**A Review on Current Status and Future Directions on Sesame Phyllody**

**Abstract**

 Sesame (*Sesamum indicum* L.), is an important oilseed crop belongs to Pedaliaceae family and has earned a poetic label ‘Queen of Oilseeds’ due to high quality polyunsaturated fatty acid, which restrains oxidative rancidity. It is one of the first oil crops used in humans. It is extensively farmed and has a mild flavour and a great nutritional content, making it quite popular in the diet. Sesame seeds are high in protein and fats and offer several health advantages. Sesame seeds are high in lignan-like active components, according to a variety of in vitro and in vivo investigations, as well as clinical trials. Due to the presence of the natural antioxidants like sesamin, sesamoline and sesamol, sesame oil has good stability. Their effects on human health are many and include antioxidant, blood lipid control, cholesterol reduction, liver and kidney protection, cardiovascular system protection, anti-inflammatory, and anti-tumor properties. Furthermore, it has been demonstrated that sesame aqueous extract is safe for use by animals. In numerous aspects of everyday life, including food, feed, and cosmetics, sesame is utilised as a significant medicinal and edible comparable food. Sesame is being used in an increasing number of health food applications. In order to enable the development of further sesame functions, this study examines the state of research on the use of sesame in nutritional value, chemical composition, pharmacological effects, and industrial applications.

**Keywords:**Bioactivity, Nutritional value, Food use, Phytochemical composition, sesame, sesamin.

**Introduction**

 Sesame (*Sesamum indicum* L.) commonly called as ‘til’ is an important oilseed crop, belonging to the Pedaliaceae family. It is widely farmed in tropical and subtropical countries (Bedigian and Harlan, 1986), earning the title of 'Queen of Oilseeds' for its high-quality polyunsaturated fatty acids. The family Pedaliaceae consists of 16 genera and 60 species (Weiss, 1983); out of which only *Sesamum indicum* is cultivated. Seeds of sesamum are rich source of edible oil (50%), protein (20%), oleic acid (47%) and linolenic acid (39%) (Shyu and Hwang, 2002). Sesamum oil contains sesamin and sesamol which are responsible for very high stability of oil at room and frying temperatures [13-17]. Its roots may be traced back to East Africa and India (Nayar and Mehra, 1970). Sesame, also known as til, gingelly, and benniseed, is an annual flowering plant with lanceolate leaves and tubular blooms that produce little oil-rich seeds in capsules (Shah, 2016). Major sesame-producing countries include Aden, France, Russia, Italy, Spain, Cyprus, East and West Africa, Malta, India, China, Sudan, Burma, and Mexico, with cultivation concentrated in Indian states such as Madhya Pradesh, Rajasthan, Uttar Pradesh, Andhra Pradesh, Orissa, Gujarat, Tamil Nadu, and Karnataka (Piploda *et al.,* 2022). In India, the sesame crop covers 1.62 million hectares, producing 0.788 million tonnes at a productivity of 485 kg/ha (INDIASTAT, 2021-22). Sesame is a short-day plant that flourishes on well-drained sandy loam soils. It can tolerate high temperatures and little water supplies, but is sensitive to salt (Ramirez et al., 2005). The seeds include 46-64% oil, 25% protein, minerals, and unsaturated fatty acids, which provide stability through natural antioxidants such as sesamolin, sesamin, and sesamol, leading to possible health advantages (Elleuch *et al.,* 2007). The medical value of sesame seeds are accepted worldwide due to the rich source of linoleic acid, Vitamin E, A, B1 and B2 (Brar and Ahuja,1979)

**Distribution**

 Sesame phyllody has been mostly documented in African and Asian countries; so far, it has been reported in Uganda, Sudan, Burkina Faso, Israel, Nigeria, Ethiopia, Tanzania, Venezuela, Mexico, Iraq, Thailand, Oman, Pakistan, Myanmar, Turkey, Taiwan and India [18-20]. Sesame phyllody in India has a larger geographic distribution. Still, it has been primarily recorded thus far from the south (Tamil Nadu, Karnataka, Andhra Pradesh, Telangana, Maharashtra), north (Madhya Pradesh, Rajasthan, Gujarat, Uttar Pradesh, Delhi, Haryana), east (Odissa, Chhattisgarh, West Bengal) and North East (NE) India (Assam, Mizorram, Tripura, Manipur, Nagaland, Arunachal Pradesh, Meghalaya).

