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Seasonal dynamics of aphids on lemon (*Citrus limon* (L.) Burm. f.), orange (*C. sinensis* (L.) Osb.) and clementine (*C. clementina* Hort. ex Tan.) in Skikda (Algeria)

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Abstract
Aphids are important pests of many cultures in different regions worldwide. In this study, aphids and their seasonal dynamics were compared between three citrus species (orange, lemon and clementine) from an orchard composed of different citrus species, situated in Skikda (Northeast of Algeria). We sampled monthly, from January 2012 to December 2013, shoots or leaves from each species. Then we counted the number of aphids, aphid mummies and predators. We identified, during the investigation, four aphid species in total. The most abundant species observed was *Aphis spiraecola*. Moreover, the lemon trees were relatively the less infested species by aphids. On the other hand, this study showed the variability of the infestation degree by aphids between years. Nevertheless, we noted the highest levels of aphids in either spring or autumn. Thus, the monitoring of aphids should be carried out through the year in order to control these pests efficiently.

Keywords: citrus aphid, sweet orange, lemon, clementine, infestation degree, climate change

1. Introduction
Commercial citrus fruits fall into several main groups such as sweet oranges (*C. sinensis* (L.) Osb.), clementines (*C. clementina* Hort. ex Tan.) and lemons (*C. limon* (L.) Burm. f.) [1]. Citrus grown in tropical and subtropical regions is the largest fruit crop in the world [2]. The world production of citrus fruits is estimated at around 100 million of tones [3].
Citrus has been utilized in more medicinal preparations than majority of other plants and finds its use in the remedy of scores of ailments ranging from toothache, diarrhea, constipation, insomnia to vomiting [4].
As in many countries, the citrus fruits have an interesting socio-economic role in Algeria. In 2013, the harvested area was 41 382 ha for orange; 12 115 ha for tangerines, mandarins, clementines and Satsuma; and 3 897 ha for lemons and limes [5]. Besides, the citriculture employs on average 140 days/ha/year, without counting those generated by the environment of this sector (transformations, commercialization) [6].
Several pests and diseases, such as Tristeza and aphids, can reduce citrus production and cause significant damage when conditions are favorable for these enemies. Tristeza caused by the *Citrus tristeza virus*, spread to most citrus production areas, devastating citrus plantations in America several decades ago and then in many parts of the world, including Mediterranean countries such as Spain [7]. It is a quarantine disease [8]. The contamination happens by grafting and also by vectors (aphids) such as *Toxoptera citricidus* Kirkaldy, *T. aurantii* B., *Aphis spiraecola* Patch and *A. gossypii* Glover [9].
Aphids are among the most interesting, unusual, and thoroughly studied of all insect groups [10]. There are 4000 species of aphids in the world of which about 250 are serious pests of agriculture in world [11]. They differ from other plant sucking bugs of the Aphidoidea in that the females of at least a few generations are parthenogenetic and viviparous [12]. Aphids are important pests of various plants. During ingestion of nutrient compounds from phloem sap, aphids inject salivary toxins and transmit virus diseases [13]. Moreover, the injections of citrus aphids cause a characteristic winding of leaves, and slows branch growth [14].
Generally speaking, it is very difficult to give a precise assessment of the potential economic losses due to aphids [15]. The economic impact of each species depends on the type and extent of the damage caused and the economic importance of the host [16].

The knowledge of the aphid fauna of North Africa at the start of 21st Century is very scanty because of principally two factors: (i) the shortage of faunistic studies in the zone and (ii) the dispersion and antiquity of the aphid bibliography in some countries [17]. The present study was designed to provide data on citrus aphids including the determination of different aphid species attacking orange, lemon and clementine trees on one hand, and their relative abundance on the other hand that might be used for developing pest management strategies.

2. Materials and methods

2.1. Sampling

In 2012 and 2013, samples were taken every month from a citrus orchard in northeastern Algeria (Skikda) (36° 42' N, 6° 47' E), planted with approximately 15-year-old citrus trees. 3 citrus species were monitored: 'Washington Navel' sweet orange (*Citrus sinensis*), 'Eurika' lemon (*C. limon*) and clementine (*C. clementina*). On each sampling date and for each citrus species, we counted aphids (nymphs + adults) and their enemies on one shoot on 5 randomly selected trees during the first year of the study; and on 4 leaves per tree of 4 randomly selected trees during the second year.

2.2. Identification

Aphids, collected and then preserved in ethanol, were identified using identification keys of Blackman and Eastop [18] and Stoetzel [19].

2.3. Data analysis

Differences in numbers of aphids in each sampling date between citrus species were analyzed by ANOVA using SPSS program (IBM, version 10.0.5). Microsoft Excel 2007 was used to draw graphs.

