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THE IMPACT OF CLIMATE VARIABILITY ON OCCURRENCE OF SESAME PHYLLODY AND SYMPTOMATOLOGY OF THE DISEASE IN A MEDITERRANEAN ENVIRONMENT

M. Ilhan CAGIRGAN[1], Nalla MBAYE[1,2], R. Soner SILME[1], Nofou OUEDRAOGO[1,3], Hasan TOPUZ[1]*

[1]Antalya Mutation Project, Department of Field Crops, Faculty of Agriculture, Akdeniz University, Antalya, TURKEY
[1,2]Present address: Universite Cheikh Anta Diop, Faculte des Sciences et Techniques, Departement de Biologie Vegetale, Dakar-Fann, SENEGAL
[1,3]Present address: Institute for Environmental and Agricultural Research (INERA), Ouagadougou – 04 Centre, BURKINA FASO
**Corresponding author: cagirgan@akdeniz.edu.tr*

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ABSTRACT

Although climate change and variability is considered as an alerting situation and a big challenge to food security, we describe here a positive impact of it regarding disappearance of sesame phyllody in an unusually cool and rainy growing season of 2010 at West Mediterranean region of Turkey where the disease has been devastating last five years and it would occur at any rate in the same field since the start of sesame cultivation in 1995. Phyllody symptomatology and incidence were studied in three groups of plant material; i.e., (1) in a 2-year agronomic performance trial, (2) in the breeding nurseries (on the regenerated branches in the stubbles and unselected left-plants), and (3) in the M_1 plant progenies (grown as M_2 families beyond the commercial growing season for a training purpose). Unexpectedly, in 2010, there was no any single phyllody incidence (0%) in the first and second group material in comparison to the previous years, e.g., 6.0% in 2009). Although the incidence was nil in the third group material of M_2 families until onset of capsules (sown very late), phyllody symptoms started to appear as capsules grew and reached at 3% at the physiologic maturity. Also, stubbles of cut plants and unselected-left plants in the field after harvest (especially of F_1s with heterosis) grew new late branches like ratoon crop and developed phyllody in them, providing a good match between vectors and plant growth. Much of the impact of climate change and variability on sesame phyllody may be through the vectors of the disease and, thus, subject to the effects of fluctuating climate variables on their biology and population dynamics. To reveal the uniqueness of the year 2010 and its effect on the disappearance of the disease, the climate data clearly indicated a cool and rainy season and possibly a mismatch for the cycle of the vectors and crop growth. Three types of main symptoms which specify the phyllody disease were observed, i.e., \`virescence\`, \`phyllody\`, and \`ploriferation (witches' broom)\`, but the latter was less-frequent. Also among several indirect symptoms such as stunted habitus, exudates, vivipary, and yellowing, we described here a new effect of the disease causing short filament, and thus pin-type flower. Finally climate change and variability may also offer some positive impact to exploit for the benefit of food security and such cases should be considered in the crop management tactics and strategies as well as in modeling studies aiming to forecast impact of climate variability.

Key words: Climate change, disease, food security, indicum L., phytoplasmas, pin flower, strategy, variability, vectors

INTRODUCTION

Climate change and variability is considered as a big challenge to food security. As projected and partly experienced, the main impacts of climate change on crop production has been through fluctuations in temperatures of minima and maxima, in rainfall patterns in amount, spatial and temporal distributions, increased rates of evapo-transpiration, elevated repeatability of floods and droughts, and intrusion of salty water with the raise of sea level affecting coastal areas (Lagoda, 2011). As a response to these effects, new cultivation techniques with better adapted genotypes are adopted (Spencer 2011). Consequently, climate change has an effect on agricultural production and farming practices over the globe, which may lead also to a dramatic change in crop health.

To cope with the expected impact of climate change and to reduce food insecurity, modeling is done to help policy makers and to governments. Several models and projections of climate change impacts on future crop production and food security losses from a given factor (e.g. a disease as in Evans et al. 2010) are available (Roos et al. 2011). However, there are uncertain factors in these models which may also hold unpredicted impacts such as interactions between abiotic and biotic stress factors. Thus, these models require validation. And real case situations should be taken into consideration by developing these models that the real effects of the impacts would not be always negative as showcased in this paper regarding phyllody disease of sesame.

