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COMPETITIVE INTERACTIONS OF *Capsicum annuum* L. WITH *Chenopodium murale* L. : A REPLACEMENT SERIES STUDY

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ABSTRACT

In agricultural ecosystems, crops are usually affected by competition with weeds, and the effects of this process are influenced by plant population density, proportional abundance and by species involved. The present study evaluates the competitive interactions of Capsicum annuum L. and Chenopodium murale L. The experiment was conducted in a greenhouse belonging to the Higher Institute of Agricultural Sciences of Chott-Meriem, Sousse, Tunisia during the 2011-12 crop season. The experimental units were plastic pots of 8 cm diameter, and the treatments were based on a replacement series, with a constant total density of six plants per pot. The treatments included seven combinations of C. annuum or C.murale plants (6:0, 5:1, 4:2, 3:3 and 2:4, 1:5, 0:6), corresponding to relative abundances of 100, 83.3, 66.6, 50, 33.3, 16.6 and 0% of C. annuum (and the reverse for C. murale). Competitiveness was analyzed using replacement-series and additive-series experiment diagrams and competitive indices. Competitiveness indices examined were relative yields (RY), aggressivity (AGR), relative crowding coefficient (RCC), competitiveness (C), competitive ratio (CR), relative competitive index (RCI) and actual dry weight loss (ADWL). Chenopodium murale exhibited clear differences in growth attributes and competition indices from C. annuum. C. murale showed significantly higher growth, relative yield, aggressivity and biomass. However, C.annuum is a weak competitor in the mixture, and C. murale is a stronger competitor.

Key words: Aggressivity, competitive ability, *Capsicum annuum*, *Chenopodium murale,* replacement series, competitiveness.

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INTRODUCTION

In Tunisia, *Capsicum annuum* L. (Solanaceae) is one of the most important nutritious and highly remunerative vegetable crops grown for its fruits and it is an important commercial crop grown on a wide range of soils at altitudes varying from sea level to 2000 m. The yield of *C. annum* in Tunisia averages 12.5 t/ha, which is relatively low compared to yield observed in other Mediterranean countries such as Spain (35 t ha^{-1}), Italy (28 t ha^{-1}), Greece (23 t ha^{-1}), and Morocco (14 t ha^{-1}) (Boughalleb and El Mahjoub, 2005; Grissa, 2010). Low yields obtained in Tunisia are probably due to the impact of weed infestations, which is one of the limiting factors in *C. annuum* production (Adigun, 1984; Boatwright and McKissick, 2003). One of the main problems affecting crop yield and quality is weed competition (Hager *et al*., 2002; Khan *et al.,* 2016; Ali *et al.,* 2016). Hachem (2001) had shown that *Chenopodium murale* was the most frequently weed in *C. annuum* field. *Chenopodium murale* is a widespread noxious weed infesting more than 25 crop species (mainly field crops) and tree orchards in at least 57 countries around the world (Holm *et al*., 1997; Lazarides *et al*., 1997). *Chenopodium murale* affects native plants and cultivated plants (Marshall *et al*., 2000) through its adaptability to various environments and by growing in a wide range of soil types (Holm *et al*., 1997; Guertin, 2003). It causes considerable yield losses, especially in vegetables, through both competition and allelopathy. It is highly competitive in wheat (Singh, 1973). A density of 248 plants/m² of *C. murale* caused 16% loss of wheat yield in Pakistan (Holm *et al*., 1997).

Adim (2009) had reported that maximum yield loss due to *C. murale* was estimated 92.92% in first year and 80.95 in second year for transplanted onion; however in direct-seeded, yield loss was estimated 100% in two years. In garlic, when *C. murale* was a dominant weed species occurring at a density of 50 plants m-², bulb yield reduction reached 78% (Qasem, 1996). In tomato, a pot experiment with two *C. murale* and one tomato plant/pot resulted in a 33% reduction in tomato shoot dry weight compared with the control (weed-free tomato) (Qasem, 1997). During trials with tomato and bean crops, *C. murale* was shown to accumulate nutrients (nitrogen, phosphorus, potassium, magnesium) at higher levels than either crop plant; it accumulated lower amounts of calcium than either crop plant. It is regarded as a nutrient accumulator (Qasem, 1992).

The allelopathic impact is mainly due to the harmful effect that *C. murale* imposes on different crop species including *Triticum durum, Hordeum vulgare*, *Abutilon indicum* and *Evolvulus numularius* and a number of vegetable crops such as *Lactuca sativa, Phasaeolous vulgaris, Brassica nigra* through extracts, leachates and/or its residues in the soil (Qasem, 1993; 1995; Datta and Ghosh, 1987; Holm *et al*., 1997, Porwal and Gupta, 1986). In agar medium containing root exudates of *C. murale,* root and shoot length of wheat were reduced by nearly 44% and 32%, respectively, whereas seedling weight was reduced by about 52% (Batish *et al*., 2007). The aqueous extract of *C murale* affects the growth parameters of *Hordeum vulgare* (plant height, number of tillers, number of leaves, root fresh and dry weight) were infected, significant effect at 25 and 50%, highly significant effect at 75 and 100% were recorded (Al-johani *et al.,* 2012). Alam and Shaikha (2007) reported that the aqueous leaf extract of *C murale* may release some toxic phenolic allelochemicals which deteriously the seedling growth of rice plant. Hesammi (2012) indicated that extract of *C. murale* decreased the germination of *Phasaeolous vulgaris* grains, furthermore, the increase of extract density became more intense this effect. A 2% aqueous extract of *C. murale* exhibited a significant negative effect resulting to 34% reduction in germination of *Avana fatua* (Shafique *et al*., 2011). Allelopathic agents were also detected in the pericarp and perianth associated with its seeds (Qasem, 1990).

