. Mulching, organic manure application and proper nitrogen application may improve soil structure and enhance soil health which can help in increasing productivity [97].

Peter et al. [91] suggested that in rain-fed cumin, an application of 16 to 20t/ha of FYM is appropriate, but for irrigated conditions, an extra 30kg of N/ha had been recommended. Patel et al. [86] recorded that the maximum seed production (869kg/ha), net return (Rs. 70,765/ha) and benefit-cost ratio (4.4:1) was achieved thru applying prescribed dose of N by mustard-cake and fertilizer in 1:1 ratio. Moreover, it was found that there was reduction in wilt incidence by applying 30kg/ha N, 20kg/ha P2O5, and 30 kg/ha $K_2O$ [2,12]. Increasing dissolved phosphorus in soil enhances the nutritional condition of the plant and contributes to a greater seed production [99,100]. The average micronutrient uptake for cumin are Mn-201.8g/ha, Fe-439.8g/ha, Zn-22.2 g/ha, B-37.4g/ha and Cu-107.6g/ha. Aishwath et al. [2] reported that in sandy loam soils of Rajasthan, by applying 30kg N/ha and 20kg/ha ZnSO4 greatly increased seed production. The addition of organic manure and nitrogen to the soil can improve soil health and nutrient availability, resulting in higher productivity [97,61]. Soil testing laboratories available at district levels in Gujarat and Rajasthan are 267 and 203, respectively till the year 2021. These laboratories should be made mobile and available at village level so that farmers can easily access them and apply the required dose of nutrients to their soil [115].

**Management of Crop input Constraint**

The management of marginal land problem can be done by adopting techniques such as diversification of crop by crop rotations, mixed and intercropping [75,126]. In intercropping cumin crop can be grown with the other crops in the pattern i.e., Coriander-Cumin, Maize-cumin-summer moong, Coriander-cumin-green gram, cluster bean- cumin and Pearl millet-cumin [124]. Quality of seed can be improved with the application of *panchgavya* foliar and leaf extracts of plant. The maximum cumin seed germination was observed after foliar application of neem (*Azadirachta indica*) leaf extract combined with *panchgavya* [61]. *Trichoderma asperellum* and *bavistin* seed treatments can be used to manage diseases like wilt and cumin blight [121]. Another two more seed treatment methods were suggested by Malhotra, [64] and Lal et al. [55] to enhance the seed germination. Malhotra, [64] proposed that soaking seeds in water for 8 hours afterward, drying them in the shade before planting, and using a bio-inoculant like *Azospirillum* or *Azotobactor* may enhance germination. Whereas, Lal et al. [55] suggested that the treatment of seed with *T. viride* (4g kg/ha) and Bavistin (2.5g/kg) in a closed container and then shade dried for some time before sowing can improves seed germination [55]. Mahajan et al. [61] found that pre-sowing seed treatment with *T. harzianum*, ethephon, and *A. versicolar* boosted emergence by 23, 20, and 18.46%, respectively, compared to the control and seed priming also increased seed germination by 26%. It was also found that application of seed treatment reduces the chances of attack of disease.

Further, constraint related to fertilizer application can be managed by application according to the recommended dose {30:20:10 (N:P:K)} or on the basis of the soil testing report [78]. Use of organic manure and site specific micro-nutrient can also help in managing constraints related to fertilizer application [26]. The application of 6-8 t/ha FYM or 5 t/ha compost for three weeks before sowing of the crop maintains good soil structure and biological property [88]. Malhotra, [64] reported that the inoculation with VAM fungi (*Gigaspora calospora, Glomus fasciculatum, Glomus mosseae* and *Acaulospora laevis*) had reduced the chances of wilt incidence in cumin and it also improved nutrient uptake. The constraint related to pesticides can be managed by adopting practice like spot application of insecticides, fungicides and integrated disease management module [26,41]. The application of neem oil can also be helpful in protecting the crop against insects [107].

The scarcity of water can be managed by use of improved irrigation methods such as drip irrigation and sprinkler irrigation methods. Surface irrigation methods result in more water loss and very less water use efficiency compared to drip and micro sprinkler irrigation. It was also revealed that irrigating the crop by drip or micro sprinkler technique had produced more yield compared to surface irrigation [113]. The water productivity was also highest in case of drip irrigation method (41.28kg/ha cm), followed by micro sprinkler (21.73kg/ha cm) and surface irrigation method (8.43kg/ha cm). There was 46% saving in water and 10-12% increase in seed yield with drip irrigation method as compared to surface irrigation [11]. The use of micro sprinkler in irrigating cumin crop is discouraged because it requires more energy than a drip system [54]. In order to provide irrigation by micro-sprinkler system the optimum IW/CPE ratio should be 0.8 [35,97]. Drip fertigation also plays an important role in effective weed management [74].