**Vectors**

Fig .1 insect vectors of sesame phyllody

The main insect vectors of sesame phyllody are *Orosius albicinctus* and *Hishimonus phycitis*

**Symptoms**

 The characteristic symptoms of this disease consist of malformation of the floral organs which appear as green leaf-like structures. Phytoplasmas are associated with over 1,000 plant diseases causing devastating losses in crops and natural ecosystems worldwide (Lee *et al.,* 2000; Bertaccini, 2007). Some of these diseases, especially those of woody plants, are lethal. Plants infected by phytoplasmas exhibit a wide range of specific and non-specific symptoms. Specific symptoms include flower discolorations and distortions such as virescence (green coloration of flower), phyllody (appearance of shoots from the flower), big bud (hypertrophied bud), flower proliferation and other flower abnormalities – all resulting in sterility, reduced internodes, cracked seed capsules. Other common symptoms include witches broom, rosetting, fasciation, yellowing and leaf browning, etiolation and leaf size reduction (Bertaccini, 2007; Hogenhout *et al.*, 2008 ; Hogenhout and Music, 2010; Marcone, 2010; Bertaccini and Duduk, 2011; Gogoi *et al.,* 2017b). Most plants show apical dominance, but phytoplasma infection can cause the proliferation of side shoots and an increase in size of the internodes (Lee *et al*., 2000; Hogenhout *et al.,* 2008; Seruga *et al.,* 2008).

 The most common non-specific symptoms in woody plants are foliar yellowing and reddening, small leaves, leaf roll, leaf curl, vein clearing, vein enlargement, vein necrosis, premature autumn colouration, premature defoliation, vein necrosis, undersized fruits, poor terminal growth, sparse foliage, dieback, stunting of overall plant growth, and decline (Akhtar *et al.,* 2009). Very infrequently, phytoplasma-infected plants are completely symptom-free throughout their lifetime and exhibit a temporary or permanent remission of symptoms (Marcone, 2010).

 Symptoms of sick plants might vary depending on the phytoplasma, host plant, disease stage, plant age at infection, and environmental factors (McCoy, 1979; McCoy *et al.,* 1989; Lee, 1989; Lee *et al.,* 2000; Seemuller *et al.,* 2002). Callose deposition around sieve plates and plasmodesmata, starch buildup in chloroplasts and their disorganisation, and phloem necrosis all precede the manifestation of symptoms. (Musetti, 2000).

B

A

D

E



Fig.2 Most common non-specific symptoms in woody plants

**Etiology**

 Prior to the 1970s, the sesame phyllody (SP) disease was for the most part recognised by symptoms, mycoplasma-like bodies nearness under electron magnifying lens and under light magnifying instrument utilising Diene's stain indicating blue colour of phloem tissues in contaminated plants (Cousin *et al.,* 1971; Choopanaya, 1973; Klein, 1977; Raj Purohit, 1978; Salehi and Izadpanah, 1992; Akhtar *et al.,* 2009).

 Southern hybridisation with particular DNA probes was used to identify phytoplasmas associated with sesame phyllody (Nakashima *et al.,* 1999). Only a decade ago, they were identified using molecular methodologies such as PCR and restriction fragment length polymorphism analyses (Al Sakeiti *et al*., 2005; Sertkaya *et al.,* 2007; Cengiz *et al*., 2014; Nabi *et al.,* 2015a; Madhupriya *et al.,* 2015). In addition to 16S rDNA phytoplasma-specific primers, other genes such as secA, tuf, and groEL were used to improve the representation of phytoplasmas associated with this illness (Nabi *et al.,* 2015a). SecA gene primers were shown to be more specific in identifying SP phytoplasma strains (Nabi *et al*., 2015a; Madhupriya *et al*., 2015).

 In silico restriction enzyme digestion of 16Sr DNA, followed by virtual RFLP analysis of a 1.25 kb sequence of 16S rDNA, was used to characterise the SP phytoplasma to the ribosomal subgroup level (Nabi *et al*., 2015a; Madhupriya *et al.,* 2015.

