International Journal of Agriculture and Earth Science (IJAES) E-ISSN 2489-0081 P-ISSN 2695-1894
Vol 11. No. 2 2025 www.iiardjournals.org

Functional Traits Analysis and Competition Coexistence in Crops-Invasive Weeds Interaction Under Induced Salt Stress

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DOI: 10.56201/ijaes.vol.11.no2.2025.pg56.65

Abstract

Weeds are an important component of agroecosystems that interact with crops and negatively affects food crop production through competition for light, soil nutrients and reduces yields of major crops by a global average of 34%. This study examines functional traits and competition analysis of Solanum lycopersicum and Capsicum annuum in mono and mixed culture with two invasive alien weeds (Euphorbia heterophylla and Acanthospermum hispidum) under different sodium chloride (NaCl) concentrations. Data for the study was obtained from field measurement and laboratory experiment. Results from the study showed that canopy height was significantly higher in monoculture at 5% NaCl concentration for both S. lycopersicum 88.23±1.12 and C. annuum 70.13±6.40, while the lowest values were recorded at higher salinity levels in mixed cultures. Leaf dry matter content and relative water content remained relatively stable across treatments, with the highest values observed in monoculture at 5% to 25% salinity. Specific leaf area exhibited variability, being highest in the mixture of S. lycopersicum and A. hispidum mixtures with 35.02±22.80 at 10% NaCl treatment and C. annuum and A. hispidum mixtures with 27.56±11.37 at 25% NaCl treatment. Yield was significantly higher in the S. lycopersicum and A. hispidum at 15% NaCl treatment with 1.41±0.01 and in C. annuum monoculture at 5% NaCl with 0.65±0.10. Relative yield and relative yield total followed similar trends, with the highest values recorded in optimal salinity. It is therefore concluded that the competitive balance between invasive weeds and crops is partially altered and also recommended that further studies should be carried out to identify the mechanism of intraspecific trait variation in weeds and the consequences of weed fitness.

Key words: Functional traits, Competition, Salt stress, S. lycopersicum and A. hispidum

INTRODUCTIONS

Weeds are an important component of agroecosystems systems and may interact with crops and other organisms in different ways and negatively affect food crop production by competition with crops for light and soil nutrients and reduce yields of major crops by a global average of 34% (Oerke 2006). The economic cost of plant invasion to agriculture is growing due to the increasing number of new introductions which create a tremendous impact on crop production and reduce agricultural productivity by way of considerable mechanisms: competition for light, water, nutrient, allelopathy effects and decrease the crop yields and inhibition of seed germination Pimentel, *et al*.(2005), and the costs of their management to regulate the damage they cause, reaches about $336 billion USD (equivalent to # 554,880,000,000,000 NGN) in the US, Australia, United Kingdom, South Africa, and India alone and the menaces caused by them are increasing each day as the world becomes increasingly interconnected (Moles *et al.*,2012).

Generally environmental factors occurring in varying magnitudes will boost plant invasions globally, but its consequences could vary by region (Jia *et al.*, 2016). As species respond differently to environmental changes such as stress and increased CO_2 that may promote invasion (Vilà, and Weiner, 2004). In addition, stress-tolerant species are already favoured in some areas in anticipation of changes triggered by climate change (Lockwood *et al.*, 2013). However, Bollen *et al.*, (2016), maintained that that salinity can exacerbates the replacement of crops by invasive weeds (Legault *et al.*, 2018), but salinity also can also restrain the spread and performance of some weeds (Qi *et al.*, 2017; Liu *et al.*, 2019). Therefore, whether salinity can enhance the invasion of invasive weed species is debatable (Guo *et al.*, 2023).
However, some studies have been conducted on whether competitive interaction between invasive weeds and crop species are affected by salinity. According to the stress gradient hypothesis, interactions among plants are context-dependent, moving from competition to facilitation as environmental stress increases (Bertness and Callaway, 1994).
Several studies of competition between crops and weed species were conducted and the results of these studies have been used in planning of integrated management practices such as crop rotation, succession, and winter crops as tools for suppressing weed occurrence (Ceccon, 2007). Most of those studies unravel the dynamics of weed infestation in certain crops based on dry mass accumulation, plant height, and number of branches, number of inflorescences and other measured parameters (Bianchi *et al.*, 2010). On the other hand, there is still a big gap involving physiological, high specialized studies and utilization of such studies for practical everyday weed control on crops Therefore, this study was carried out to investigate how traits mediated competitive interaction between crops and weed under salt induce stress focusing on four functional traits with high intraspecific variability (Siefert *et al.*, 2015). These are, canopy height (CH), relative water content, specific leaf area (SLA) and leaf dry matter.