Sesame (*Sesamum indicum* L.) is one of the oldest oilseed crops grown in the countries where hand labor is inexpensive throughout the tropics and subtropics. Its seeds are rich in good quality of edible oil (50%), which is highly resistant to natural oxidation attributed to the antioxidative activity of sesame lignans, which are available in sesame seeds. Oil soluble lignans, sesamin and sesamolin, are further demonstrated to be of remarkable antioxidative activity *in vivo* and functional characteristics of sesame seeds have increased the demand of sesame seed and caused a good liquidity of the crop globally. As a result, recently sesame production reached at the level of 4.3 million tons from 7.9 million hectares (FAO) with a gradual increase. Sesame is suitable for various cropping systems either as a main or second crop (Cagirgan 2001). But the major factors that limit its cultivation are seed shattering at maturity which requires manual harvest making it difficult to manage large areas of land, indeterminate growth habit and susceptibility to diseases (Ashri 1998; Cagirgan 2006; Cagirgan et al. 2009; Silme and Cagirgan 2010).

Among the diseases, phyllody is one of the major constraints of sesame production (Kolte, 1985), causing devastating yield losses in diverse low- and high-value crops worldwide (Klein 1977; Salehi and Izadpanah 1992; Kersting 1993; Nakashima et al. 1995; Al-Sakeiti et al. 2005; Akhtar et al. 2009). The major symptoms of the disease are floral virescence, phyllody and proliferation. Other symptoms which sometimes accompany the disease are yellowing, cracking of seed capsules, germination of seeds in the capsules and formation of dark exudates on the foliage. Abraham et al. (1977) noted that affected plants become stunted and the floral parts being modified in to leafy structures bearing no fruits and seeds causing yield loss up to 33.9 per cent.

In Turkey, sesame phyllody disease was first reported from the Aegean region in 1954 and the causal agent was thought to be a virus (Turkmenoglu and Arı 1959). Phyllody is caused by phytoplasmas discovered in 1967 and named mycoplasma-like organism (Doi et al. 1967; Ahrens and Seemüller 1992). Phytoplasmas belong to the class Mollicutes gram positive (low-G+C) bacteria that lacks cell wall with single membrane (Weisburg et al. 1989; Woese 1987; Hogenhout et al. 2008). Phytoplasmas cannot be cultured outside their hosts in cell-free artificial culture media, which are phloem-limited (Doi et al. 1967) and obligate symbionts of plants and insects. Affected plants from disease cannot produce healthy seeds due to abnormal floral growth that cause direct yield loss in sesame.

Insect vectors of phytoplasmas are classified in the Order Hemiptera mostly leafhoppers, plant hoppers and psyllids (Weintraub and Beanland 2006). Two different insects, *Circulifer* (=*Neoaliturus*) *haematoceps* (Mulsant and Rey) and *Orosius orientalis* (Matsumura) [=*albicinctus* (Distant)] were identified and reported as vectors of phyllody disease in Turkey (Baspinar et al. 1993; Kersting 1993; Sertkaya et al. 2007) and Iran (Salehi and Izadpanah 1992; Esmailzadeh-Hosseini et al. 2007). In India and Israel sesame phyllody is transmitted only by *Orocius albicinctus* (Kolte 1985; Klein 1977) but *Orosius cellulosus* was identified in Upper Volta (Desmidts and Laboucheix 1974). Apart from the insect vectors, sesame phyllody can be transmitted by dodder and graft inoculation. *Vinca rosea* is used as an effective indicator. It is widely believed that the disease is not transmitted by seeds. Lately, sesame phyllody phytoplasmas from Turkey were characterized both from infected sesame plants and vector *Orosius orientalis* by PCR-RFLP and they grouped in 16SrVI which reference phytoplasma in this group is clover proliferation (Sertkaya et al. 2007).

Although different management practices can affect the appearance of the disease by mismatching vector and plant growth cycle, it is difficult to apply. Control of the disease by killing the vectors by insecticides may be effective to some extent. Treatment of infected plants with an antibiotic (Akhtar et al. 2009) might be another but ineffective possibility. Consequently identification of useful resistance sources to phyllody beyond the wild relatives of sesame such as *Sesamum alatum* remains as an important task of the sesame breeding program aiming at developing cultivars resistant to phyllody. Cagirgan (unpublished) observed nonoccurrence of phyllody disease on true determinate mutants in his breeding nurseries. The detailed studies on the nature of the resistance in this material are underway by Dr Ozdemir of Adnan Menderes University and her team (personal communication).

