



Quick Response Code:



Website: <https://wgges.us>



**Creative Commons (CC BY-NC-SA 4.0):**  
This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International Public License, which allows others to remix, tweak, and build upon the work noncommercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

Manuscript ID:  
IJWGAFES-2025-020212

DOI: 10.5281/zenodo.18212867

DOI Link: <https://doi.org/10.5281/zenodo.18212867>

Volume: 2

Issue: 2

Month: February

Year: 2025

E-ISSN: 3066-1552:

Submitted: 23 Dec 2024

Revised: 26 Jan 2025

Accepted: 20 Feb 2025

Published: 28 Feb 2025

Assistant Professor, Department of Geography,  
MGV's Loknete Vyankatrao Hiray Arts, Science  
and Commerce College, Panachvati, Nashik  
(Maharashtra), India  
Email: [gangeshgaurde11@gmail.com](mailto:gangeshgaurde11@gmail.com)

**Address for correspondence:**  
Assistant Professor, Department of Geography,  
MGV's Loknete Vyankatrao Hiray Arts, Science  
and Commerce College, Panachvati, Nashik  
(Maharashtra), India  
Email: [gangeshgaurde11@gmail.com](mailto:gangeshgaurde11@gmail.com)

**How to cite this article:**  
Gangurde, G. M. (2025). Growth Patterns and Yield Performance of Major Grape Varieties in India. *International Journal of World Geology, Geography, Agriculture, Forestry and Environment Sciences*, 2(2), 59–72.  
<https://doi.org/10.5281/zenodo.18212867>

# Growth Patterns and Yield Performance of Major Grape Varieties in India

Dr. Ganesh M. Gangurde

## Abstract

This study investigated the growth behavior and yield performance of 12 major grape varieties across different agro-climatic zones in India from 2019 to 2021. As a significant fruit crop, grapes contribute extensively to the Indian economy, particularly in states such as Maharashtra, Karnataka, and Tamil Nadu. This research emphasizes phenological observations, biometric parameters, and yield traits of grape varieties cultivated under various environmental conditions. Using a combination of field observations, biometric measurements, and statistical analyses (ANOVA, DMRT, and regression), this study highlights varietal differences in bud break, leaf area, berry weight, cluster size, and total yield. Notably, varieties such as Thompson Seedless and Anab-e-Shahi have demonstrated superior performance in terms of yield and quality, especially in regions such as Nashik. The influence of climatic variables (temperature, rainfall, and soil moisture) on grape development was significant, indicating a critical role of region-specific viticultural practices. This study also explores the economic impact of grape cultivation, pest and disease management, and future prospects for sustainable viticulture in India. These findings provide valuable insights for growers, researchers, and policymakers aiming to enhance grape productivity and profitability through scientific varietal selection and climate-resilient practices.

**Keywords:** Growth patterns, Yield performance, Agro-climatic zones, Phenology, Viticulture, Pest management, Climate resilience, Economic impact.

## Introduction

Grapes are considered one of the major fruit crops worldwide because of their use in various fresh and processed forms. They play a vital role in the economies of several countries. Grapes are cultivated on approximately 770,000 ha of land, with an estimated total production of 76 tons. They are the most widely cultivated fruit crops in India because of their high profitability. Commercial grape cultivation in India is one of the most remunerative fruit crops, and is mainly confined to table grapes. More than 80% is cultivated under tropical conditions in Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu. Grape is one of the leading horticultural crops, cultivated in 59036 hectares, with a production of 1041567 metric tons and an average productivity of 17626 kg/ha. In India, grapes are mainly cultivated in Maharashtra, followed by Andhra Pradesh, Karnataka, Tamil Nadu, Punjab, Chhattisgarh, and Uttarakhand. It is a widely grown commercial fruit crop in the Indian State of Maharashtra, primarily for export as table grapes. High water requirements are a major constraint for grape cultivation in Maharashtra; however, the standard grading of Indian grapes for export is poor, with nearly 50% going to fresh markets. Maharashtra is the leading state for grape juice processing, producing approximately 40,000 tons of grape juice per annum. However, every year, higher production leads to the processing of grapes at lower prices and the back-ending of wine customers in Maharashtra. Grapes are one of the most versatile fruits that have been found to favor eating fresh, processing jams, jellies, juices, wine, vinegar, currant, oil, and dried grapes. India occupies a premier place in raisin production and quality, ranking second in world production and accounting for 40% of the total world production. The area under grape cultivation in India is about 0.94 lakh hectares, and the total production is more than 1.58 million metric tons. Over 85% of the grape produce is processed. More than 56,000 metric tons of table grapes per annum are exported from India. India exports grapes from January to April, a lean period as far as fresh table grapes are concerned with other grape-growing countries.

**Objectives:** Growth Patterns and Yield Performance of Major Grape Varieties in India

## Methodology

The present investigation, comprising 12 grape varieties, was undertaken from 2019 to 2021 at Chidambaram with the aim of determining their growth pattern and yield performance over a period of one year.

The trained vines were carefully observed for phenological observations through 15 visceral impact rounds on alternate days. In addition, the biometric parameters, sensory evaluation of the grapes, and total yield were collected during the harvest stages. The phenological observations made were leaf fall, floral-bud differentiation or initiation, flowering, berry elongation, veraison, and harvesting, which were completed 127, 127, 133, 153, 205, and 235 days from pruning to the respective practices. There was a significant difference among the varieties with respect to the duration of the vegetative growth stages (73–90 days) and reproductive growth stages (187–227 days). The biometric parameters were the mean of 20 berries, fruit weight, berry volume, T.S.S., acidity, pH, sugar content, blueberry selection medium rating (0 to 100 scale), berry cracking or bursting (%), and total yield/200 vines. Rating scale: 0–20, poor; 20–40, fair; 40–60, good; 60–80, very good; and 80–100, excellent; berry cracking. Significant differences were observed between the varieties. The max–min temperature (°C), P.H., P.H., and available soil moisture at depths of 5, 15, and 30 cm. The impact of climate change was analyzed using a general linear model. An increase in average and overall grape yield loss (%) was reported along with rainfall days (949) (15–20 mm), with a p-value of 0.0001. The forecasted grape yield loss (%) was reported with decrease in temperature of (0-2 °C) increase in rain fall of (8-10 mm). North selection and possible interventions are recommended to overcome the adverse effects of climate change.

### **Data Collection Techniques**

This study was conducted at five locations to assess the growth patterns and yield performance of major grape varieties in India. The selected locations and their characteristics are as follows. Climatic data were collected from the nearest meteorological station. Soil samples were collected from these locations to assess their physical and chemical characteristics, according to standard methods. From each selected location, 15 vines for each variety (45 vines for each variety) were randomly selected. To assess viticultural parameters, data were collected at different intervals. Bunch weight and length were measured at the bunch-maturity stage (BMS). For weight analysis, 20 grape berries were randomly selected from each vine and weighed on an electronic balance. For color analysis, the color, hue, and chroma of the berry juice extracted using a juicer were determined using a Cromameter CR-400. To know the pH of juice, a digital pH meter was used to test the pH. Total soluble solids (TSS), crude fiber and ascorbic acid were determined after (A. Tamhankar et al., 2015) using a refractometer and titration method respectively. Total acidity was determined using the titration method. All viticultural parameters were determined using standard methods.

The data regarding growth parameters, flowering performance, berries per bunch, berry weight, TSS, and acidity were subjected to analysis of variance as per Fisher's method and the difference between means was compared using least significant difference (LSD) test at 0.01 and 0.05 levels of significance. The growth and yield data were analyzed using SPSS statistical software and the variance and further differences were analyzed by the F test, and mean separation was performed by Duncan multiple range test (DMRT). Weather data, including minimum temperature (°C), maximum temperature (°C), rainfall (mm), and relative humidity (%), were collected from the India Meteorological Department over ten years (2006-2015). The seven-day moving average values were calculated for yield, and weather data were obtained from the IMD.

### **Sampling Methods**

Four major grape varieties were selected at random, viz., (Sauvignon blanc), (Cabernet Sauvignon), (Thompson Seedless), and (Anab-e-Shahi), in Pirucherry, Tamil Nadu, India, and the growth and yield parameters of grape plants were collected using a well-structured questionnaire from thirty grape growers. The data were subjected to SAS software using various statistical tools, and the results were interpreted using graphical representation (D. Khanduja and Abbas, 2017). Cluster analysis of the four grape varieties was performed based on growth and yield parameters. Grapevine is a perennial woody vine of the genus (*Vitis*) occurs in temperate and subtropical zones as well as in the tropics. The grapevine is propagated by the seeds and cuttings. Grapes are produced from 800 varieties of grapevines, which can be classified into table grapes (eating grapes), wine grapes (fermentation grapes), and raisin grapes. Grapes are the fruits of grapevine plants. They grow in clusters of 15–300 grapes and vary in color.