However, studies on the effect of *C. murale* on *C. annuum* are limited. The lack of information about the negative effect caused by *C. murale* on *C*. *annuum* development and losses caused to yield; three separate experiments were conducted: 1) to examine the effect of *C. murale* density on *C. annuum* growth during the seedling stage, which is the most sensitive growth stage; 2) to obtain the appropriate plant density of both plants to maximize reduced weed growth, and thus ensure control; 3) to test the competitive ability of *C. annuum* towards the weed *C. murale* using a replacement method. the objectives of the present study were to investigate the effect of *Chenopodium murale* on *Capsicum annuum* seedling growth and to evaluate the competitive abilities of these species. The hope was that a suitable *C*. *annuum*: *C. murale* ratio could be found to ensure maximum weed control at no cost, since costs are traditionally associated with chemical control or weeding. To test these objectives, several competition indices have been used in this study to explore the net balance of plant interactions (Weigelt and Jolliffe, 2003). These include the competitiveness (C), the competitive intensity (CI), the competitive ratio (CR), the relative competition index (RCI) used for measuring competition.

MATERIALS AND METHODS

To assess the competitive ability between *C.annuum* as a crop and *C.murale* as a weed, three experiments were performed. The first, with monocultures of *C.annuum* aimed to determine the population of plants from which the dry weight (DW) (g per pot becomes independent from the population, according to the "law of constant final production" (Radosevich *et al*., 1997) and to study the intra-competition**.** The second experiment used an experimental additive series and the third experiment used an experimental replacement series under greenhouse conditions. In this first intra-competition experiment of *C. annuum*, *C.annuum* at two leaf-age seedlings were planted at a density of 1,2,3,4,5,6,7 plants spaced 2cm each other.

In the second experiment (additive series experiment), *C. annuum* density was kept constant, while various densities of *C.murale* were allowed to compete with *C*. *annuum*. The latter was planted at a fixed density of one plant/pot while *C.murale* was sown at 1, 2, 3 or 4 plants in the same pot*. C.murale* seedlings were established 2 cm from *C. annuum* seedlings in the first experiment; in the second experiment *C. murale* was sown at 1, 2, 3, 4, 5 or 6 plants in the same pot*.*

In the substitutive experiment (third experiment), the main characteristic was to vary the proportions of both species while maintaining the overall density of the two species constant. Pot experiments were set up with the following treatments: 1) 100% *C*. *annuum*(*6 plants/pot*); 2) 83.3% *C*. *annuum* (*5 plants/pot*); 3) 66.6% *C*. *annuum* (*4 plants/pot*); 4) 50% *C*. *annuum* (*3 plants/pot*); 5) 33.3% *C*. *annuum* (*2 plants/pot*); 6) 16.6% *C*. *annuum* (*5 plants/pot*); 7) 0% *C*. *annuum*.

The greenhouse study was conducted in the fall of 2011 and 2012 (i.e., a two-year study) at Higher Institute of Agricultural Sciences of Chott-Mariem (Sousse,Tunisia). The experimental units were plastic containers (8 cm in diameter and 10 cm deep) filled with a standard horticultural potting medium (sand, manure, perlite; 1:1:1, v/v). Based on previous observations, this container size was chosen to provide unrestricted *C*. *annuum* and *C. murale* growth for 40 days. *C*. *annuum* seeds var. 'Baklouti' were sown in each pot filled with a standard horticultural medium. One *C*. *annuum* seedling at the true two-leaf stage was transplanted into each container. *C. murale* seeds were collected from local field stands of populations growing in *C*. *annuum* fields near Higher Institute of Agricultural Sciences of Chott-Mariem. These seeds were sown in each pot and seedlings that emerged were thinned to the desired densities and were allowed to interfere naturally with *C*. *annuum* for the reminder of the *C*. *annuum* season, i.e., 40 days. The variables measured in *C*. *annuum* and *C. murale* were whole plant dry weight, determined as explained next.
40 days after planting, *C*. *annuum* and *C. murale* dry weight was separated. Roots of *Capsicum* and *Chenopodium* were washed gently and thoroughly to remove soil particles so that the root tissues remained intact. Above- and belowground biomass for both species from each pot was placed in separate paper bags. DW was determined by drying the whole plant in an oven for 48 h at 80°C.

The relative performance of each species in the *C. murale* /*C*. *annuum* combination was calculated. To analyze the data of the variable dry weight of the competitor *C. murale* and *C. annuum* cultivar Baklouti, the method of graphical analysis of relative yield was used (Radosevich, 1987; Roush *et al*., 1989; Cousens, 1991; Bianchi *et al*., 2006). The procedure consists of the construction of the diagram based on the relative yields (RY) and total (RYT). When the result of RY tends to a straight line, it means that the skills of the species are equivalent. If the RY results in a concave line, it indicates loss in growth of one or both species. On the contrary, if the RY shows a convex line, there is an advantage in growth of one or both species. When the RYT is equal to the unity (1) (straight line), there is competition for the same resources; and if it is greater than 1 (convex line), the competition is avoided. If the RYT is less than 1 (concave line) mutual growth damage occurs (Cousens, 1991). The RY of *C. murale* (RY_{ch}), the RY of *C*. *annuum* (RY_{cap}) and the total relative yield (RYT) of both species were calculated separately according to the following equations (Harper, 1977):

RY_{cap}= yield of *C*. *annuum* in the mixture / yield of *C*. *annuum* in monoculture

RY_{ch} = yield of *C. murale* in the mixture / yield of *C. murale* in monoculture

RYT = RY_{cap} + RY_{ch}

An RYT = 1 indicates that *C*. *annuum* and *C. murale* are demanding the same limiting resources. An RYT> 1 indicates that *C*. *annuum* and *C. murale* make different demands on resources, so competition is avoided and an RYT < 1 indicates that there is a mutual antagonism between *C*. *annuum* and *C. murale*.

