Revealing Diseases of Holy Basil via Taxonomic Analysis

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ABSTRACT

Agriculture is one of the requisites for survival of mankind. With the supply of food, it contributes majorly in the economy of a country. During the process of agricultural cultivation different types of crops as well as plant leaves are at risk of infecting with various diseases. Basil holds its status as an essential herb worldwide which can be used fresh as well as in dried form specially for culinary purposes and traditional medicines for curing various diseases. Basil productivity is hampered by different bacterial, viral, fungal, pests and nematodes pathogens. Geographical incidence and influence and, signs and characteristics of the various diseases have been discussed. Causal agents of disease have also been identified which hampers the growth of basil. In this paper, eight types of fungal diseases, bacterial, six types of viral diseases and five types of nematodes diseases on Basil will be discussed. Similarly, various bacterial, viral and nematodes diseases have been discussed.

1. INTRODUCTION

Holy Basil (Ocimum basilicum) as shown in Table 1, a member belonging to Lamiaceae family belongs to genus Ocimum is a perennial plant of India popularly known as Tulsi. Basil, commonly known as the "king of the herbs," is indigenous to Asia, including countries such as India, Pakistan, Thailand and Iran, and it can also be spotted in its natural habitat where it's tropical or sub-tropical areas across the globe. Basil is a sacred herb which accounts to innumerable health benefits which can be addressed through Ayurveda. Basil is highly regarded in Ayurveda because of its beneficial effects which is confirmed by the scientific research as well. Basil is used in various preparations like different cuisines, bakery products, snacks, beverages and milk-based products. Basil tea works as very effective stimulator for the body.

Table 1: Botanical Details of Basil

Family	Lamiaceae
Genus	Ocimum
Scientific Name	O. Basilicum

Basil is cultivated in field as well as beneath uncomplicated wooden or iron frameworks that provide support for plastic (typically polyethylene) or glass. Basil can be cultivated in different variety of media that includes soil as well as soilless (Using artificial substrates or hydroponics) system [1]. Basil is being monitored these days with the help of IoT [2]. Basil productivity is hampered by different bacterial, viral, fungal, pests and nematodes pathogens. These pathogens can be soilborne or airborne and is the cause of various soilborne and foliar diseases in the plant. Soilborne diseases are caused by pathogens who inculcate the host plant following its path from the soil instead of air or water whereas foliar diseases have its effect on the plant leaves [3].

2. DISEASES OF BASIL PLANT

There are various diseases that affect the plant from its soil or leaves. The factors which are responsible for various plant diseases can be majorly categorized as biotic and abiotic factors as shown in Figure 1. Biotic factors are those which are caused by living organisms like bacteria, fungi, virus, caused nematodes and insects. On the contrary, abiotic factors are those which are caused by non-living factors like temperature, water, nutrient deficiency or any chemical injury etc. [4].

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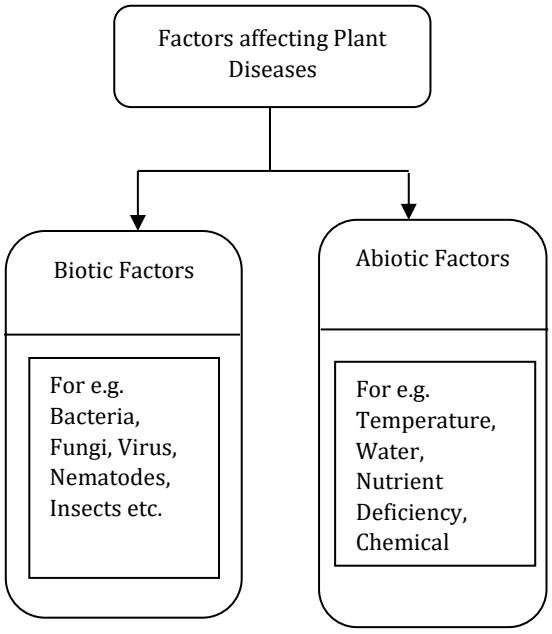

Fig. 1. Factors affecting Plant Diseases.

The diseases which affect the Basil can lie in the category of Fungal diseases, Bacterial and Phytoplasma diseases, Viral diseases, Nematode diseases and others like caused by pests etc. Let's discuss all of these disease categories one by one.