 Sesame phyllody (SP) is caused by phloem-limiting bacteria called phytoplasmas, which are bacterium-like parasites that live in plant vascular tissue. They are often transferred from plant to plant by plant-sucking insects such as leafhoppers and mites. Other than the phloem, no colour distinction was found in tissues from sick sesame plants using light microscopy (Salehi and Izadpanah, 1992; Akhtar *et al*, 2009).

 Electron microscopy indicated a large number of pleomorphic entities (phytoplasma) in the sieve elements of infected xylem cells, phloem parenchyma cells, and companion cells that were not found in healthy plants. These creatures were usually round or oval, with opaque, low electron density cytoplasm containing ribosome-like granules and DNA strand-like structures (Salehi and izadpanah, 1992; Akhtar *et al*, 2009).

**Transmission**

 Phytoplasma spreads from plant to plant principally by the feeding activity of inoculative vector insects, vegetative proliferation of infected plant material, and graft inoculation (Kirkpatrik, 1991). The phytoplasma that causes phyllody disease was effectively spread from diseased to healthy plants via grafting, dodder, and the leafhopper *O. albicinctus*. The geographic spread and effect of phytoplasma infections rely on the host range of the phytoplasma and the feeding behaviour of the insect vector (Foissac and Wilson 2010; Seruga-Music *et al*., 2008; Bertaccini, 2007).

 Disease transmission occurred in just 20% of the dodder samples. The leafhopper O. albicinctus successfully transmitted phytoplasma from infected sesame plants to 60% of healthy plants (Akhtar *et al,* 2009). Previously, dodder was used to spread sesamum phyllody phytoplasma (16SrI and 6SrII-D) from ill to healthy sesame plants (Gogoi *et al.,* 2017; Rao *et al.,* 2015; Sertkaya *et al.,* 2007). Previous attempts to transmit sesame phytoplasma by side veneer and side grafting were equally effective (Caglayan *et al*., 2019).

 The acquisition of various phytoplasmas leads to interaction with vector insects (Bosco and Amelio, 2010). Vector specificity varies from high, when phytoplasmas are transmitted by only one or two vectors, to extremely low, when a single phytoplasma can be propagated, frequently by polyphagous leafhopper species (Hogenhout *et al.,* 2008).
In nature, phytoplasma is spread by Hemiptera insects, namely phloem-feeding leafhoppers (Cicadellidae) and psyllids (Marzachì *et al.,* 2004). In their natural insect carriers, phytoplasmas penetrate through the intestinal wall, circulate in haemolymph, and proliferate in organs such as salivary glands, where phytoplasma cells are incorporated into saliva injected into plants during inoculation (Weintraub, Beanland, 2006).

 Phytoplasmas can be conveyed by propagation material, allowing for long-distance dissemination and introduction into previously undiscovered regions. Recent investigations on the detection of phytoplasma in the seed and seedling progeny of lucerne (Khan *et al.,* 2002), canola (Olivier *et al*., 2006), maize, tomato, and oilseed rape (Alberto *et al.,* 2011) plants indicate that seed transmission in certain plant-host phytoplasma pathosystems is possible. Furthermore, all phytoplasmas can be disseminated experimentally by the plant parasite dodder (Cuscuta spp.) and by grafting infected plant material onto healthy plants.

 It was earlier proposed that jassids from the Deltocephalus genus may transmit the phyllody disease (Vasudeva, 1955; Vasudeva and Sahambi, 1958), but this has not been empirically proven. Subsequently three leafhopper species viz., *Neoaliturus haematoceps*, *Circulifer haematoceps* from Iran and Turkey (Salehi *et al*., 1992; 22 Kersting, 1993) and *Orosius orientalis*, *Orosius albicintus* and *Hishimonus phycitis* from Iran, Pakistan, India and Turkey (Hosseini *et al.,* 2007; Akhtar *et al.,* 2009; Pathak *et al*., 2012; Cenzig *et al.,* 2014; Nabi *et al.,* 2015b; Gogoi *et al.,* 2017a; Kalita *et al*., 2018) were reported to transmit the sesame phyllody disease.