The relative crowding coefficient (RCC) is used to determine the competitive ability of a plant to obtain limited resources when grown in a community setting compared to its ability to utilize those resources when grown in a monoculture setting (Aminpanah and Javadi, 2011; Aminpanah, 2013). According to this definition, an RCC value > 1 signifies a competitive advantage for *C*. *annuum* compared to *C. murale* and the larger the RCC value, the greater the competitiveness with the other species. In contrast, an RCC value < 1 indicates that *C. murale* is more competitive than *C*. *annuum*. An RCC value = 1 indicates that there is no competitive advantage or disadvantage between both species. RCC indicates the relative dominance of one *C. annuum* over *C. murale*. RCC was calculated for both species using the formula (Hoffman and Buhler, 2002):

RCC = ((DWcap1×5 / DWch5×1) + (DWcap2×4 / DWch4×2) + (DWcap3×3 / DWch3×3) + (DWcap4×2 / DWch2×4) + (DWcap5×1 / DWch1×5)) / 5) + (DWcap6×0 / DWch0×6))

Where DWcapn×n is the DW of *C*. *annuum* at a ratio of n:n and DWchn×n is the DW of *C. murale* at different proportions.
An increase in the RCC value for a species as the proportion in the plant mixture increases indicates that the relative competitivenness of that species has increased (Morales-Payan *et al*., 2000; Williams and McCarthy, 2001; Zarochentseva, 2012).

The following index assessed was aggressivity, which is often used to determine the competitive relationship between *C*. *annuum* and *C. murale* in a mixed crop. Aggressivity of *Capsicum annuum* (AGR_{cap}) was calculated as follows (McGilchrist and Trenbath, 1971):

$$AGR_{cap} = (DW_{Capmix}/DW_{Capmono}) - (DW_{ch\,mix}/DW_{ch\,mono})$$

Where AGR_{Cap} is the aggressivity of *C. annuum* in relation to *C. murale*. DW_{capmix} and DW_{chmix} are the dry weights of *C. annuum* and *C. murale* in mixtures with each other. $DW_{Capmono}$ and DW_{Chmono} are the weights of *C. annuum* and *C. murale* respectively, in monoculture. If $AGR_{cap.} = 0$, both species are equally competitive, if AGR_{cap} is positive, then *C*. *annuum* is dominant, if AGR_{cap} is negative, then *C*. *annuum* is weak and *C. murale* is more aggressive.

The competitiveness of *Capsicum* (Ccap) is the difference between the relative yield of *Capsicum* and the relative yield of *Chenopodium.* It indicates which of the species is more competitive. It is defined as (Cousens and O'Neill, 1993):

$$C_{Cap} = RY_{Cap} - RY_{Ch}$$

If Ccap is positive, *C. annuum* is more competitive than *C. murale,* however if Ccap is negative *C.murale* is more competitive than *C. annuum*

The competitive ratio (CR) represents the comparative growth of the species *C. annuum* over *C. murale*. Greater is the CR value more competitive is *C.murale*. It is the ratio of per plant weight of weed when grown in the mixture with the crop to that of crop when grown in weed-free condition and is difined as (Willey and Rao, 1980):

$$CR = RY_{Cap}/RY_{Ch}$$

Actual dry weight loss (ADWL) index, which gave more accurate information about the competition than the other indices between components of the mixture. The ADWL is the proportionate dry weight loss or gain of the mixture compared to sole crop. The ADWL was calculated as (Banik, 1996):

$$ADWL = ADWL_{Cap} + ADWLC_{Ch}$$

Where

$$ADWL_{Cap} = \{(DW_{cap}mix/\text{part of } Cap \text{ in mix}) / (DW_{cap}mono/\text{part of } Cap \text{ in mono})\} - 1,$$

$$ADWLC = \{(DWchmix/\text{ part of } Ch \text{ in mix}) / (DW_{Ch}mono/\text{ part of } Ch \text{ in mono})\} - 1$$

The AYL can have positive or negative values indicating an advantage or disadvantage remained in intercrops when the main aim is to compare yield on a per plant basis.

We used the relative competitive index (RCI) (Gan *et al*., 2009) to measure the interspecific interactions of *C. annum* and *C.murale*. The RCI was calculated as follows (Grace, 1995):

$RCI_{ca} = (DW_{noC.murale} – DW_{C.murale})/DW_{no\ C.murale}$

Where, RCI is the coefficient of relative competition intensity, $DW_{noC.\ annuum}$ is the performance of the *C. annuum* in the absence of *C.murale* and $DW_{C.murale}$ is the performance of the *C.annuum* in the presence of *C.murale* (Silliman and Bertness, 2004). RCI range has no minimum value but has a maximum value of 1 indicating maximal competition. If RCI = 0 there is no competition. If RCI_{cap} is negative, the performance of *Capsicum annuum* is better with the presence of the alien weed than without *Chenopodium murale*. If RCI_{cap} is positive, *Chenopodium murale* has a negative effect on *Capsicum annuum.* The opposite is for RCI_{Ch}.