2.1 Fungal or Fungus like Diseases

Fungal or fungus like diseases are those which are caused by various fungal species like rusts, smuts or mildew etc. which infect the plant tissues resulting in hampering of its growth and appearance. Fungal diseases are a common threat to crops. Fungal Diseases are categorized as shown in Table 2. Numerous fungal diseases have been encountered on Basil which are discussed as below:

2.1.1 Alternaria Leaf Spot:

Geographical Incidence and Influence: The Alternia leaf spot was first investigated in Italy and after then in the Japan [5]. First report of disease in Europe [3]. The leaf spot was noted in post harvesting shipment of the basil from Israel to Europe [9]. Majority of isolates from basil of A. alternate are toxigenic [10].

Signs and Characteristics: Alternia Leaf spot can be discovered by brown ring like spots, or blotches of brown. Specifically, in Basil it has black leaf spots in the midst of yellow haloes, black stems blight, lesions on leaf, dieback and plant death as shown in Figure 2.

Causal Agent: Alternaria alternata (Fr.) Keissler [5].

Pathogenicity: Alternaria spp which causes the leaf spot of Basil occurs due to seed transmitted and makes it understandable that for disseminating the pathogen seeds are of utmost importance [11].

Fig. 2. Alternia Leaf Spot of basil: Lesion on leaf (left), Dieback Symptoms(right) [5].

2.1.2 Gray Mold /Botrytis Blight

Geographical Incidence and Influence: Botrytis Blight harms a wide variety of herbaceous and ornamental plants. Most infections happen in cool, rainy and summer weather. With the exception of the roots, it affects every component of the plant, including the leaf, stems and crowns, flowers and flower buds, seeds and seedlings, bulbs, etc. This disease is widespread and found its occurrence in Hawaii, USA [7], Italy [17], Israel, Greece, Hungary, Turkey, Bangladesh, Korea, Chile and Brazil.

Fig. 3: Botrytis Blight: Fast discoloring and dead tissue and prominent growth of greyish spores (arrow). (University of the Connecticut ©2021 All Rights Reserved, L. Pundt)

Signs and Characteristics: Gray Mold also known as Botrytis Blight is caused by Botrytis Cinerea. This fungal pathogen poses significant challenges on flowering plants, particularly in greenhouse environments. It often manifests as yellowing plant tissues, typically resulting from nutrient deficiencies. Botrytis produces a huge amount of gray reproductive spores which are dusty that can be easily spread by splashing water or wind as shown in Figure 3. Spores doesn't give rise to new infections unless comes in contact of water. Only tender, injured, weakened, old and dead tissues of most crops are attacked [6].

Causal Agent: Botrytis *Cinerea Pers.: Fr*

2.1.3 Colletotrichum Black Spot/ Septoria/ Cercospora Leaf Spot/ Anthracnose

Geographical Incidence and Influence: Black spot occurs due to Colletotrichum fungus whose isolates belong to C. ocimi within C. destructivum species complex. This hampers the growth & yield of Basil. Colletotrichum is reported in few countries that include Cambodia, Italy [8-9], USA [7], India, Australia etc.

Signs and Characteristics: There are so many plant diseases. Out of various diseases anthracnose is the most destructive. Its occurrence is identified by dark brown to black spots on the leaf. These spots can sometimes expand and integrate with each other to form bigger patches under adequate environmental conditions. These spots may have dead tissue that falls out, giving the impression of a shot hole as shown in Figure 4. Defoliation, tip dieback, stem lesions, and even the loss of whole plants are all possible outcomes of the illness. The leaf lamina may tear when the lesions dry out [7].

Fig. 4. Signs of the Colletotrichum black spot (McGovern, 2023).

Causal Agent*: Colletotrichum gloeosporioides Penz. & Sacc. in Penz. [Glomerella cingulata (Stoneman) Spauld & H. Schrenk]; C. ocimi and C. destructivum [members of the C. destructivum complex]; Colletotrichum sp.*

2.1.4 Downy Mildew

Geographical Incidence and Influence: One of the deadliest illnesses in the USA and Europe is downy mildew. It was initially identified as Peronospora spp. in Uganda, Africa in 1932, then as P. lamii in 1937. It has also been seen in Brazil, Croatia, Australia, Asia, Europe, and the United States.