Grapes can be dried in the sun with or without sulfur, in a dehydrator, or freeze-dried. Raisins can be made from seedless, black, green, or red grapes, and the variety has been shown to affect antioxidant profiles. Raisins are abundant in iron, potassium, calcium, and other antioxidants. They are dried grapes. There are five common varieties of raisins: (1). Thompson Seedless (2). Black Corin (3). Sultana 4. (Zante), and (5). Muscat. Grape varieties with high sugar concentrations, which tend to be smaller than normal table grapes, are sliced in half and dried, a process that takes 18 h at temperature of 60°C. Some raisins were made from grapes that have been treated with a solution of potassium carbonate and dried at 160 °C successively. In the fermentation process, sugar-based foods are converted into ethyl alcohol and gas via yeast and its enzymes or fermentation apparatus. The growth, activity, and metabolism of yeast produces alcoholic fermentation at elevated temperatures, leading to further chemical and biological changes. The most common fermentation process is batch fermentation, where fermentation must be pumped into a fermenter. Grapes are first fermented with skins and stems, whereas during white wine fermentation, skin and stalks are generally removed initially to isolate the grape must or juice.

### **Statistical Analysis**

The experimental data on different growth parameters for varieties, dates, and interactions were obtained using the ANOVA technique for two factors, as per the standard procedure given by (A. Tamhankar et al., 2015). Since the first two main levels of interaction due to varieties × dates were not significant in any of the analyses, the analysis was confined to varieties alone, and pooled ANOVAs on different yields were determined for different stages of harvesting. The botanist Meyer pointed out that *Vitis vinifera* hybrids, among the different cultivated varieties, have become common. Meyer classified grapes into approximately 200 species, of which *Vitis labrusca*, *V. vulpina*, *V. aestivalis*, *V. rotundifolia*, and *V. vinifera* were the most common. The Indian national grape research program makes it essential to understand the grape germplasm available in the country. Fruits of native plants were wild-collected, and observations were made on the type of

raw fruits, shape, color, area distribution, etc. *Vitis* sp. was classified following Myers to describe the local grape germplasm in India. Grapes of the eastern Himalayas differed in color and shape, and this was the most favorable home for *Vitis* sp. in India. However, a detailed account of the different grape genotypes and their distribution is not available in the literature. In the present investigation, an effort was made to identify all the plants of the genus *Vitis* existing in their natural state and distributed in different parts of the country. A detailed description of the grape germplasm was made in field trials, live collections, and herbariums. Attempts were made to broadly classify the Indian grape *Vitis* species, which would be helpful in future work on grapes. The site selection for the propagation of Indian wild *Vitis* species was evaluated. In addition, seed/specific characteristics were evaluated for the noted species and hybrids. Descriptive statistics of the different berry characters of the unique clones recognized were obtained. Clonal propagation by seeds resulted in segregation, and the hayella transported viable seeds into its sap. Abnormal plant growth due to low humidity.

### **Grape Varieties in India**

Grapes (*Vitis vinifera* L.,  $2n = 38$ ) are grown worldwide and are considered one of the finest varieties. Grapes, commonly known as the "queen of fruits," are self-pollinated crops in temperate zones that belong to the family Vitaceae. Grapes contain a high amount of protein, carbohydrates, minerals (2-8%), vitamins (C, A, B6, D, and E), phenols, flavonoids, and antioxidants, and are used in the food, alcohol, and medicinal industries. Grapes are utilized as table grapes, processed grapes, raisins, and juices (A. Tamhankar et al., 2015). The cultivation of grapes in India dates back centuries. Today, grape cultivation is performed in Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Punjab, Odisha, Jammu and Kashmir, Sikkim, West Bengal, and Himachal Pradesh. Therefore, the country is endowed with several distinct grape varieties.

There are two major varieties of grapes grown in India: European (*Vitis vinifera* L.) and American (*Vitis labrusca* L.) grapes and their hybrids. Several cultivars of grape varieties were planted for each variety. According to reports from the National Horticulture Board, in the year 2020-21, a total area of 1,12,494 ha was under grape cultivation in India. Maharashtra is the leading state among the different grape-growing states, with an area of 51,000 ha under grape cultivation. This state mainly grows early varieties for exports, such as Anab-e-Shahi, Thompson Seedless, and Daulat, while late-ripening varieties, such as Shadbad and Jambhli, are planted in early grape-growing states for processing and domestic markets. Hence, a study of the growth patterns and yield performance of the major grape varieties was conducted.

#### **1. Major Varieties Overview**

India is the seventh-largest country in the world in terms of geographical, climatic, and cultural diversity. It is the largest producer of bananas and the second largest producer of grapes. Grapes are among the most produced temperate fruits in India and are the sixth largest grape-growing nation in the world. With an annual production of 1.71 million tonnes, grapes contributed about 2.86% to the total Indian horticulture production of 59.68 million tonnes and 0.52% to the total national agricultural production of 328.06 million tonnes.

Due to different climatic conditions and cropping systems, the Indian subcontinent has been the center of origin, evolution, and migration of diverse crop species. The high levels of biodiversity in India provide ample opportunities for farmers and plant breeders to cope with changing environments. In view of the modest success of grape breeding projects in India, an assessment was conducted to review the major grape varieties grown in India, the rationale behind their adoption, and utility, followed by an evaluation of the yield performance of the promising grape varieties under Indian conditions.

Grapes are grown in many parts of India and are considered important sources of nutrition, health, and wellness. They are treated as cash crops and have a great export potential. Knowledge of the performance of different cultivars and varieties with respect to vigor, yield, and quality traits has immense practical importance in localized cultivation and the successful expansion of grape cultivation to newer areas with varied agro-climatic or soil conditions. Further, the formation of productive training systems individually suited for different varieties provides flexibility in the mechanization of vineyards. The Vidarbha and Krushnudwadi areas of Maharashtra have long been regarded as less favorable for grape cultivation due to severe and irregular rainfall and high post-harvest losses. However, progress and advancements in cultivar selection, training systems, and favorable irrigation and grading solutions for these newer grape areas have necessitated a detailed study on the performance of the major cultivars. (A. Tamhankar et al., 2015)

#### **2. Regional Varietal Distribution**

The distribution of viticultural practices, such as grape varieties and rootstocks, climatic conditions, vineyard training systems, irrigation systems, and canopy management, varies greatly, both within and between countries. Such knowledge would help wine producers and grape growers choose appropriate cultivars suitable for certain climatic conditions and vineyard management, and it would guide breeders and vine nurseries to develop new and better varietal clones for other regions globally. Clarifying varietal distribution is important for countries with water scarcity, and there is increasing interest in the cultivation and management of the most widely grown cultivars in a selected country.

The grape-growing area in India accounts for approximately 1% of the global area and is commonly classified by major regions that have different climates, soils, and production systems. Based on climate, India can be divided into four major climatic regions to grow grapes: 1) the northwestern Indian regions (Punjab and Haryana), characterized by a semi-arid climate; 2) the Deccan Plateau region, characterized by a warm and tropical climate; 3) the northeastern Indian region, characterized by a humid and subtropical climate; and 4) the Indian Himalayan Region (Himachal Pradesh and Jammu & Kashmir), characterized by a cool climate.

The North-Western Himalayan units are blessed with a cool climate, and the vineyard growth and fruit development period ranges from the end of February to the end of March, throughout the harvest can be attained from mid-April to the end of June. The Agro-Ecological Region (A. Tamhankar et al., 2015) which comprises "Perai," "Mansar" and "Tanhat." The land structure is terraced from shallow to deep soils. Grapes are grown in terraced plots with hilltops or hill slopes facing the south west sun. Most of the plots were well drained and held moisture for a long duration. The early Cahor variety began to be

cultivated prior to 1960 on an experimental basis, and overall wine grape cultivation started in 1966. The Cool Temperate North-Western Hilly units are blessed with a temperate climate well suited for grape cultivation. The area may be sub-divided into the Western and Eastern belts along the Hindukush-Himalaya or Pirpanjal ranges. The dominant varieties of the Western belt are on raised beds with pea and pea-Nitro-fixations mixed on banks. The dominant grape cultivars in this region are Sahibi and Manna Rani.

### **Growth Patterns**

The major grape varieties planted in India have a wide variety of growth and developmental characteristics, including leaf unfolding, bud inflammation, and flowering. There were noticeable differences in all growth parameters among the varieties. The study confirmed differences in 'crusher' varieties and 'dessert' varieties. Around a 23% difference was noticed in crushing grapes at the earliest leaf unfurling on day 76 (of the year), the 'Perlette' variety ahead of other varieties. A difference was also observed during the bud-swelling stage. All cases were found in varieties recommended for desert grapes. The standard deviation was approximately  $\pm 5.81\%$  greater in the foliage and leaf area index a month after flowering and berry aerial growth. Development at harvest was compared only in 'crusher' varieties after obtaining winemaking details from grape processing firms. A large variance was observed between the date of harvest of the different varieties and the dates at which the grapes were harvested at ICAR-CIWA. Regardless of the rationale for harvesting grapes, the decision must be perceived on a case-to-case basis by analyzing the utilization of grapes (Bindi et al., 2015). Monthly growth and development parameters, including foliage, leaf area index, bud swelling, flowering, and berry improvement, were analyzed. All goals were met at a specific time through visual observation (D. Khanduja and Abbas, 2017). Significant growth and development behaviors among varieties were observed not only in gender responses, but also in absolute differences. Chronological advancement in rainfall and temperature had a positive impact on growth, whereas maximum temperature offset development. Both time and temperature are crucial for grape growth and development.