Thus, indices RCC, CR and C indicate which species manifests itself as more competitive, and their joint interpretation indicates species competitiveness more surely (Cousens, 1991). The species *C. annuum* is more competitive than *C.murale* when CR > 1, $RCC_{C.\ annuumx}$ >$RCC_{C.\ murale}$ and C > 0; on the other hand, the species *C. murale* is more competitive than *C. annuum* when CR < 1, $RCC_{C.\ annuum}$ < $RCC_{C.\ murale}$ and C < 0 (Hoffman and Buhler, 2002).

The data collected were analyzed statistically using Fisher's analysis of variance and treatment means were compared using the least significant difference (LSD) at a probability level of 0.05 (Steel *et al.*, 1997), using Fisher's protected LSD at *P* = 0.05.

RESULTS AND DISCUSSION

Weeds are one of the most important factors that influence the agricultural production systems (Keramati et al., 2008; Oad et al., 2007; yaghoobi and Siyami, 2008; Aghaalikhani and Yaghoobi, 2008).They reduce crops quantity and increase the cost of production. Weeds are the most costly agricultural pests. Worldwide, weeds cause more yield loss and add more to farmers' production costs than insect pests, crop pathogens, root-feeding nematodes, or warm-blooded pests (Boatwright and McKissick, 2003; Kraehmer and Baur, 2013). Many factors interact to determine the outcome of competition between weeds and crops. Weed density is a major factor. It is well known that crop density is important in limiting the competitive effect of weeds (Tollenaar *et al*., 1995; Wilson *et al*., 1995; Hosseini *et al*., 2006; Khan *et al.*, 2015). Other factors such as soil type and climate are out of farmers control but crop density can be controlled.

Effect of density of *C.murale* on *Capsicum annuum* dry weight

In this study, *C. murale* density had a significant effect on the dry weight of *C*. *annuum*. Dry weight of *C*. *annuum* decreased as *C. murale* density increased. Both high and very low *C.murale* densities negatively interfered with and reduced *C*. *annuum* dry weight. This significant reduction of *C*. *annuum* dry weight at all densities suggests that *C*. *annuum* plants cannot compete without suffering severe damage to growth (Fig. 1). A significant effect on *C*. *annuum* dry weight grown in the same pot for 40 days after plantation was observed as *C.murale* density increased. *C*. *annuum* plants accumulated maximum dry weight (20.01 g/pot) when grown without *C. murale* while lowest dry weight was obtained when one *C*. *annuum* plant was mixed with four *C.murale* plants (0.8 g/pot). On average, dry weight was reduced by about 96.0% due to competition from one *C. murale* plant. When *C. murale* was planted at a density of four plants, it reduced the dry weight of *C*. *annuum* by about 98.0% (Fig. 1). The greater the weed density is, the greater the yield losses.

As *C. murale* density increases, *C. annuum* growth reduction increases as observed for other crops (Qasem, 1996; 1997; Holm *et al*., 1997). Several studies have shown this to be the case for *C.murale* competition in *Triticum durum.* A density of 248 plants/m² of *C. murale* caused 16% loss of *Triticum durum* yield in Pakistan (Holm *et al*., 1997). These results correlate well with other studies. In *Allium sativum*, when *C. murale* was a dominant weed species occurring at density of 50 plants m^{-2}, bulb yield reduction reached 78% (Qasem, 1996). In *Solanum lycopersicum,* a pot experiment with two *C. murale* and one *S. lycopersicum* plant/pot resulted in a 33% reduction in *S. lycopersicum* shoot dry weight compared with the control (weed-free *S. lycopersicum*) (Qasem, 1997). However, the *C. murale* dry weight per pot increased as its density increased until three *C. murale* per pot after which its dry weight decreased (Fig. 1).

Moreover, the total dry weight (*Capsicum* + *Chenopodium*) per pot increased when the *C. murale* increased until three C*. murale* per pot after which this total dry weight decreased (Fig. 1). This dry weight reduction might be caused either by competitive effect or allelopathy effect of *C. murale.*

Relative yields

The relative yield (RY) values indicate the relative competitive ability of the two species. Data on relative yields (RY_{Cap}, RY_{Ch}, RYT) of different intercropping patterns are presented in Table 1, Figure 2). These parameters based on dry weights were significantly affected by the relative proposition of each species in the mixture. The maximum relative yield (RY_{Cap}) of *Capsicum* was related to treatment (*Cap*6*Ch*0) with 1.0. Also, the highest relative yield (RY_{Ch}) of *Chenopodium* was obtained in the treatment (*Cap*1*Ch*5) with a mean of 1.46. The RY of *C*. *annuum* decreased from 1.0 to 0.06 when its proportion in the mixture decreased from 0 to 6 plants/pot, respectively. However, the RY of *C murale* increased from 0 to 1. 46 when its proportion in the mixture increased from 0 to 6 plants/pot. This behavior (decrease of RY_{Cap} and increase of RY_{Ch}) shows that *C.murale* is more competitive than *C.annuum* and it contributes more than expected to the overall productivity of the association (Radosevich, 1987).

