Review Article

From Farm to Market: Unravelling the Volatility of Tomato Prices in India

Abstract:

Tomato is one of the most important crops in the horticulture sector with a share of ten percent in India. Tomato is essential to provide money for growers, employment opportunities, household and nutritional dietary requirements. Even through it has higher benefits, there are certain conditions like inadequate post-harvest practices, such as improper storage, poor marketing and transportation, and inadequate processing and preservation facilities which affect the tomato production and its supply and those conditions make a glut in market. Due to those condition, there is a price volatility of tomato in the market which affects the farmers, traders and consumers at greater extend. There is a finding that the price inflation occurs in the period of July to August and lower price during December to March as seasonality plays major role. The pre-production, production, harvesting, primary processing, packaging, interventions throughout the value chain, marketing and involvement of government are much needed to reduce the price volatility of tomato.

Keywords: seasonality, climate change, storage, post-harvest loss, marketing

1. Introduction:

Tomato which is scientifically known as *Solanum lycopersicum* belongs to the family Solanaceae, it is said to be originated in South America, Mexico, and Central America. One of the most popular vegetables in the world, its annual production is estimated at about 90 billion USD (Canton, 2021). Knowing the importance of tomato, it ranks second after potato among different countries (Prajapati et al., 2014). Tomatoes can be eaten as fresh or in processed form. Fresh fruits are used in salads, sandwiches, and salsa; processed fruits are eaten dried or in the form of pastes, preserves, dices, sauces, soups, juices, and drinks.

The tomato is essential to the production of money for growers, employment opportunities, and household and nutritional dietary requirements. Tomatoes are composed of 93–95% water, with the remaining 5–7% consisting of lipids, organic acids, sugars, carotenoids, inorganic chemicals, and alcohol-insoluble particles (Preedy, 2008). Tomatoes commonly ingested either raw or processed, and they include a substantial amount of antioxidants like vitamin C, lycopene, phenolics, flavonoids, and β carotene, which can aid in the antioxidant as well as free radical scavenging properties (Lenucci et al., 2006). It has been demonstrated that eating enough fresh tomatoes or tomato-based products on a daily basis helps to avoid the development of a number of cancers.

In spite of the numerous benefits that tomatoes offer, post-harvest losses of about 40% makes tomato production as low or non-profitable in the majority of the world's regions (Aidoo et al., 2014). Growers, processors, and traders receive low returns as a result of these losses, which

ultimately have an impact on the nation's foreign exchange revenues and level of self-sufficiency. Inadequate post-harvest practices, such as improper storage, poor marketing and transportation, and inadequate processing and preservation facilities, led to a glut in the market during the tomato harvest peak, which prevented growers from receiving the anticipated return on their capital investment (Issahaku, 2012).

Due to fluctuations in arrivals, tomato prices showed significant volatility, which frequently led to profitable or loss-making transactions. As prices rise when food supply declines in proportion to demand (due to low output or restricted food imports) and fall when supply increases in proportion to demand (due to a bumper crop), as prices are an estimate of availability. Since prices fluctuate over the year in most of the tomato growing regions, it is crucial for producers, consumers, and policymakers to understand the pattern of these variations in order to make informed decisions.

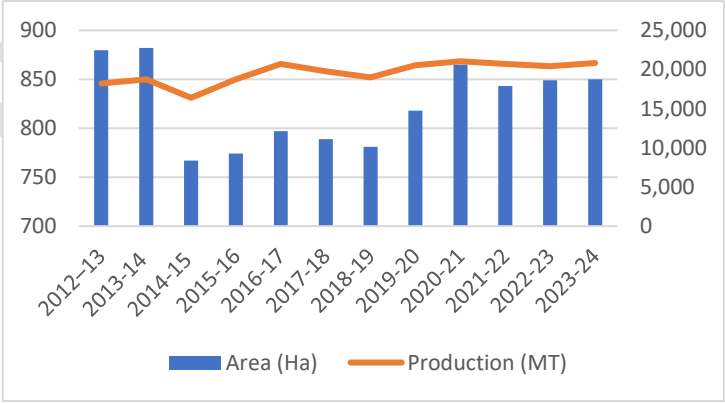
Seasonality and perishability issues are frequently the key features associated with vegetable marketing. Farmers set their prices as low as possible for their goods during harvest season, but during the off-season or drought, prices rise due to lower production and seasonal variations (Cashin & Pattillo, 2000). Following harvest, storage conditions and handling have an impact on the nutritional value and quality of fresh vegetables such as tomatoes (Sablani et al., 2006).

Also in the past, supply shortages were caused by farmer or transporter strikes or protests. Due to farmer protests that resulted in a decrease in tomato supply, tomato prices skyrocketed in July 2017- jumping by 138% month over month. In the marketplace, the traders deal with spoiling issues of tomatoes since it is perishable, so it need to be sold as quickly as possible to avoid going bad. Factor influencing price fluctuations in tomato marketing include variations in yield, farmers and middlemen seasonal supply preferences for urban markets over processors because of low farm gate prices, and the socioeconomic profiles of marketers along their supply chains. They have an impact on ongoing availability due to their perishable nature.

2. Area and production:

The tomato cultivation area is increased by 1% and production is increased by 1.9% compared to the previous year. (Fig 1).