**Management of Agronomical Constraint**

The effective management of constraints in agronomical practice can improve the productivity and quality of the seed. During the field preparation the stubbles of previous crop should be removed from the field. Land should be well levelled by plankers for uniform and better germination of seed and plant growth. A total of 3-4 ploughings are required. The first ploughing should be done by primary tillage implement that turns the soil thoroughly. Thereafter, 2-3 harrowing are required to get the fine tilth of soil [56]. The planking should be done after each ploughing to conserve the moisture.

The Sowing time is a crucial factor involving no cost but this factor decides the extent at which incidence of disease and pest can take place. Therefore, in order to protect cumin from incidence of pest and diseases it should be sown at appropriate time. The sowing time should be chosen such that the flowering phase of cumin may avoid higher humidity levels in the atmosphere. The best sowing period is from the middle of November to the first week in December. However, Bhati et al. [9] suggested that the second half of November is the ideal period for sowing to obtain good yield. Deepak et al. [25] reported that the Crop sown in November experienced a much greater incidence of cumin wilt and blight than crops sown in December and infestation was least when the crops were sown in the second week of December. Most of the farmers sow cumin by broad casting method, while this method is least efficient. Line sowing is therefore advised by NRCSS, Ajmer, as it also promotes intercultural operations and provides better surroundings and space for the plants. As the cumin seeds are small in size so sand or screened friable soil can be mixed with seed just before sowing. Therefore, the uniformity can be maintained when seeds are dropped in the shallow opened furrow. The row-to-row distance and depth of sowing should be maintained at 25 and 1.5 cm respectively. A thin layer of soil should be placed to cover the seeds. Deeper sowing can cause delay in seed germination. Since germination is a problem in cumin, therefore soaking of seed in water for 8 hours before sowing improves germination. The soaked seed should be dried in shade before sowing.

Weeding operation is necessary for better initial growth of crop it can be achieved by integrated approaches of weed management. At first, hoeing and weeding should be done 30-40 Days After Sowing (DAS) when height of plants are around 4-5cm. Additionally the rows of plants are trimmed to a maximum of 10-15cm. In case of weeds return, another one or two hoeing and weeding sessions help in greater crop growth. The common weeds for this crop are Bathua (*Chenopodium album*), Zeeri (*Plantago pumila*), Piaji (*Asphodellus tenifolius*), *Heliotropium ellipticum*, Khartua (*Chenopodium murale*) and Pilisanjee (*Melilotus indica*). Among these weeds the Zeeri, is most prominent weed and it is very much similar to the cumin plant before flowering, unfortunately this weed contaminate with cumin and reduced the quality and market price of seeds. Therefore, it should be removed at the flowering stage. Choudhary, [19] reported that hand weeding may provide the highest seed yield, however, the benefit-cost ratio was higher when herbicides were employed since manual weeding is more expensive than herbicidal spray. Therefore, herbicide becomes popular among farmers for controlling weeds of cumin. The most effective weed control and maximum possible yield of cumin can be achieved by pre-emergence applications of fluchloralin at 0.75kg/ha or pendimethalin at 1.0kg/ha combined with one-hand weeding at 25 DAS [89]. However, Lal et al. [56] and Yadav et al. [128] suggested that the best integrated weed control strategy for cumin was pre-emergence treatment of oxadiargyl @ 0.075kg/ha immediately after planting followed by one hand weeding at 45 DAS. The effective control of weeds can be achieved by hand weeding at 25 and 45 DAS. Mehriya et al. [71] reported that in the case of cumin, the crucial time frame for crop-weed competition was between 15 and 60 DAS.

