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RESEARCH ARTICLE

The competitiveness of the invasive weed *Parthenium hysterophorus* with field tomato (*Lycopersicum esculentum*) in Israel

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***Abstract* -** Crop-weed competition is a significant barrier to successful crop production. Understanding invasive weed competing with field crops is rather difficult, mainly due to the absence of physiological and ecological knowledge, which allows selective and appropriate control of the weed. *Parthenium hysterophorus* is a worldwide noxious annual weed infesting field crops and orchards**.** A competition experiment between *P. hysterophorus* and field tomatoes in containers under controlled conditions resulted in a decrease in tomato biomass production. We found that the presence of *P. hysterophorus* at all planting ratios in a replacement series caused a significant reduction (~18% to 40%) of tomato shoot biomass m^{-2}, whereas *P. hysterophorus* plants gained ~11 to 75 % in shoot biomass m^{-2} at all planting ratios with tomato plants. Our results emphasize the need for efficient management of this invasive weed to achieve reasonable yield and allow marketable cropping.

Keywords - competition, invasive weed, *Parthenium hysterophorus*, dry weight

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INTRODUCTION

Parthenium hysterophorus is an annual or short-lived perennial plant native to the subtropics of North and South America. It is a notorious invasive species which has spread to Australia, Africa, Asia, Oceania, and the Middle-east. It has become a serious agricultural and rangeland threat affecting crop production and animal husbandry, as well as human health and biodiversity (C.A.B.I. 2014, Adkins & Shabbir 2014). In Israel, *P. hysterophorus* was first detected at 1980 in a fishpond bank in Bet She'an valley (Dafni &Heller 1982). *P. hysterophorus* was probably introduced to Israel via the importation of animal feed grains from the U.S.A. (T. Yaacoby, personal information), exhibiting a slow dispersal for almost 30 years, and recently started to invade new areas (Yaacoby 2008, 2011, Yaacoby and Rubin 2014). Due to its high impact on agriculture and the natural environment, a nationwide survey was conducted, recording the current locations where the weed was established (Matzrafi et al. 2021)**.**

Currently, the European and Mediterranean Plant Protection Organization (E.P.P.O.) officially recorded *P. hysterophorus* presence only in Israel (E.P.P.O. quarantine database 2013). The species was also introduced to India and Ethiopia, possibly as a contaminant of grain from the USA-AID. In addition, there are records of its introduction (India and Ethiopia) as a contaminant of pasture seed and food aid (Murphy and Cheesman 2006), and through seeds attached to animals and vehicles (harvesters, military machinery, and other anthropogenic and transportation means) (Auld et al. 1982).

P. hysterophorus matures very quickly, with flowering commencing 4–6 weeks after germination, reproduces only by seeds and is known to be highly prolific, as a single plant may produce, on average, 40,000 seeds (Dhileepan 2012). *P. hysterophorus* seeds exhibit dormancy mechanisms and can form persistent seed banks, especially where the seeds are incorporated into the soil at moderate depths (Navie et al., 1998). The species tolerates a wide variety of soils and is a pioneer that can colonize a wide range of habitats: grazing land, summer crops, disturbed and cultivated areas, roadsides, recreation areas, as well as riverbanks and floodplains. Given suitable ambient temperatures, it can establish in areas receiving very low rainfall (Navie et al., 1996).

P. hysterophorus causes significant negative impacts on pastures and crops, reaching 40% yield loss in several dryland crops (Khosla and Sobit 1981, cited in Kandasamy 2005). In India, losses in crop yield ranged between 6.5 to 55%, with maximum losses observed in arugula (55%) and sunflower (52.5%) (Khan and Aneja 2016). Interference can cause yield losses of. In Ethiopia, when *P. hysterophorus* was left uncontrolled throughout the growing season, the grain yield of *Sorghum bicolor* was reduced by 40 to 97% (Tamado et al., 2002). Furthermore, because *P. hysterophorus* contains sesquiterpenes and phenolic metabolites, it is toxic to cattle, horses and other animals (Navie et al. 1996). In addition, frequent contact with *P. hysterophorus* or its pollen can produce severe allergic reactions such as dermatitis, hay fever and asthma in humans and livestock (Sahrawat et al., 2018).