The aims of the study were (i) to showcase that climate variability can be of positive impact on the nonoccurrence of a normally devastating vector-borne disease, sesame phyllody, (ii) to compare the incidences of phyllody in different growing conditions and (iii) to describe main symptoms associated with the disease in a Mediterranean climate.

MATERIALS AND METHODS

Environmental and growing conditions

The studies were based on the planned activities in 2009 and 2010 and previous observations which drove us to fight against phyllody since 1994 where sesame started to be grown in a travertine soil after having cleared the rocks at a rooting depth gradually in the campus of Akdeniz University, Antalya, Turkey. The altitude of the research field from sea level is approximate 51 m and is located at 30° 44' E and 36° 52' N. It has a typical soft Mediterranean climate with long hot and dry summers, and mild winters. Most of the rainfalls occur in the winter. Since the effect of the global climate change and variability has been clearly felt and the climate data for the last two years (2009 and 2010) and for long term were obtained to reveal climate variability in rainfall (mm), temperature (^{0}C) and relative humidity (%) (Fig.1-3). Plants were irrigated by sprinklers as the plants need. Normal agronomic practices were applied as described elsewhere (Cagirgan 2006) except the 3rd group of the material, which was grown from transplanted seedlings, which were raised in a seedling growing company's facilities before transplanting.

Plant material

The studies on phyllody was based on the plant material of the sesame breeding program as part of Antalya Mutation Project at Akdeniz University which composed of three groups of plant material in the course of study. (*i*) First group was agronomic performance trials with 4-replication arranged in randomized complete blocks design grown in two years (2009 and 2010). These experiments were sown in the middle of June in the regular second crop planting period. This group provided the data for the years showing clear-cut presence or absence of the disease for the two years. (*ii*) Second group of the material was the M_2 families of the sesame cultivar "Birkan" irradiated with 300 Gy of gamma rays and grown as M_1 plant progenies of 2,500 in total, which was planted very late, beyond the agroecological practice, in August 2010. This group provided the data on the delayed-occurrence of the disease caused by the climate variability unusually prevailed in the year 2010. (*iii*) Third and last group was the F_1 and F_2 nurseries, and advanced breeding material planted at the same time with the first group in the regular second crop sowing time in 2010. After the harvest of the F_1 and F_2 nurseries by cutting the plants, some heterozis or vigority induced ratoon development provided young plantlets on which phyllody developed. So this group was used to compare with the late-sown M_2 families.

Incidence and symptomatology

Incidence is defined as the number of plant units showing phyllody symptoms in relation to the total number of plants examined. Percentage disease incidence values were determined, in the first and second groups of plant material, by dividing the number of diseased plants by the total number of plants observed. In 2009, observations for sesame phyllody were done at the harvest of the agronomic performance trials as the routines of the data sheet. However, in the following year, in 2010, we started it from flowering, in order to showcase the disease incidence for a training purpose. The first case became visible in the M_2 families after flowering. Both symptomatic and asymptomatic plants were tagged at different growth stages. All plants were surveyed for the known symptoms of phyllody disease and tried to distinguish new ones which might be specific to the region and the material studied. Also observation was made on the regenerated plantlets from stubbles after harvest by cutting of F_1 plants. Observations were also made on the left (unselected) plants in the field of the F_2 populations. The total area grown sesame where phyllody incidence was observed was 0.4 ha.

RESULTS AND DISCUSSION

Climatic parameters in relation to disease incidence

The vegetative growth period of sesame in 2010 after sowing had relatively higher rainfall (Fig 1) in comparison the previous year, 2009, and to the last ten years average which caused also cooler temperatures (Fig. 2) and higher humidity (Fig. 3). Consequently, the year 2010 became a unique year in terms of climatic parameters differentiating from the previous and group of other 10 years.