MATERIALS AND METHODS

Study Area

The study was carried out in Kebbi state Nigeria. The state lies between latitude 11°30 Nand 14° 00'N, and longitude 4°00''E and 6° 40 E and altitude 351.0 m above sea level and the vegetation type is Sudan savannah ecological zone (SERC, 2015). laboratory and field experiments were carried out in the Botany laboratory and Botanical Garden of Kebbi State University of Science and Technology Aliero.

Experimental Site

For this study, a survey was carried out in some of the wetland areas of Sokoto State to determine weed species that are present (invasive weeds) in the area. A total of four species (2 invasive weeds and 2 crop species) were selected and grown in mono and mixed cultures conditions in the Botanical Garden of Kebbi State University of Science and Technology.

Plants Collection and Growing Conditions

The seeds of crops namely *Solanum lycopersicum* and *Capsicum annuum*were purchased from Sokoto State Central Market, while the invasive weeds seed namely; *Euphorbia heterophylla* and *Acanthospermum hispidum* were surveyed in Dundaye agroecosystem Sokoto State. During the survey the weeds were identified locally, collected as (Dan Madaro and Kashin Yawoo) and subjected to identification and authentication by taxonomist in the herbarium Department of Plant Science and Biotechnology Kebbi State University of Science and Technology Aliero where voucher specimens were deposited at the herbarium. Four (4) plots of $4m^2$ were laid and harrowed in the Botanical Garden for seedbed preparation, both seeds were broadcasted in each plot using a hand. Before the broadcasting, weed seeds were pre-soaked in a 70 °C hot water bath for 4 to 5 min, then dried at room temperature to increase germination rate (Khedir and Roeth, 1981). The plant materials obtained from germination of the seeds in the seed bed. After three weeks, When the seedlings developed 3 to 4 true leaves, healthy and uniform seedlings were selected and transplanted into the field laid out of $1m^2$in a randomised complete block design (RCBD). The treatments consisted of a factorial combination of two crops and two weed infestation levels arranged in crops-free and crops-weed mixture each respectively. To mimic salinity sodium chloride (NaCl) was applied to each plot replicated three times at concentration of 5, 10, 15, 20, and 25%, compositions respectively. The Plants will be watered twice a week including those from the control treatment. After three consecutive applications of NaCl at interval of two weeks, five plants from each of the trial plots were randomly selected, tagged avoiding the border rows.

Functional Traits and Competition Coexistence Determination

Functional Traits

Four functional traits related plant functional responses to resource availability that includes; Canopy Height (CH), Leaf Dry Matter Content (LDMC), Relative Water Content (RWC) and Specific Leaf Area (SLA) (Gaba *et al.*,2017).CH and SLA (ratio of leaf area to leaf dry mass) are indicators of plant competitive abilities for light. RWC, SLA and LDMC (ratio of leaf dry mass to leaf fresh mass) are physiological markers of plant resource use strategies LDMC is positively related to the outcome of competitive interactions and to the ability to conserve acquired resources (Singh and Singh, 2012). The Canopy height of each plant was measured in the field every two weeks from a regular interval. Canopy height was the height from the ground to the highest point of the growing plant.

To obtain an accurate measurement of relative water content (RWC), and leaf dry matter content, fully expanded younger leaves from each treatment were gathered. After the surface of the leaf had been carefully dried with newspaper, it was first wrapped in polythene bags and then transported to the laboratory. To determine the fresh weight of the leaf (FW). After that, the samples were placed in plastic tubes that contained distilled water and allowed to sit in the dark for an entire night. The following morning, these leaves were delicately swollen with paper to determine the turgid weight, and the results were recorded (TW). After that, a hot air oven will be used to dry the leaves at a temperature of 110˚C until the weight remained the same. After that, dried leaves will be weighed to record their dry weight (DW). The RWC were determined by applying the formula presented below according to Schonfeld *et al.* (1988) as follow:

