

The impact of Sharav weather conditions on airborne pollen in Jerusalem and Tel Aviv (Israel)

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Abstract Pollen grains have been a major focus of research mostly in temperate regions due to their effects on human health, especially allergies and asthma. The current study investigates a subtropical region characterized by a Mediterranean climate where Sharav conditions are experienced during the spring and autumn. The aim of the current study was to investigate whether Sharav conditions impacted airborne pollen concentrations of allergenic *Amaranthaceae*, *Poaceae*, *Morus*, *Pinus*, and *Quercus* more than standard Warm days during the main pollen seasons in the years 2010–2014 in Tel Aviv and

Jerusalem (Israel). Slight variation was observed between the main pollen seasons in Tel Aviv compared to Jerusalem resulting from differences in temperature and relative humidity percentages. Additionally, more Sharav conditions occurred in Jerusalem than in Tel Aviv during the study period. The highest pollen concentrations occurred during Sharav days for *Amaranthaceae*, *Poaceae*, and *Pinus* but not for *Morus* and *Quercus*. Therefore, individuals who are allergic to *Amaranthaceae*, *Poaceae*, and *Pinus* pollen, and exposed to high pollen concentrations during Sharav days, might suffer more allergy symptoms than on Warm days.

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Morus · *Quercus*

1 Introduction

Over the past few decades, a considerable amount of research has been channeled toward the study of bioaerosols, airborne particulate matter of biological origin, that have been implicated in a broad range of adverse health effects (Douwes et al. 2003; Goyer 2001). Airborne microorganisms, including pathogenic viruses, bacteria, and biological particles, such as pollen and fungal spores, have gained much attention due to their hazardous effects on human health as they

lead to infectious diseases, acute toxic effects, pneumonia, cancer, and allergies such as rhinitis, conjunctivitis, and asthma (Blachere et al. 2009; Bousquet and Khaltaev 2007; Burge 1995; Douwes et al. 2003; Seemungal et al. 2001). An additional hazard of bioaerosols is embodied in their potential spread within a short period over a wide area due to their ability to remain suspended in the atmosphere for a medium–long time, depending on their settling velocities (Kang et al. 2014; Hong et al. 2015).

1.1 Pollen allergy risk

Several studies have been carried out in different areas in Israel in order to define the pollen allergen risk. Each focused in a single area and examined different types of pollen and various influences. Those studies found that some pollen grains stay around most of the year, and hay-fever patients experience minor symptoms beyond the peak season (Geller-Bernstein et al. 2001). Sensitivity to different pollen types varies from place to place depending on the environment. For example, Zeldin et al. (2008) found that 43% of the patients with allergic rhinitis were sensitive to trees, 40% to weeds, and 53% to grass. But there were no significant differences in the prevalence of sensitization to any of the evaluated allergens except for weeds, which was higher in the arid region. In Netzer Sereni, located between Tel Aviv and Jerusalem, 50% of the atopic residents were symptomatic and most prevalent allergenic pollen in the air was trees such as pecan, palm, olive and cypress, grass and weeds (Rachmiel et al. 1996).

Two of the five pollen types in the current study have been previously investigated in Israel: Poaceae (Rachmiel et al. 1996; Waisel et al. 2004) and Amaranthaceae (Waisel et al. 2007). *Quercus* was surveyed in Israel. Over the years, *Quercus* pollen identified and counted at the monitoring stations in Tel Aviv and Jerusalem. Three species of *Quercus* were identified and were characterized in Israel's native flora: *Quercus ithaburensis* Decne., *Quercus calliprinos* Webb, and *Quercus infectoria* var. *veneris* (A.Kern) H.Lindb. The three species bloom in early spring (March–April) with a great difference between the flowering dates of these species, and among individual trees growing in various habitats. But the frequency of allergic reactions to oak pollen and their strength has hardly been studied in Israel (Waisel et al. 2007).

Poaceae pollen is known to have a strong influence on those who are sensitive to grass pollen, which may be manifested by severe symptoms. Its pollen is light and carried in the wind sometimes for long distances. The threshold level of Poaceae pollen concentrations in the air is very low; 3 pollen grains per cubic meter of air may cause allergic symptoms in sensitive people (Rachmiel et al. 1996).

Amaranthaceae is represented by some species of desert plants as well as others in the prairie. Some species are also present in courtyards of houses and in urban gardens. Some species from the Amaranthaceae bloom in spring, others from spring till end of the autumn. *Chenopodium* species flower during autumn. Different frequencies of sensitization to *Chenopodium* pollen have been observed, with 30% in the coastal plain and near 90% in the prairie. Distribution of Amaranthaceae is limited, but since they are abundant in the country near human residences, they have an additional contribution to allergy (Waisel et al. 2007). Laor et al. (1993) found that the coastal region of Israel has a higher prevalence of asthma than inland regions, probably due to the dampness and low altitude. But they did not observe any pollen. However, Zeldin et al. (2008) found that in the arid region the prevalence of sensitization to weeds was higher than in the coastal region.

1.2 Relationship between airborne pollen and meteorology

Some studies have been conducted around the world examining the relationship between meteorological parameters, such as temperature and relative humidity with airborne pollen grains. A positive correlation has been found worldwide between rising temperatures and rising allergenic pollen concentrations (e.g., Ayres et al. 2009; Bergmann 2016). Studies conducted in the Mediterranean Region have shown not only positive correlations between pollen concentrations and temperature but also negative correlations with relative humidity (Alcázar et al. 2009; Aboulaich et al. 2013; Garcia-Mozo et al. 2007; Helfman-Hertzog 2011; Moreno-Grau et al. 2000). A few studies conducted in the temperate, eastern or western Mediterranean regions have shown contrasting results; positive correlations with relative humidity and negative correlations with temperature were found for *Morus* in Bodrum, Turkey (Tosunoglu and Bicakci 2015), *Quercus* in Córdoba, Spain (Garcia-Mozo et al. 2007), and *Pinus* in Adana, the east

Mediterranean coast of Turkey (Altintas et al. 2004). Aerobiology in the tropics and subtropics has been poorly analyzed to date despite having a significant portion of the world's population (Moreno-Sarmiento et al. 2016). Most of Israel, the focus of the current study, is characterized by a Mediterranean climate, but during the spring and autumn seasons the country experiences Sharav conditions.