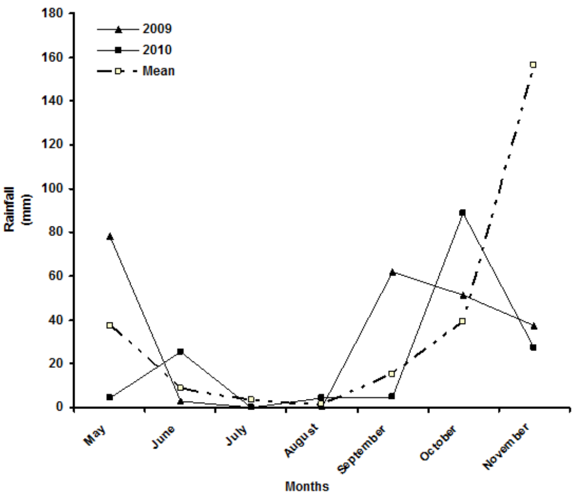

Figure 1. Monthly total rainfalls (mm) in 2009, 2010 and average of last ten years.

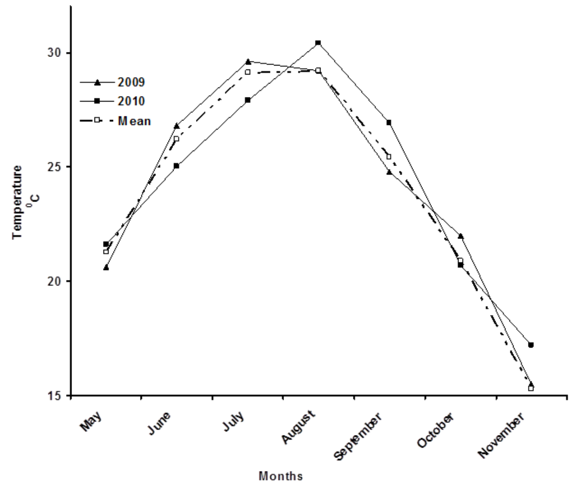

Figure 2. Monthly averages of temperatures (^{0}C) in 2009, 2010 and average of last ten years.

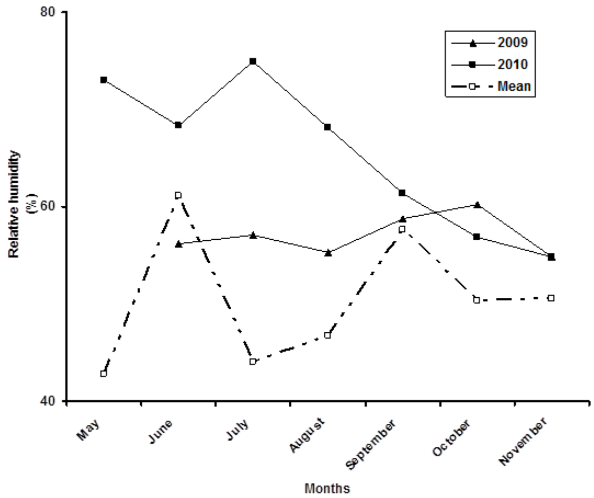

Figure 3. Monthly averages of relative humidity (%) in 2009, 2010 and average of last ten years.

Material group 1. As a requirement for official second crop registration trials which were set up and grown in the normal growing seasons of 2009 and 2010, phyllody incidence data were collected for each trials and incidence were determined, which were 6% in 2009 and 0% in 2010 (Table 1).

Table 1. Incidence (%) of phyllody disease in Antalya

Years	Incidence (%) (Timely sowing)
2009	6
2010	0

Clearly there was no any event of phyllody in 2010, which was attributed to the unusually cool sowing and vegetative growth season. Since 1995, when the field opened to cultivation by clearing the rocks at the university campus in order to grow sesame, phyllody has always occurred at any rate (The first author's observations) until the normal growing season of sesame in 2010, which was suddenly disappeared.

Material group 2: The breeding nurseries of F_1 and F_2 also did not show any infected plant with phyllody symptoms within normal growing season until harvest which was done by cutting the plants of F_1 and capsule harvest of the F_2 plants. Upon observing some phyllody events in the regenerated branches in the stubbles of cut plants (of F_1s especially) and unselected left-plants of F_2, we focused on again incidence of phyllody. Consequently a comparative study between cut plants and left plants for the incidence was done (Table 2), more phyllody disease in the cut plants (39 %) was observed than in the left plants (13.18 %). It should be added that incidence was gradually increased and it was highest in cut plants (39 %) because of the F_1`s genetic structure. It should be underlined that all these events occurred after harvest. Material group 1 dried down after harvest but very few regenerated branches appeared showing also some phyllody symptoms (data not shown).