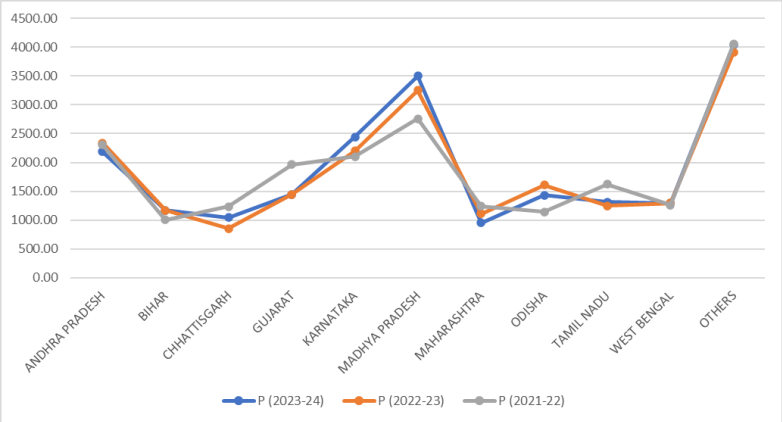
Fig 1: Area and Production of tomato



Source: Final Estimates from 2012 to 2022-23 and First Advance Estimates of Area and Production of Horticulture Crops, 2023-24, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.

Most of the states in India cultivate tomato, but only few of them sell their produce to the neighbouring states. Because metropolitan areas are the primary tomato-consuming regions, results on higher farmers shares of consumer rupees.

Fig 2: Major tomato producing states and growth in production in past years



Source: Final Estimates from 2021-22 to 2022-23 and First Advance Estimates of Area and Production of Horticulture Crops, 2023-24, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.

Madhya Pradesh, Andhra Pradesh, Karnataka, Gujarat, Odisha, Chhattisgarh, West Bengal, Tamil Nadu, Bihar, Maharashtra, Uttar Pradesh, Haryana, and Telangana are the main states in the nation that produce tomatoes. Approximately 90% of the nation's total production is produced in these states. The state that produces the most tomatoes among them is Madhya Pradesh.

The decline in production in 2022–2023 is primarily due to declines in production in key states like Chhattisgarh (-19.7%), Tamil Nadu (-26.10%), and Gujarat (-23.9%) (fig 2). Gujarat saw insufficient rainfall during the previous season, whereas Chhattisgarh and Tamil Nadu have been experiencing annual production declines followed by increases in the following year. (NABARD 2023).

3. Challenges in tomato production and marketing leading to price fluctuations:

3.1. Seasonality:

Seasonality is the separation of the year according to variations in the climate, natural systems, and daylight hours. Seasonality is more noticeable in perishable commodities like fruits and vegetables since they have a brief period of time between harvest and consumption (Amikuzuno & Ihle, 2010).

It's possible to grow the crop all around the year in India. India experiences two primary tomato crops each year: Rabi and Kharif. While the rabi crop is available from March to August, and Kharif crop becomes available starting in September (Table 1). For tomatoes, July and August

are a lean production time because of yield fluctuations. Tomato prices reach their lowest trade from December to March. February and March saw the lowest price indices (Sunji, 2018).

Table 1: Harvesting period of the tomato crop

States	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Andhra Pradesh												
Arunachal Pradesh												
Assam												
Bihar												
Chhattisgarh												
Delhi												
Goa												
Gujarat												
Haryana												
Himachal Pradesh												
Jammu & Kashmir												
Jharkhand												
Karnataka												
Kerala												
Madhya Pradesh												
Maharashtra												
Manipur												
Meghalaya												
Mizoram												
Nagaland												
Orissa												
Punjab												
Rajasthan												
Sikkim												
Tamil Nadu												
Tripura												
Uttar Pradesh												
Uttranchal												
West Bengal												
	Year around				Peak production				Lean season			

Source: Directorate of horticulture / agriculture

Seasons involved in both planting and harvesting of the crops, which in turn affects the success or failure of those crops and even the tomato market. Tomato plants are often tiny and

have thin, extended branches when grown in high temperatures. This reduces the potential of the truss to set and bear large fruits (Abdalla & Verkerk, 1968). When summer temperatures rise, tomato plant ability to grow vegetatively and bloom is negatively impacted (April-September). During this time, a lot of blooms don't set fruit, and tomatoes aren't readily available in stores (El-Amin & Ali, 2012).

Tomatoes are available year-round, at different prices. In the dry season, when irrigation is the primary source of water supply, tomato prices are higher, and in the wet season, when gardens are rain-fed, they are at their lowest. Tomato prices peak during the following harvest season. Five major obstacles were identified by in-season analysis: high labour intensity, high product perishability, poor profit margin, insufficient credit, and high transportation costs. Off-season marketing included low consumer sales and no tomato availability (Erie et al., 2017).

The majority of field crops are typically sold to markets during harvest, which is a multi-season process. Harvest pressures cause crop prices to drop sharply to a lower level, and storage costs during the season play a critical role in determining the direction of prices in the future. (Al-Hiyali, 2022). There was a significant seasonal farm gate pricing range in India for typical plastic crates, from Rs 50 to Rs 1200. It has been reported that during a glut, farmers and dealers would sooner give up on their tomatoes than invest in their harvesting, transportation, and marketing.