The Eastern Mediterranean climate is semiarid, occurring in a narrow transitional zone between humid and arid climates. It is associated with a well-defined precipitation pattern of winter rains related to the cyclonic activity created or intensified within the Mediterranean Basin (Gat 1982). Köppen (Kottek et al. 2006) defined the Mediterranean climate (Csa) as one in which the mean temperature of the coldest month is between -3 and 18 °C, the summer is dry, and the amount of rainfall during the wettest month is at least three times greater than that of the driest month; the mean temperature of the warmest month is above 22.8 °C; and the mean annual rainfall amount (mm) ratio is higher than 20 times of the mean annual temperature (°C). In this climate zone, rain mainly occurs during the winter, while the summer is dry.

The spring and autumn of Israel are influenced by Sharav cyclones (also known as Sirocco, Ghibli, Simoom, and Khamsin); they are hot continental-tropical depressions formed over North Africa, south of the Atlas ridge. Their tracks lie mainly along the North African coast, shifting to the north near the southeastern Mediterranean (Alpert and Ziv 1989). These cyclones instigate warm and dry weather conditions in areas over which they move (Air Ministry Meteorological Office 1962; Alpert and Ziv 1989; Winstanley 1972). Sharav conditions in the eastern Levant are observed during the phase when wind blows from the eastern sector (southeasterly–easterly–northeasterly), they are characterized by hot and dry conditions (Bitan 1983), and they are accompanied by frequent dust and sandstorms (Saaroni et al. 1998). The winds veer from strong easterly to southerly winds, with southwesterly winds when the Sharav ends (Alpert and Ziv 1989; Winstanley 1972).

Sharav is most common during the spring (Bitan 1983), peaking in April (Alpert et al. 2004a). Sharav in Israel can be described by two factors: region (coastal plain and the mountains) and condition (light or

intense). The Israel Meteorological Service (IMS; cited by Goldreich 2003) defined light Sharav conditions: coastal plain: $30\% < RH_i \leq 50\%$; mountains: $20\% < RH_i \leq 45\%$; and intense Sharav conditions (coastal plain: $RH_i \leq 30\%$ and $T_i > \bar{T}$; mountains: $RH_i \leq 20\%$ and $T_i > \bar{T}$). Hence, the cities participating in this study are representative of these two areas. Sharav conditions defined by regional factor are characterized by relative humidity below 50% in the coastal plain (Tel Aviv) and below 45% in the mountains (Jerusalem). The typical duration of a Sharav cyclone ranges from few hours to 24 h due to the front's quick passage (Saaroni et al. 1998), and the affected area is relatively small (200–500 km) (Alpert et al. 2004a, b). The number of Sharav events varies in different studies as a function of different methods and models by which Sharav conditions are defined. Saaroni et al. (1998) identified 34 Sharav days during 1983–1988 in the eastern Mediterranean basin and the Levant region; Alpert et al. (2004b) identified 4, 9, and 3 Sharav days in 1970, 1985, and 2000, respectively, in the eastern Mediterranean, and Dayan et al. (2012) identified 21 Sharav days during 1995–2004.

The same meteorological parameters that define Sharav conditions, namely high temperature, low relative humidity, and southerly or easterly dry wind, also influence pollen release. While the microbial content of dust storms affecting the Israeli region remains almost unknown (Grishkan et al. 2012), it is known that the particulate matter during dust storms is associated with an increased risk of acute coronary syndrome in Israel (Vodonos et al. 2015), as well as hospitalizations of patients (Ebenstein et al. 2015) and chronic obstructive pulmonary disease and respiratory mortality in Iran (Khaniabadi et al. 2017). However, during sandstorm dust in Riyadh, viable fungi, including yeasts, were the most frequent, along with pollen from *Acacia*, *Prosopis*, *Washingtonia*, *Chenopodium*, and *Rumex* (Kwaasi et al. 1998). To date, however, no studies have investigated the effects of Sharav on airborne pollen concentrations in Israel. Therefore, the current study was undertaken to study the impact of Sharav conditions on the release of pollen in two sites located in both the coastal area of Israel (Tel Aviv) and the mountainous inland of the country (Jerusalem).

2 Material and methodology

2.1 Study area

The study was carried out in two different areas (Fig. 1). One air sampling station was located in the city of Tel Aviv (latitude 32°06'N, longitude 34°48'E, and 40 m a.s.l.), which is characterized by a Mediterranean climate with temperate winters (13.9 °C in January), humid hot summers (27.8 °C in August), and annual rainfall of 583 mm (average data from 1981 to 2010). The airborne pollen sampler was situated in the botanic gardens of Tel Aviv University near the center of the city, at a distance of 2.8 km from the coastline. The Tel Aviv botanical garden plant diversity is great because one of the goals is to protect endangered species. These plants are integrated in the landscape with the local vegetation of Israel and its environment, i.e., tropical vegetation, Mediterranean forests, and Australian vegetation.