 Grafting and dodder have proven efficient methods of spreading sesame phyllody phytoplasma Salehi *et al*. (1992); Akhtar *et al*. (2009); Pathak *et al.* (2012); Gogoi *et al*. (2017a); and Vamshi *et al.* (2019). However, no sap and seed transmission were confirmed (Choonapaya, 1972; Akhtar *et al.,* 2009; Gogoi *et al.,* 2017a; Vamshi *et al.,* 2019).

**Genetics of phyllody**

 Kothari *et al.* (1982) conducted a thorough analysis of ultrastructural alterations in phloem cells from brinjal plants with few leaves. Mycoplasma infection caused the formation of a divider in development, the expansion of the endoplasmic reticulum, and the deformation and destruction of mitochondria, plastids, and tonoplasts. Joshi and Bose (1983) sought to correlate histopathology with yield trait characteristics in sesame because of the change in leaf structures and failure of pollen grain and ovule development.

 Singh and Mitra (1990) also observed a few modifications, including the transformation of shame into a deformed, bloated mass of wilted cells. Ovules were prematurely terminated, and the gynoecium was transformed into a green extended verdant structure. Shukla *et al.* (1988) investigated histological alterations in green shoots of sick sugarcane plants. The investigation revealed fundamental alterations in the chloroplast, mitochondria, and cores of infected leaf tissues. The unwell plant had fewer and smaller chloroplasts, as well as undefined grana and stroma.

 Nalini *et al.* (1996) also observed histological and biochemical changes in influenced plants, such as shrinkage of anther sacs with sterile dust grains, hypertrophied anther dividers, saccate pistil with phylloid ovules, and conversion of ground tissue to mesophyll in the calyx and corolla, as well as increases in polysaccharides and protein content in phyllody-influenced chickpea plants.

 The changes seen in the calyx, corolla, and regeneration parts of the phyllody-influenced blooms are: Calyx: In normal blooms, the calyx was green, gamosepalous, and s-partite. The shards in the calyx were straight and apices. However, in phylloid blossoms, the calyx tube is completely divided, resulting in a polysepalous state. The sepals were overflowing in pedicels and had a leafy look. They were smaller and easier to set up than foliage leaves. The corolla turned green in shading in the phyllody influenced blossoms.

 The exterior of the Corolla was rough. Ordinary blooms went from being gamopetalous to polypetalous. Petal apics were altered. Androecium: Unlike the four epipetalous stamens found in ordinary blooms, phylloid blossoms also have a fifth stamen. Furthermore, the stamens were not epipetalous and had a green shade. Gynoecium: The ovary was increased in size, and the shame was transformed into two smoother greenish structures.

 Monoclonal gold-marked antibodies have been developed for Immunosorbent Electron Microscopy (ISEM) to detect PLOs such as maize tough trick (Chen and Jiang, 1988), peach eastern X malady (Jiang et al., 1989), and aster yellows (Lin and Chen, 1985). With the development of nucleic acid corrosive tests and the disclosure of polymerase chain reaction (PCR), another step in the discovery of PLOs has been taken.

 Nucleic acid hybridisation based on DNA testing with great specificity has been used to detect a few PLOs, including western X (Kirkpatrick *et al.,* 1987), clover multiplication (Deng and Hiruki, 1991), faba bean phyllody (Saeed *et al.,* 1994), and periwinkle small leaf (Davis et al., 1990). The PCR was used to amplify a DNA segment specific for PLOs in nucleic acid concentrations from plants contaminated with these infections. Namba *et al.* (1993) demonstrated the efficacy of PCR in detecting unhealthy PLOs, as well as the establishment of a phylogenetically based PLO taxonomy.

 The management of phytoplasma infections relies on accurate and prompt detection. Several molecular diagnostic techniques for phytoplasma detection have recently been developed, including nested PCR *(*Hodgett*s et al.,* 2007, 2008*),* real-time PCR (Christensen *et* *al*., 2004; Hodgetts *et al.,* 2009), and Loop Mediated Isothermal Amplification (LAMP) assays (Tomlinson *et al.,* 2010a), which can detect low titers of phytoplasmas in plant tissues. Loop Mediated Isothermal Amplification (LAMP) is quickly gaining popularity as a plant pathogen detection method (Bekele *et al.,* 2011).