Table 2. Comparative incidence of the phyllody disease on regenerated branches of the material group 2 (breeding nurseries F_1 and F_2) grown in 2010

After harvest	Incidence
Regenerated branches in the stubbles of cut plants	39.0
Regenerated branches in the unselected left-plants	13.2

Material group 3: In the M_2 families, incidence of phyllody disease increased from October to November passing from 1.44 to 3 % (Fig. 4), which were sown beyond the agronomic practices.

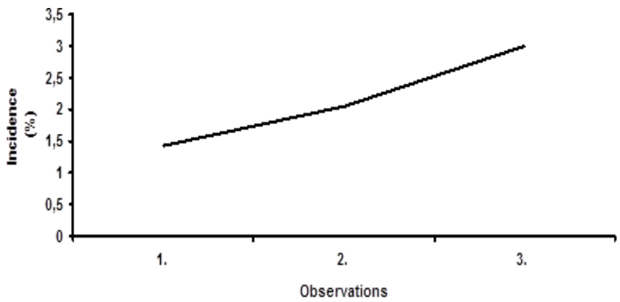

Figure 4. Phyllody incidence by time in the M_2 Population.

The incidence varied depending on the period of observation. The incidence were high in normal season (6%) compared in very late season (3 %). That means late sowing reduces disease incidence. The same observation was made by Raychaudhuri and Nariani (1989). As observed by the first author, in 2009, The Sesame Main

Crop Variety Registration Trial set up at the West Mediterranean Agricultural Research Institute in Aksu, Antalya had to be cancelled due to the fact that a devastating effect of the phyllody incidence occurred in the sesame plots.

In cut plants (Fig. 5f) the major new coming branches showed phyllody disease. This observation can be explained by either the latent period or presence of phytoplasmas in insufficient quantities to induce disease before harvesting. Indeed, according to Hogenhout et al. (2008), symptoms can develop 7 days after introduction of the phytoplasma to plants by the insect vector, but can take much longer, depending on the phytoplasma and plant species. The latent period, i.e. the time between initial acquisition of the phytoplasmas by the insect vector from plants and the ability for the insect to introduce phytoplasmas back into plants, can vary between 7 and 80 days (Moya-Raygoza and Nault 1998; Murral et al. 1996).

Regarding the question of occurrence of phyllody with the start of sesame cultivation in the field and observing phyllody in the same year, the answer is simple because vectors were available to infect sesame and inoculum was available around wild crops when one consider that no seed transmittance of the inoculum. Indeed, we observed phyllody in jute (*Corchorus olitorius* L.), for the first time in 2010 which was grown as weed (Cagirgan et al. 2010, unpublished) in the sesame field coinciding with sesame phyllody appeared in the late sown material. We expect that it should be affected by the same phytoplasma and molecular diagnostic studies are underway. Furthermore, the sesame breeding material in 2010 was forwarded from 2009 which was F_0 and $F_{1,}$ suggesting no seed transmittance but availability of inoculum and vectors in a proper host period. Also, to avoid outcrossing to produce the elite seed of a new variety, `Birkan`, the first author (unpublished) grew sesame in 2009 in Kizilkaya, (in Burdur province, Turkey) where there was no any sesame grown for last 20 years, if any at gardens. Interestingly highly phyllody incidence was noted, suggesting that phytoplasmas were available in neighboring wild plants; and also in the availability of the vectors, the incidence could occur. Indeed, phytoplasmas, as the cause of phyllody, are insect-transmitted plant pathogenic prokaryotes associated with serious diseases in widely grown crops such as corn, sugar beet, oil-seed crops fruit trees grapevine, and vegetables (Klein 1977; Salehi and Izadpanah 1992; Kersting 1993; Al-Sakeiti et al. 2005, Sertkaya et al. 2007; Akhtar et al. 2009). There is no doubt that plant diseases are a significant constraint to the crop production. However, climate change could have positive, negative or no impact on individual plant diseases. Variability in the weather conditions influences all stages of host and pathogen life cycles as well as the development of disease as in the study. It is therefore clear that a virulent pathogen cannot induce disease on a susceptible host cultivar unless weather conditions are not suitable as also suggested by Chakraborty et al. 2000. As a raising cash crop in underdeveloped countries where hand labor is inexpensive to afford harvest costs, farmers can make money from sesame and buy food to feed the hunger.