The second air sampling station was located on Jerusalem's municipality building. The city of Jerusalem is located in the Judean Hills between 650 and 857 m a.s.l. (31°46'N, 35°14'E) situated between the Mediterranean Sea and the Judean desert at an average distance of 55 km from the Mediterranean

Sea. The climate is characterized by hot dry summers (25.0 °C August) and cold wet winters (9.8 °C January), with an average of 320 days of sunshine per year. The mean annual rainfall is approximately 554 mm, and snow is not uncommon in Jerusalem during the winter. Species from *Quercus*, *Morus*, and *Pinus* are present in urban spaces near the municipal building. In addition, Jerusalem is surrounded by mountains with Mediterranean forests, woodland, and scrub including species from *Quercus* and Pinaceae as well as grasses, *Olea europaea*, and others. The mountains around the city are about 6 km from the monitoring station.

2.2 Aerobiological sampling

Daily pollen concentrations were recorded in both Jerusalem and Tel Aviv during the years 2010–2014 using Hirst-type volumetric spore traps (Hirst 1952). The samplers were located on the roofs of buildings, 12 meters above ground. The presence of five types of pollen: *Amaranthaceae*, *Poaceae*, *Morus*, *Pinus* and *Quercus* representing anemophilous pollen-releasing plants, was measured during spring and autumn, when the Sharav events usually occur in Jerusalem and Tel Aviv. Each pollen type comprises several species in

Fig. 1 Location map of air sampling stations

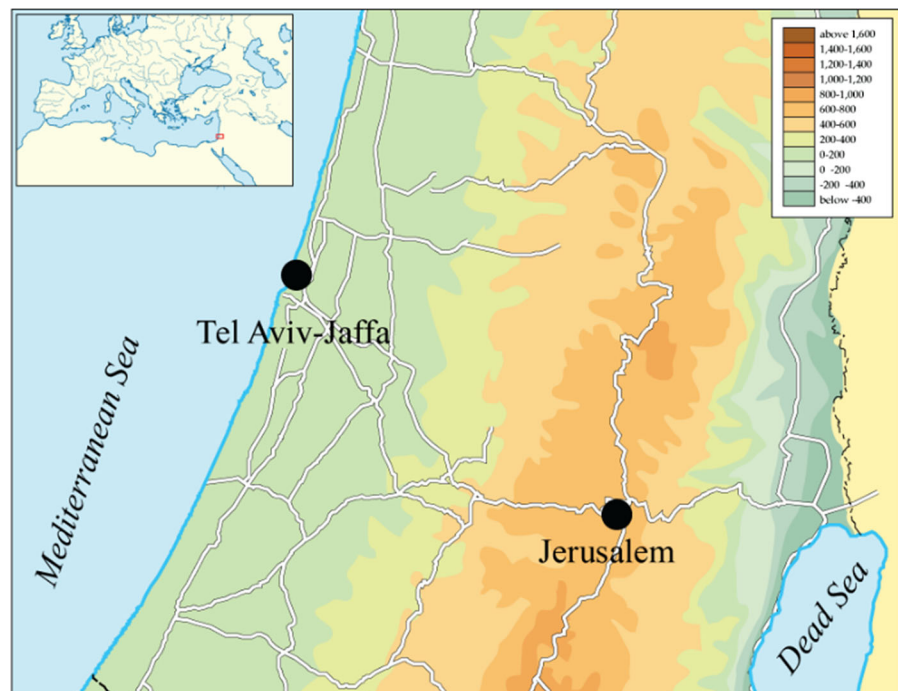


Table 1 The number of Sharav, Warm, and Cool days per taxon in Jerusalem and Tel Aviv during 2010–2014

Pollen type	Jerusalem			Tel Aviv		
	Sharav days	Warm days	Cool days	Sharav days	Warm days	Cool days
<i>Amaranthaceae</i>	430	322	753	92	645	826
<i>Poaceae</i>	342	237	595	56	557	717
<i>Morus</i>	75	24	85	20	81	154
<i>Pinus</i>	203	70	245	22	155	293
<i>Quercus</i>	118	28	134	25	37	307

The number of days varies between taxa due to their variation in flowering periods and MPS duration

Israel, some of which vary in their pollen-releasing periods, for example: *Amaranthaceae* (*Chenopodium vulvaria*, *C. opulifolium* and *Salsola kali*), *Poaceae* (*Digitaria sanguinalis*, some species of *Aegilops*, such as *A. longissima*, *A. geniculata*, *A. biuncialis*, *Sorghum halepense*, *Lolium rigidum*, *Hyparrhenia hita*, *Phalaris paradoxa* and *P. minor*, *Cynodon dactylon*, etc.), *Morus* (*Morus nigra* and *M. alba*), *Pinaceae* (*Pinus pinea*), and *Fagaceae* (*Q. ithaburensis* and *Q. calliprinos*) (Shmida 2005).

Data were analyzed for the main pollen season (MPS), which was defined as follows: “pollen season start” was the day when the sum of the daily concentrations reached 2.5% of the annual pollen sum, and the “pollen season end” was the day when the sum of the daily concentrations reached 97.5%. Therefore, the pollen season encompassed 95% of the pollen recorded during the entire year (Goldberg et al. 1988). The average of the MPS was calculated for each pollen type.