3.2. Abiotic stress:

According to studies, rising temperatures, altered precipitation patterns, and an increase in the frequency of certain extreme weather conditions are already having an impact on food security (Mbow et al., 2017). In addition to creating new health hazards for people, climate change may also have an effect on international trade, the food market, and price stability (FAO 2015). Due to the climate change, it was estimated that worldwide agricultural productivity would decrease by 3 to 16% by 2080; however, this estimate may differ depending on the region (Bhandari et al., 2021).

Extreme weather that strikes at different points during the crop cycle lowers productivity more than typical loss of yield (Beillouin et al., 2020). The main abiotic stresses that cause serious cellular damage in both wild and the cultivated plant species include rising temperatures (heat), droughts, cold, and salinity; these are thought to be the outcome of changes in the climate (Bita & Gerats, 2013).

A heat wave that struck India in February and March of 2023 destroyed crops. Due to the very high May temperatures and June rains, production stayed low in Maharashtra and the southern regions. In states that produce a large amount of tomato, heavy rains reduced production and harmed the crop. Seventy percent of the crop sowed in June was destroyed by heavy rains in the main agricultural areas of Karnataka (Bhardwaj, 2023).

3.2.1 Temperature:

The temperature has a greater effect on plant phenology as well as the pest and disease incidence. As tomato transplanting month is becoming drier and hotter, and temperature increase has caused the phenology to shorten (Cammarano et al., 2020). If there is higher temperature during blooming, it causes pollen sterility, colour disorder, poor fruit quality, deformed flowers, poor floral abscission, and poor flowering ((Johkan et al., 2011), (La Pena & Hughes, 2007)).

Elevated CO_2 concentrations lead to high air temperatures, which can cause heat injury and physiological abnormalities such as photosynthesis in vegetable crops. These effects will lower

crop yields and negatively impact farmers livelihoods. Cultivars among species vary in their sensitivity to heat, with reproductive development being more vulnerable to high temperatures than vegetative development (Johkan et al., 2011).

Tomato growth is normally stable between 21°C and 24°C; beyond this range, yield will decline (Attoh et al., 2014). Insect and pest growth is directly impacted by temperature variations; warmer temperatures accelerate insect growth. A persistent increase in temperature has the potential to increase crop damage from bacteria, fungus, and insects (Johkan et al., 2011).

3.2.2 RH:

The southwest monsoon rains, that are having an impact on soil moisture, productivity, and food price inflation, are crucial to India's agricultural sector. Tamil Nadu and the surrounding areas are impacted by the northeast monsoon rainfall. Rainfall was above normal in 2019 and 2020, but below normal in 2014 and 2015. Too much rain doesn't really affect tomato output because it happens all year round in the states. But there is substantial damage from floods, cyclones, and hailstorms.

Tomato plants suffer from high relative humidity and heavy precipitation since these conditions promote the growth of leaf diseases (Kalibbala & Bakuneeta, 2011). Low relative humidity (20–40%) inhibited the development, spore germination, and host tissue death while also slowing the progression of the disease (Guzman-Plazola et al., 2003). High relative humidity (70%–90%) in the research area promoted tomato growth along with spore germination, and after long-term exposure, the occurrence of diseases also rose in proportion.

3.3. Biotic stress:

Climate-related factors contribute to the invasion of insect pests that cause preharvest losses, postharvest spoiling, and quality degradation that varies depending on the crop (Oerke, 2006). The spread of illnesses and pests significantly lowers tomato yields and producers profit margins.

Tomato productivity is decreasing due to climate change, which is driving up the use of chemical fertilizers and pesticides. The prevalence of disease is rising, while productivity has decreased due to warm summers and harsh winters. Farmers apply fungicides more often throughout the winter months since fungus infestations are more common during these times. The use of pesticides rises along with increased pest manifestations on warm days (Bhandari et al., 2021).

In 2022, intense heat and unexpected rain caused a spike in plant viruses, especially in the states of Maharashtra and Karnataka, which hampered tomato crop growth. Farmers in Karnataka and Maharashtra have reported crop losses ranging from partial to whole, with the Agricultural Produce Market Committee obtaining just 0.95 lakh tonnes of tomatoes as opposed to the previous year (Bhardwaj, 2023).

3.4. Postharvest loss during supply chain:

Postharvest loss plays a major role in the reduction of perishables that is available to the consumer. Reducing hunger, increasing revenue, and enhancing global food security all depend heavily on addressing the problem of post-harvest losses. Reducing post-harvest losses is said to

be essential to guaranteeing future global food security, according to many researchers (Belik, 2018).

Tomato postharvest quality is influenced by a number of interrelated elements that start to play a role in the pre-harvest stages, such as the cultivar type, the cultural methods used, the maturation stage, the current temperature and relative humidity, as well as the handling and storage procedures (Isack & Lyimo, 2015) (Fig 3). In India, a significant percentage of fruit waste occurs in the postharvest stages as a result of inadequate packaging, incorrect quantity planning, additional transportation checkpoints, and unnecessary handling by farmers, agents, and retailers ((Gustavsson & Stage, 2011), (Lebersorger & Schneider, 2014)).

Fig 3: Reason for postharvest loss of tomato

Post-harvest losses restrict tomato production and the amounts of high-quality tomatoes that reaches customers. Poor handling of the tomato was caused by its perishable nature, outdated equipment, and a lack of knowledge among market participants and producers (Bombelli & Wright, 2006). The repeated loading and unloading of tomatoes cause damage to the fruits and shortens their shelf life (Vala et al., 2021).