Europe: In European Countries, it was first detected in Switzerland (2001), Italy (2003), United Kingdom (2009), Hungary (2010), Spain (2016) [10]. Downy Mildew was widespread in Argentina in 2008. It was then detected in Czech Republic and Cyprus in 2012.

United States: Downy Mildew was found its foremost occurrence in South Florida in 2007, Sebastopol, Sonoma County and Argentina in 2008, Canada in 2011 and Mexico & Hawaii in 2015 [11].

Asia: Iran was the first country to observe Downy Mildew in 2006, then it was found in Japan in 2007 followed by Taiwan in 2011 [12]. Then, China and Korea have observed this disease in 2016 and 2017 respectively [13].

Australia: The disease was exotic till 2017 until South-east Queensland reported it first in 2017.

Croatia and Brazil then reported about the pathogen in 2015 and 2019 respectively [10].

Fig. 5. Downy Mildew: Yellowing of leaves-Upper leaf surface. (Cornell University ©2021 All rights reserved, M. T. McGrath,)

Signs and Characteristics: The Downy Mildew is not easily recognizable when made its first occurrence which is chlorosis which seems more like of a nutritional deficiency as shown in Figure 5. But later on, spores and pathogen develop exclusively on the lower side of leaves which is the key factor of its diagnosis as shown in Figure 6.

Causal Agent: Peronospora belbahrii

Fig. 6. Downy Mildew: Spores and pathogen growth-Lower leaf surface (Cornell University, ©2021 All rights reserved, (M.T. McGrath)

2.1.5 Fusarium Wilt

Geographical Incidence and Influence: Fusarium Wilt has been investigated in many countries that includes Asia [14], America, Australia [15], South Africa, Europe [16] and Middle East.

Signs and Characteristics: Fusarium Wilt sometimes does affect a Basil plant but it can infect other plants by carrying disease with it. And at times when basil gets affected with it, infection is carried either by seeds from infected plants or from soil. Infected plants will grow up to 12 inches tall after which they become stunted and started to wilt. Discoloration of internal stem tissue or black/brown streaks are initial symptoms of it which is then followed by plant death as shown in Figure 7. It cannot be cured so destruction of plant is the solution.

Fig. 7. Fusarium Wilt on Basil. (Gerald Brust, 2021).

Causal Agent: Fusarium oxysporum

2.1.6 Root Rot or Pythium Damping Off

Geographic Occurrence and Impact: Pythium is a parasitic oomycete which is formerly classified as fungi. Root Rot and Pythium Damping off in the plant of Basil has been investigated in USA [7], South Africa, Europe [17-19].

Signs and Characteristics: Pythium is responsible for root rot in which potting medium close to the roots of Basil turns to rot or sometimes it becomes dark or discolored. It can be due to poor drainage system or overwatering of the plant. Both before and after emergence, seedling damping off may also be brought on by the pathogen.

Causal Agent: Pythium ultimum [Trow. (1901)], P. irregular [Buisman (1927)], P. aphanidermatum [(Edson) Fitzp.], Pythium spp.

2.1.7 Rhizoctonia Root, Crown, and Stem Rot, Blight

Geographical Incidence and Influence: Crown Rot or Rhizoctonia is a fungus which is soilborne found in natural outdoor soil. It is a major herbaceous plant disease found its existence worldwide.

Signs and Characteristics: Rhizoctonia produces black-brownish structure known as sclerotia which remains in soil or plant tissues for years. It spreads over the upper region of the growing medium and hence easily act against the stem of the plant at the soil line. Stems decay easily and has a shriveled and dry look. As shown in Figure 8. destruction of stems and the aerial tissue along with an abundance of fungi mycelia resembling webs. Rhizoctonia causes Cutting rot, damping off, stem rot, root rot and aerial blight.

Causal Agent: Rhizoctonia solani Ku¨hn [Teleomorph: Thanatephorus cucumeris (A.B. Frank) Donk]

Fig. 8. Visible signs of Rhizoctonia web blight (McGovern, 2023)

2.1.8 Sclerotinia Stem Rot/White Mold

Geographical Incidence and Influence: Canada [20], Turkey, Hungary, India [21-22], Israel, Korea, and the USA [23-25] have been reported with Sclerotinia Stem Rot.