2.3 Meteorological parameters and statistical analysis

Meteorological data were obtained from the Israel Meteorological Service Weather Stations at the two cities. Daily averages were calculated for maximum and mean temperatures, relative humidity, and wind direction. Monthly averages were calculated for the meteorological data during the 5-year period of the research. All days were divided into three categories:

1. *Sharav days, when $RH_i \leq 50\%$ in Tel Aviv or $\leq 45\%$ in Jerusalem, and $T_i > \bar{T}$;
2. Warm days, when $RH_i > 50\%$ in Tel Aviv or $> 45\%$ in Jerusalem and $T_i > \bar{T} + 0.5$ °C;
3. Cool days, all days when $T_i < \bar{T}$.

where RH_i is the mean daily relative humidity [%], T_i is the mean daily temperature (°C), $\bar{T}$ is the mean monthly temperature (°C) and i denotes the Julian day (Goldreich 2003). Wind directions were divided into four categories: *North*, between 316° and 45°; *East*, between 46° and 135°; *South*, between 136° and 225°; and *West*, between 226° and 315°.

Normality test was applied to the different variables: temperature, relative humidity, wind direction, and pollen concentrations. Then, pollen concentrations were analyzed by Kruskal–Wallis ANOVA against the three categories as defined by temperature and humidity and also against wind direction. In both cases, post hoc (Hodges–Lehmann estimator) was used subsequently to determine those conditions (Sharav, Warm, or Cool days in the case of day type and wind direction in the case of wind) under which pollen concentrations were significantly different (IBM-SPSS, version 23).

Due to the variance in the definition of Sharav days for Tel Aviv and Jerusalem, and because of different MPS durations and different flowering periods of the species included in this study, the number of Sharav, Warm, and Cool days differed between both cities¹ (Table 1).

3 Results

The maximum temperatures and relative humidity averages during the study period were higher than the long-term average maximum temperature for 1980–2010 in both cities, especially in Jerusalem. The differences between both periods are higher than

¹ There was no distinction between the two conditions of Sharav (light or intense), as described in the Introduction.

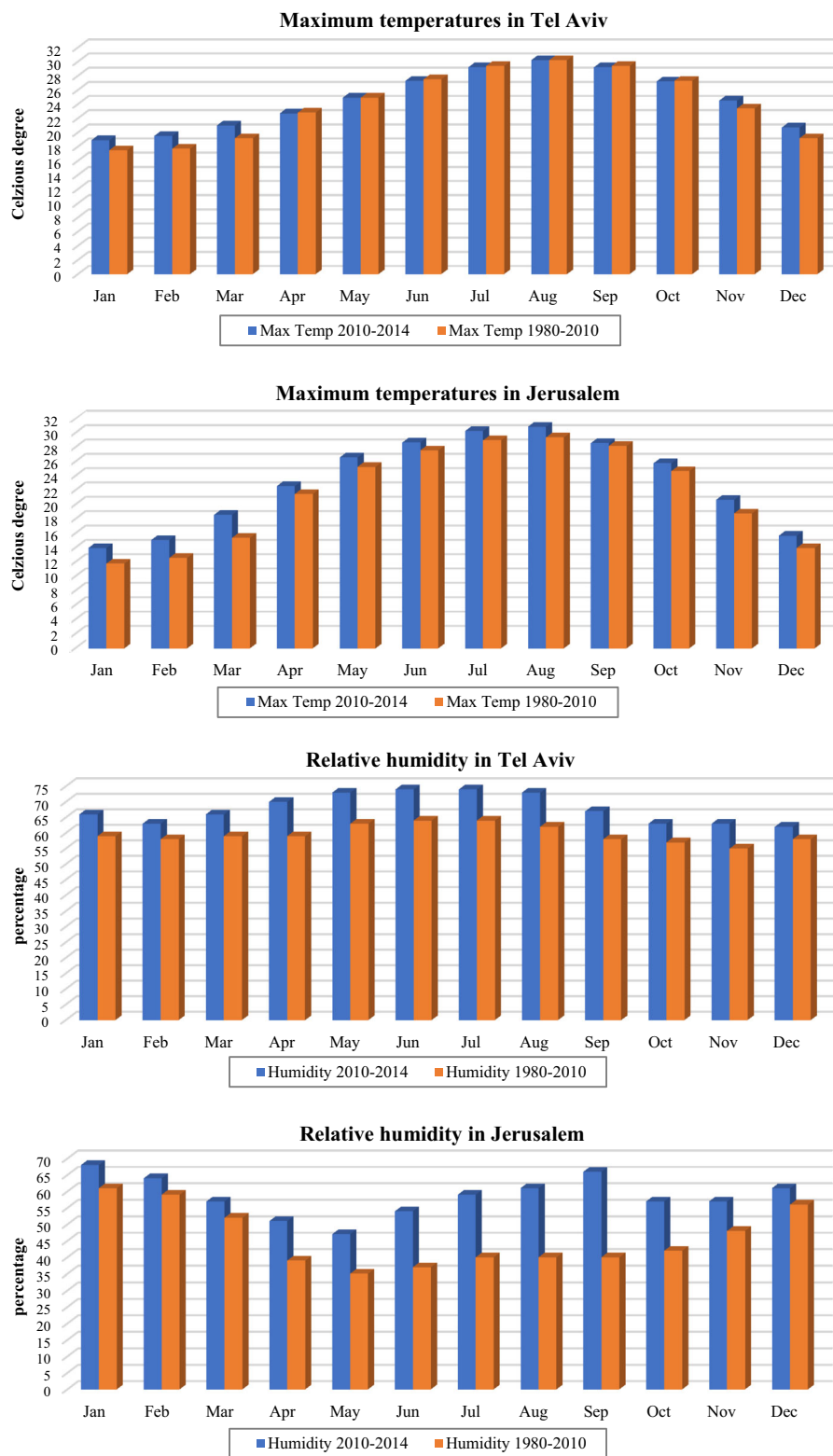


Fig. 2 Comparison of maximum temperatures and relative humidity between 1980–2010 and 2010–2014

Table 2 Average dates for main pollen season (2010–2014) per taxon in Jerusalem and Tel Aviv

	Jerusalem		Tel Aviv	
	Period	No. of days	Period	No. of days
<i>Amaranthaceae</i>	Feb 6–Dec 10	308	Jan 27–Dec 10	318
<i>Poaceae</i>	Mar 9–Nov 3	239	Feb 19–Nov 14	269
<i>Morus</i>	Mar 18–Apr 23	36	Mar 17–May 8	52
<i>Pinus</i>	Mar 9–Jun 22	105	Mar 2–Jul 3	93
<i>Quercus</i>	Mar 14–May 8	55	Feb 15–May 1	76

in Tel Aviv, especially during the winter and spring (Fig. 2).