Some of the cultural practices like harvesting, sorting and grading, postharvest treatments, packaging, transportation and storage has a great effect on the postharvest losses (Abera et al., 2020). Tomato harvest time is thought to be the primary factor in the postharvest losses. Due to poor time management and harvesting criteria, tomatoes were lost during the harvesting process. During the harvest, there is mishandling which leads to mechanical injury in field as well as in the market area. The longer the tomato fruit remained on the farm after it reached maturity, the greater the loss (Ayandiji et al., 2011).

The sorting and grading are done in tomato based the appearance and the quality of the fruit. Uniform shape and absence of growth or handling flaws are the main criteria for standard tomato quality (Suslow & Cantwell, 2009). But most of the farmers avoid such operation due to the reason that the wastages are high compared to the quality ones. Because of the variations in fruit quality, respondents frequently experienced price changes. The price of the commodity also gets reduced when it is treated with chemicals as the external appearance gets affected.

Tomato harvesting and transportation are done using wooden boxes. Larger, overfilled boxes are used for field filling, whereas smaller boxes are meant for long-distance transportation. Deterioration and mechanical damage can result from the rough wood surface. Expensiveness and a lack of knowledge regarding cross-contamination are factors in the widespread use of used cartons. During transport tomatoes gets exposed to sunlight over a long period of time, which reduces the quality of the fruit and thereby reduces the price.

The total amount of tomatoes available in the market declines as a result of decreased supply brought on by postharvest losses. Because of this, when tomatoes are scarce, demand increases and prices rise occasionally, particularly during off-seasons when supplies are limited.

3.5. Market dynamics:

The tomato industry faces numerous challenges throughout its value chain, despite its contribution to the reduction of poverty. These challenges include agronomic ones such as the prevalence of disease and pest infestations, as well as physiological disorders like sunburn, scald, or cracking; institutional challenges include subpar post-harvest technologies that are perishable, as well as poorly established both urban and rural market infrastructures which enable unpredictable fluctuations in the cost of tomato.

The market demonstrated that the variations in raw product supply during the season were the cause of price volatility. Price volatility suggests that performers have trouble predicting their revenue, which results in insufficient planning. That commodity prices, which are highest during lean production period and lowest during peak output, may represent seasonal production patterns (Goodwin et al., 2002).

Approximately 1.8 million metric tons of fresh tomatoes are produced annually, but over half of that quantity are lost because of inadequate transportation, storage facilities, and processing firms (Ugonna et al., 2015). Vehicle breakdowns and wooden crates holding tomatoes result in losses and increases marketing expenses for retailers, wholesalers, and buyers. Transport costs are typically used by wholesalers as a justification for lowering farm gate prices. Increased distances between the production unit and consuming areas may lead to greater transportation costs, which frequently get carried by sellers and eventually to the customers (Singh et al., 2015). The lack of information in the supply chain also results in higher costs of the tomato. This greatly affect the farmer community.

3.6. Perspective of the stakeholders:

Price fluctuations directly impact those stakeholders, who are vital to the tomato supply chain. Market dynamics can also impact the trader preferences about stock holding and supply timing (Grossman, 1987). Based on the type of supply, traders modify their prices (Issahaku, 2012). Prices are shifted upward as supply declines and vice versa. Based on which the annual wholesale price of tomato varies.

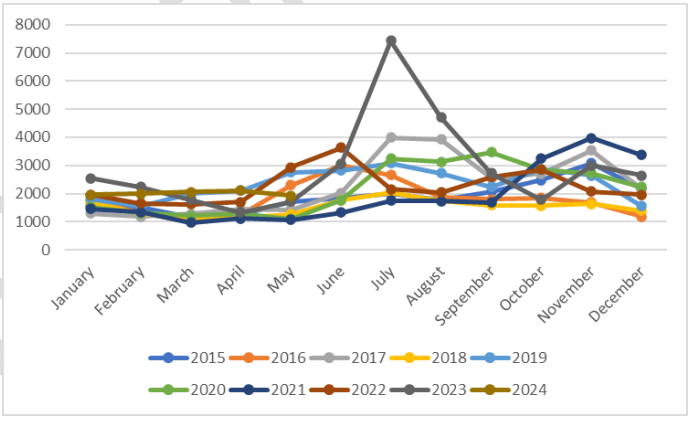
As the tomato supply is distributed, it seems to be a greater issue for wholesalers than for retailers. The tomatoes are grown on smaller farms dispersed across the region makes it problematic for distributors and retailers to gather tomatoes. Additionally, it raises transportation costs, which are ultimately carried to the customer. According to the farmers the dispersed structure of their farms, makes it challenging to market their produce and occasionally results in losses. The inadequate road system connecting farms to markets exacerbates the situation.

When it comes to agricultural commodity markets, particularly tomatoes, trader activities and market speculations have a big impact on price volatility. Speculation is the practice of trading or determining financial decisions not on the intrinsic worth of the commodity, but rather on anticipated price movements. Price swings can be amplified by speculative trading beyond what would be caused by basic supply and demand variables alone (Will et al., 2012). Traders like wholesalers and middlemen have the ability to impact market dynamics by choosing how much stock to store, when to supply it, and how much to negotiate prices.