**Management strategies**

 Sesame phyllody can be controlled by employing resistant cultivars, early seeding, or pesticides against leafhopper vectors. Crop hygiene methods that may assist to minimise phyllody incidence in sesame include early rouging of symptomatic plants, limits on the cultivation of vulnerable types, and reduction of leafhopper vector hosts. Some cultural measures, notably rotation management and sowing dates, might also be useful (Beech, 1981), since it has been observed that the severity of phyllody is regulated by the time of sowing (Rhind, 1935). This resulted in suggestions for early and late sowing (Joshi, 1961).

 Early sesame sowings promote excessive vegetative growth, which attracts insects and increases the probability of phyllody disease. However, in later sowings that produce smaller plants, the prevalence of phyllody will be significant due to the insect vector's co-migration from neighbouring host crops reaching maturity. Chemical insecticides have been effective in controlling the vector (Tandon and Banerjee, 1968; Rosy *et al.,* 1996), but complete disease elimination is impossible because small areas are susceptible to re-infection with leafhoppers migrating from adjacent natural or cultivated host plants acting as phytoplasma reservoirs. Sevithion (carbaryl 40%, parathionmethyl 10%) at 1.5 kg/ha of monocrotophos (0.025%) and methyle-o-demeton at 0.025% considerably decreased the vector population (Abraham *et al.,* 1977; Pathak *et al.,* 2013). Tetracycline-HCl (500 ppm) at weekly intervals partially recovered the plants from the typical symptoms. However, killing the leafhoppers through foliar application of insecticides has been shown to be ineffective.

 The development of cultivars with long-term resistance to phyllody would be the ideal management tool, and it should be a fundamental part of sesame breeding initiatives. Because most farmed germplasm is vulnerable, using wild relatives as sources of resistance genes may be a more practical approach. Tandon and Banerjee (1968) discovered modest resistance to phyllody in various Indian sesame cultivars. Varietal resistance to both the vector and the illness is the most effective strategy to manage this disease (Beech, 1981). Resistance to phyllody disease has been found in the wild species *S. alatum* (Srinivasulu and Narayanaswamy, 1995; Singh *et al.,* 2007). However, the transfer of this characteristic from wild to cultivated variety was mainly unsuccessful due to a high level of crossability barriers (Kedharnath *et al.,* 1959). Though Ramalingam *et al.* (1992) were eventually able to effectively develop an interspecific hybrid between *S. alatum* and *S. indicum*, the crossability was extremely low (0.04%). Sing *et al.* (2007) investigated 150 sesame genotypes, 32 released cultivars, and four wild sesame species in the field. Allelic testing on intraspecific crosses revealed the presence of recessive resistance governed by two independent non-allelic genes with duplicate dominance in cultivated varieties, whereas interspecific crosses of wild species revealed the dominance nature of resistance with one dominant and one recessive gene.

**Future directions**

 Sesame phyllody poses a possible hazard to sesame cultivation. As a result, actions must be taken to prevent it from spreading further. Some of them are listed below: An extensive investigation of the country's sesame growing areas was conducted to discover places and seasons free of phyllody disease. Identifying alternative hosts and weeds that might act as reservoirs for phytoplasma and insect vectors during the season and off-season. Leafhoppers are significant vector species for disease transmission. More understanding on vector phytoplasma and vector-plant interactions is required for better management of phytoplasma-related illnesses in sesame. Identifying crucial variables that promote phyllody growth. It is critical to research the genetic variety of sesame phyllody in different sesame-growing nations to identify the many phytoplasmas infecting this plant. Epidemiological research should be conducted to remove alternate plant hosts and control insect vectors in order to prevent the illness from spreading further. Sesame phyllody management measures also require consideration in order to generate resistant genotypes. The introduction of inherent or transgenic resistance into agronomically superior crops. Farmers will be able to use a sustainable comprehensive phyllody management solution. Sesame seeds are a good source of healthy fats, protein, B vitamins, minerals, fiber, antioxidants, and other beneficial plant compounds. Sesame can be used to produce bio-pesticides and herbicides. It can also be a cost-effective alternative to expensive proteins in animal feed. It helps in blood sugar control, combat arthritis pain, and lower cholesterol.

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