The MPS was defined for each pollen type at both sites, Jerusalem and Tel Aviv, during the five studied years (Table 2). The average pollen season of the herbaceous *Amaranthaceae* and *Poaceae* lasted nearly throughout the year, with different species flowering during different periods and, therefore, peaking at different seasons. The consequence is that the herbaceous taxa have two periods of possible Sharav in a year. Thus, the peak period of *Amaranthaceae* occurred during the autumn, whereas the peak period of *Poaceae* occurred during the spring (Fig. 3). The MPS of the three tree pollen types—*Morus*, *Pinus*, and *Quercus*—occurred during the spring (Table 2, Fig. 4). The MPS in Tel Aviv started earlier than in Jerusalem and ended later than in Jerusalem, except for *Quercus*, which ended a week earlier.

The highest pollen concentrations were detected during the Sharav days for *Amaranthaceae*, *Poaceae*, and *Pinus* pollen, but not for *Morus* or *Quercus* pollen (Table 3). Highest concentrations were mostly associated with easterly winds, with the exception of *Morus* in Tel Aviv and *Quercus* in Jerusalem that peaked with westerly winds and *Pinus* in Jerusalem that peaked when southern and eastern winds (Table 4).

Kruskal–Wallis test results showed mostly significant differences between the mean ranks of pollen concentrations during the three weather categories: Sharav, Warm, and Cool days. The greatest differences of the three categories days were between Sharav days and the Cool days (using Hodges–Lehmann, post hoc) for the herbaceous plants in both areas and for *Pinus* only in Tel Aviv. The highest differences for *Quercus* were between the Warm days

and the Cool days. There were no significant differences between the mean ranks of pollen concentrations of *Morus* during the three weather categories or during the different wind directions (Tables 5, 6).

For the pollen types *Amaranthaceae* and *Poaceae* in both sites as well as *Pinus* and *Quercus* in Tel Aviv, there were significant differences between the wind sectors; the greatest differences were observed between west and east sectors (Table 6).

4 Discussion

The MPS started about a month earlier in Tel Aviv compared to Jerusalem (except for *Morus*) and lasted longer. This difference may be ascribed to the difference in temperature between the two cities resulting from their different altitudes (Korner 2007). Whereas Jerusalem is located several hundred meters higher than Tel Aviv and inland, far from the sea, which moderates the air temperatures in Tel Aviv (Daly 2006), Tel Aviv was warmer overall than Jerusalem, by an average of 3.7 °C during the 5 years of the study.

The annual average number of Sharav days in springtime in Tel Aviv during the research period was higher (17–22 days) than previous periods (3–9 days). Any comparison between the annual number of Sharav days during the years 1983–2004 (Alpert et al. 2004b; Dayan et al. 2012; Saaroni et al. 1998) to the current research period is not possible because different methods were used to define Sharav conditions. The earlier studies characterized Sharav by synoptic situations, while the current study used only two parameters (mean temperature and relative humidity). Therefore, we cannot conclude that the number of