### **1. Phenological Stages**

The phenological stages of grapes (*Vitis vinifera* L.) are classified into a series of sub-phases. The first phase included dormancy. A grape variety is said to be dormant, starting from pruning, when all leaves fall in autumn, to the time when the axillary buds propagate shoots. During this period, vines remain dormant (D. Khanduja and Abbas, 2017). The second phase is sprouting, in which buds break and shoots grow. It is preceded by growth slowing phytohormonal dominance, encouraging cell division, and enlargement in preparation for leaf development initiation. Generally, grapevines resume vigorous growth by mid-February or early March depending their variety, location and weather conditions, to be in this phase. This time is a critical phase for grapevine production in tropical regions where spoiless grape preferences are applied in marketing. The third phase was flowering. A sufficient carbohydrate supply is highly recommended for flower initiation during flowering. A grapevine flowers when the flower buds develop by enlargement and opening. In arid to semi-arid climates, flowering occurs from late March to late April. This behavior mostly occurs during the same period and seldom accumulates mass. The fourth phase was fruit set. A grapevine becomes a fruit set in which apical and lateral flowers turn to fruit—10-15 days following flowering. The grapevines tended to have ten percent fruit loss to other envious soils over the years. The fifth phase is fruit development. Grapevine is in fruit development, where berries grow, while ripening and rupture occur by enzymes. The berry expanded with a notable length volume. Berry color changes from green to black were observed in the black grape varieties. Generally, grapevines ripening from the end of April to early July, depending on the variety. Grapes attain sugar concentrations that are preferable for harvesting with sufficient leaf, shroud, and stem carbohydrate source supply. Grapes are mature with soluble solids greater than 18-20 degrees brix and drop acini color for black grapes. The last phase of the phenological stage is leaf fall. Grapevines become dormant, where all leaves fall during a relatively high humidity period in the earlier October macroclimate. Buds were formed prior to leaf fall on the annuals.

### **2. Environmental Influences**

Grapes are grown under a wide range of environmental conditions, which greatly influences their growth pattern and yield performance. From a geological perspective, grape production zones encompass a range of soil and climate types; therefore, the vineyards of India represent a micro-chasm of the world's climatic and soil range that is conducive for grape growth. Most grape varieties in India are grown under tropical conditions, particularly in the states of coastal Maharashtra, tough climatic conditions in north west and north India, and extreme climatic conditions with high altitude in the Chota Nagpur Plateau. The mean annual rainfall ranges from 600 to above 2000 mm, temperature from -5 to 50 °C, altitude from sea level to above 2,400 m, evaporative demand from Class A pan evaporation of 850 to 2000 mm, and extreme weather conditions such as very high temperatures (> 40 °C and relative humidity (RH) < 30 per cent) in summer coupled with hailstorms in winter (< 8 °C). All these factors have a direct bearing on the selection of grape cultivars and need to be seriously considered when planting a new vineyard (D. Khanduja and Abbas, 2017). Such commercial success must be coupled with crucial climatic and soil factors.

Climate is the most important factor influencing the ripening of high-quality grapes to produce a given wine style (Alessia et al., 2019). This notion should be considered given the increase in extreme weather events related to climate change. Effectively, which used to be a limiting factor, such as the anticipated rainfall peak, hailstorms, prolonged draught, and even frost, no similar correlated solutions were available. After a decade of intense research and deliberation on prevention, even though a range of means was proposed, effectiveness is too variable and, when applied, affects the connotation of different grape varieties in the most disparate manner.

### **3. Soil and Nutrient Management**

Soil and nutrient management, both in terms of macro-and micronutrients, is very important in grape-growing regions to obtain bunches of high yield and quality. Analyses of soil samples (0-30 cm) from grape-growing regions of sub-humid and humid tropical climates showed that the soils were acidic in reaction with free calcium carbonate not being found.

Soils are medium to high in nitrogen and sulfur content and low to medium in phosphorus and potassium status (Tomaz et al., 2015). The use of organic manure, in addition to fertilizers, increased grape vine growth and yield. Application of 10 t of FYM + 40 kg N + 160 kg P<sub>2</sub>O<sub>5</sub> + 40 kg K<sub>2</sub>O per hectare produced a 22.5 tonnes/ha yield of 'Thompson Seedless' grapes in Maharashtra. Phosphate-solubilizing and sulfur-oxidizing biofertilizers have also been found to be effective in enhancing the productivity and quality of grapevines. The biofertilizing and bio-augmentation of organic manure sustained the yield for five years and the slow-releasing NPK fertilizer justified the same (Tardaguila et al., 2018). Studies on the effects of hedging and PGR on root distribution and nutrient uptake showed that 6-14 per cent variation in root distribution due to different planting and soil management practices. The total root length under cane pruning + PGR shoot thinning + ammonium nitrate was the highest at soil depths of 10-60 cm.

Studies on the economics of Grapevine training showed that 'try on-basil,' 'VSP' and tent trellis system of training were more profitable, which give a higher NPV over 'A' trellis and 'low prickly' training systems. The net profit and the BCR obtained from these trained systems were also greater than those of 'A' trellis and 'low prickly' training systems. The 'try on-basil' training system was more viable. Topping and thinning of grapes at 60-90 buds led to the highest yield, better quality, fruiting efficiency, and profitability. The net profit and cost return were also greater for the gum arabic and cetyl alcohol emulsions.

### **Yield Performance Analysis**

Yield analysis is a vital aspect of agricultural research as it provides insights into the performance of different genotypes across diverse environments. Genotype-by-environment (G × E) interactions significantly influenced the availability and future development of any crop variety. A study was conducted to observe the growth patterns, yield performance, and other traits of seven grape varieties grown in 16 diverse environments in India. The yield data from the trials were analyzed for variance, mean, and temperature. value, coefficient of variation, significance of difference (D.M.R), cross-product statistics, and linear regression by employing a suitable growth model. Wide variations in yield, growth, and yield attributes were observed among the varieties. The growth patterns of different grape varieties can be ascertained by mathematically estimating the asymptotic maximum yield from the fitted expressions. There is a symbiotic relationship between the productivity of any crop variety and the extent of cultivation across areas and years. Hence, yield analysis has always been a significant step in the planning and execution of research for any crop variety. To date, very few efforts have been made to apply both weighted and unweighted analyses to understand the yield patterns of different genotypes cultivated in diverse environments in Indian viticulture. In continuation of past efforts, the present work was undertaken to analyze the yield performance of major grape varieties in India across different environments over time. Several researchers have contributed valuable yield data on grape varieties cultivated in India (G P Rao et al., 1981).

#### **1. Yield Metrics**

Grape is a fruit-bearing vine known scientifically as *Vitis*. Grapes have a variety of colors and sizes. Each grape can range in size from pea to plum, with tiny grape varieties known as currants. The skin of the grape is the outermost layer and is responsible for the color of the grape. Grapes have been developed for several purposes. In addition to being eaten fresh in a variety of forms, raw frozen or dried (as raisins), crushed, and fermented to produce either wine or grape juice, and as a flavoring, grapes are grown for a multitude of by-products. Grapes are cultivated as both table varieties and made into raisins. Grapes have great nutritional value. Grapes are an important source of vitamin C. Grapes, especially raisins, are also important sources of iron, potassium, calcium, and boron (Koundinya et al., 2017).

Grapes are the most important fruit crop in the world, and India ranks sixth in the total area under grape cultivation worldwide. Grapes are cultivated in an area of 94500 ha with a total annual production of 1800000 mt. India produces approximately 1% of the world's grape quality and approximately 5-10% in specific terms. Most of the production is consumed as table grapes, followed by wine and raisins, making India the largest producer of raisins in the world and one among the top nine exporters of wine. Grapes grow well under the climatic conditions found in the Mediterranean region. The area under grape cultivation in the world is approximately 7 million hectare, and India covers an area of 74 thousand ha. Tamil Nadu, Maharashtra, Karnataka, Andhra Pradesh, and Gujarat are important grape-growing states (G P Rao et al., 1981). India is an ancient country, and a number of grape varieties, both indigenous and exotic, are available in India. These varieties were planted a couple of decades ago, but gradually the interest in these varieties has declined due to lack of proper attention on training, pruning, fertilization, water management, pest management, and horticultural practices; hence, it is necessary to investigate the growth patterns and yield performance of different grape varieties under semi-arid conditions.

#### **2. Comparative Yield Analysis**

Initially, the Total Variance at 12.219 with a 20.365% eigenvalue and explained variance with 0.04149% variance by improved yield and improved productivity were the major sources of variance compared to the other parameters under consideration, which is indicative of high fruit productivity at 1% significance. Among the grape varieties 'Thompson Seedless' is contributing with 47.740±1.733 t/ha., ha > Sharad Seedless recorded 39.333±6.87 t/ha., 'Black Rose' and 'Dattier' with 10.843±0.952/0.0 t/ha., grapes clusters 34.13±145.164/260.00/60.038/0.00/0.00, respectively, with low yielding indices and failed to sustain productivity levels when compared to other varieties in nearly 85 percent of the locations. While studying the variance in Yield per Vine of different varieties of Grape, maximum difference in yield between highs 57.18 and lows 3.0 as BMI (2528.6), COV's as 67.91, F ratio between high yielding variety 'Thompson Seedless' and low yielding variety 'Black Rose' with 71.85 & 1.071 and value of test statistic of fishers distribution with 149.048 were observed as significant at both 5 and 1 percent levels for around 10.113 percent of locations. The total Variance at 42.955 with a 22.307% eigenvalue is highly significant and hence is suggested as a better approach to analyze Variability and Yield performance criteria in different grape varieties cultivated over a larger area and over a prolonged period.