A better knowledge of the ecology and biology of invasive, competing species has resulted in increased use and development of more mechanistic-based and dynamic population models for weed management. The use of prediction models is an essential and integral part of plant competition study (Park et al., 2003). Knowing the competition capacity of such a weed is crucial for developing future crop management programs. Different types of competition experiments are used in agricultural studies (Spitters and van den Bergh 1982). Here we applied replacement (substitution) experiments to assess the impact of weed interference on the target crop tomato.

Replacement experiments measure the competition between species by the replacement principle. A range of mixtures is generated, starting with a monoculture of species 1, progressively replacing plants of species 1 with those of species 2 until a monoculture of species 2 is obtained. The replacement-series design (substitutive experiment) was developed to overcome some of the criticisms of the additive design (Gibson et al., 1999, Jolliffe 2000) and is often used to determine which of two species is the most competitive, as well as to gain insight into plant-to-plant interactions (Radosevich 1987). The replacement series is most valuable for providing information about the interactions among species, and these interactions can be categorized as negative, positive, or neutral.

There are four possible outcomes for the interaction of a crop species and a weed when grown in a replacement series: (1) the two observed yield responses are straight lines: The ability of each species to interfere with the other is equivalent, or the two species are located so far apart that no interaction occurs between them, (2) one response curve is concave, and the other is convex: one species is more aggressive than the other (concave response), (3) both response curves are convex, and the total yield of the two species in a mixed stand is less than that of their respective yields in a pure stand: It is a case of mutual antagonism, (4) both response curves are concave, and the total yield of the two species in a mixed stand is greater than that of their respective yields in a pure stand - it is a case of symbiosis.

The advantages of this approach are: a) well-suited design to rank the competitive ability of a species under a given set of conditions, b) appropriate design to examine both competition mechanisms and outcomes between crops and weeds (Akey et al., 1991; Wang et al. 2006) and between two weed species (Blackshaw and Schaalje 1993) or weed biotypes (Higgins and Mack 1987; O'Donovan et al., 1999), c) useful in predicting shifts in species composition over time (Conard and Radosevich 1979; Radosevich and Holt 1984), d) yield ratios can be calculated to describe patterns of resource use and relative aggressiveness among the species (Harper 1977). However, the replacement approach has some disadvantages. In most fields, weed invasions initially increase the number of plants without substitution. In addition, experimental outcomes may depend upon the total plant density selected and specific resource supply conditions used.

In the present study, we applied replacement (substitution) experiments to assess the interference impact of *P. hysteronphorus* on the target crop – field tomato.

MATERIALS AND METHODS

Plant material. Seeds of *P. hysterophorus* were collected from a highly infested chickpea field in Jordan valley (Kibbutz Degania, 32°42'29"N, 35°34'28"E). Field tomato M-82 seeds were obtained from HUJI, the Faculty of Agriculture, Rehovot.

Seed germination and seedling emergence. Germination of *P. hysterophorus* and Field tomato (M-82) was carried out in a controlled environment (28/22ºC day/night, with a 12 h photoperiod).

Plant growth. Uniform seedlings at first to second leaf stage were transplanted in 90 L (60X50x30 cm) styrofoam container filled with a 4:1 ratio of planting mix (20:35:20 coco, peat, tuff, respectively), loamy sand soil (Typic Haploxeralfs) pH 7.5, containing 6% clay, 3.5% silt, 90% sand, no organic matter.

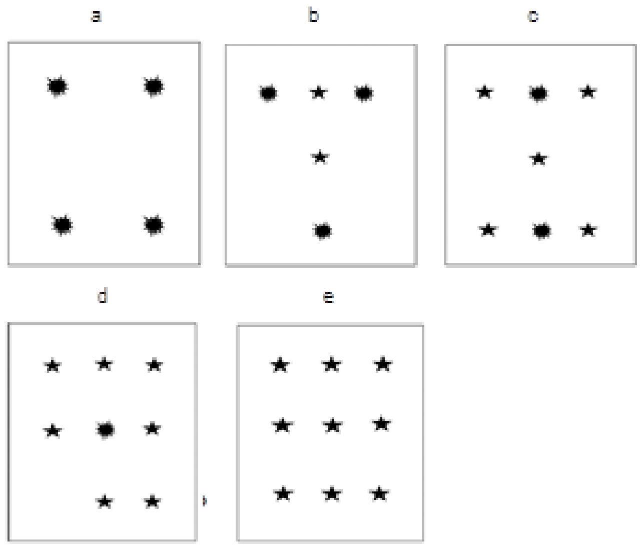

Figure 1. Tomato/Parthenium planting ratios: a- 100/0, b-75/25, c-50/50, d-25/75, e- 0/100, respectively (planting layout were: tomato ✸ *P. hysterophorus* ★)