Fig. 3 Seasonal average of herbaceous pollen during 2010–2014

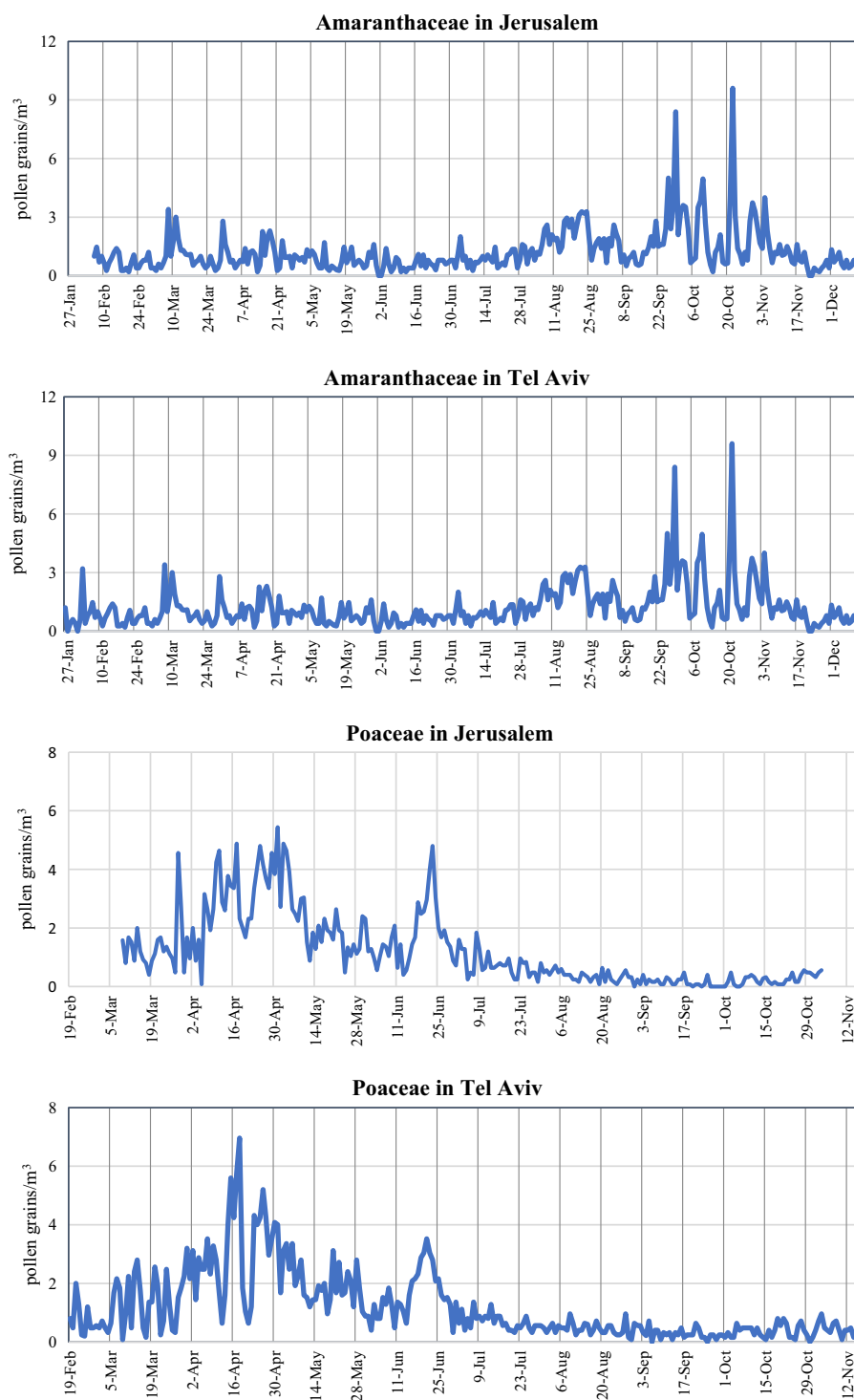


Fig. 4 Seasonal average of tree pollen during 2010–2014

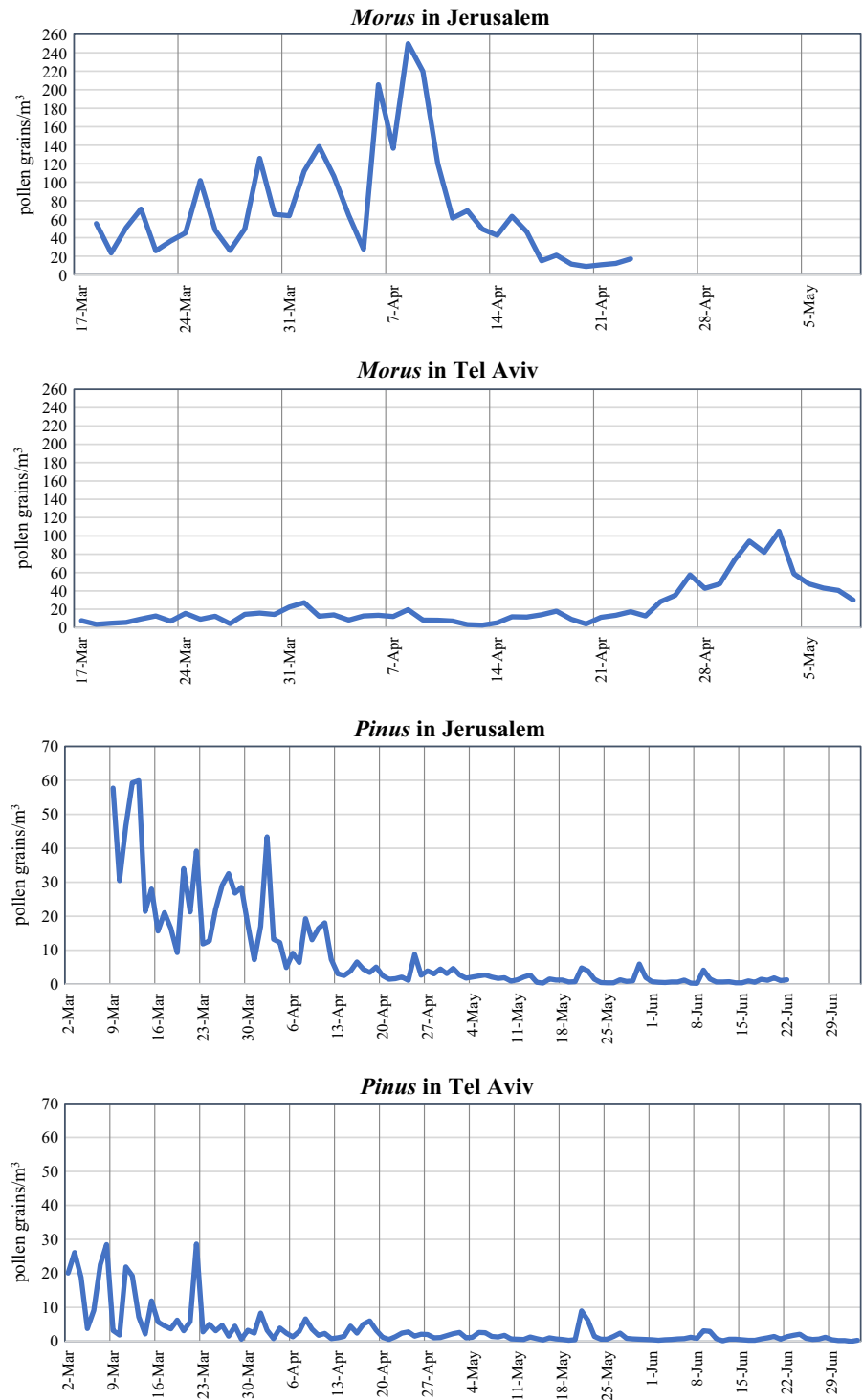
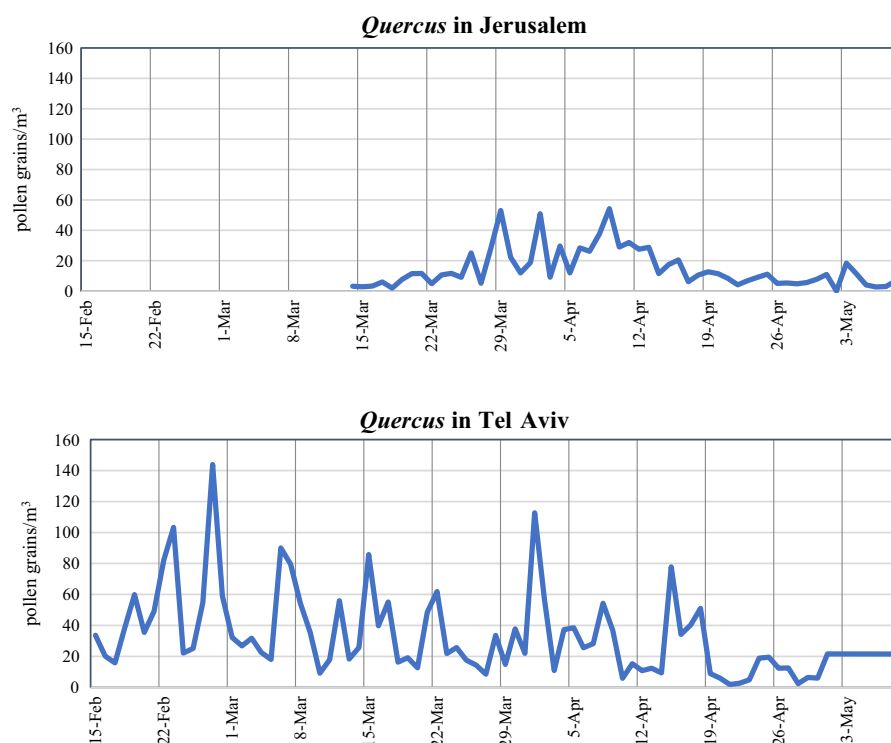