Using integrated approach, disease and pest can be managed effectively such as management of aphids, wilt, blight, downy mildew and powdery mildew which are the most detrimental biotic stresses in seed spices [39,48,108]. In order to manage the wilt disease, soil solarization (covering of moist soil with plastic sheets) can be an effective method to kill soil born pathogen which causes wilt. The incidence of this disease can be reduced by crop rotation of cluster bean-wheat-cumin, cluster bean-mustard-cumin, cluster bean-cumin and crop rotation with sorghum to great extent. Three varieties of cumin i.e., GC-1, GC-3 and GC-4 showed lower incidence of wilt [64]. Aghnoom et al. [1] reported that seed treatment with *Trichderma harzianum* reduced the wilt incidence by 65% and thus, it was found to be more effective than treatment with fungicides. Wilt incidence can also be reduced by inoculation of cumin plants with *Glomus fasciculatum*, *G. mosseae* and *Acaulospora laevis* [12]. Biocontrol agents like Aspergillus flavus, *T. harzianum* and *A. niger* was also found effective in controlling the wilt disease [13,90]. Application of carbofuran 3g @ 66 kg/ha before sowing was most effective in reducing wilt incidence followed by phorate 10g @ 20 kg/ha and aldicarb 10 f@20 kg/ha [13,27]. The seed treatment with carbendazim 3g/kg seed and one spray of carbendazim (0.1) or benomyl (0.05%) was also found effective in reducing wilt incidence [12]. Healthy and disease-free seed should be procured and treated with Bavistin @ 1.0g/kg seed before sowing. In the early stage of crop growth drenching with 0.2% captan can be done for wilt management [56,70].

In order to control blight disease, Ghosh et al. [29] reported that *T. viride*, *T. hamatum* and *A. awamori* were effective in controlling the growth of A. alternate blight. Mehta and Solanki, [72] recommended four sprays of Dithane M-45 (0.2%) for the effective control of this disease. The foliar spraying with Rovral 50 WP (0.2%) or Companion (0.2%) seven times at an interval of seven days from disease initiation (flowering stage) decreased the effect of blight [47]. Lal et al. [56] reported that the foliar spray of cuman (0.1%) and Diathane Z-78 (0.2%) at monthly interval after flowering control the disease by 72.6 and 61.7%, respectively. Whereas, Bhatnagar et al. [10] reported significant effect of three sprays of Blirox-50 and Topsin-M at an interval of 7, 10 and 15 days after incidence in reducing the intensity of disease. Kishore et al. [49] and Lal et al. [56] suggested that the disease can be controlled more effectively by seed treatment of Mancozeb, followed by captan, thiram and carbendazim. The cumin variety GC-1 and GC-2 is tolerant to this disease which can also reduce the incidence of the disease [118].

After wilt and blight, powdery mildew is the most severe disease in cumin. Gupta and Bhawaria, [34] found that powdery mildew can be managed by two applications of Bavistin followed by Sulfex and Sulphur dust whereas, two sprays of Karathane (Dinocap) can reduce disease intensity and increase the yield by 75.6% [56]. Among the different fungicides tested against E. polygoni (powdery mildew) in vivo conditions, propiconazole (0.025%) was the most effective fungicide as compared to the others, with maximum disease control of 79.28 % [27]. Pipliwal, [92] found that the extracts of neem leaves, garlic clove and onion bulb were effective in reducing the growth of powdery mildew pathogen. Two sprays of mancozeb (0.25 percent) and two sprays of *T. harzianum* can also be used to treat the disease, commencing 30 days after emergence and at an interval of 10 days. Whereas, two sprays of mancozeb (0.25%) followed by two sprays of *Pseudomonas fluorescens* was also found to be effective. Tolerant varieties to this disease are GC-1 and GC-2 which should be used to achieve better yield [118].

The prominent insect of cumin crop is Aphid, leaf eating catterpiller and thrips that can be managed with biological and chemical methods. Biological control by conserving the parasitoids and predators like *Trichogrammatids, Braconids coccinellids, Chrysopids* and *Syrphids* fly can help in control of insects and pests. The sucking pest population can be controlled by Augmentative release of *Coccinella septempunctata* @ 5000 beetels/ha. Installing the bird patcher @ 10-15/ha can promote predation of moths and larvae by birds [94]. Chemical control by foliar spray application of dimethoate (0.03%) and NSK 5% against sucking pest was effective in controlling the population of pest effectively. In case of severe attack of defoliators the application of endosulphan (0.07%) spray can also help in controlling the population of defoliators [94].