Signs and Characteristics: Sclerotinia sclerotiorum causes the disease white mold which is also known as cottony rot has many other names as watery soft rot or stem rot, drop, crown rot and blossom blight. Most common symptom is the presence of white and fluffy mycelial growth which then is followed by pale yellow to brown colored lesions at the soil line on the stem as shown in Figure 9. It causes wilting, leaf drop and ultimately the death of plant.

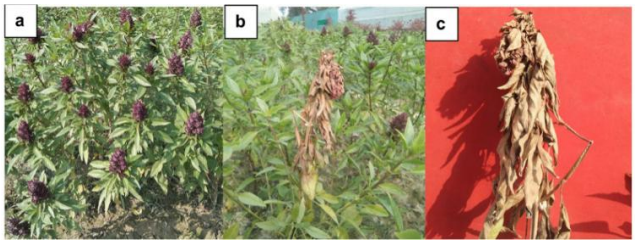

Fig. 9. Sclerotinia stem rot of Basil, (a) Healthy Plants (b) Diseased Plants (c) Mycletial growth on stem and leaves [22]

2.2 Bacterial and Phytoplasma Diseases

Bacterial diseases are caused by bacteria, which are single-celled microorganisms with a cell wall and no true nucleus. Bacteria can invade and multiply within a host organism, disrupting normal functions and causing symptoms. Phytoplasmas are specialized bacteria that lack cell walls and are obligate parasites of plant phloem tissue. Phytoplasma are bacterial plant pathogens transmitted by insects with devastating damage to plants and crops. Few bacterial diseases discovered are categorized in Table 2 and explained as below:

2.2.1 Basil Shoot Blight /Bacterial Leaf Spot

Geographical Incidence and Influence: The Bacterial Leaf spot occurrences on Basil is found in Argentina, Brazil, Egypt, Hungary, Italy [26], Japan, USA.

Signs and Characteristics: The most characteristic symptoms are water-soaked irregular/angular/or delineated black-brownish spots on leaf and the streaks onto the stems as shown in Figure 10. The disease might not affect much under field conditions but is very harmful for production of seedlings.

Causal Agent: Pseudomonas syringae *Complex: P. syringae [Van Hall, 1904]; P. viridiflava [Burkholder 1930] Dowson 1939; P. cichorii [Swingle 1925] Sapp [species] 1928*

Fig. 10. Bacterial Leaf Spot (Florida, 2024).

2.3 Viral Diseases

Viral Diseases are caused by viruses that are non-cellular infectious agents typically 30nm in size. Plant viruses can be transmitted from parents to offspring (vertically) or from diseased plants to healthy ones (horizontally). Few viral diseases are shown in Table 3. Virus that can affect Basil can be classified as:

2.3.1 Venial Mottle Mosaic Virus (VMMV)

Geographical Incidence and Influence: The Venial Mottle Mosaic Virus (VMMV) has been investigated in Nigeria [27].

Signs and Characteristics: It is caused by whitefly resulting in chlorotic type spots and the deformation of leaf. Differences in the color of stem, the leaf, leaf veins and the petiole can also be seen. The symptoms of the disease spreads and can be observed swiftly on entire plant.

Causal Agent: Whitefly

2.3.2 Pepino Mosaic Virus (PepMV)

Geographical Incidence and Influence: First report of Pepino Mosaic Virus ever on Basil has been reported in Sicily of Italy [28].

Signs and Characteristics: Chlorosis interveinal on fresh leaves can be seen on Basil plant. Disease was transmitted mechanically from infected tomato which produces chlorotic spots and deformation of leaves. Disease was not severe on basil but Basil seems to be a virus reservoir as it gets easily infected mechanically when cultivated next to tomatoes.

Causal Agent: Whitefly/Mechanically transmitted from infected Tomato

2.3.3 Alfalfa Mosaic Virus (Lucerne mosaic virus (LMV)

Geographical Incidence and Influence: Alfalfa mosaic virus (AMV) is highly common viral disease. It is discovered in Egypt [29], Southern Italy, and USA.

Signs and Characteristics: It generally consists of white -yellow colored mosaic of "calico-type". Leaf necrosis, chlorotic sectors and malformation of leaves is another symptom of AMV on Basil.

Causal Agent: Seed and Aphid specifically green peach aphid (Myzus persicae).