3. Results and Discussion

3.1. Aphid species

During 2 years of investigation, four different aphid species in total were determined (*Aphis spiraecola*, *A. gossypii, A. nerii* and *Myzus persicae*) including 4 on clementine, 3 on orange and 2 on lemon (Tables 1 and 2).

Table 1: Aphid species identified in the studied orchard during 2012. ++ Less dominant species; +++ Dominant species

	'Washington Navel' Sweet orange	'Eurika' Lemon	Clementine
Aphis spiraecola (Patch, 1914)	+++		+++
Aphis gossypii (Glover, 1877)	++	+++	

Table 2: Aphid species identified in the studied orchard during 2013. + Rare species; ++ Less dominant species; +++ Dominant species

	'Washington Navel' Sweet orange	'Eurika' Lemon	Clementine
Aphis spiraecola (Patch, 1914)	+++		+++
Aphis gossypii (Glover, 1877)		+++	++
Myzus persicae (Sulzer, 1776)		+	+
Aphis nerii (Boyer De Fonscolombe, 1841)	++		+

Our findings are consistent with the results of the earlier studies that also indicated differences in aphid species between infested orange, lemon and clementine [20] and between attacked orange and clementine [21].

The aphid species detected in this study have an immense importance worldwide. *Aphis gossypii* is a cosmopolitan polyphagous aphid that found in all temperate, subtropical and tropical regions. It attacks numerous ornamental plants and citrus [22]. Likewise, *A. nerii* is widely distributed in the warmer regions of the Old and New World, plus the tropics and subtropics [10]. Holman [23] reported more than 50 plants attacked by this pest. Moreover, spirea aphid *A. spiraecola* (formerly known as *A. citricola* Van der Goot), reproduces parthenogenetically throughout the season, and may spend the summer on alternate (noncitrus) host plants [24]. Additionally, the green peach aphid *Myzus persicae* is a very important pest on many crops in many parts of the world. It can transmit over 100 virus diseases of plants in about thirty different families [25].

The most abundant species observed in our study was *Aphis spiraecola*, and with lower degree *A. gossypii*. They attacked the three examined species. Mostefaoui *et al.* [26] explained the higher abundance of *A. spiraecola*, comparing with *A. gossypii*, by a better tolerance to high proline contents of clementine, and a better conversion of foliar energy metabolites. *A. spiraecola* and *A. gossypii* are considered, for many years, among the most important citrus pests in the Mediterranean, in the three citrus species (orange, clementine, lemon) [27].

3.2. Aphid population dynamics

ANOVA analysis showed significant differences, in the infestation levels between screened citrus species, in October ($P = 0.045$) and in November 2012 ($P = 0.030$), and in March ($P = 0.007$), April ($P = 0.029$), September ($P = 0.014$) and October 2013 ($P = 0.016$). In most cases where the significant differences were noted, the lemon was the less infested species. For the rest of months, there were no significant differences between citrus species ($P > 0.05$). It seems that the most infested species (clementine and orange) presented adequate nutritive quality in these periods, characterized by the production of new shoots and appropriate climatic conditions.

In general, clementine was the most infested species with 1596 and 3541 aphids in 2012 and 2013 respectively, followed by sweet orange (1119 and 3836 aphids) and lemon (534 and 1353 aphids). Accordingly, Roistacher *et al.* [28] recorded fewer aphids per cm^2 of leaf area on young lemon leaves compared to young leaves of sweet orange. However, Marroquín *et al.* [29] found that clementine was the most visited species followed by lemon, then sweet orange.

We remarked changes in aphids' populations within the year. Figure 1 shows population dynamics of citrus aphids during 2012, reached to its highest peak in November for orange and clementine (X = 208.8/shoot and X = 126.4/shoot respectively) and in April for lemon (X = 68/shoot).

During the second year of the study (Figure 2), the maximum density of aphids was recorded in April for orange (X = 85.75/leaf), in July for lemon (X = 31.88/leaf) and in September for clementine (X = 70.69/leaf).