The aphid population can be controlled by several methods such as yellow colour attracts the aphids which can be utilized in trapping the pest. Sticky traps and water traps have been used in minimizing the aphid population [56]. There was less attack of aphid on the cumin crop sown in middle of November. Early application of 5% Neem Seed Kernel Extract (NSKE) or 2% Neem oil successfully reduced aphid populations. Spraying pesticides such as dimethoate (0.03 percent), 0.025% solution of methyl demetone or 0.04% solution of monocrotophos prevents crop damage at higher population levels [118]. Insects natural enemies like *Coccinellid* predators, viz., *Adonia* sp., *Bromides suturalis* F., *Coccinella* sp, *tumpunctata* L. and *Menochillus* sesxmacalatus have been observed feeding on the aphid of cumin. The predatory bird mina (*Acridotheres tristis*) was also found feeding on the aphid [56]. The thrips can be controlled effectively by Spraying of Dimethoate (0.03%), Neem oil (2%), NSK (5%) or Imidachloprid (0.005%) [56]. Application of fish oil or tobacco decoction (0.05%), rosin soap is also found effective in controlling thrips [118].

The cumin crop should be harvested at its physiological maturity (complete yellowing of plant and matures nearly 90-120 days) to get high yield and better-quality produce [56]. Delay in harvesting degrades the quality of cumin seeds. Early morning harvesting is recommended to prevent seed breaking and production losses [42]. The traditional way to practice of threshing cumin crop by beating on drums wood logs and under tractor wheels on mud floor can contaminate the seeds and reduce the quality of produce. The crop should thus be hammered and trodden on a clean threshing floor [42]. Threshing can also be performed by mechanical threshers in large scale cultivation.

**Management of Extension Constraint**

The extension constraint can be managed by the efforts of KVKs, SMS and various govt. agencies only a small percentage of farmers accessed KVKs and their facilities, the majority of them lived in the center's immediate vicinity. There is a need to expand both the staff size and the number of KVKs within a district. This might contribute to a more comprehensive coverage of rural communities [52]. Extension workers to farmer ratios vary widely throughout the country, ranging from 1:300 in Kerala to 1:2000 in Rajasthan [57]. There is need to educate farmers through various outreach methods, such as frontline demonstrations, trainings and workshops for adoption of improved methods and technologies for cumin cultivation [26]. Morwal et al. [78] reported that there was 31.9 to 62.19% increase in yield due to Front Line Demonstration (FLD) over farmers' practice (traditional) in cumin cultivation. The number of FLD programmes to be increased and more area to be covered under this programme. The number of training programmes can be increased through collaboration with different KVKs, SAU and ICAR institutes to make farmer aware about new technology.

Knowledge of Farmers for different facts about cumin production technologies can be expanded through a comprehensive training programme as well as field demonstrations, which might be more successful in achieving potential yield [77]. It is also necessary to improve proper communication method such as leaflets, SMS services, technical bulletins, radio talks and newspapers to make farmer aware about the recommended technologies [83].

The National Commission on Farmers had recommended that farm schools may be established in the fields of outstanding farmers to fulfil the literacy rate of farmers. The farm school can help in developing a cost effective extension system and improve literacy percentage of the farmers [52].

**Management of Marketing Constraint**

Marketing limitations play a vital part in determining the price of farmers' hard work in producing their crop. Hence, management of these constraints must be kept at first priority. An efficient marketing system is one of the pre-requisites for raising the income of the farmers [125]. The farmers having low economic condition should be made aware about institutional loan facilities. The process of loan should be made easy by banks and other cooperative societies [41,68]. The crop insurance should be given based on cultivated area. The available policies are for limited time, which means that the effect of natural disasters would be addressed if their occurrence takes place in that particular time [41]. The crop insurance should cover total time of crop cultivation i.e., sowing to harvesting. In order to overcome the financial constraints, continues efforts are done by government such as subsides on costly inputs like protected cultivation, improved seeds, micro irrigation, fertilizers, weedicides and pesticides that may help in managing the financial constraint of the farmers [42]. There is enough evidence available that the adoption of recommended and new technology can increase net income returns and will reduce the risk of the farmers [26,78,107].

The facilities to determine moisture content should be made available at market level (Jain and Pagaria, 2016). Large scale storage structures facility to be constructed for the farmers. The facilities of cold storage, weighing, generator and electricity should be provided and their regular maintenance and monitoring should be done [68,119].

The cleaning, grading, processing, packing and sorting facilities should be strengthened in the markets, so farmers can get high income returns for their produce [53]. Transportation facilities for connecting villages to the markets should be improved. Thus, the farmers can sell their product to that mandi where they can get higher price [68]. Government should fix the MSP that can reduce the risk of farmer and encourage the farmer to produce more cumin [83]. Market price fluctuation can be overcome by providing trainings to farmers through KVKs and other farm advisory and other effective communication sources through leaflets, SMS services, newspapers, technical bulletins and radio talk so they can get information about prices in different mandis and can sell their product accordingly.