The De Wit competitiveness diagrams of the relative yield (RY) of the *C. annuum* and *C. murale* is shown in Figure 2. The RY of *C. annuum* (Figure 2) increased as the proportion of it in mixtures with *C. murale* increased, resulting in a convex curve. As the proportion of *C. murale* in the mixtures increased, the RY of *C. annuum* decreased in a linear manner and near to the expected curve (Figure 2). *C. murale* responded to *C. annuum* to form a concave curve. The most important index of biological advantage is the relative yield total (RYT) that was used to quantify the yield advantages in a replacement series (Mead, 1986). The RYT of the mixtures varied from unity to 1.60, but decreased slightly from 1.60 to 1.52 for intercropping patterns from *Cap*5*Ch*1 to *Cap*1*Ch*5 respectively. The highest value of RYT was observed 1.60 in treatment (*Cap*5*Ch*1). No significant differences (p= 0.05) were observed between these different intercropping patterns when comparing different RYT values of these intercropping patterns except for *Cap*6*Ch*0 and *Cap*0*Ch*6 where the relative yields were unity (1.0). The intercropping treatment between to *C.annuum* and *C.murale* used the environment 52 to 60% more efficiently than a monoculture system of both species individually. Each species damaged the environment of the other species more than its own environment. This represents a case of mutual antagonism (Harper, 1977).

In this study, the relative yield total (RYT) in all intercropping treatments was more than unity, indicating that the two species (*C.annuum* and *C.murale*) used available resources efficiently and that the two species competed for the same resources available in the environment and also indicating partial resource complementarities between competing species. It means the competing species use partially different growing resources or utilize the same resources, but more efficiently due to differences in plant architecture, physiology or growing cycle (Bulson et al., 1997).

Many studies showed this tendancy. Naderi and Ghadiri (2009) indicated that the mean value of *Brassica napus* RY (0.718) and the mean value of *Brassica kaber* RY (0.483) showed that either one of the species has more intraspecific competition than interspecific competition. Moreover, the relative yield indicated *Axonopus* *compressus* is a stronger competitor than *Asystasia gangetica* (Samedani et al.,2013) when they were in mixture. In Similar studies, Khosh Njada *et al.* (2013) found that the RY of *Avena sativa* was lowered when intercropped with *Trifolium* sp. regardless of ratios. Shaker-Koohi and Nasrollahzadeh (2014) found that maximum and minimum relative yield (RY) of *Sorghum bicolor* was related to treatment (2:1) with 0.89 and treatments (1:3) to 0.39, respectively. Also, the highest relative yield (RY) of *Vigna radiate* was obtained in the treatment (1:3) with a mean of 0.84. Shaker-Koohi and Nasrollahzadeh (2014) indicated also that the relative yield total in all intercropping treatments was more than one; the highest value was observed 1.36 in treatment (1:1). Ghaderi et al. (2008) showed the maximum RY for *Medicago sativa* and *Triticum aestivum* was 1.02 and 0.36, respectively; the best RYT for *Medicago sativa* and *Triticum aestivum* intercropping was 1.15. In the same way, studies on legume and non-legume mixtures have attributed high values of RYT to the use of different nitrogen sources in addition to differences in DW (Semere and Froud-Williams, 2001). Esmaeilia *et al.* (2011) found that the RYT of *Hordeum vulgare* and *Medicago scutellata* in intercropping system was higher than one. Guiguo *et al.* (2011) indicated that the intercropping pattern of *Medicago sativa* L. with *Zea mays* L. displayed a biomass yield advantage based on greater RYT values. Likewise, Gholamreza *et al*. (2011) demonstrated that the RYT for all the treatments between *Solanum tuberosum* and *Carthamus tinctorius* was above one; that is, in all the treatments the mixed cropping is preferable to the pure one. However the RYT is not always more than one, Samedani *et al*. (2013) from their replacement study between *Axonopus compressus* and *Asystasia gangetica* showed that the relative shoot dry weight (RY) of the *A. compressus* increased as the proportion of it in mixtures with *A. gangetica* increased. As the proportion of *A. gangetica* in the mixtures increased, the RY of *A. compressus* decreased and the RYT value was less than 1.

The De Wit competitiveness diagrams of the relative yield showed two straight lines which indicate that the ability of the two species to competition is equivalent, whereas concave and convex lines indicate that one species is more competitive than the other gaining resources at the expense of the other species. The convex curve for *C.murale* and the concave curve for *C.annum* indicate that the competitive ability of *C.murale* was more than that of *C.annum.*

The findings of Wall (1997) showed a convex curve for *Triticum aestivum* and a concave curve for *Erucastrum gallicum* for the treatment *T.aestivum and E.gallum,* the author indicated that *T. aestivum* was more competitive than *E. gallium*. Naderi and Ghadiri (2009) found a convex line for *Brassica napus* and a concave line for

Brassica kaber; the convex line for *Brassica napus* and the concave line for *Brassica kaber* indicate that the competitive ability of *Brassica napus* was more than that of *Brassica kaber*. These species were exploiting the resources indifferent ways or somehow benefiting each other. Ghadiri (2005) reported the same response for *Convolvulus arvensis* and *Phasealus arvensis.* However, the findings of Wall (1997) indicated that *Erucastrum gallicum* and *Linum usitatissimum* in mixture were making exploitation of the same resources. Fleming *et al.* (1988) in a study on competitive relationship among *Triticum aestivum*, *Aegiolps cylindrica* and *Bromus tectorum* found that the competitive ability of *Aegiolps cylindrica* and *Triticum aestivum* was similar, but both species exhibited a more competitive ability than *Bromus tectorum*.

Aggressivity

The aggressivity values provide a quantitative competitiveness. The aggressivity indices for *C.murale* vs *C.annuum* series were significantly greater than 0 at P=0.05 (Table-2). This indicated that *C. murale* was more aggressive than *C.annuum*.