Large inventories hoarded by traders in expectation of price hikes may cause a brief scarcity of supply, which would raise prices. On the other hand, if traders place an excessive quantity of tomatoes on the market at once, it can cause a surplus of supply and depress prices. Price talks between traders and farmers are another way that traders might affect pricing. Traders may have a great deal of negotiation power and can somewhat set pricing when there are few other buyers for farmers' produce.(Ali et al., 2023)

As a middleman between producers and retailers, wholesaler opinions on changes in prices are impacted by supply and transportation costs. Tomatoes are purchased by wholesalers at wholesale prices from producers and resold to consumers at the higher price. In order to increase their profits, distributors may bargain with farmers for lower pricing when tomato resources are ample. The farmers typically accept prices because they lack strong marketing knowledge, expertise, and bargaining strength (Muthyalu, 2013). The wholesale price get peaked during July 2023 of more than Rs.7000/quintal compared to other months it is due to unpredicted climate change (Fig 4).

Fig 4: All India Monthly Average Wholesale Prices of Tomato



Source: Agriculture marketing

Retailers directly influence customers as they are the last in the tomato distribution network. They keep a careful eye on changes in wholesale prices and modify their retail rates accordingly. Retailers might increase retail pricing if wholesale tomato costs rise by passing the cost along to customers. When determining prices, retailers also take patterns of demand and customer preferences into account. Retailers may modify pricing to optimize profits during peak demand periods, such as festival seasons or unfavourable weather circumstances when consumers seek to stock up on tomatoes. (Ali et al., 2023)

3.7. Consumer demand:

Tomatoes can be eaten as a sauce, cooked, stewed, raw, or in the combination with various other dishes. They can be processed whole, as a paste, juice, dice, powder, or in other ways, or utilized as an ingredient in cooking. The taste for tomatoes was found to be the second cause for its consumption (Brug et al., 1995). On the other hand, more than eight percent of respondents claimed to eat tomatoes because of their high levels of vitamins, minerals, fibre, and antioxidants, among other nutrients.

The range of food options available to urban customers is often wider, and this includes processed tomato. To rural areas it is mostly in fresh form, it is due to the nature of their consumption in regional cuisines and traditional meals. One of the main factors preventing the general population from having a sufficient diet high in vegetables is poverty (Ball et al., 2006). The individuals with lower occupational levels prefer to eat tomatoes less frequently and in smaller amounts than those with higher occupational levels. (Galobardes et al., 2001).

Consumers with higher incomes generally have more purchasing capacity and may choose processed tomato products or superior tomatoes. These customers might be more prepared to spend more for specialized or organic tomatoes, increasing the market for these goods. Price was by far the most significant factor for the "Price sensitive consumers" class, which also demonstrates a preference for organic tomatoes, in line with (Ekelund & Tjärnemo, 2004). Lower-class consumers, on the other hand, might value cost-effective, fresh tomatoes as a staple in their daily meals (Skreli et al., 2017).

4. Ways to mitigate the price fluctuation:

4.1. Pre-production:

The breeding of the tomato should be done based on the need, whether it is used for fresh consumption or for processing. The complex traits that need to be taken into account during breeding include the fruit's biochemical composition, which defines its taste and nutritional value; fruit resistance to mechanical damage and cracking (cracking shortens the fruit's shelf life at harvesting locations and factories that use it as raw material); fruit resistance to cracking, which lowers the crop's marketability; and fruit transportability, which allows juice to seep through cracks and decreases the overall quality of the transferred products.

The shelf-life of tomatoes is a crucial consideration for the fresh consumption. A longer shelf life is observed in transgenic tomatoes that overexpress certain cloned ripening genes, including as ethylene synthase and polygalactoronidase. While fresh-market tomatoes are physically picked all season long, processing tomatoes—used to make ketchup, paste, and other products—are gathered all at once by machines. For tomatoes to be harvested by machines, multiple characters are required. All tomatoes must be ripened at the same time—that is, at harvest—and their growth must be determinate. Tomato fruits should also be able to separate from the stem easily to avoid harm from the stem during storage and transportation.

The number of fruit quality characteristics, including colour and soluble solids content (Brix), are crucial for processing tomatoes. Sugars and organic acids make up the majority of the dry matter in tomatoes, their concentrations are important in determining how palatable the fruit is because they are the primary producers of the fruit's sweet and sour/acid tastes, respectively (Kozlova et al., 2020). The requirement of hybrid for processing should have pear shaped polar diameter pulp (Tiwari, 1996), minimum of two to three locule (Thamburaj, 1998) and thick

pericarp (Kumari et al., 1998). Thicker pericarp would also withstand long-distance transportation (Bhutani & Kalloo, 1991).

Although there is the production of resistance varieties in tomato against pest and disease and climate change, the cultivation of such varieties by the farmers is the major question. These area of the usage of the varieties should be improved or the hybrid that a farmer use should be developed with such kind of resistance.