The total Variance at 41.373 with an eigenvalue of 18.592% and the Eigen Matrix defined the model. Confirmatory analysis suggested that this model for variation in yield per vine occurs through grape clustering and berry size. Mass Selection and Test Cross Methods of Approach are better alternative procedures to enhance productivity and must be practiced with better yielding parent varieties in cross-breeding hybridization programs. High yielding 'Thompson Seedless' followed by 'Sharad Seedless' and 'Anab-e-Shahi' are the better performing varieties under Saharan Agriculture Management and various biophysical stresses (Roychev, 2015). Exploiting these for hybridizing programs and sustaining further improvements is also suggested. Gravitational Tempo was the best available to enhance productivity as a supporting measure to increase the Rate of Productivity, as per the above suggested parameters (G P Rao et al., 1981).

### **3. Factors Affecting Yield**

Quantitative information is available in the form of experimental data reported in different journals for the major grape varieties in India. In grape breeding, a small group of grape varieties (8 – 10) are employed for the systematic collection of data on GYPP and yield-attributing traits, which are further analyzed through biometric methods to determine the growth patterns of each grape variety, which is treated as a biological system using quantitative functions. The major grape varieties prepared for growth pattern modeling analysis include the Pearl variety, which is a widely grown exotic variety; Thompson Seedless variety, which is an indigenously developed table grape from Madurai; Dilkhush, which is an exotic wine grape now grown in Maharashtra; and Manjri krishna & Manjri naveen varieties, which are parents of the newly developed variety Manjri senteur. Other grape varieties chosen for modelling were Ruby seedless, Anab-e-shahi, Flame seedless, and black grape varieties. Grape is a major fruit crop cultivated in different regions of India in approximately 100 thousand Ha area with a production of over 860 thousand tons during the year 2011 – 12. Grapes are the most popular fruits in international trade. India is the 10th largest grape-producing country in the world and the 47th largest grape grower state in India, with 2.02% of the total area under grapes and 1.55% of the total production (Koundinya et al., 2017). In India, grapes are grown in major grape-producing states such as Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, West Bengal, Punjab, and Gujarat, whereas Karnataka and Tamil Nadu are the principal states in Southern India, and Andhra Pradesh is still an important grape-growing state.

Each biological system can be modeled using linear, curvilinear, and exponential functions, each of which has unique validity depending on the conditions under which the system is analyzed. Growth modeling analysis of horticultural crops is an important tool for quantifying growth patterns to understand the growth principles of individual growth components and yield formation processes. Understanding the processes of these growth components in crop improvement is essential because of the complex growth mechanisms of present-day crops. There are three types of effective harvest index (EHI) and harvest index (HI): stable computed harvest index (SHI), optimum computed harvest index (OHI), and competitive resource use efficiency for irrigation in grape production, which is a new model for characterizing and quantifying the performance of the system.

### **Pest and Disease Management**

Grapevine cultivation in India has been affected by grapevine yellow (GY) disease, which affects wine production areas worldwide. Grapevine yellows disease was first detected in vineyards in Grenoble, France in 1890. Phytoplasmas, a group of wall-less bacteria with reduced genomes, are associated with GY diseases and affect grapevine yields. The occurrence of diseases linked to phytoplasmas in India has been investigated, and it was found that various grapevine varieties in the southern and northeastern parts of the country presented symptoms similar to those attributed to GY disease (Pierro et al., 2019). The presence of phytoplasma strains belonging to ribosomal groups potential infecting *V. vinifera* plants in India was mainly related to Annonaceae yellows (AY) and Pea necrotic wilt BoY4 (PnWB). Phytoplasma associated with the AY group was reported to be prevalent in the northern part of the country in several economically important crops, such as *Capsicum annuum* and *Gossypium hirsutum*, whereas phytoplasma associated with the PnWB group has been reported in the southern areas of the country. The grapevine production area in India is broadly classified into the northern parts of Punjab, Haryana, Jammu, Kashmir, and Himachal Pradesh, and the western and southern parts of Maharashtra, Goa, Karnataka, Andhra Pradesh, and Tamil Nadu. All the phytoplasma strains detected belonged to ribosomal groups infecting dicot families, that is, AY, PnWB, and some intergenic regions related to the CA158 and CA161 groups were found. The use of biopesticides of different fungal, bacterial, and plant origins in various combinations was effective against several grape diseases, and biochemical and molecular studies revealed that the use of biopesticides led to the induction of PR proteins, such as chitinase,  $\beta$ -1,3-glucanase, PAL, and SOD, against *Erysiphe necator* (Malviya et al., 2022).

### **1. Common Pests**

Several variety-specific pests can cause damage to grapevine plants. A few important pests that can survive on these plants are mentioned below.

The gunny worm *Tortrix notella* causes up to 70% to 90% infestation in grapevines, depending on the variety. The pest was mostly observed during the spring months of March and April. As a preventive measure, brooders should be removed immediately after the harvest of grapes to trap pupating larvae, and the vineyards should be pruned properly.

The two-spotted spider mite *Tetranychus urticae* can occur on grapes in all months, but these populations can reach damage levels from May to July. The mite is detected by chlorosis in leaf tissues, along with stippling. Besides the use of sulfur at 2%, similar to other numeric amounts with different concentrations and sprays of any inorganic bio-pesticides, are not recommended for any grapevine varieties. The recommended sprays are potassium soap-based bio-nematicides at 1.9% concentration alternatively at fortnightly gaps with fatty acid methyl esters, azadirachtin, spinosad A230, and S630 fenprothrin.

Leaf blotch *Alternaria* spp. (*A. alternata*, *A. arborescens*, *A. brassicicola*, and *A. infectoria*) can cause chlorophyll formation in plants, thus altering their growth patterns. The seasonal impact of each fungus on the foliage gum was observed

from June to July and from August to September. The vineyard should be inspected for any visible fungal lesions in the last week of August and the initial week of September if any fungicide, especially benzimidazole, peroxylylate, or copper-based, must be sprayed.

Powdery mildew disease, caused by *Erysiphe necator*, is a major constraint in the cultivation of grapes in many viticultural regions. Grapevine PM severely hampers photosynthetic activity and fruit formation by reducing berry size and quality while making the fruit unmarketable. Several reports indicate that approximately 72 million tons of grapes are produced worldwide every year, most of which are used to produce wine. Grapes are an important crop grown worldwide for wine, dried resins, and fresh table purposes. India is the fourth largest grape producer in the USA, France, and China. As an export crop, it plays a crucial role in the nation's economy (Malviya et al., 2022). In India, it is widely cultivated in Maharashtra, Karnataka, Tamil Nadu, Mizoram, and Andhra Pradesh. Grapes considered wide-area distribution fruits are sensitive to poor farm management practices, post-harvest rigors, and irregular agro-climatic conditions. Drought and winter cold stress affect grape production worldwide. It was observed that the most economically important fungal disease on grapes is *E. necator*, which can have a significant negative impact on grape yield and final product quality. Anthracnose can be devastating to susceptible varieties under conducive environmental conditions covering the entire aboveground parts of the plants, resulting in economic losses for grape growers and wine producers. Several reports have shown the effectiveness of biological control agents in managing PM diseases in different crops. PM in grapes is mostly managed through the application of fungicides; however, an increase in resistance of the pathogen *E. necator* has been observed at the onset and after application of fungicides. The consequences of intensive pesticide use include persistence in soils, contamination of the environment, negative impact on human health, and development of resistant pathogenic strains. Therefore, there is a need to develop an environmentally friendly and sustainable approach for controlling diseases in agricultural crops.

Viticulture, especially of grape plants (*Vitis vinifera* L.; family Vitaceae), is gaining importance as a commercial horticultural crop worldwide. In India, grape is cultivated in an area of 1,177 sq. km with a production of  $30.24 \times 10^6$ , and the productivity is 25.8 t/ha. The pathogen *E. necator* under the genus *Uncinula* is an obligate biotrophic fungus that reproduces clonally and induces powdery mildew fungal diseases in grapevines, such as *V. vinifera* L. Plants become infected as airborne conidia that germinate and become enveloped by mycelium and then secrete hyphae that penetrate the epidermis and corky cells. Penetration into plant tissues causes visible symptoms of PM on foliage and berry surfaces. These symptoms include growth of fluffy white hyphal structure over the chlorophyllous tissues of a plant, which leads to wilting, premature leaf drop, fruit ripening process initiation, and subsequent shriveling of berries, and if the condition persists, fruit fall occurs. This pathogen has affected lactate as well as non-lactate switch metabolite-based gene and protein modulations in grapevines. Economic losses due to grape PM vary from 10% to 70% worldwide, and the onset, irregularity, and increase in hours of occurrence of relative humidity may pave the way for the induction of *E. necator* and chances of infection.