The aggressivity values for *C. annuum* were highest (-0.14) in the 5/1 *C. annuum/ C.murale* mixtures while the lowest aggressivity (-1.40) of *C. annuum* was noted when *C. annuum* was decreased from 5 to 1 plants (Table 2). In other words, when the number of *C. annuum* plants increased from 1 plant to 5 plants pot^{-1}, its aggressivity increased from -1.40 to -0.14 without reaching zero, indicating that *C. murale* had an aggressivity value greater than zero. Walha *et al*. (2009) showed that when the aggressivity value of one component is negative, that component is less competitive than the other component and does not have a dominant effect (Bhatti *et al*., 2006). The result of this study indicated that *C. murale* was more aggressive than *C. annuum* and had a dominant effect in agreement with Dhima *et al*. (2007). These results support the findings of Sarkar and Chakraborty (2000), Sarkar and Sanyal (2000) and Sarkar *et al*. (2001), who reported the dominant effect of *Sesamum indicum* having a positive aggressivity value when grown in association with *Vigna radiate*, *Vigna mungo* and *Arachis hypogaea*. Zand and Beckie (2002) reported that mean value of aggressivity for hybrid *Brassica napus* grown in association with *Avena fatua* was 1.52; however, the corresponding values for open-pollinated cultivars *Brassica napus* was 0.78. Naderia and Ghadiri (2009) found that the values of *Brassica napus* aggressivity were greater than those for *Brassica kaber's* one and they concluded that this result indicated that *Brassica napus* was more aggressive than *Brassica kaber*. Atis *et al*. (2012) found that the aggressivity of *Vicia sativa* grown in mixture with *Triticum aestivum* was positive and that of *Tricicum* was negative. They showed that *Vicia* *sativa* was the dominant species in the mixture of *Vicia arvensis* and *Triticum aestivum.* Prather and Callihan (1991) showed that, at equal density of 130 plants/m^2 of each species either *Triticum aestivum* or *Centaurea solstitialis,* the aggressivity of *Triticum aestivum* was half as competitive as *Centaurea solstitialis* (aggressivity=0.49), however the aggressivity of *Centaurea solstitialis was* 1.5 times as aggressive as *Triticum aestivum* and these aggressivity values varied with the increase of density.

Relative crowding coefficient

The relative crowding coefficients of all treatments between *C.annuum* and *C.murale* are presented in Table-2.These parameters varied significantly with the proprtion of each species in the mixture. For *C.annuum* the RCC decreased from 2.70 to 0.06 when the proportion decreased from 5 to 1 respectively. Also, the RCC of *C.murale* increased from -6.67 to +0.4 as the its proportion increased from 1 to5 respectively. When the proportion of *Capsicum* in relation to *Chenopodium* was more than one plant per pot, the RCC_{cap} was positive and greater that that of RCC_{ch}, *C. annuum* had a higher coefficient when it was more than one plant per pot, thus indicating its dominance in the mixture. However, at one plant of *Capsicum* per pot the RCC_{cap} became lesser than that of $RCC_{ch,}$ thus indicating its dominance in the mixture. This result supported the findings of Banik *et al.* (2000) in chickpea-wheat intercropping. The competitive relationships between *Trititum aestivum* and *Lolium multiflorum* or between *Trititum aestivum* and *Raphanus raphanistrum* plants are altered by the proportion of plants that compose the association. *Trititum aestivum* (RCC= 1.83) shows superior competitive ability to *Lolium multiflorum* (RCC=0.30) but when *Trititum aestivum* (RCC=0.35) in association with *Raphanus raphanistrum* (RCC=1.53) inferior to *Raphanus raphanistrum* when the species have similar proportions of plants in the associations and when these species occur in the same ecological niche (Rigoli *et al*., 2008). Mean values of RCC for *Brassica napus* were greater than those for *Brassica kaber*. This indicated that *Brassica napus* as observed in this experiment was more aggressive than *Brassica kaber* (Naderi and Ghadiri, 2009). Zand and Beckie (2002) reported that mean values of RCC for hybrid cultivars of *Brassica napus* was 1.58, the corresponding values for open-pollinated cultivars of *Brassica napus* were 0.76. Moreover, the relative crowding coefficients indicated *A. compressus* is a stronger competitor than *A. gangetica* (Samedani *et al*., 2013). The relative crowding coefficient of *Lycopersicon esculentum was* 2.07 at the proportion 75/25 with *Amaranthus viridus*, it was twice as aggressive as *A.viridus*. However when the proportion was changed to 50/50 or 25/75 the *Lycopersicon esculentum* aggressiveness was changed to

1.11 and 1.23, yet *Lycopersicon esculentum* was more aggressive than *A. viridis* when in mutual coexsistence (Silva *et al.*, 2013). Yamouti *et al.* (2011) found that the RCC of *Triticum turgidosecale* and *Raphanus raphanistrum* were 1.04 and 0.95 respectively; according to Hoffman and Buhler (2002), they demonstrated that *Triticum turgidosecale* was more competitive than the *Raphanus raphanistrum.* Ghadiri (2005) also, reported that RCC of *Phaseolus arvensis* and *Convolvulus arvensis* showed that *Phaseolus arvensis* was at least 3 times more aggressive than *Convolvulus arvensis.* Moreover Morales-Payan *et al*., indicated that the RCC at > 36 kg/ha of both species (*Cyperus rotundus* and *Coriandrum sativum)* at equal proportion 50/50 was the same but when the addition of nitrogen to < 72 kg /ha, the competitiveness *Cyperus rotundus* was enhanced about 15 times more competitive than *Coriandrum sativum* (Morales-Payan *et al*., 2000).