2.3.4 Cucumber Mosaic Virus (CMV)

Geographical Incidence and Influence: Cucumber Mosaic Virus was observed in India, Korea, Nigeria. Another isolate of CMV subgroup II was identified in the India [30].

Signs and Characteristics: Mosaic, leaf distortion and chlorotic spots are common symptoms of CMV. CMV reduces the amount of chlorophyll a and chlorophyll b, photosynthesis, the total of chlorophyll and total of carbohydrates gradually in the spoiled basil. However, it boosts the amount of total protein, total phenol, flavonoids, amino acid proline, also the percentile of essential oils (w/v) in the infectious basil plants [31].

Causal Agent: Seeds, Aphids (60-80 different species), Mechanically Sap Inoculation from naturally infected basil to basil.

2.3.5 Tomato Spotted Wilt Virus (TSWV)

Geographical Incidence and Influence: It is one of the most serious losses causing viruses and is devastating for many important crops. TSWV was spotted in France [32].

Signs and Characteristics: Chlorotic & necrotic rings, leaf distortion spots are visible.

Causal Agent: Thrips (order Thysanoptera, family Thripidae)

2.3.6 Basil Mosaic Virus (BsMV)

Geographical Incidence and Influence: BsmV has been reported in Pingtung County in southern Taiwan. The virus has been discovered as a member of the genus Fabavirus known as Broad bean wilt virus which belongs to the family Comoviridae [33-36]. Basil Mosaic Virus was also observed in Egypt.

Signs and Characteristics: Foliar Symptoms that was observed on infected plants consists of mosaic and leaf discoloration.

Causal Agent: Aphids (Aphis gossypii Glover and Myzus persicae Sulzer)

2.3.7 Other Viruses

Some other virus including Tomato chlorotic spot virus (TCSV), The Beet severe curly top virus (BSCTV), Bush bean mosaic virus (BBMV), Chili leaf curl virus (ChLCV), Cowpea aphid-borne mosaic virus (CABMV), Tomato yellow leaf curl virus (TYLCV) were also observed on Basil.

2.4 Complex Diseases

As it is said that plants tend to be infected with one pathogen strain/species in nature mainly in the context of complex multi-species. Majority of the studies carried out in laboratories mainly focusses on single strain that grows in natural environment. And therefore, they are unable to justify the complex nature of few plant diseases. So, Complex diseases are those which involve more than single pathogen and have complicated diagnosis and control. Association of a beta satellite with three begomoviruses of Basil [34-39].

2.5 Nematode Diseases

Nematodes are roundworms that belong to nematode class which can parasitize various plants and animals. Nematode pathogens are shown in Table 4. Few nematode pathogens that are discovered on Basil are:

2.5.1 Root Knot (Meloidogyne spp.)

The Root-knot nematodes are tiny, worm-like creatures that can wreak havoc on your basil plants. These pests belong to the Meloidogyne genus and cause knotty growths on plant roots, aptly named "galls." If you notice small, rounded swellings (galls) on your basil's roots, it's likely due to root-knot nematodes as shown in Figure 11.

Infested plants may exhibit wilting, yellowing foliage, and stunted growth. It was reported in Brazil, India, Italy, USA [35-45] and Venezuela.

Fig. 11. Root Knot Nematode in Basil (McGovern, 2023)

2.5.2 Foliar nematode (Aphelenchoides ritzemabosi)

Foliar nematodes are microscopic worm-like organisms belonging to the genus Aphelenchoides. They inhabit and feed on the leaves and other above-ground parts of over 450 plant species across more than 75 plant families. The three most economically significant species within this group are Aphelenchoides fragariae, A. ritzemabosi, and A. besseyi. Foliar nematodes are different from other plant-

parasitic nematodes in that they infest the aerial parts of plants instead of just living in the soil and roots. Their damage can decrease crop yields and affect the appearance and marketability of ornamental plants. It has been reported in the Italy and USA [12].

2.5.3 Lesion nematode (Pratylenchus scribneri)

Lesion nematodes, belonging to the genus Pratylenchus, are soilborne, plant-parasitic roundworms. They cause root lesion disease in various host plants across temperate regions worldwide. Unlike cyst or root-knot nematodes, that has the tendency to stay at one place, lesion nematodes are somewhat migratory endoparasites. They give feed and reproduce within root and moving around as they do so. Typically, they feed on the root cortex, and their species can be distinguished by the morphology of their stylets (hollow feeding organ of plant parasitic nematodes such as aphids or leafhoppers) primarily. It has been reported in USA.