4.2. Production:

In comparison to European nations, tomato yields in India are extremely poor as its cultivation is done in open conditions. To increase the productivity of Indian tomatoes, polyhouses must be widely used. This will assist in maintaining a tomato production cycle and shielding the crop from pest infestations. A single greenhouse tomato plant can yield up to 15 kg at harvest time and up to 60 kg after a year, when it has finished its whole life cycle (Makunike, 2007). Since building polyhouses requires a lot of capital, the government can provide financial assistance to large and medium-sized farmers or marginal or small-scale farmers who have the desire to implement this technology through Farmer Producer Organizations (FPOs). On the other hand, the use of climate-resilient cultivars and organic farming as sustainable agricultural techniques may boost crop resilience and production, which could eventually have a good effect on tomato pricing and supply.

It has been successful for private businesses to introduce various hybrid and disease-resistant seed kinds. The provision of superior seeds is a fundamental necessity that substantially enhances the likelihood of crop success. However, since it is so common in India for corporations to replicate the genetic material of seeds generated after years of research, there is no incentive for private enterprises to continue investing in seed research in the absence of a robust intellectual property rights (IPR) regime. Therefore, the IPR system for tomato seeds needs to be strengthened.

An excessive dependence on synthetic pesticides for pest management may have negative effects on the environment, including poisoning of water and soil supplies, damage to creatures that are not the intended targets, and the emergence of resistance to pesticides in pest populations. Contact to chemical pesticides or eating contaminated fruit can also pose health concerns to farmers, farm workers, and consumers. National implementation plans and integrated pest management regulations are examples of policies that legislators ought to put into effect (Tudi et al., 2022).

Biological, mechanical, chemical, and cultural treatments are only a few of the strategies used in integrated pest management (IPM), a complete approach to controlling insect populations (Barzman et al., 2015). Farmers have been able to reduce their need on chemical pesticides by using IPM techniques such crop rotation, biological control, and cultural practices (Han et al., 2024). Growers can lower production costs, lessen their impact on the environment, and guarantee a more sustainable method of tomato production by using fewer chemical pesticides (Singh et al., 2023).

In recent years, smart agriculture has received a lot of attention and has been put into practice ((Ardiansah et al., 2020); (Kumar et al., 2022); (Villa-Henriksen et al., 2020)). It is now a crucial component of modern agriculture, assisting producers with critical decision-making and real-time monitoring.

4.3. Harvesting:

Maturity during harvest and the harvesting process can affect the fruit's taste, hardness, and shelf life after harvest as well as the extent and severity of external damage, all of which can have a negative impact on the quality of tomatoes and the availability of tomato to the market. Compared to tomatoes taken during the immature or nearly mature stages, those collected later then the mature green stage will ripen to a better flavour and have a well-developed cuticle, which will prevent water loss (Kader, 1984).

Harvesting fruit early allows for a longer commercial time and harder fruit that is appropriate for transportation. Trade publications, however, advised against harvesting fruit too soon in order to meet consumer demands for a stronger flavour. It is therefore possible to harvest tomatoes for far-off markets at the "mature-green" or "breaker" stages, while nearby outlets can harvest tomatoes at the "breaker", "turning", "pink," or "light-red" phases. When the tomatoes are cluster or vine-ripe, they are picked between the "light-red" and "table-red" stages.

4.4. Handling on quality of tomato:

4.4.1. Sorting and grading:

The sorting and grading procedures must be carried out after harvesting before marketing or processing. This can be carried out based on factors like as size, variety, colour, maturity, and the existence of illnesses and pests. This will eventually result in a high return and market value by minimizing physical damage as well as the spread of pests and diseases. Following grading, products of varying sizes may be offered for sale at various price points. For the local market the sorting and grading can be done manually and for processing it needs to be done mechanically. Manual grading is the norm, and it takes a lot of time. This technique is not being carried out properly due to a lack of knowledge and enthusiasm, as well as the unavailability of suitable grading and sorting devices or grading buildings. So, there is a need for awareness about their importance in the supply chain.

4.4.2. Precooling:

During the harvest and postharvest processes, the tomato fruit gathers heat, which lowers the fruit's storage quality (Venema et al., 2005). If the heat is not reduced, then it leads to the increased respiration rate, metabolic activities and the raised ethylene production. Precooling is one such process which can reduce such activities and there by increases the storage life of tomatoes. But such activities are normally not followed by the farmers as there is no bulk yield. So, such kind of activities needs to be improved.

4.4.3. Packaging:

Reduced PHLs during wholesale selling were the outcome of better handling techniques used in India with better containers (vented plastic boxes). Twenty kilograms of tomato fruits can fit in the plastic crates. To further reduce bruises and vibration damages during transit, these plastic containers might be lined using ventilated fiberboard liners (Saran et al., 2012). By shielding the packaged tomato fruit, (Babarinsa et al., 2018) found that the use of plastic crates reduced average damage losses by 88% when compared to using a truck basket.

The usage of plastic films is becoming more and more popular among the many methods devised to prolong the postharvest life of fruit since it is user friendly in handling by both the farmer and the consumer. We can use the controlled or modified packaging which has gas of CO_2 and O_2 in controlled form. It helps in the enhancing the shelf-life and quality of the fruit. We can also use the intelligent packaging which is one of the smart packaging which says about the quality of the produce throughout the supply chain as it has a barcode to detect.