Fig. 4 continued

**Table 3** Mean pollen concentration during Sharav (S), Warm (W), and Cool (C) days in Jerusalem and Tel Aviv during 2010–2014 with temperature (°C) and relative humidity (%) values, respectively

Pollen type	Jerusalem			Tel Aviv		
	Type of days	N	Mean (pollen grains/m ³)	Type of days	N	Mean (pollen grains/m ³)
<i>Amaranthaceae</i>	S (27.6), (33)	430	2.0	S (26.7), (39)	92	2.1
	W (27.2), (59)	322	1.5	W (27.4), (70)	645	1.2
	C (21.8), (71)	753	0.7	C (23.8), (70)	826	0.6
<i>Poaceae</i>	S (29.0), (33)	342	1.9	S (29.1), (37)	56	3.7
	W (29.5), (59)	235	1.2	W (28.2), (71)	556	1.3
	C (24.1), (69)	595	0.8	C (24.5), (71)	717	0.9
<i>Morus</i>	S (26), (32)	75	62.2	S (31.0), (36)	20	15.6
	W (22.9), (58)	25	93.2	W (24.0), (69)	83	20.2
	C (17.0), (72)	85	38.7	C (20.8), (71)	158	27.9
<i>Pinus</i>	S (27.7), (31)	202	13.6	S (30.5), (36)	22	24.8
	W (27.2), (54)	68	8.9	W (26.5), (72)	155	5.9
	C (20.5), (69)	245	8.9	C (22.5), (73)	293	2.7
<i>Quercus</i>	S (26.3), (31)	118	8.8	S (28.7), (39)	25	41.3
	W (22.7), (57)	26	21.3	W (22.9), (69)	37	93.5
	C (17.6), (72)	134	9.8	C (19.7), (70)	307	22.5

Table 4 Mean pollen concentration with wind direction in Jerusalem and Tel Aviv during 2010–2014

Pollen type	Wind direction	Jerusalem		Tel Aviv	
		N	Mean (pollen grains/m ³)	N	Mean (Pollen grains/m ³)
<i>Amaranthaceae</i>	North	44	0.7	16	0.5
	East	149	2.7	47	2.0
	South	256	1.4	686	0.9
	West	1048	1.0	812	0.9
<i>Poaceae</i>	North	45	1.0	16	1.9
	East	58	1.7	24	3.0
	South	150	1.7	508	1.3
	West	907	1.1	779	1.0
<i>Morus</i>	North	3	31.9	4	24.0
	East	14	59.3	12	13.5
	South	49	57.3	116	23.6
	West	117	54.7	129	26.4
<i>Pinus</i>	North	26	5.2	8	2.1
	East	31	13.2	11	18.1
	South	207	14.4	177	8.0
	West	352	9.8	273	2.2
<i>Quercus</i>	North	7	4.8	2	31.2
	East	22	5.5	14	58.8
	South	75	9.1	205	39.9
	West	174	12.1	148	15.9

Sharav days increased during the research period compared to earlier periods. In Jerusalem, which is located far from the coast, the relative humidity is normally low and therefore many days may fit into the definition of Sharav conditions. Therefore, the definition of Sharav in Jerusalem should be changed to less than 45% relative humidity for a better definition on intense Sharav days. Karo and Kutiel (2012) have suggested a new approach for defining and identifying extreme anomalous hot and dry weather events in Israel based on the characteristics of each region in each season.