Actual yield loss (AYL or DWYL)

The DWYL values for *C. annuum* were all negative and ranges from -0.43 to -89 indicating a yield loss of 43% - 89%, compared to sole *C. annuum* DW. The DWYL values for *C. murale* were positive in all proportion mixtures indicating a yield gain of 11 % to 458 %, compared to sole *C.murale* DW. The total DWYL values were positive in 5/1, 4/2, 3/3 combinaisons and negative in 2/4 and 1/5 combinations. The total DWYL values showed an intercropped DW loss with a minimum DW loss value of 7 %. Likewise, Takim (2012) found that the AYL values for *Vigna unguiculata* intercropped with *Zea Mays* were all negative and ranges from - 0.257 to -0.813 indicating a yield loss of 25.7% - 81.3%, compared to sole *Vigna unguiculata* yield under the southern Guinea savanna conditions in Nigeria. However under the East Mediterranean conditions in Turkey, Yilmaz et al (2007) reported that the AYL values for *Vigna unguiculata* intercropped with *Zea mays* were all negative and ranges from -0.02 to -0.42 indicating a yield loss of 2 - 42% compared to sole *Vigna unguiculata* yield.

Competitive indices

The competitiveness (C) is a measure of ability of a species to deplete the limiting resources. The competitiveness is determined according to Cousens and O'Neill (1993) by the difference of relative yields between the components in mixture. The competitiveness of *C.annuum* (C*cap*) is the difference between the relative yield of *Capsicum* and the relative yield of *C.murale.* This competitiveness is not only negative but also decreased as the proportion of Capsicum decreased from -0.14 to -1.40. The opposite is for *C.murale.* This indicated that the *C. murale* is more competitive than *C.annuum*.

The competitive ratio (CR) of *C.annuum* increased from 0.04 – 0.83 with increasing density of the *C.annuum* in the intercrop combinations from 1/5 to 5/1. The competitive ratio of *C.murale* had the opposite response (1.19-24.33). The values of competitive ratio for *C.murale* were greater than for *C.annuum* in all intercrop combinations (Table-2). Egbe (2010) found that the competitive ratio of *Glycine max* increased (0.76 to 1.15) with increasing density of the soybean in the intercrop combinations with *Sorghum sp*. The competitive ratio of *Sorghum* had the opposite response (1.23 to 0.76). Egbe (2010) indicated that *Glycine max* had a higher competitiveness at higher densities than *Sorghum sp*. Moreover, Jamshidi (2011) showed from his study that the values of the competitive ratio for *Triticum aestivum* var 'Zarrin' were greater than for *Triticum aestivum* var. 'Gaspard' in all seeding ratios.This study had shown that the RCI_{Cap} of *C.annuum* is positive indicating its performance is not better with the presence of than in the absence of *C.murale* and *C. murale* has a negative effect on *C. annuum.*

In conclusion*, C.murale* exhibited clear differences in growth attributes and competition indices from *C.annuum*. *C.murale* showed significantly higher values for all growth attributes, Dry weight, relative yield, aggressiveness and Competitive indices. *C. annuum* exhibits weak inter-specific competitiveness; However, *C.murale* is a strong competitive in inter-specific interactions.

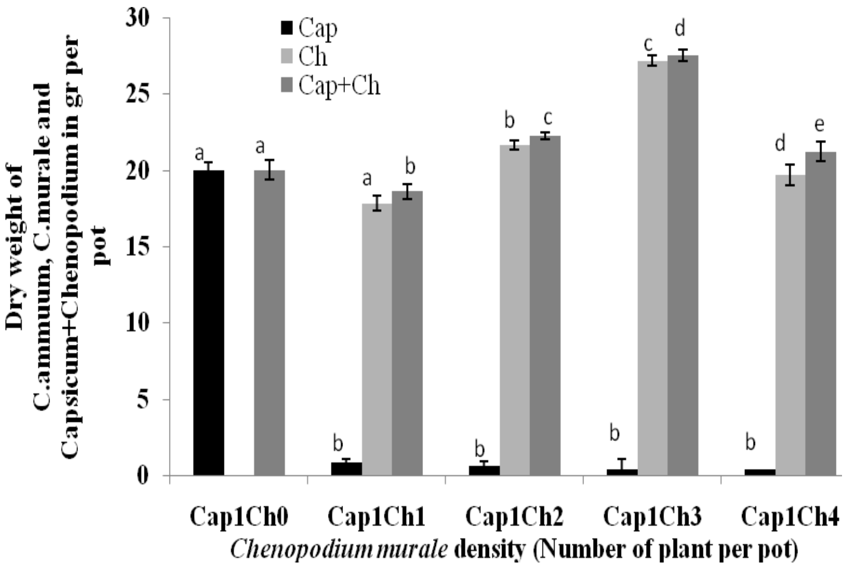

Figure 1. Effect of *C. murale* density of *C. annum* dry weight per pot and the effect of *C. annuum* on *C. murale* dry weight.

Cap= *Capsicum*, Ch= *Chenopodium.* Vertical bars represent standard errors of means, letters on bars represent meam separation. Vertical bars represent standard errors of means. Data sets of 5 replicates were subjected to ANOVA, and means were separated using the *F*-test and LSD at the 0.05 level. Bars with the same letters are not significantly different across proportion.

Table-1. Relative yield (RY) of *C.annuum* and *C. murale* and total relative yields 40 days after transplantation RY and RYT are averages of three experiments and five densities. Proportion refers to *C.annuum* and *C.murale* respectively in replacement treatment study.