4.4.4. Transportation and storage:

The tomatoes can be transported during morning hours to avoid the scorching sun. We can use normal vehicle for transporting for local market. But when it needs to be transported to distant market there is a need for refer van as most losses in the supply chain happens during transportation. The ideal storage temperatures for tomatoes vary based on the maturity of the fruit because they are susceptible to cold. For delayed ripening, storage temperatures between 13 ^{0}C and 95–97% relative humidity are advised. Most kinds hold well for two to three weeks at this temperature and change colour quite slowly. In cold storage, 8–10 °C and 85–90 % relative humidity is sufficient to keep unripe tomatoes for four weeks. Ripe fruits are kept for one week at 70 ^{0}C and 90% relative humidity.

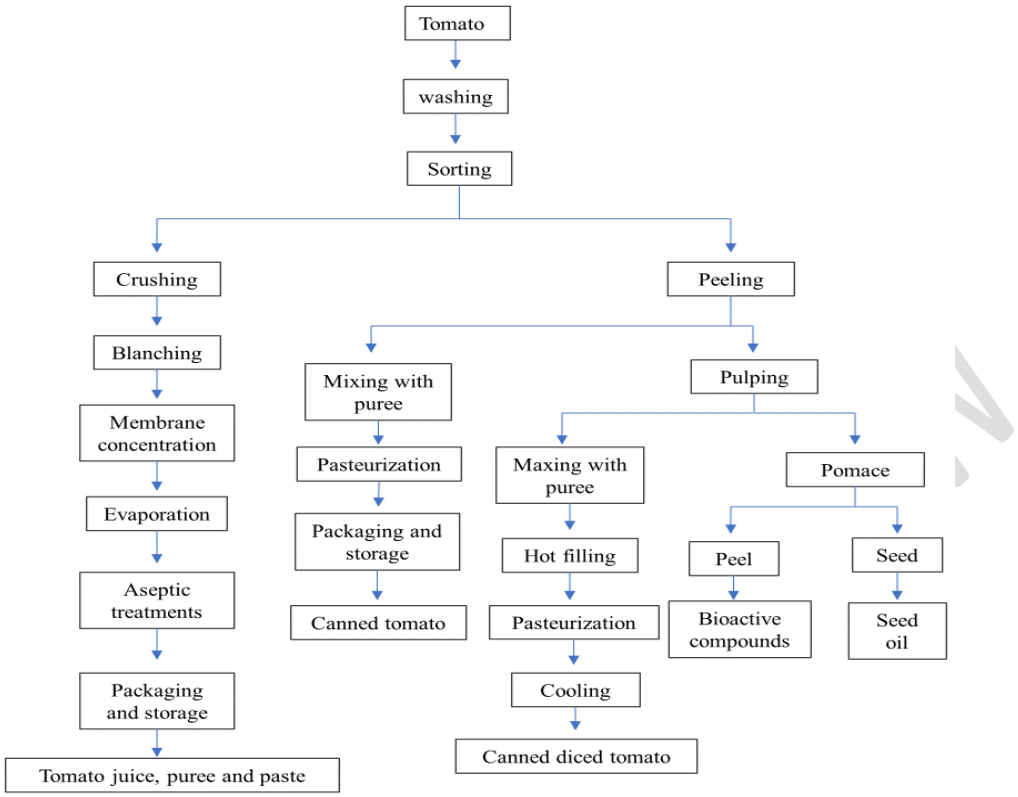
Storage can be done temporally by famers in rural godown till achieving the favourable market price. This type of godown helps the marginal and small farmers to avoid the distress sales. The Indian government has therefore launched the Gramin Bhandaran Yojana, capital investment subsidy scheme for building, renovating, and expanding rural godowns. Banks will be able to provide credit support to marginal and small-scale farmers who have a Kisan Credit Card against a negotiable warehouse receipt for storing their produce in warehouses, with the benefit of useful interest subvention. This will serve to discourage farmers from selling their produce in distress and to encourage them to store it in the warehouses against warehouse receipts.

4.5. Processing:

Simple technology interventions that have a very significant value addition potential for perishables produce in short term (Cold storage like Micro cold-storage) and long-term technologies like Infrastructure cold storage, Processing (Juicers, mixers, grinders, Oil extraction) and Removing moistures (Solar dryers, Heat pump dryers). Small-scale processing facilities that provide tomato pulp and puree for large-scale ketchup production facilities can be encouraged to be established by FPOs. This will guarantee that farmers who have excess output sell it at fair prices and have access to direct marketing options.

The main products of the tomato include tomato puree, paste, dice, canned products (fig 5). There will be also a by products from the processing of tomatoes. Tomato pomace is the term for the skin as well as seeds (lignocellulosic-based substrate) that make up this material. It can be used to make vitamin B12 and pectin, which are supplements and non-conventional oil sources for human consumption. Lycopene can be extracted from tomato processing waste, tomato paste, and tomato pulp waste (Motamedzadegan & Tabarestani, 2018). By this the landfilling of waste can be reduced.

Fig 5: Flowchart of Tomato processing



Fresh tomato manual processing takes a lot of time, labour, and is prone to producing items that don't meet specifications. Standard quality products can be produced with minimal labour and an efficient processing time thanks to an automatic mechanized downstream processing system. The development of an energy-efficient processing system for small-scale production is a problem because the volume of material acquired from smallholder farmers is anticipated to be minimal. As a result, an automated and energy-efficient processing system must be developed.