The seedlings were planted as shown in Fig. 1, giving a maximal number of a) four tomato seedlings per container, corresponding to field planting spacing of 30 to 40 cm between plants and rows, equal to 16 plants m^{-2}), and b) nine *P. hysterophorus* seedling per container (according to weed infestation found in a tomato field in Jezreel valley, equal to 36 plants m^{-2}). Plants were grown in a screen house at the Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Rehovot, Israel (31°54'18"N, 34°48'17"E), under natural daylight and temperatures, and were fertilized with a soluble 20-20-20 (N-P-K) fertilizer and irrigated as required. At harvest time, 35 days after planting, the total shoot fresh and dry biomass were determined. The experiment was conducted with four replicates.

The seedlings were planted in several densities according to the replacement experiment design: 100% crop - No weed, 75% crop - 25% weed, 50% crop - 50% weed, 25% crop - 75% weed and No crop - 100% weed.

RESULTS AND DISCUSSION

Our results show that the presence of *P. hysterophorus* plants caused a reduction of tomato fresh and dry biomass compared to tomato planting alone (Figs 2, 3). Tomato fresh weight was reduced while the competing *P. hysterophorus* plants' fresh weight increased (Table 1). Tomato plants lost 18 to 40% of their F.W. when replaced by *P. hysterophorus* plants, whose F.W. increased by 11 to 75%.

In terms of total biomass accumulation (tomato + P. *hysterophorus*), their combined biomass in all mixture ratios was higher than when species were grown as monocultures. Notably, we found that *P. hysterophorus* biomass was significantly lower when planted alone (Table 1), probably due to severe intra-species competition.

Following these substitution scenarios, expected tomato biomass per unit area (Table 2) predicts losses of up to 85%. This prediction is not surprising, as other studies reported a massive reduction in the biomass of grain sorghum due to competition with *P. hysterophorus* in Ethiopian dryland. Such heavy loss occurs even at low densities of *P. hysterophorus,* e.g., five plants m^{-2} (Bajwa et al., 2020).

A large body of evidence supports increased weed competitiveness in fields amended with nitrogen, phosphorus and potassium (DiTomaso 1995; Buhler 2002; Zimdahl 2018). Even though we amended the competing plants with N:P:K fertilization, we did not reach the high levels occurring in the field reservoir under intensive fertilization. Nevertheless, our findings may serve as a baseline for predicting field competition. We assume that the competitiveness of *P. hysterophorus* in crop fields will be at least as high as that we measured in our controlled experiment.

In addition to the weed/crop competition outcome presented above, we found a strong intraspecific competition between *P. hysterophorus* plants when grown in a monoculture (100/0 ratio). The recorded fresh and dry weight of *P. hysterophorus* plants in monoculture was much lower compared to the weight in the 75/25 weed/crop planting ratio - 202 vs 334g $plant^{-1}$, respectively (Figs 1 and 2).

Figure 2 shows the relation between raw material consumption (in thd. tonnes) and GDP per capita in PPS at the EU level for 2000-2020 smoothed by the nonlinear curve. The graph suggests nonlinear relation between raw materials consumption and GDP per capita. The relation is moderately negative, the value of $\tau = -0.212$, which became barely statistical significant (p-value<0.05). The results suggest that rising income can moderate raw materials consumption, but after some income level (not determined), it appears that raw materials consumption has risen again.

Invasive weeds are a real threat to agriculture and the environment in Israel (Dafni and Heller 1980; Yair et al., 2019) and the rest of the world (Paini et al., 2016). According to C.L.I.M.E.X. and other modules (McConnachie et al. 2011, Kriticos et al. 2012, 2015), Israel, like most of the Mediterranean region, will suffer from *P. hysterophorus* spreading to almost 100% of the agricultural land, especially in irrigated crops. Field tomatoes, like other row crops, e.g. cotton, maize, and sunflower might be the next target for *P. hysterophorus* infestation in Israel. Our findings indicate the significance of the expected negative impact of *P. hysterophorus* on the field tomato crop, suggesting the need for a non-compromising control.