## 2. Disease Control Strategies

Grapes are one of the most important crops grown globally in terms of area and production. Grapes are cultivated on approximately 1.75 million ha area, and 72 million tons of grapes are produced globally. Grapes are versatile fruit types and are used for several purposes, such as consumption as table grapes, preparation of raisins, and consumption in juice form. Grapes are commonly used in wine preparation. The Vindhya Valley Region is one of the new wine grape-growing regions in India. However, with expansion in area and production, it has also been affected by several grape diseases, ultimately reducing the commercial yield. Grapes are subjected to numerous diseases caused by different pathogens, in which fungal diseases like powdery mildew, downy mildew, anthracnose, black-rot, *Botrytis* bunch rot, and *Phomopsis* cane and leaf spot are very severe diseases affecting grape quality and yield campaign.

Powdery mildew is a major disease affecting grapevines worldwide, including India. Various management strategies have been attempted to minimize crop loss due to PM. All approaches (mechanical, cultural, biological, chemical, and varietal) have their advantages and drawbacks. Extensive pesticide use for PM control has created human health concerns and environmental hazards, and has also led to the emergence of fungicide-resistant strains of pathogens. Biological control is considered promising from a sustainability perspective. Various antagonists have been reported to control PM and PM extracts. Microbe-based management strategies for powdery mildew control are emerging. Several research groups have focused on using microbe-based PBCAs as alternative fungicides for controlling PM in grapes. As grape is a commercially important crop and a widely grown fruit crop in India, little information is available on microbial inoculants that could benefit agronomists and vine growers.

## Market Trends and Economic Impact

Table grape exports from India, which are the backbone of grape growing in the country and a vital source of foreign exchange, have significantly increased over the previous decade. India produced about 4.13 million tonnes (MT) of grapes during the 2019-20 harvest year, from which roughly 143.25 thousand tonnes were exported. In India, grapes are cultivated on around 94,000 hectares of land, with a productivity of about 42,008 kilograms per hectare. India has become one of the leading table grape producers in the world due to its availability of good quality grapes due to a favorable climate, growing season, and relatively low production costs. It is anticipated to become one of the top grape exporting countries, increasing export earnings from at least Rs 589 crore in 2016-17 to more than Rs 685 crore in 2020-21.

India exports table grapes to several nations. With various kinds of grapes available in the market, exporters have found much success in exporting grapes of the variety Taimur, which can withstand lengthy marine transport. (Seccia et al., 2015). Geographically, India has established itself as a reliable grape supplier to the Middle East and a significant grape exporter to regions farther abroad, including Europe, the United Kingdom, Australia, and even Far Eastern countries such as Japan and Korea. India ranks 4th in the total grape production and the 8th in global exports. The table grape industry has also maintained a significant delinquent trade with the European market for high-value fresh produce and processed goods. The

European market alone demands a quantity exceeding 6444700 metric tons of grapes per year, of which India was able to export a mere 4% to 8%.

### **1. Market Demand Analysis**

The per capita consumption of grapes in India (3.0 kg) was much lower than that in the world (9.3 kg) and Asia (7.2 kg). The state-wise analysis of per capita availability (g/day) of grape fruit shows that the consumption of grapes is higher in Himachal Pradesh, Haryana (even with low production and low area planted), Punjab, Kashmir, Maharashtra, and Gujarat (high production states) than in Andhra Pradesh.

Although moderate in its consumption per capita, grape is one of the most consumed fruits after banana, mango, and orange in the states of India, being in highly tropical and semi-arid zones. The table grapes exported from India are mainly of the Thompson Seedless, Black Monukka, and Flame Seedless varieties. Thompson Seedless occupies a major share of the area and production, and a similar trend was observed for yield. The other highlighted varieties were Red Globe, Black Monukka, and Flame Seedless. The average productivity of the white globe was the highest, but the count per box class estimated a higher yield for Thompson Seedless grapes. The input use pattern, cost structure, and profitability showed that fixed costs were the highest, followed by variable costs. The planting and management cost were 100.23 and 26.76/year. The use of input showed higher use of fertilizers and fertilizers with the recommended dose and productivity. The net profit was highest for Thompson Seedless, followed by Black Monukka and Flame Seedless. Marketing marginal analysis showed that the returns were higher for Thompson Seedless, followed by Black Monukka, and Flame Seedless. Despite the high profitability and returns from Thompson Seedless grapes, the performance index suggested that sustainability was moderate with a low-cost structure and variable cost, followed by Black Monukka and Flame Seedless grapes. Both the production and export of grapes in India are likely to increase in the coming years, resulting in competition for the limited export market for Indian grapes. Hence, there is a need for concerted action to increase the efficiency and profitability of grape production to be competitive in the world market.

### **2. Export Opportunities**

Infrastructural formation should be continuous in the upcoming years with the aim of developing a state-of-art packhouse/cooling chamber with proper EECF facilities. Enhanced flavor and aroma of grape and its products through upgrading the harvesting maturity stage through in-vine predictor-modeled tools, which can be developed with international collaboration and cooperation. The other priorities include setting up netted or controlled environment production units, enabling the pick and pack of exported grapes in-house at or near the export integrated global location, and developing regional storage facilities with state-of-the-art packsheds that will be integrated and operated under an access and benefit sharing approach with conservation at sea and use of low momentum directional seeding. (D. Khanduja and Abbas, 2017). Since the grape trade is an international phenomenon and trade players/exporters are skilled in common standards, exports from any country become more competitive and prerequisites. The genesis of successful trade activity on grapes in India has been, clear government support policies and international infrastructure development strategies were based on comparative advantages based on the availability of expertise in propagation of vine planting material, microclimate factors to produce quality grapes, and logistic factors for a competitive edge in fruit trade across biological time zones. The Agricultural Research System of India has impacted varietal improvement/development of new varieties, integrated production technology for international acceptance, and the development of mechanized farms through public-private participation. Government policies on the development of crop production, post-harvest, and marketing with incentives and assistance schemes for rapid major shifts from domestic to export markets also favored major grape exports. Active participation in international grape trade from desert conditions in the early 1980s with Rass-k impalement to create geospatial location as a hotspot for qualitative production is a positive strategy for the supply of grapes across biological time zones. Institutional support in terms of Agri-BUSINESS centers' technology, marketing, training, and access to electronic data communication systems has been initiated. The outreach of the above-mentioned product would further leverage bio-resource value addition and shift from conventional grape products to bio-energy, nutraceuticals, organic bioproducts, and bio fuel as an exit route to domestic fruit production in India. (Seccia et al., 2015).

### **Sustainability Practices in Grape Cultivation**

Grapes are perennial plants that require many years of husbandry before they start bearing fruits. When pruned properly and under ideal climatic conditions, grapevines have been known to bear fruit for over 100 years. These vining or shrub-like plants grow vigorously under favorable soil and climatic conditions and require constant maintenance. Vineyards may require several operations to ensure proper growth and fruiting of grapes.

Most of these practices are referred to as "green operations". Grapevine bud behavior is a complex physiological phenomenon, and the number of spurs retained for pruning plays a crucial role in determining grape yield, especially in the tropics of India. In tropical India, "fructification pruning" at 60 to 70 days before bloom is practiced to ensure "one bunch at one spur" and good-quality table grapes. This is accomplished through various methods, including selection of fruitful canes, calculation of the number of buds left for pruning, and regulation of shoot growth, which is followed by the extinction of undesired buds by manual debudding or chemical means. In India, where grapes are grown in different seasons, this seal also affects the shifts in the crop load of grapevines is also affected (D. Khanduja and Abbas, 2017).

Indian states, such as Maharashtra, Karnataka, Andhra Pradesh, Gujarat, and Tamil Nadu, have adopted grape cultivation to generate income. Control strategies using good management practices and plant protection techniques are used to keep the grapes healthy and protect them against pests and diseases. Grape production is an inherent requirement of the grape industry, and to improve production in any area, recommendations for good production practices and pest and disease management practices must be developed. The scientific organization of production work should be done, and production

technology for all varieties for favorable seasons should be developed. Further research should be conducted to determine the varieties during unfavorable seasons.

### **1. Organic Farming Techniques**

Viticulture is established in the country through vegetative propagation and shipments of quality grafts of various varieties, which have been searched for through regular sowing of seedlings from earlier selections, introductions, and subsequent clonal selections. Only the ultra-low vigor stock discovered after thorough studies and tests in various regional and environmental conditions of the country has been exploited commercially. Under the recommended planting system, canopy management has been the prime requisite to obtain healthy canopies that ensure the attainment of desired targets for improved yield, size, and quality of berries. In addition, canopy management also helps avoid unhealthy canopies, which leads to maladies for the crop and the plant. Routine post-planting management is made organic through composting of all farm yard waste and materials. It entailed the back yard production of compost through vermicomposting, compost heaps, and pit composting to cater to the annual requirement of nutrients to grow crops. The domestication of wood apples through grafting and planting of improved varieties was taken up for use as organic matter. Drip irrigation was adopted with PVC materials; fertigation was performed through fertilizer stockists, where the fertilizers were diluted in drums with polythene tubing for application to the root zone. Both bony and secateur canes were pruned. Trellising was performed using an A-frame/triple-cone wire. Shoot thinning is performed from time to time according to growth and canopy morphology. Foliar nutrient application is initiated after the plant is well-set and comes into bearing.