Proportion of *C.annuum* /*C.murale*	Relative Yield of *C.annuum* (RYcap)	Relative Yield of *C.murale* (RYch)	Relative Yield Total (RYT)
6Cap	1.00 a	0.00 a	1.00 b
5/1	0.73 b	0.87 b	1.60 a
4/2	0.52 c	1.02 c	1.54 a
3/3	0.38 d	1.20 d	1.58 a
2/4	0.19 e	1.31 e	1.50 a
1/5	0.06 f	1.46 f	1.52 a
6Ch	0.00 g	1.00 g	1.00 b

Values within a column followed by different letters are significantly different at P≤ 0.005 based on the F-test and LSD.

Table-2. Values of RCC, Aggressivity and Actual yield loss (AYL) for the mixture of *C.annuum* and *C.murale* as affected by plant density in replacement treatment study.

Proportion of *C.annuum* /*C.murale*	RCC		AGR_{cap}	Actual yield loss (AYL)		
	RCC_{Cap}	RCC_{Ch}		AYL_{Cap}	AYL_{Ch}	Total AYL
5/1	2.70 a	-6.67 a	6.69 a	-0.75a	4.58a	3.83a
4/2	1.08 b	-4.01 b	5.10 b	-0.80a	1.89b	1.09b
3/3	0.61 c	-1.45 c	-0.83 c	-0.60a	1.02c	0.52c
2/4	0.23 d	-1.66 d	-4.22 d	-0.89a	0.82d	-0.07d
1/5	0.06 e	+0.4 e	-3.17 e	-0.43a	0.11e	-0.32e

Values within a column followed by different letters are significantly different at P≤ 0.05 based on the F-test and LSD. RCC_{Cap} =RCC of *Capsicum,* RCC_{Ch} = RCC of *Chenopodium*, AGR_{Cap} = aggressivity of *Capsicum*, AYL = Actual yield loss, AYL_{Cap}= Actual yield loss of Capsicum AYL_{Ch} = Actual yield loss of *Chenopodium*, and Total AYL= Total Actual yield loss. Values within a column followed by different letters are significantly different at *P* ≤ 0.05 based on the *F*-test and LSD.

Table-3. Competitive indices of *Capsicum* compared to *Chenopodium*, expressed by the competitiveness (C), relative competitive ratio (CR), competitive intensity (CI) and relative competitive intensity for intercompetition between *C. anuum* and *C. murale.*

Proportion of *C.annuum* /*C.murale*	C_{Cap}	CR_{Cap}	CR_{Ch}	RCI	
				RCI_{Cap}	RCI_{Ch}
5/1	-0.14 a	0.83 a	1.19 e	0.78 a	+ 0.07 a
4/2	-0.50 b	0.50 b	1.96 d	0.86 a	- 0.20 a
3/3	-0.82 c	0.31 c	3.15 c	0.79 a	- 0.01 a
2/4	-1.12 d	0.14 d	6.89 b	0.96 a	+ 0.10 a
1/5	-1.40 e	0.04 e	254.33a	0.90 a	- 0.11 a

Values within a column followed by different letters are significantly different at P≤ 0.005 based on the F-test and LSD. C_{Cap} = competitiveness of *Capsicum*, CR_{Cap} relative competitive ratio of *Capsicum* CR_{Ch} = relative competitive ratio *of Chenopodium,* RCI_{Cap} = relative competitive intensity of *Capsicum* , RCI_{Ch}= relative competitive intensity of *Chenopodium.* Values within a column followed by different letters are significantly different at $P \leq 0.05$ based on the *F*-test and LSD.

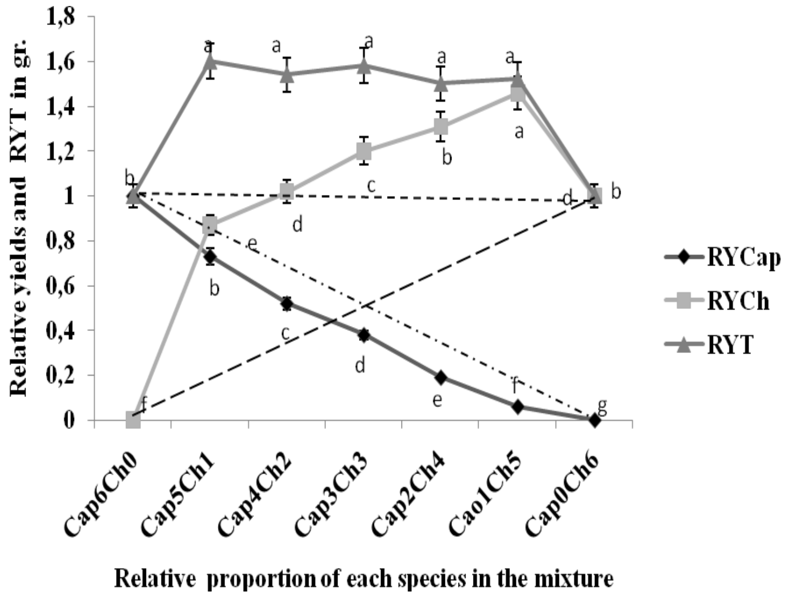

Figure 2. Relative yield (RY) and total relative yield (TRY) for the total dry matter of *Capsicum annuum* and *Chenopodium murale* coexisting as a function of proportional abundance.

Vertical bars represent standard errors of means, letters on bars represent meam separation. Vertical bars represent standard errors of means. Data sets of 5 replicates were subjected to ANOVA, and means were separated using the *F*-test and LSD at the 0.05 level. Bars with the same letters are not significantly different across proportion.

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