Table 1. Mean fresh (F.W.) and dry (D.W.) weight of tomato and Parthenium plants in different planting ratios: 25/75, 50/50, 75/25, 100/0, and 0/100, respectively. ANOVA for F.W. (F (7,31) = 3.878, p>0.001) and D.W. (F (7,31) = 9.055, p>0.0001). Capital letters show significant differences between weed and tomato at each planting ratio (t-test p<0.05)

Planting ratio	Parthenium F.W. (g $plant^{-1}$)	Tomato F.W. (g $plant^{-1}$)	Container total F.W. (g)
T-100	0	340^{A} (±71.98)	1,360
T-75 + P-25	210^{B} (±33.65)	307^{A} (± 37.89)	1,343
T-50 + P-50	262^{AB} (±69.32)	186^{B} (±36.12)	1,683
T-25 + P-75	333^{A} (±118.05)	196^{B} (±72.16)	2,533
P-100	210^{B} (±24.83)	0	1,894
Planting ratio	**Parthenium D.W. (g $plant^{-1}$)**	**Tomato D.W. (g $plant^{-1}$)**	**Container total D.W. (g)**
T-100	0	52^{B} (±5.49)	211
T-75 + P-25	41^{CD} (±7.99)	42^{BCD} (± 4.55)	212
T-50 + P-50	50^{BC} (±8.78)	31^{E} (±4.06)	317
T-25 + P-75	64^{A} (±12.25)	40^{DE} (±4.84)	493
P-100	37^{DE} (±3.21)	0	333

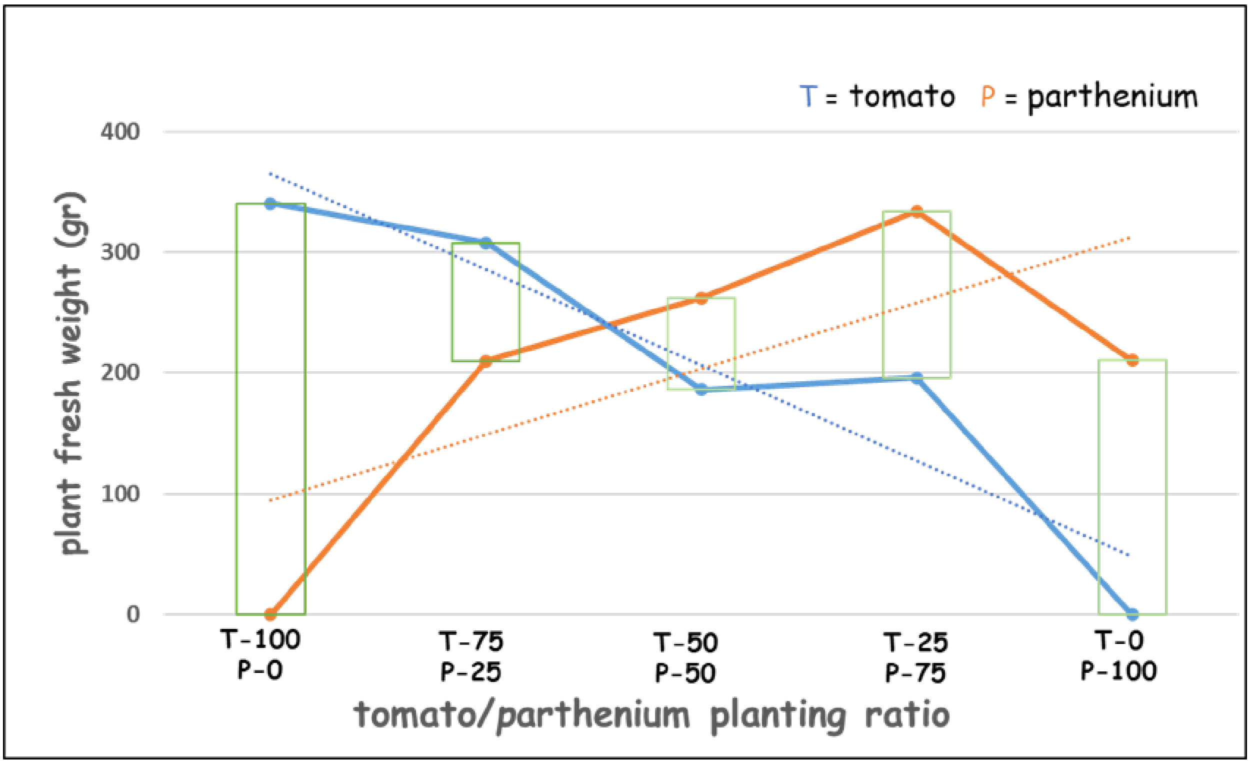

Figure 2. Effect of competition between tomato and Parthenium plants grown at four different ratios on shoot fresh weight