$$RWC\ (\%) = (FW - DW) / (TW - DW) \times 100$$

Competition determination

At the termination of each experiment, above-ground biomass of each species separately was harvested and dried for 48 h at 110 ^{0}C and weighed. All results are given as above-ground dry biomass (g) of each species in a plot. The growth of individual plants in mixed cultures of species was compared with the growth of individuals in pure stand monocultures at the same overall density. The total density of all plants is held constant and only the proportions of the different species differ. This design provides a method of measuring the effects of interference (competition) amongst species despite the often-large differences in absolute yield between different species. From the yield (above-ground biomass) of each species in each plot, the total number of individuals in the plot and the proportions of each species in the plot and two variables were calculated as follows:

Relative yield per plant, RYP, and relative yield total, RYT. These variables are defined in the following way.

First, let p = initial proportion of species i in a mixture,

q = initial proportion of species j in a mixture,

so that p + q = 1 in a mixture of two species,

Now define Y_i = biomass yield of species i in a monoculture of species i,

Y_{ij}= biomass yield of species i in a mixture of species i and j.

All values being per plot. Given a constant total density, then

$$RYPU = Y_{ij}/(pY_i) \text{ and}$$

$$RYP_{ji} = Y_{ji}/(qYj).$$

Relative yield per plot may be interpreted as the average performance of an individual in a mixed culture in comparison with the average performance of an individual of the same species in a monoculture of the same total density. Relative yield per plot as calculated here is closely related to the relative yield (RY) as defined by de Wit (1960):

The relative yield total, RYT, is the weighted average of the relative yields of the mixture components:

$$RYT_{ij} = pRYPi_j + qRYP_{ji}$$

If the growth of an individual is unaffected by the identity of the neighbouring individuals, then RYP_i = 1 0; but RYP_i> 1.0 implies that individuals of species i suffer less interference from individuals of species j (between-species competition) than they do from individuals of their own species (within-species competition); and RYPij< 1. 0 implies that within-species competitions less than that between species.

Relative yield totals were calculated on a plot-by-plot basis and averaged according to the following equations:

$$\mathbf{RYT_{ij}} = \sum_{u=3}^{n=3} \frac{RYTiju}{n}$$

Where u = number of the replicate (1, 2, 3, 4 or 5) and n = number of replicates =3.

RESULT AND DISCUSSIONS

Crop and weed functional traits varied among species, inTable1 it is depicted that canopy height was relatively higher in monoculture at 5% with the recorded value of 88.23±1.12while the least value was obtained in the mixture of *S. lycopersicum* and *E. heterophylla* with the obtained value of 55.53±2.66 at 15% level of NaCl concentration while In *C. annuum* the canopy height was relatively higher in monoculture at 5% with the recorded value of 70.13±6.40while the least value was obtained in the monoculture with the obtained value of51.80±2.25at 20% level of NaCl concentration and its significantly different Table 2.The findings indicate that lower salinity levels (5%) generally promote better growth outcomes, while higher salinity levels (15% and above) adversely affect plant performance which is in close agreement with that of Perejitei. (2019), The interaction effect occurred because, as stubble height increased from 10 to 40 cm, canopy height increased to a greater extent for treatments defoliated every 3 and 6 weeks compared with 9 and 12 weeks.

There was no significant different in leaf dry matter content at all level of treatment in which the highest value was 0.18±0.12 in monoculture at 25% level of concentration while the lowest value was obtained in the mixture of both *S. lycopersicum* and *A. hispidum* at 10% level of concentration with recorded value of 0.14±0.08.The relative water content remained quite stable among the treatments with no significant difference in both monoculture and mixed culture but the highest value was recorded at 10% concentration with the value of 9.57±1.30 in monoculture Table 1. However, *C. annuum* similar trend in leaf dry matter and relative water content at all level of treatment in which the highest value was 0.27±0.12in monoculture at 5% level of concentration while the lowest value was obtained in the mixture of both *Capsicum annuum* and *Euphorbia heterophylla* at 25% level of concentration with recorded value of 0.14±0.08 but the highest water content value was recorded at 5% concentration with the value of 5.85±1.30in monoculture while least of 3.82±1.30value was recorded in the mixture of *C. annuum* and *A. hispidum* Table 2.The stability of the water and dry matter content showed that the plants maintained their water status despite salinity stress, a response observed in other studies as well. Maintaining relative water content is crucial for plant survival under saline conditions, as it helps in sustaining physiological processes. This finding agreed with that of Gumi *et al*. (2013), in his study on Salinity Stress: effects on growth, biochemical parameters and ion homeostasis in *Solanum lycospersicum* L. (Cv. Dan eka).