One aspect will be rejuvenating the TN farmers' economy through value addition of tomatoes. India ranks 6th in world tomato production and tomato is one of the high yield vegetables in Tamil Nadu. But the major concern with tomato growing farmers is that they are getting very low returns with loads of marketable surplus during Rabi season (Feb-June), Rs.2- Rs.5/kg for tomato. Owing to its perishable nature and due to lack of cold chain storage and processing units nearly 25-40 % of the produce worth Rs.25-30 thousand crores is gutted, which is a great national loss. Hence the most attractive option will be value-added products. Tomato-based processed food consumption in India is growing at an annual rate of over 30% creating massive demand for existing processors. Value added products like tomato puree, paste, tomato powder, sauce, ketchup, chutneys and soup powder may be prepared. Unlike most foods, cooking or processing of tomato as tomato paste, powder, soup, tomato sauce is beneficial to health, since cooking heat breaks down the cell walls, increasing the available lycopene content. So, the suggestive strategies be to establish a processing unit, whereas all the processed products can be prepared in one place say at block level and tomato production localities and secondly, provide capacity building and hands-on training on value addition of tomatoes to the farmers and entrepreneurs.

4.6. Marketing system:

Economic development benefits greatly from an effective marketing system since it increases output, prevents needless price and output fluctuations, lowers the unfair proportion of consumer prices, and promotes stability in prices (Kahlon & George, 1985). Many of these issues can be greatly reduced by having access to market intelligence on various topics, such as potential markets, the volume of new products entering the market, and current and anticipated prices in various regional, national, and worldwide markets at various times of the year (Kumar et al., 2005).

During times of supply-demand imbalances, price stabilization techniques, minimum support prices, and strategic buffer inventories can assist control price volatility and guarantee food security. The stabilization of tomato prices and the defence of farmers interest will depend on the successful execution of these initiatives. If fewer intermediaries are involved and the government steps in to help set up and manage marketing cooperative unions, farmers will be able to use these unions as lucrative avenues for selling their produce. This will lead to an increase in the producer's share of the consumer price (Kheirandish & Gowda, 2012). Policies aimed at stabilizing agricultural prices will benefit both producers and wholesalers. By stabilizing prices at a single market level, it is possible to maintain stability across the entire supply chain (Ait Sidhoum & Serra, 2016).

Implementation of the e-NAM for tomato was done in two selected APMC's namely Palamner and Madanapalle in Andhra Pradesh. This shown a positive result for the farmers by slightly higher price (Rs. 4-5/q) and reduced the commission from 10% to 4%. The farmers got higher net return (32%) due to reduction in the marketing cost (34.15%). Traders benefited by reduced market fee of 0.75% against 1%. The major constraints in the adoption of e-NAM by the farmers and traders are non-awareness of e-NAM, non-implementation of online payment and the lack of market intelligence.

Future tomato prices will be heavily influenced by changes in consumption patterns and demographics. There could be a rise in demand for both processed and fresh tomatoes as a result of urbanization, income growth, and dietary changes. Recognizing patterns in demand and modifying output in accordance with them might help guarantee sufficient supply and stable prices.

4.7. Government intervention:

In order to step in and stabilize the market when prices fluctuate too much, the government set up a Price Stabilization Fund. In order to stabilize prices, this fund is used to buy extra tomatoes from the marketplace when they're on sale and release them when they're not. In order to guarantee that farmers get paid fairly for their goods, the government also established a minimum support price for tomato and other agricultural products. By giving farmers a safety net, this aids in price stabilization.

To maintain a balance between domestic supply and demand, the government controls the import and export of tomatoes. Imports may be permitted to keep prices stable during periods of scarcity, while exports may be prohibited to keep domestic prices from falling precipitously during seasons of excess. In order to keep price steady during bumper harvests, the government might keep a buffer stock of tomatoes. This is buying extra tomatoes from growers and putting them in storage so you can use them later or give them away.

A strong agriculture export policy must be established by India's Department of Commerce (DoC) in order to boost farm productivity, transportation, and market access along the whole value chain. To ensure a mutually beneficial connection between sustainable farming and export potential, this strategy should be in line with current agricultural framework and surplus produce. Farmers should benefit financially from the strategy by taking advantage of significant export potential. Promoting agriculture exports, enhancing farmer realization, and conforming to Indian government policy are the objectives of the Agriculture Export Policy. With the goal of achieving food security and becoming as a major global agriculture exporter, it advocates a "Farmers' Centric Approach" for increased revenue and value addition.

Conclusion:

India's growing tomato costs are becoming a serious issue that affects growers and customers alike. A comprehensive investigation of the causes of the skyrocketing tomato prices finds a complicated web of problems, such as problems with production, damage by pest and diseases, inefficiencies in the supply chain, the consequences of climate change, and market dynamics. As the climate plays a critical role in price volatility, climate-smart farming methods and climate-resistant varieties should be supported by research and technological adoption, with a focus on climate change resilience. For the purpose of controlling supply-demand imbalances and averting price spikes, it is essential to understand customer behaviour and preferences in order to predict demand trends and the involvement of traders and market speculation needs to be properly controlled. The government can provide financial assistance to large and medium-sized farmers or marginal or small-scale farmers who have the desire to implement this technology through FPOs. Also, there must be a development of infrastructure for marketplace, processing plant, storage facilities, road networks, and dams. By this the price stability can be attained.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Details of the AI usage are given below:

1.

2.

3.

Reference:

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