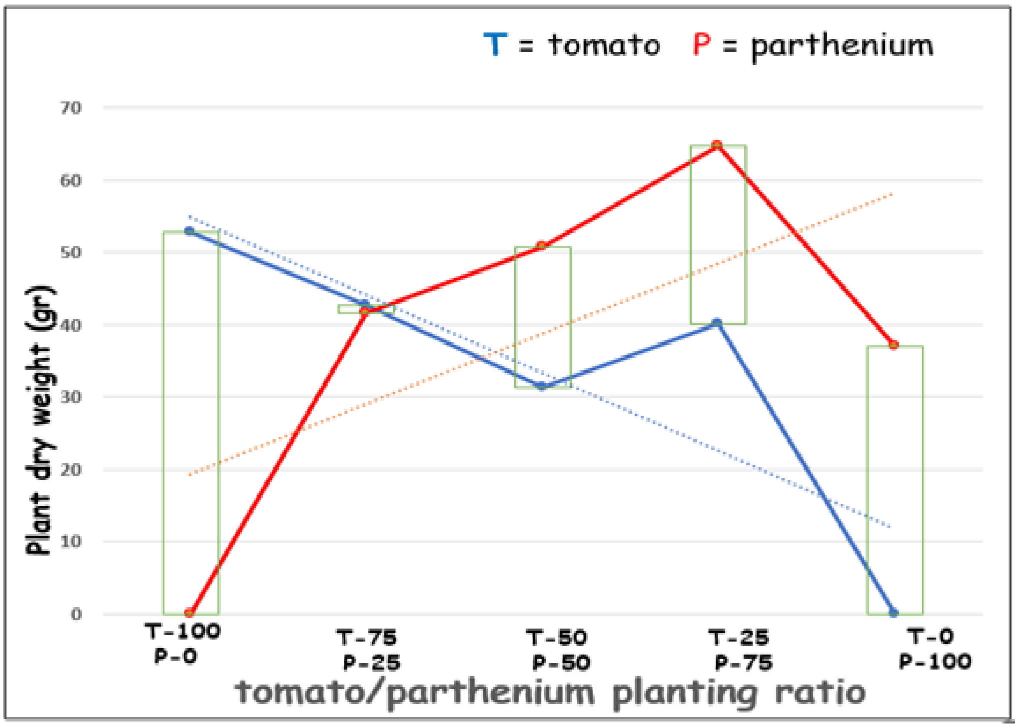

Figure 3. Effect of competition between tomato and *Parthenium* plants grown at four different ratios on shoot dry weight

Table 2. Tomato and *Parthenium* shoot fresh and dry weight as calculated for 1 m^{-2} according to all planting ratios

Planting ratios	Parthenium		Tomato		Total D.W. ($g\ m^{-2}$)	Total F.W. ($g\ m^{-2}$)
	DW ($g\ m^{-2}$)	FW ($g\ m^{-2}$)	DW ($g\ m^{-2}$)	FW ($g\ m^{-2}$)		
100 -0	0	0	832	5,440	832	5,440
75 -25	336	1,680	516	3,684	852	5,364
50 -50	1020	5,240	248	1,488	1,268	6,728
25 -75	1820	9,352	160	784	1,980	10,136
0 -100	1332	7,560	0	0	1,332	7,560

CONCLUSION

The results of this experiment suggest that *Parthenium hysterophorus* is a harmful weed for the field tomato crop at various establishing ratios. The competition experiment showed that after 35 days of growth, *P. hysterophorus* already caused a massive reduction of tomato fresh and dry shoot weight, even under optimal growing conditions for both species. We expect that *field* conditions will be much less favourable due to the presence of other weeds competing with the tomato crop.

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