Similarly, specific leaf area the data are more spread out, the highest values were obtained at 10% mixture of *S. lycopersicum* and *A. hispidum* with the obtained value of 35.02±22.80 whereas the least value of 18.15±3.54was recorded at 20% concentration in monocultureTable1. In *C. annuum* the specific leaf area was highest in the mixture of *Capsicum annuum* and *A. hispidum* with the recorded values of 27.56±11.37 at 25% level of concentration whereas the least value of 11.39±3.54 was recorded at 5% concentration in monoculture Table 2.The Variations in specific leaf area under salinity stress have been reported in other studies, indicating adjustments in leaf morphology as a response to environmental stressors which is in agreement with Sumalan and Ciobanu (2010) in his study on the Effects of Salinity Stress on the growing rates and physiological characteristics of *Lycopersicum esculentum*

The yield of plant was higher in the mixture of *S. lycopersicum* and *A. hispidum* at 15% level of concentration with the recorded value of 1.41±0.01while the least value was obtained in the monoculture at 10% level of concentration with the value of 0.49±0.05. The relative yield has similar trend with yield value was highest in the mixture of *S. lycopersicum* and *A. hispidum* at 15% level of concentration with the recorded value of 2.23±0.01while the lowest value was obtained in monoculture at 25%level of concentration with the value of 0.96±0.17. Relative yield total was relatively higher and lower in the mixture of *S. lycopersicum* and *E. heterophyyla* at 20 and 10% level of concentration with recorded value of 6.24±7.73 and1.22±0.01 respectively Table 1. The yield of plants was higher in monoculture at 5% level of concentration with the recorded value of $0.65±0.10^{b}$ while the lowest value was obtained also in the mono culture at 20% level of concentration with the value of 0.37±0.05. The relative yield have similar trend with yield value was highest in the monoculture 5% level of concentration with the recorded value of 1.30±0.20 while the least value was obtained in mixed culture of *C. annuum* and *E. heterophylla* at 15%level of concentration with the value of 0.82±0.01Relative yield total was relatively higher in the monoculture at 5% level of concentration with the obtained value of 5.84±0.01 and the lower value was in the mixture of *C. annuum* and *A. hispidum* at 10% level of concentration with recorded value of 0.80±0.008 Table 2.These results unravel that certain plant mixtures may confer a competitive advantage under specific salinity conditions, potentially due to complementary interactions between species. However, high salinity levels generally reduce yield, as supported by literature indicating that salinity stress adversely affects reproductive development and fruit production in tomatoes which is in accordance with Singh, (2012).

Table 1 Functional Traits and Yield of Mono and Mixed Culture of *Solanum lycopersicum* and Invasive Weed Species