During Sharav days, airborne pollen concentrations were higher than during Warm and Cool days for *Amaranthaceae*, *Poaceae*, and *Pinus* in both the coastal plain and the mountains in Israel. This is likely a result of the higher temperatures associated with south and easterly winds (Bitan 1983; Saaroni et al. 1998), which originate inland and bring with them both warm air and low relative humidity. Our

results are reminiscent of conditions described in Melbourne (Australia) and Manila (Philippine); grass pollen was low when the mean wind vector was from the southwest but high and extreme when the mean wind vector came from the northwest (Morton et al. 2011; Sabit et al. 2016).

In the current study, pollen concentrations were also higher during Warm days compared to Cool days, in line with similar results in other research projects that were conducted in different Mediterranean climate sites (Aboulaich et al. 2013; Alcázar et al. 2009; Garcia-Mozo et al. 2007; Helfman-Hertzog 2011; Moreno-Grau et al. 2000). Notwithstanding, the combination of high temperature and low relative humidity triggers a higher release of pollen compared to high temperature alone. Low humidity plays an important role during pollen emission because it is allowing drier and lighter-weight pollen to be transported with the sand and dust storms arriving from North Africa. These conditions, then, result in

Table 5 Influence of temperature and relative humidity on pollen concentration. Post hoc comparison of mean ranks for Sharav, Warm, and Cool conditions following Kruskal–Wallis ANOVA

Pollen type	Jerusalem		Tel Aviv	
	Kruskal–Wallis H (df,N)	Lodge–Lehman post hoc value	Kruskal–Wallis H (df,N)	Lodge–Lehman post hoc value
AMARANTHACEAE	99.1 (2.1505)***		171.2 (2.1563)***	
Cool and Sharav		230.4**		409.0**
Cool and Warm		198.4**		263.0**
Warm and Sharav		32.0		146.0**
POACEAE	70.8 (2.1172)***		43.4(2.1329)***	
Cool and Sharav		186.4***		326.1***
Cool and Warm		52.0		69.0**
Warm and Sharav		134.4***		257.1***
<i>PINUS</i>	2.9 (2.515)		30.7 (2.470)***	
Cool and Sharav				164.9***
Cool and Warm				17.4
Warm and Sharav				147.5***
<i>QUERCUS</i>	11.9 (2.278)**		51.5 (2.369)***	
Cool and Sharav		4.0		57.3*
Cool and Warm		55.8**		127.9***
Warm and Sharav		51.8**		70.7*
<i>MORUS</i>	2.3 (2.183)		1.5 (2.259)	

Post hoc Lodge–Lehman estimator values are listed for each pollen type

Significant values are bold and marked * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

increased particulate matter during the Sharav days in Israel, which might also contain some pollen from North Africa.

Some Sharav days are accompanied by dust or sand storms that originate in the North African coast and shift northward near the southeastern Mediterranean (Alpert and Ziv 1989). This study has presented possible relations between pollen concentrations during hot and dry conditions and sand and dust storms; however, this study has not examined the relationship between allergy symptoms with these last parameters. But the current study shows that the pollen concentration averages were higher during Sharav days than other days. Two possible explanations could be: (1) the easterly dry wind causes release of more pollen than during the Warm and Cool days. (2) The sand and dust storms carry pollen grains from North Africa and bring it to Israel. In their study, Kwaasi et al. (1998) detected pollen in their analysis of sandstorm dust, including novel pollen from plants that do not grow in

Riyadh. Kwaasi et al. (1998) attributed those pollen to sandstorms that had reached Riyadh from an outside source.

5 Conclusions

The combination of high temperatures, low relative humidity, and easterly winds—defined as Sharav conditions—resulted in the release of more pollen grains during the pollen season of Amaranthaceae, Poaceae, and *Pinus* than during Warm or Cool days. Therefore, patients who are allergic to these pollen types are exposed to higher pollen concentrations in Sharav days during the spring and autumn months. In contrast, patients who are allergic to *Morus* pollen (in Jerusalem only) and *Quercus* (in both cities) would suffer from a greater degree of higher pollen concentrations during Warm spring days and not during Sharav days.

Table 6 Influence of wind direction on pollen concentration. Post hoc comparison of mean ranks for North, East, South, and West winds following Kruskal–Wallis ANOVA

Pollen type	Jerusalem		Tel Aviv	
	Kruskal–Wallis H (df,N)	Lodge–Lehman post hoc value	Kruskal–Wallis H (df,N)	Lodge–Lehman post hoc value
AMARANTHACEAE	18.0 (3.1497)***		13.2 (3.1561)**	
North and West		– 26.0		– 113.7
North and South		– 74.0		– 125.7
North and East		– 175.8		– 338.4*
West and South		47.9		12.0
West and East		149.8***		224.8**
South and East		101.9		212.7**
POACEAE	10.2 (3.1160)**		9.2 (2.1327)*	
North and West		– 0.5		
North and South		– 53.1		
North and East		– 120.9		– 136.9
West and North				87.0
West and South		52.6		17.3
West and East		120.4*		223.9*
South and East		67.8		206.6*
South and North				69.7
PINUS	10.4 (3.515)		40.0 (3.469)***	
West and North				57.7
West and East				151.2**
West and South				72.0***
North and South				– 14.3
North and East				– 93.5
South and East				79.1
QUERCUS	1.9 (3.278)		32.9 (3.369)***	
West and East				89.3*
West and North				124.2
West and South				61.0***
South and North				63.2
South and East				28.3
East and North				34.9
MORUS	0.7 (3.183)		3.1 (3.259)	

Post hoc Lodge–Lehman estimator values are listed for each pollen type

Significant values are bold and marked * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

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