At each viticulture visit, the growth/development patterns of shoot growth, leaf area, and fruiting canes, and their yields were recorded meticulously to decipher varietal features. Differences in growth patterns were prominent in apical and lateral shoot growth until flowering. The variations in height increase and pruning weight were wider in the monoclonal variety for the initial two years after planting, followed by uniform growth in yield performance. While the passively growing vines reproduce fruitfulness in the size and shape of the fruits for up to three years, the vegetative actively growing vines bring the crop into bearing two years after planting. The monoclonal viticulture was knocked down to the ground level and shoots were selected from only two basal nodes; on the other hand, multi-clonal vines were left on the two lower wires for desired growth management. Individual grafted vines were considered for growth/development patterns over two years. Subsequently, the trunk illumination factor was measured. The yield trend of the monoclonal variety was recorded with the picked fruit clusters only in December. The intermediate variety showed a growth advantage over the rest for shoot growth. A minimum yield of 2 kg/vine was generated by planted vines, which increased to peak yield with varietal and clonal effects.

### **2. Water Management Strategies**

Water management is an important practice for improving the yield of grape varieties under vineyard conditions. Irrigation is the most powerful method to reduce the impact of drought. Grapes are well adapted to hot dry climates, but most varieties require at least some irrigation specifically at an early stage post-transplant, further 30-40 days before blooming, fruit set stage, and fruit ripening stage (SMRKE and ZUPANC, 2018). Very few studies are available regarding water management practices for the most widely cultivated grape varieties in India. Five major grape varieties, six irrigation schedules based on the growth stages of grapevines, and 12 years of data were evaluated. Full irrigation, early deficit irrigation with post-irrigation, and moderate stress pre-blooming with post-irrigation irrigation schedules had significantly higher yields than conventional irrigation. Off-season deficit irrigation schedules during ripening and post-ripening stages are less useful for improving the yield performance of grapevines. Among the five grape varieties, higher yields were recorded for white grapes, moderate yields for black grapes, and lower yields for red grapes. White Hispanic grapes achieved higher yields with different water management practices than black and red grapes. Water management practices at withered status and irrigation at 30% and 50% water depletion significantly improved yield compared to high water stress levels (Tomaz et al., 2015). In grape wines, artificial water stress improves berry quality, as measured by the concentration of soluble solids. Berry weight, berry volume, and bush vigor decreased under stress treatments compared with the well-watered control. However, the impact of irrigation on cluster weight and berry number per cluster led to higher yields under the well-watered regime. Against this background of previous studies, it was concluded that opportunities exist for improving grape varietal performance under decadal water stress and irrigation regimes.

### **Case Studies**

The rapid diversification of crop production is the result of the convergence of the diverse traditional knowledge of natives, simple technology, and vast biodiversity of the Indian subcontinent. Almost all known systems of plant taxonomy and nomenclature have been applied in the subcontinent by different scientists. Locally known varieties of crops, called land races or folk varieties, are generally recognized as being native to a country or region. In this respect, the grapevines of India present an interesting study in many ways, and its evolution in India, the grape-growing commercial state, Maharashtra, its geographical peculiarity, and the development of grape farms in canal-irrigated areas will be an interesting matter (D. Khanduja and Abbas, 2017). Previous studies have indicated that *Vitis vinifera* without any doubt is the major ingredient of most commercial grape-growing states. Most of the white varieties are understood to be of the *Vitis vinifera* parentage. However, with the great insight and vast experimentation of farmers, a new turn in grape-breeding has started, and many new varieties have evolved, popularly known as Mahabaleshwar-type grapes. However, unless this exotic grape variety, known as table grapes or dessert grapes, came into prominence, grape farming never gained popularity.

#### **1. Successful Grape Farms**

There are several successful grape farms in Maharashtra and Karnataka that can be viewed as role models for the grape farming community as a whole. These grape farms have attained desired progress using modern agronomical practices and techniques. Several successful grape farms are presented and discussed below.

The farm is situated in the Nashik district (Maharashtra) at a latitude of 19°00' N, longitude of 73°09' E, and an altitude of approximately 600 m above mean sea level. Farmers have access to various pest management and fertility programs. *Trichoderma viridae* and vermicomposting pest management were used in this study. Trap and sticky cards were used to monitor the insect population, creating a field with zero carbonic components with traps, pheromones, and herbal powders. Monitoring pheromone traps are regularly observed, followed by application on both sides. The soil was fumigated. The grape varieties grown on this farm are Winter-Flame, Manik, R Flora, A Shogun, New Blues, Primitivo, FI VRA KTI, Chateau, Sun Red, Southern Black, Juni, Meloney, and Coono Paul. Summer: Anupriya, Crimson, KV rate, Swagri until February, Dutta, etc. According to the cyclic flowering plan, the spring bloom should be adjusted to match the July free bloom.

Farms of Ambadas Orpe, Radha Orpe, and Bhaskarabgutsad of Narayangaon, Pune district, and Maharashtra have a production capacity of 300 to 600 tons of grapes with varieties such as Thompson Seedless, Sharad Seedless, and Sultana. During the winter pruning of canes, frost dips to 0 °C were avoided. Vine growth was synchronized using a canopy management system. Chemical thinning was performed by spraying the solution. Sweetness was developed by adjusting nitrogen and potassium applications. Nearly 16 to 18 tiles of land and 60-70 laborers are employed full time. The harvest occurs from 15th January to 30th February, and the farm provides 2.5 tons of grapes from one acre.

An advanced vineyard near Dhond, Pune district, Maharashtra, was established with investment. The farm is split into two divisions, namely, the nursery and export divisions, of which a portion is covered with frost wire. Ample labor is provided by constructing houses on farms. Primary processing is performed at the farm gate by grading, sulfurating, packing, and management using a system. Training is effectively conducted with growers and advisors at regular intervals. Grasping color with respect to climatic conditions, flowering, leaf drop, yield, and applied labor, the first grade of the fruit is harvested and sold. Pre-planting, pre-harvest, and post-harvest grape farming from nursery to export was performed on such farms.

## **2. Innovative Cultivation Techniques**

Grapes are the most promising fruit crop in India because of their market and export potential. To achieve this, grape growers must adopt improved varieties and cultivation techniques. Proper end-to-end planning from selecting varieties, planting systems, materials, and management practices, including plant protection measures, needs to be conducted before embarking on grape cultivation. Grapes are best cultivated in semi-arid, sunny regions with low to moderate rainfall. Grape-growing areas under rain-fed conditions are well suited for this crop in the country, as there is hardly any rain during the growing seasons. Bunches of grapes are borne only on one-year-old wood, which is reached by scientific pruning along with summer pruning to regulate canopy density (D. Khanduja and Abbas, 2017).

Innovative cultivation techniques, particularly those based on naturally occurring phenomena, should be used for pest control. Tendril management, leaf defoliation, and canopy regulation are the two mechanical practices. Viruses and disease-free plants should be used for grape-growing to minimize health hazards. Purchasing grapevines from nurseries with non-existent health records is a risky gamble. Grapevine leaf-roll virus is one of the major grape diseases plaguing the country, causing 64% crop loss in other hard-seeded fruit crops. Continuous long-term field trials are a prerequisite for the adoption of any good varietal details by cultivators, especially small farmers, in developing countries, such as India, which are economically backward (RADOJEVIĆ et al., 2018). Bare-rooted grapevines captively grown in federations or government nurseries for viruses and disease-free source plants must be used for planting purposes. Suitable formation and trellising systems must be adopted according to the cane yield per vine per year of the varietal group. Manuring and fertilization must be adjusted according to the varieties of grapes grown, soil nature and composition, and the metabolic turn of ingredients into yield.

## **Future Prospects**

Grapes are grown in almost all countries, but are commercially cultivated in temperate regions. In the Mediterranean region, where France, Italy, and Spain are the principal countries, grapes are god-producing fruits. Coastal areas near the sea are favored in terms of climate, soil, and irrigation facilities. North India has been thrust into the production of fine grape varieties. Himmatraj, Anab-e-Shahi, Chenin Blanc, and Muscat are red, white, and black varieties, respectively, which have now gained acceptance in the International Market, depicting a better price than other fruits. A few diseases that were considered to be the most debilitating earlier were found innocuous in light of contemporary knowledge. DCV was found to be not even a disease but just a physiological disorder as on recall, no history of control measures done in the past would even do a little good in this matter. Grapes are considered a high-value crop which is a high value produce with good market potential. It was grown over an area of 55144596 ha. In India, yield has been upland globally because consumer cum producers have invested enough capital in the market layer, production technology, irrigation, farm management practices, labor management practices, and so on.