Symptomatology

Three main types of phyllody disease symptoms were observed in the field; i.e., `virescence`, `phyllody` and `proliferation` in flowers (Fig. 5). But `virescence` and `phyllody` were recorded more frequently than the floral `proliferation`. From these main symptom classes, `phyllody` is the production of leafy structures in place of corolla in flowers (Fig. 5a); `virescence` is the color change of corolla from white (or pink) to green (Fig. 5b); and `proliferation` is the symptom resembling witches' broom (Fig. 5c). Affected plants from the disease could not produce healthy fruits called capsules and healthy seeds in it, if any. Similar symptoms were reported in Iran, Israel, Oman, Pakistan, Thailand and Turkey (Choopanya 1973; Klein 1977; Salehi and Izadpanah 1992; Baspinar et al. 1993; Akhtar et al. 2009).

Regenerated branches in the stubbles of cut plants showed `phyllody` (Fig. 5f) and `virescence`, but the major late-coming branches of the unselected left plants showed only `virescence` (Fig. 5g) symptoms. To our best knowledge, there is no study reporting phyllody and its symptoms in the regenerated branches of sesame.

Phyllody infected plants were observed to be varied in size and form that may be due to different time of infection as also reported previously by (Akhtar et al. 2009; Klein 1977). Further, Fig. 5c originally exemplify and compare a late-period infected plant`s flower, (that requires careful inspection otherwise seems to be as if a healthy-looking one), with a normal non-infected healthy plant. When closed up, it was become clear that infection prevented functioning of the filaments and they stayed low and caused `pin type` flower (Fig. 5d). Some indirect symptoms in the infected plants such as powdery mildew and formation of exudates on the foliage in M_2 families (Material group 3) were high in frequency. Vivipary (germination of seeds in the capsules symptoms), and yellowing were also noticeable. The time of infection affects severity of phyllody disease. Infections in early stages of plant grow had severe symptoms on whole plant and plants infected during flowering had severe symptoms on the upper part of the plant (Akhtar et al. 2009). Klein (1977) observed that plants infected early showed symptoms such as stunting, reduction of leaf size, short internodes.