2.5.4 Sting nematode (Belonolaimus longicaudatus)

The sting nematode (Belonolaimus longicaudatus) is a plant-parasitic nematode that can cause significant damage to various plants, including basil. The sting nematode is an ectoparasite, spending its entire life cycle in the soil. Eggs are laid in pairs by the female nematode, hatching into second-stage juveniles. It feeds on plant roots from the outside, causing damage to root tips and limiting water and nutrient uptake. The nematode's stylet (a needle-like structure) injects digestive enzymes into root tissue, leading to root meristem death. It has been reported in USA [35].

2.5.5 Stubby root nematode (Paratrichodorus christiei):

The stubby root nematode (Trichodorus spp.) gets its name from the stunted appearance of roots it feeds on. These microscopic, worm-like nematodes remain outside the root in the soil, unlike root knot nematodes or soybean cyst nematodes which create visible structures within roots. They possess a wide host range, affecting crops like soybeans, corn, sorghum, peanuts, and even turf grasses. Symptoms include irregular patches of poor growth, stunting, wilting, and nutrient deficiency. Soil assays are necessary for accurate diagnosis, as nematodes cannot be seen without aid. Managing stubby root nematodes involves crop rotation, maintaining optimal growth conditions, and seeking diagnostic assistance. It has been reported in USA [35].

3. COMPARISON OF DIFFERENT CLASSIFICATION MODELS

Various Classification Models have been used to detect diseases on Basil using basil leaf dataset. Early disease detection helps in controlling the loss of plant due to various diseases and reverse its effect by giving proper treatment. A study on various classification models is done on how accurately detection of disease on Basil can be done. A line chart is made with after comparing accuracy of different models as shown in Figure 12. Different individual studies were done on each model to find its accuracy for disease detection. After using Random Forest an accuracy of 94.31 is observed. Similarly, Naïve Bayes shows accuracy of 91.86, KNN shows 92.43, SVM shows 92.89, Discrimant analysis shows 92.30, Bayesian generalized linear shows 72.04, Extreme gradient boosting shows 93.87 and customized CNN shows 94.24.

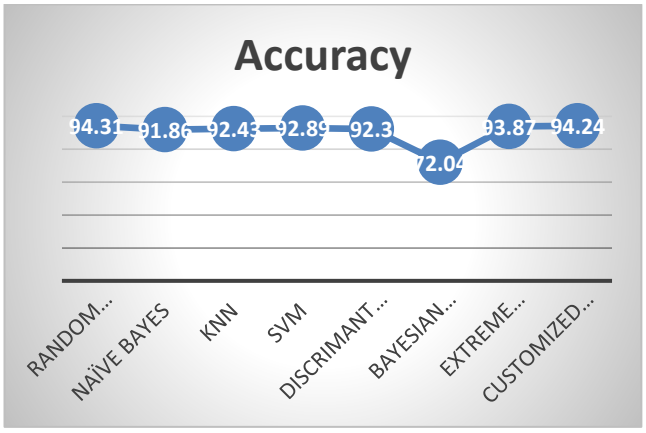

Fig. 12. Different Classification Models with its accuracy.

4. CONCLUSION AND FUTURE WORK

In this paper, we have studied various types of diseases on Basil plant which can be fungal, bacterial and phytoplasma, Viral, complex or nematode diseases. Various diseases which can be occurred due to these have been discussed with its geographical incidence and influence, and signs & characteristics to understand where certain diseases are more prone to occur and what symptoms does it shows on various basil types. Basil is a very crucial herb and is highly regarded in Ayurveda. So, it is popular worldwide and so discussing about its diseases is very important so that after observing certain symptoms predictions can be made for various diseases and proper methods to prevent and cure can be taken. Causal agents of disease have also been identified which hampers the growth of basil. Eight types of fungal diseases, bacterial, six types of viral diseases and five types of nematodes diseases on Basil have been discussed. Many other diseases also tend to occur but are rare to happen. In this paper, various classification models have been compared and its accuracy have been shown with the help of a line chart. Furthermore, diseases which can affect Basil will be discovered and studied in the future aspect.

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