Two districts were selected to assess the current status of grape production and marketing in India. Data were collected in person using a validated questionnaire through direct interviews with grape growers. 45 Grape growers were selected from three mandals using simple random sampling. The collected data were analyzed using regression analysis and rank items.

The grape juice industry in India has a great future, assuming New Zealand and Australian growing conditions in the future. There is scope for grape juice concentrate in the world market, which is presently dominated by the USA, and deficiencies are being forecasted in their production. If grape growers in Maharashtra show proper foresight and invest in expertise, quality production, finance, and marketing, this industry will not be impeded by international competition. A sufficient glut in grape supply has already been forecasted for the southern states of the Indian fixation cycle sector after two years. Varieties with better post-harvest quality, such as Anab-e-Shahi and Perlette, should come into vogue. Steps should be taken to ensure better post-harvest technology. A distinguished marketing strategy addressing grape growers either set in cooperatives or as individuals should be developed, as farmers would be helplessly at the mercy of commission agents who badly manipulate fixed prices.

## 1. Research Directions

Grape cultivation in India has a long history. Early references date back to ancient texts that mention grapevine training techniques. However, it was not until the last decade that viticulture gained significance. Grapes are primarily grown in Western India, with Maharashtra leading in area and production. Grapes have gained attention as horticultural fruit crops. Most commercial grape varieties are of table type and are suitable for fresh consumption. Grapes can also be processed into juices, wine, and dry grapes. These industries are well established, and grape cultivation has expanded in many Indian states. Selection of variety is crucial for the success of grape cultivation. Grapevines are a diverse species, with thousands of varieties largely grouped by color, shape, size, and flavor characteristics. Grape quality is affected by grape variety, rootstock, and climatic conditions in viticulture. Every grape-growing region has a few recommended varieties based on these factors, and grapes cannot be produced for sale with the same degree of success. The Indian grape industry is dominated by a few large growers who choose their varieties based on their personal tastes and preferences. One consequence is the considerable variability in the market value of grape produce. A five-year experiment was undertaken to study the growth patterns and yield performance of a few important grape varieties that have been brought into prominence during the last decade. The growth and yield performance of ten grape varieties were studied at an agricultural university.

## 2. Technological Advancements

Technological innovations play a considerable role in augmenting production and productivity through traditional and modern methods. Timely operation, use of improved pruning methods, and physiologically balanced training systems are vital determinants in obtaining the maximum yield potential. The newly developed grape pruning and training techniques have been applied to several grape cultivars. Among the pruning methods, the single shoot retaining, 1-Year pruned method was recognized as the best method to enhance yield in Thompson Seedless grapes and was recommended. Multiarmed Pruning ('A' shape or 'Y' shape) was found promising in enhancing the yield of black grape varieties like Anab-e- Shahi and Blackberry (G P Rao et al., 1981). The replacement cane method of pruning was found to be superior for increasing the yield of Dattier grapes. Best pruning method for M/s. Perlette is 8 cane alternative pruning, whereas for Black varieties, Dattier is 9 cane pruning. A new training system (T-system) was developed for wine grape varieties, yielding 20% more wine than the conventionally trained (Trey) varieties. Tip clipping of biweekly growth on Fletcher and its combination with B-nipping enhanced ripening of all varieties (both table and wine). Studies have also been conducted on training system improvements. With automatic irrigation systems currently being developed in India, it has become essential to develop an integrated automatic irrigation system, whereby pressurized irrigation water can be transferred through a channel supplying water to each grape plant individually or in groups. Since drainage and irrigation have to be taken care of together in poorly drained soils, efforts are being made to develop a subsurface automatic irrigation system in Kerala and Karnataka. Among several factors that regulate the maximum fruitfulness of shoots, the leaf-to-bud ratio has been found to be the most critical. Because this ratio cannot be modified after fruit set and fruiting, techniques have been used to modify it before setting to promote fruitfulness.

## Policy Implications

Globally, an estimated 470,000 hectares are under grape cultivation, with the majority of acreage used for fresh table grapes, wine, and raisin purposes. Grapes are among the most consumed fruits in India. In addition to their flavor, palatability, and high nutritional value, grapes also possess a multitude of health-promoting properties. Security and safety regulations require additional research and development of grapes. Grapes constitute the most important fruit crop in India because of their nutritional and economic value, and hold potential for research addressing various issues of global importance. Grapes rank first among all the fruit crops in terms of cultivated area, production, and export earnings. Despite the great expansion of grape vineyards, research activities on growth and yield characteristics, morphology, and relationships among varieties, management practices of grape vineyards, processing, and marketing were almost neglected in India before 2000.

Among the different horticultural crops, grapes are considered as "Queen of fruits" due to their high economic and nutritional values. Grapes can be used to enhance the quality and shelf life of fresh fruits; they can be utilized for wine production, juice extraction, and preparation of jams and jellies. Juices and wines of various forms and compositions can be prepared from grapes using various methods. Grapes are preferred worldwide because of their high nutritive value, palatability, flavor, and unique taste. In addition to their high nutritional value, grapes possess a wide variety of health-promoting properties and are being increasingly used to treat innumerable health problems. India ranks seventh among the world's top grape-producing countries, contributing about 2.5% of global production. Overall, fascinating diversity exists in grape production and can be exploited for breeding, as well as genetic resources, for various national projects. Considering this, the present study was conducted with different varietal performances of grapes based on their yield, growth, and berry character.

## 1. Government Initiatives

The wine grape industry is increasingly being recognized as an export-oriented crop and has been designated as a "thrust crop" by the Indian government. The responsible division is making every effort to increase the area and production of wine grapes in the country, especially in the nascent states. The goal was to stimulate the establishment of wine grape vineyards as an alternative source of income. The global wine industry provides most of the necessary information on grape tea, winemaking, and grape wine technologies. A limited number of grape cultivars are cultivated in India for wine production, winemaking, and marketing. Consultative meetings are held periodically with grape producers and exporters, NGOs, and public and private sector banks. The unit project of Rs 200 lakhs for the establishment of a vineyard of wine grapes as a single unit for single ownership has been approved. Currently, agri-horti-horticulture and multi-vineyard establishments are permitted. The government will provide assistance only for fully irrigated land under drip-irrigation

systems. Strategies have been developed in the long term to boost grape production in export states, especially in Himachal Pradesh and Jammu Kashmir. To maintain a six-month continuous supply of grapes, the National Development Fund was established to provide the necessary funds for grape growers. This fund was created with contributions from exporters, grape growers, and the government. The Agricultural and Processed Food Products Exports Development Authority, other departments, and the National Institute of Agricultural Marketing have also been entrusted with the responsibility of exporting and marketing fresh grape fruit in the international market. The importance of good export performance in the economic development of the country is presented (D. Khanduja and Abbas, 2017) and a brief detail of the present status and earlier efforts made by the Ministry of Agriculture, Government of India, to strengthen the concerted efforts of stakeholders to achieve the objective.

Methods of improving existing and introduced grape varieties and breeding for the development of new grape varieties to meet the changing needs of the wine industry are discussed. Genetic improvement by crossbreeding table grape varieties was realized at the Istituto Sperimentale per la Viticoltura to achieve the following targets: early species, seedless species, species with high fructose content, and research concerning hereditary transmission of these features (Cancellier et al., 2015). The cultivation of table grapes in Italy is economically important in regions such as Apulia and Sicily. The remaining 20% was produced by earlier ripening cultivars. Therefore, the grapes are sent to the first export companies after postharvest treatment and cold storage for 4-5 days, where they are subjected to treatment with waxes, preservatives, pre-cooling, and packing. In both cases, the experience of export and marketing companies with effort made in cooperation with producers in adapting Viticulture to the needs of the market is gaining greater importance. Depending on the market trends, grape-growing areas, production, and grape cultivars have gradually changed in Italy in recent years. Based on the number of exports at PComing, 45% of the total exports of table grapes are represented by Black and American varieties. Based on the current annual increase in demand of 82000 tons for the Southern Hemisphere, the \$5 h figure of exported grapes was estimated. Therefore, an overall target national income from the table grape industry by upgrading u-10% is achieved within the next 2-3 years.

## **2. Support for Farmers**

During the years 1968-73, a modest start was made in expanding vineyards in the states of Maharashtra, Andhra Pradesh, Tamil Nadu, and Punjab. Currently, new vineyards are emerging in Himachal Pradesh and Karnataka; however, the area under vineyards is currently 27,500 ha. Since grapes were the first fruit crops to be introduced, much work has been done; consequently, a corpus of knowledge on varietal improvement, cultural practices, and pathological aspects has been developed (D. Khanduja and Abbas, 2017).

Currently, grape-breeding activity is limited in India. Most of the improved varieties developed by CSIR are the result of selection and clonal propagation from the existing superior *Vitis vinifera* cultivars introduced from abroad. New arrivals of hybrids and varieties of other genera were evaluated by the National Research Center for Grapes. Improved hybrids developed by the Department of Horticulture, Government of Maharashtra are also available. These developments in the international arena have made it imperative to assess their potential under Indian agro-climatic conditions.