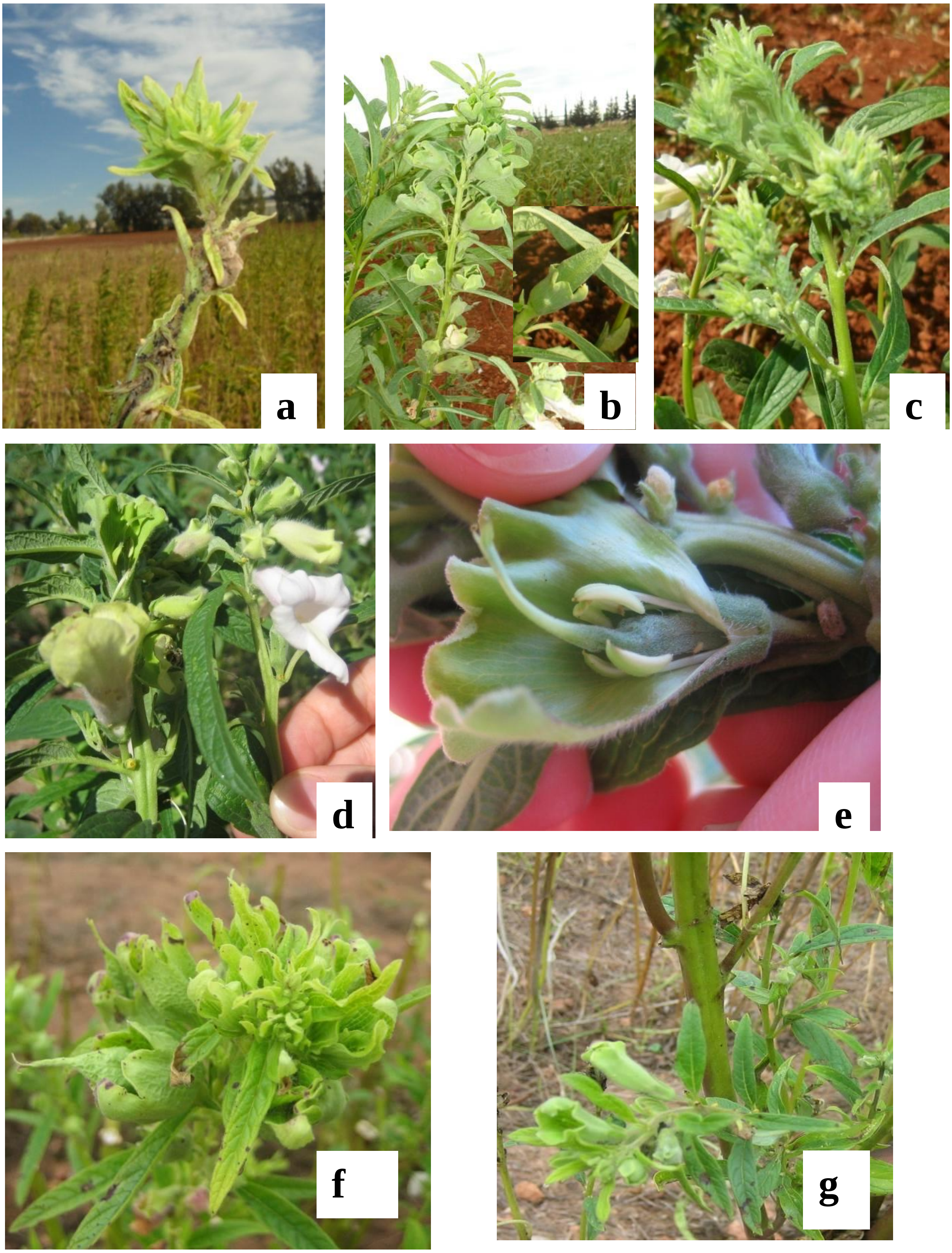

Figure 5. Different symptoms of phyllody disease**:** Phyllody (a), virescence (b) and Proliferation (c). Healthy (white) and infected flowers (d). Non-functioning filaments under Virescence (e). Late phyllody disease occurrence with `phyllody` symptom on regenarated branches on stubbles of cut-plants (f) and with `virescence` symptom on the regenerated branches of unselected left-plants (g).

It should be remembered that high occurrence of the indirect symptoms in the study should be driven by the late sowing of the nursery beyond the normal sowing time. Some symptoms such as germination of seeds in the capsules, yellowing, and cracking of seed capsules and formation of dark exudates on the foliage have been previously reported (Akhtar et al. 2009; Salehi and Izadpanah 1992).

This study revealed a unique case of nonoccurrence of phyllody disease by interrelating local climate variations in the West Mediterranean Region of Turkey. Specifically, it also analyzed the local climatic variables and the incidence of phyllody during 2009 and 2010 based on observations on the occurrence of phyllody during last 15 years. The results showed that the higher rainfalls in frequency and its cause to lower temperatures but higher humidity were the reasons strongly related to dis-occurrence of the disease as such a unique year, 2010.

Climate change and variability could significantly affect plant diseases transmitted by vectors. Precipitation, temperature, and relative humidity, among other climatic factors, are known to affect the occurrence of the disease and reproduction, development, behavior, and population dynamics of the insect vectors transmitting these diseases. Whether climate changes increase or decrease the incidence of a plant disease will depend not only on the actual climatic conditions but also on local non-climatic epidemiologic and ecologic factors. Although prediction of the specific impact of sustained climate change on phyllody diseases is difficult, its effects should be more complex by changing the balance vector-host-pathogen and should not be worse in every case as long as increasing efforts on adapting to the effects of climate change and developing locally appropriate strategies and tactics to control and prevent diseases.

In conclusion, this study clearly revealed that the influence of climate variability, appeared as a unique one, on the occurrence of phyllody disease transmitted by vectors and provided an example of the case that impact of climatic variability would not always be negative, specifically when dealing with vector-borne diseases which needs better understanding of the variability effects of alterations of vector–host–pathogen relationships under conditions of sustained climate change. This is an example on how a cool and rainy vegetative growth unmatched with the vector's cycle to develop phyllody in the regular cropping season.

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