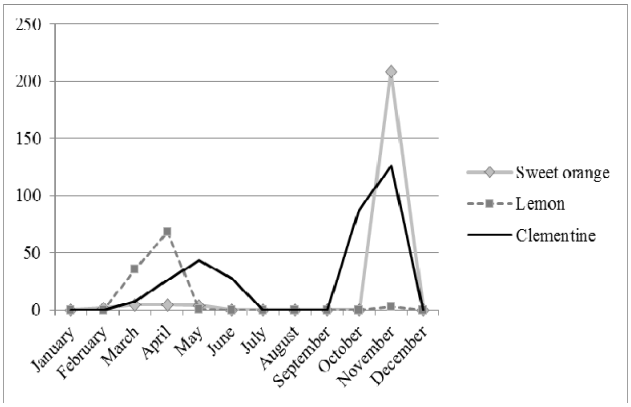

Fig 1: Monthly fluctuations of aphids in the studied citrus orchard from January to December 2012. Values indicate mean number of aphids per 5 shoots

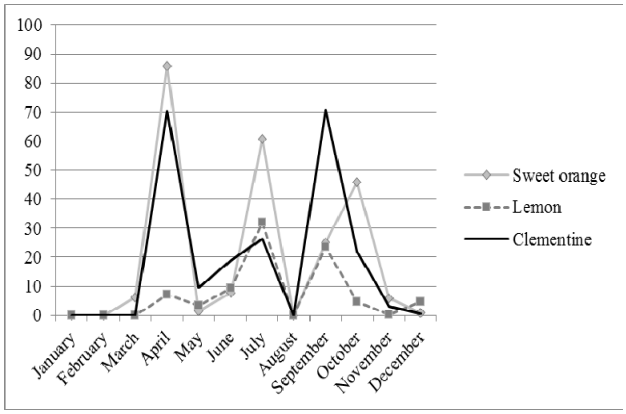

Fig 2: Monthly fluctuations of aphids in the studied citrus orchard from January to December 2013. Values indicate mean number of aphids per 16 leaves

Although, there was some degree of infestation in some months of summer and winter, we observed that the highest levels of aphids were concentrated in spring and in autumn, which coincide with the apparition of new flushes and moderate temperatures.

Saharaoui and Hemptinne [30] revealed that the spring flush of growth of lemon is the most infested by aphids.

On the other hand, we remarked an increase in the number of the identified aphid species from two in 2012 to four in 2013 (Tables 1, 2). In addition, we detected changes in the number of aphids between years (Figures 1, 2). For example, no aphids were installed on citrus trees in five months during the first year of the investigation (January, July, August, September and December) and only in three months during the second one (January, February and August). Similarly, Powel *et al.* [31] found changes in spirea aphid populations, on sweet orange, between years.

The failure of models to predict aphid population dynamics for practical purposes is due to the extremely wild oscillations in aphid numbers caused by intrinsic (size, fecundity, mortality, migration rate) and external factors (weather, especially temperature) [32]. Temperature has the major effect on the biology and life cycle of aphids [33]. Aphids can produce 1-5 generations more with an increase a 2ºC in a temperature [34]. A significant increase in mean temperatures during winter and spring will induce earlier growth of new shoots and aphid infestations in citrus [35]. Phenological observations in the temperate regions have shown that the bud break, flowering and fruiting in most fruit trees have advanced by several days [36]. Aphids are affected not only by increases in temperature and greenhouse gas levels, but also by changes in the landscape due to agricultural policies and by atmospheric pollution [37].

However, it is a very difficult task to draw a general conclusion about how aphid performance is likely to respond to the predicted global change scenario based on empirical studies [38].

3.3. Aphid enemies

We found mainly Hymenopterans as parasitoids, and syrphid larvae as predators of citrus aphids. During 2 years of this experiment, we recorded a low number of auxiliaries (Table 3).

Table 3: Abundance of aphids enemies detected in the studied citrus orchard during 2012 and 2013

	During 2012		During 2013	
	Predators	**Parasitoids**	**Predators**	**Parasitoids**
Sweet orange	1	0	6	32
Lemon	0	1	4	0
Clementine	6	3	8	1

Broadly speaking, the second year registered the highest level of aphid enemies. This result seems to be due to changes in climatic conditions especially the temperature. Dixon *et al.* [39] mentioned that changes in environmental conditions will have direct effects on the pests themselves and also on the biotic factors that regulate their populations, such as arthropod predators and parasitoids. Weathersbee *et al.* [40] highlighted the influence of temperature on the development of a parasitoid on five citrus cultivars. Furthermore, parasitism is a relatively minor source of mortality for *Aphis spiraecola* [41].

We recorded the lowest number of aphid enemies on lemon (only 1 parasitoid and 4 predators during two years). This may be explained by the lowest quantity of hosts (aphids) recorded also on this tree species.

4. Conclusion

According to our results, citrus aphids showed extremely variable changes within year and between years. The less infested tree was lemon. Consequently, these pests should be regularly investigated, particularly on clementine and orange, to precise the periods of their intense activity in order to control them efficiently. Furthermore, the low number of auxiliaries detected involves the test of biological control with local and introduced enemies of citrus aphids.

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