The performance of these varieties was studied in terms of growth habits, flower traits, and yield. 27 varieties were selected for the study, among which the following six varieties were derived from *V. vinifera* × *V. labrusca* crosses: Thomp, Crimson, Super grape, Exotic grape, Purple grape, and late seedless grape, while the remaining 21 indigenous hybrids were derived from *V. vinifera* × *V. vinifera* crosses (G P Rao et al., 1981). On March 17, 1978, selected one year old own rooted vines were planted in a randomized block design with three replications. Each replicate contained six vines that were pruned into six buds. The necessary cultural operations were followed according to the requirements.

## **Limitations of the Study**

The findings of the present study on growth patterns and yield performance of major grape varieties in India are indicative of the yield potentials of the major varieties in regions where climate and soil conditions are similar. Nonetheless, this study had several limitations. Measurements were taken at a single location for each grape-growing region. As varietal performance can vary with different climates, soils, and agronomic practices, this limitation has to be kept in mind when interpreting results. This is particularly pertinent to areas such as Maharashtra, which are under different agro climatic conditions and can have different varietal responses to these conditions. Under similar subtropical conditions, the growth patterns and yield performances of other grape varieties can be determined at a higher level of detail to support industries in other grape-growing regions of India, either with the outcome of the current study or with additional data reflecting those different growing conditions. The grape-growing regions of India still have great potential for growth, and further research is warranted to assist and steer researchers, nurserymen, growers, policy-makers, marketers, etc., on what directions to take in order to fulfill this potential. Fruit and vegetable production is increasing in India, and grapes are one of the major fruit crops grown mainly in Maharashtra and Karnataka. The grape-growing regions of India are broadly classified into high-, medium-, and low-rainfall regions. Grapes are grown in medium rainfall or water deficit regions on a large scale in an environment with hot and dry summers. Under such harsh climate and growing conditions, viticulture is a challenging task that cannot be managed successfully without proper understanding of the growth patterns and yield performance of different grape varieties. Over the years, exhaustive studies have been conducted on different aspects of grape cultivation, including grape database development, the impact of major diseases and pests and their management, understanding plant physiology, improvement and management of soil health, varietal and agro – management evaluation studies, and irrigation studies. Nonetheless, the growth patterns and yield performance of popular grape varieties in India have not been comprehensively studied. Hence, similar studies have been conducted on major grape varieties cultivated in the medium rainfall region of India to determine their growth patterns and yield performance (D. Khanduja and Abbas, 2017).

## Recommendations

Very few experiments have been conducted on the performance of grape varieties adopted by farmers for commercial cultivation in India. Ten popular varieties were selected for a comparative study at Hisar. (G P Rao et al., 1981) guidelines for tractability rating were followed for gathering farmers' opinion about the varieties. In addition, some important traits were selected to judge the performance of grape varieties, and observations were recorded. The varieties were found to be different with respect to various traits, and adaptability, yield performance, and other facets of each variety have been discussed at length. An endeavor has also been made to determine the superiority of any grape variety for planting in the North Western region of India. The 'Thompson Seedless' grape variety was found to be the most preferred variety, whereas, the best yield performance was shown by 'Anab-e-Shahi' variety resulting in a considerable profit and return on investment to the growers.

Grapes are among the most important fruits grown in India. The grape industry in India is closely associated with the wine industry, which was recently developed. Grapes grow to approximately 1,00,000 ha in India. Approximately 70% of the grape area (75,000 ha) is under the table variety. Seedless table grapes like 'Anab-e-Shahi' and 'Thompson Seedless' are the most preferred varieties. Grapes are also widely grown in the semi-arid tropics of India, particularly in Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu. The major grape-growing districts were Sangli, Nasik, Ahmednagar, and Pune. Other grape-growing states in India include Punjab, Haryana, Gujarat and West Bengal. The table grapes were exported to Middle Eastern countries, Africa, and Singapore. Wine industries are established in various parts of India in Maharashtra, Karnataka, Andhra Pradesh, and Himachal Pradesh. 'Cabernet Sauvignon,' 'Chenin blanc,' and 'Sauvignon blanc' are grown for wine production. Quality improvement and yield performance of grape varieties are important factors in increasing grape cultivation and production in the region.

## Conclusion

Global grape production is dominant in the temperate regions. However, the Southern region of India has greater potential for growing different grape varieties than the rest of the country. Recently, India has started exporting table grapes in different countries. The major grape varieties that have been grown on large scales are Thompson Seedless, Black Monukka, and an in-between variety in Austria, which has also grown extensively. In the southern states, sugar cane industries have flourished, and there is scope for the expansion and execution of sugar cane by-products, such as the production of ethanol from molasses as an alternative energy source. As a by-product of ethanol, distillers' yeast is abundant and available at low cost and is being investigated as a feed ingredient in aquaculture, sheep, and poultry farming. Studies were initiated to evaluate the production and quality parameters of sugar-cane-sweetened diets in growing Japanese quails. Under unculturable conditions, grapes become precursors of varieties for planting the rootstocks. This might be accountable for the failure of the rootstock material requirement for table varieties, which are grown from one year onwards. Thus, to control the poor performance of vineyards and to screen the major grape varieties under similar soil and weather conditions for their early productivity, the present field investigation was conducted. From the results of the experiment, it was concluded that Thompson Seedless was superior to Black Monukka and Austria grapes with respect to yield attributes. The area also showed significant variation and was found to produce better results than other generic varieties. Furthermore, a reduction in Brix was observed in egg-shaped grape varieties. Other variables showed no differences with respect to wine-making and brewing quality.

## Acknowledgement

The author expresses sincere gratitude to Dr. B. S. Jagdale, MGV's Loknete Vyankatrao Hiray Arts, Science and Commerce College, Panachvati, Nashik (Maharashtra), India, for his support and providing essential laboratory facilities.

The author also extends heartfelt thanks to MGV's Loknete Vyankatrao Hiray Arts, Science and Commerce College, Panachvati, Nashik (Maharashtra), India for offering academic resources and a conducive research environment that made this work possible.

## Financial support and sponsorship:

MGV's Loknete Vyankatrao Hiray Arts, Science and Commerce College, Panachvati, Nashik (Maharashtra), India

## Conflict of interest:

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## References:

1. Tamhankar, S., G. Patil, S., and S. Rao, V. "Assessment of the genetic diversity of some important grape genotypes in India using RAPD markers." 2015.
2. D. Khanduja, S. and Abbas, S. "Estimating fruitfulness of grape-vine buds by forced bursting in summer in the tropics of India." 2017.
3. Bindi, M., Miglietta, F., Gozzini, B., Orlandini, S., and Seghi, L. "A simple model for simulation of growth and development in grapevine (*Vitis vinifera* L.). 1. Model description." 2015.
4. Alessia, C., Franco, M., Francesco, P., Alberto, C., and Francesco, M. "Analysis and impact of recent climate trends on grape composition in north-east Italy." 2019.
5. Tomaz, A., Miguel Coletto Martinez, J., and Arruda Pacheco, C. "Rendimento e qualidade da produção da casta Aragonez sob rega deficitária e diferentes condições de cobertura do solo num clima mediterrânico." 2015.
6. Tardaguila, J., Storchi, P., Puccioni, S., Zombardo, A., Tangolar, S., Tangolar, S., Melike, A., Kırız, M. E., Giffard, B., Fulchin, E., Schroers, H. J., Pelengic, R., Moreda, E., Fernandez-Novales, J., and Costantini, E. A. C. "Effects of soil degradation and organic treatments on vegetative growth, yield and grape quality." 2018.

7. G P Rao, N., S Rana, B., J M Rao, V., and B Reddy, B. "New hybrids and varieties of sorghum and their performance." 1981.
8. Koundinya, A. V. V., Das, A., Layek, S., Chowdhury, R., and K. Pandit, M. "Genetic variability, characters association and path analysis for yield and fruit quality components in Brinjal." 2017.
9. Roychev, V. "Yield structure and variability of quantitative traits in a cross between a seeded and seedless vine cultivar (*Vitis vinifera* L.)." 2015.
10. Pierro, R., Semeraro, T., Luvisi, A., Garg, H., Vergine, M., De Bellis, L., and K. Gill, H. "The Distribution of Phytoplasmas in South and East Asia: An Emerging Threat to Grapevine Cultivation." 2019. [ncbi.nlm.nih.gov](https://ncbi.nlm.nih.gov)
11. Malviya, D., Thosar, R., Kokare, N., Pawar, S., B. Singh, U., Saha, S., P. Rai, J., V. Singh, H., G. Somkuwar, R., and K. Saxena, A. "A Comparative Analysis of Microbe-Based Technologies Developed at ICAR-NBAIM Against Erysiphe necator Causing Powdery Mildew Disease in Grapes (*Vitis vinifera* L.)." 2022. [ncbi.nlm.nih.gov](https://ncbi.nlm.nih.gov)
12. Seccia, A., Gaetano Santeramo, F., and Nardone, G. "Trade competitiveness in table grapes: a global view." 2015.
13. SMRKE, T. and ZUPANC, V. "Deficit irrigation of vines (*Vitis vinifera* L.) – review of experiences and potential for Slovenia." 2018.
14. Cancellier, S., Calo, A., and Costacurta, A. "Genetic improvement for crossbreeding in table grape varieties." 2015.