The effective channel to get real price benefit to farmer is Farmers > Wholesalers > Retailers > Consumers. A pricing distribution analysis and Shepherd's ratio showed that this is the most effective channel. The share of farmer in this channel was highest (70.84%) [53]. The connectivity of mandis with e-NAM (online channel) can help the farmer in selling their produce directly through online platform. That will lead to overcome the role of middle man and farmer will get better price for their produce [53].

**Export Constraint Management**

In order to solve import and export concerns, GAP (Good Agricultural Practices) guidelines for organic and non-organic seed spice farming were developed for both local and international usage [57]. Use of chemicals and pesticides can be reduced by focusing on organic cumin crop production and using bio-fertilizers and environment friendly inputs. Export process complexity can be decreased by application of single window method for traceability, export control and laboratory testing. It can facilitate exports while being more affordable and accountable [68]. Comprehensive export policy for agriculture in India to be made that can find out the problems in exports of agricultural goods and set out steps to comply with the Sanitary and Shytosanitary (SPS) requirements of main export markets [31]. Recently, the Spices Board, in collaboration with the exporting community, has taken effective steps to strengthen the supply chain and ensure future trade growth to promote exports and to improve food quality and standards. It is important to make farmers aware about the quality standards as well as good farming practises, production practises, post-harvest processing, marketing strategies, traceability and hygienic methods [53]. Campaigns should be initiated against the misuse of pesticides. Adapting improved cultivation techniques, improving extension services, promotion of organic farming and appropriate price policy can improve the export quality and quantity [53].

**Management of Mechanization Constraints**

The labour required and drudgery in the cultivation of cumin crop can be reduced effectively by managing the mechanization constraints. The land needed for cumin should be levelled and well pulverised. The land preparation can be done by first applying MB (Mould Board) plough or disk plough then for secondary tillage harrowing can be done by cultivator. Thereafter, at last planking can be done by patella for levelling the land. At some places rotavator is operated to get well pulverized soil [3]. The application of laser leveller then ploughing using MB plough and rotavator can also be done to achieve well pulverized and levelled land [42]. Traditionally seed spices are sown either in line or broadcasted. Line sowing is superior to broadcasting for intercultural activities such as weeding, hoeing, and spraying. The ideal sowing depth is 1-2 cm, and plant density is around 120 plants per square metre [82]. Line sowing is performed by dropping the seed in furrow made by simple cultivator of any device. These traditional methods have many draw backs like uneven seed distribution, improper seed placement, seed and fertilizer wastage, poor germination and more drudgery. To cope up with these constraints an attempt was made under National Agricultural Innovative Project (NAIP-II) and an improved seed cum fertilizer drill with few modifications was tested for sowing of cumin crop. There was seed saving of 4-5kg, increase in yield by 5-7%, saving in labour and it was also benefitted by timely sowing. Further, the intercultural operation was performed with ease [87].

Cumin crop require proper irrigation and drainage. Surface drains can fullfill this requirement with the help of available tractor mounted equipment.. Deep drains can be made very efficiently by tractor front mounted excavators. Whereas, shallow drains can be made with tractor mounted single bottom furrower. Furrow irrigation, pressurized irrigation with drip, sprinklers and micro sprinklers are efficient practices that can save 30-50% of irrigation water. If fields are not well levelled pressurized irrigation system is desirable [3]. Awareness among the farmers for using efficient pump and their benefits can be explained to them with the help of effective media communication, KVKs, agricultural universities and institutes. Those areas where availability of electricity is huge constraint solar operated pumps can be installed to avoid the electricity problems. Mechanical sprayers aid in pest and disease control by spraying insecticides and fungicides at the appropriate times. The available auxiliary engine operated power sprayers and dusters easily meet the requirement but are less efficient due to close spacing of crop [3]. Tractor operated sprayer demand adequate tread spacing matching to a particular tractor. These sprayers have wide swath can finish the task very quickly.

In case of harvesting, a walk-in type reaper was tested for harvesting of dill seed crop under the NAIP-II project. The reaper used for harvesting dill seed crop had given net return of 2750 Rs/ha as compared to traditional method. The harvesting with the help of machines enables the farmers to complete the process within a short climatically favourable period and thus the loss of crop due to untimely rains and summer wind storms can be saved to a large extent. There was a labour cost saving of 3400 Rs/ha [87]. Similar kind of walk behind type harvester for cumin crop can be developed and tested which can save the labour, drudgery and time of the farmers. MPUAT, Udaipur, in partnership with M/s Makewell Industries, Unjha (Gujarat), developed and tested a tractor or motor driven thresher for threshing coriander and cumin crops. Telescoping shaft was attached to tractor PTO that provided drive to power transmission. An electric motor of 5.6 kW was used for auxiliary source. The capacity of thresher was 240 to 260 kg/h. The multi-crop thresher with minor modifications under the NAIP II project was also tested for cumin and fennel crop. The modified thresher had given net return of 3.0 and 3.25 Rs/kg, respectively for threshing of fennel and cumin as compared to traditional method. The capacity of thresher was 250-300 kg/h [87].

During the post-harvest operation, the drying of crop seed should be done on raised platform or concrete floor inaccessible to domestic animals to minimize dust contamination. Precautions should be taken to prevent contamination by rodents, birds, insects and other animals during drying and handling in the open [122]. Solar powered dryers protect against contamination and are thus strongly recommended. Fan dryers may suck fine dust particles in dusty areas. Therefore, powered dryers may need a muslin filter over the air inlet. Temperature and RH must be carefully monitored during storage. Studies should be carried out for determining the most effective packaging media to store cumin seeds with higher quality and extending their shelf life [62,65]. Cryogenic grinding can be used in grinding process that retains the volatiles and also enhances the recovery by 33.9% in GC-04 and 43.5% in RZ-209 cumin varieties [102]. Improvements in cleaning, packaging and warehouses can help in maintaining the quality and flavours, also reduces the risk of seed contamination. NRCSS had produced a varieties of seed spice products including biscuits, essential oils, cryogrind powder and oleoresins [57]. A four-wheel driven trailer equipped with a portable agro-processing unit installed at CIPHET could be used to process seed spices at the farm. A Diesel Generator (DG) set could be used to run various machines for on field processing of seed spices, such as a grader, cleaner and burr mill.

## Future Perspective

Improvement in available technologies for finding out unique methodology to avoid redundant cost of cultivation, climatic issues, minimize labour, drudgery and enhancement of cumin production are the major thrust areas of research [51]. Strategies to improve the crop production, and yield potential of cumin include advanced agronomic approaches, breeding approaches, intervention of farm mechanization and improvement in extension programmes. Cumin researchers should focus on developing climate-resilient high-yielding varieties through climate-smart technologies and practices to deal with the climatic constraints [7] (Figure 3). Plant breeders combine the important yield component and quality traits [32] by utilizing modern breeding tools [45,110,111] such as speed breeding [33] should continue for cumin production. Advanced machineries and low-cost equipment for performing different field operations in cumin cultivation needs to be developed by agricultural engineers to overcome the challenges of high labour requirement, high cost and drudgery in operation and low profitability due to untimely operations. New government policies should be made to improve extension programmes like KVKs to be set up at block levels, establishing more farm schools, encouraging front line demonstration at village level and creating guidelines to conduct demonstration programme systematically. There is also need to develop effective communication methods for farmers like newspapers, leaflets, SMS services, technical bulletins and radio talks to create awareness among them about the improved recommended technologies and practices which they can utilized according to their suitability. Cumin researchers should concentrate on integrated strategies to identify best technology model for enhancing cumin production.

## Conclusion

Since last decade (2011 to 2020), there was a huge growth in cumin crop area, production and productivity. However, there is a huge gap in the potential and actual production due to different constraints in cumin cultivation. This study provides complete insight to the researchers about the existing gap and potential areas of research in the field of cumin cultivation. The major constraints in cumin production are related to climate, soil, agronomic, extension, marketing and farm mechanization which are discussed thoroughly along with their possible alternate solutions. In addition to this, study revealed that the suitable solutions related to climatic constraints are not available and therefore there is need to focus on development of climate resilience cultivars by cumin breeder. There is an urgent need to emphasize more on constraints management related to soil and extension activities to create awareness among the farmers. Introduction of farm mechanization for various field operations of cumin cultivation can be a suitable approach towards solving various constraints and improving the productivity. Overall, there is a huge scope to enhance productivity and minimizing the crop losses by managing all covered constraints.

## Author Statements

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this review article.

### Authors' Contribution

PKS, DKS, and MK conceived the idea. All authors (MK, PKS, DKS, SG, GS, AM, RN, AP, NCP and MR) contributed to writing the manuscript. MK, SG and GS prepared the all figures. PKS, DKS, MK, GS and MR finalized the manuscript. All authors have read and approved the final version of the manuscript.

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