NaCl Conc (%)	Canopy Height (cm)	Leaf Dry Matter	Relative Water Content	Specific Leaf Area	Yield g-1	RY/ plot	RY Total
Control	92.31±2.10^{j}	0.17±0.09^{a}	9.63±1.23^{a}	22.56±2.14^{ab}	0.85±0.03^{g}	1.44±0.02^{bcde}	5.18 ±0.44^{f}
S. 5	88.23±1.12^{i}	0.18±0.03^{a}	9.52±1.30^{a}	20.84±3.40^{ab}	0.82±0.15^{f}	1.63±0.31^{cde}	4.90±0.01^{e}
S. 10	81.57±3.67^{gh}	0.14±0.12^{a}	9.57±1.30^{a}	26.60±3.54^{ab}	0.49±0.05^{ab}	0.98±0.10^{a}	2.94±0.01^{c}
S. 15	85.43±3.50^{hi}	0.16±0.12^{a}	9.41±1.30^{a}	19.07±3.54^{ab}	0.65±0.06^{cd}	1.31±0.12^{b}	3.92±0.01^{a}
S. 20	83.10±1.10^{gh}	0.17±0.12^{a}	8.82±1.30^{a}	18.15±3.54^{ab}	0.60±0.09^{c}	1.20±0.17^{ab}	3.60±0.01^{d}
S. 25	80.40±2.93^{g}	0.18±0.12^{a}	8.66±1.30^{a}	20.83±3.54^{ab}	0.48±0.09^{a}	0.96±0.17^{a}	2.88±0.01^{c}
S and A 5	62.10±1.83^{cd}	0.18±0.08^{a}	9.44±1.30^{a}	24.56±13.85^{ab}	0.84±0.01^{f}	1.43±0.00^{bcde}	1.43±0.01^{a}
S and A10	68.90±1.40^{f}	0.14±0.08^{a}	9.43±1.30^{a}	35.02±22.80	0.76±0.00^{ef}	1.40±0.01^{bcd}	1.40±0.01^{a}
S and A 15	67.77±1.92^{f}	0.16±0.08^{a}	9.41±1.30^{a}	22.84±11.51^{ab}	1.41±0.01^{h}	2.23±0.01^{f}	2.23±0.01^{b}
S and A 20	67.00±1.40^{ef}	0.17±0.08^{a}	9.23±1.30^{a}	21.25±9.60^{ab}	1.02±0.00^{g}	1.71±0.01^{e}	1.72±0.01^{a}
S and A 25	63.37±1.81^{de}	0.18±0.08^{a}	8.85±1.30^{a}	23.76±13.08^{ab}	1.11±0.01^{g}	1.67±0.01^{de}	1.67±0.01^{a}
S and E 5	62.87±2.21^{cd}	0.18±0.08^{a}	9.37±1.30^{a}	19.99±8.64^{ab}	0.70±0.01^{de}	1.34±0.46^{bc}	1.34±0.01^{a}
S and E10	56.57±3.59^{ab}	0.14±0.08^{a}	9.43±1.30^{a}	26.32±16.63^{ab}	0.58±0.01^{bc}	1.22±0.01^{ab}	1.22±0.01^{a}
S and E 15	55.53±2.66^{a}	0.16±0.08^{a}	9.41±1.30^{a}	19.68±9.69^{ab}	0.63±0.01^{cd}	1.24±0.01^{ab}	1.24±0.01^{a}
S and E 20	59.00±1.40^{abc}	0.17±0.08^{a}	9.13±1.30^{a}	22.46±13.24^{ab}	0.64±0.01^{cd}	1.36±0.01^{bx}	6.24±1.73^{g}
S and E 25	59.80±1.40^{bcd}	0.18±0.08^{a}	8.91±1.30^{a}	23.83±10.29^{ab}	0.58±0.01^{bc}	1.26±0.01^{ab}	1.26±0.01^{a}

Values are means± standard deviation of three replications. Values within a column with different superscripts are significantly different ($p<0.05$). Keys: S= *Solanum lycopersicum* in Monoculture; S and A=*Solanum lycopersicum* and *Acanthospermun hispidum* in Mixed culture: Sand E = *Solanum lycopersicum* and *Euphorbia heterophylla* in Mixed culture

Table 2: Functional Traits and Yield of Mono and Mixed Cultures of *Capsicum annuum* and Invasive Weed Species

NaCl Conc (%)	Canopy Height	Leaf Dry Matter	Relative Water Content	Specific Leaf Area	Yield g^{-1}	RY/ plot	RY Totals
Control	81.23 ±1.64^{g}	0.26 ±0.03^{a}	5.93 ±1.53^{a}	21.73 ±3.42^{def}	0.60 ±0.03^{b}	1.34 ±0.12^{c}	5.68 ±1.01^{m}
C. 5	70.13±6.40^{f}	0.27±0.12^{a}	5.85±1.30^{a}	11.39±3.54^{bc}	0.65±0.10^{b}	1.30±0.20^{c}	5.84±0.01^{m}
C. 10	55.33±4.51^{abc}	0.24±0.12^{a}	5.55±1.30^{a}	10.30±3.54^{ab}	0.50±0.13^{ab}	0.99±0.25^{abc}	4.47±0.006^{k}
C. 15	54.13±3.16^{ab}	0.20±0.12^{a}	5.46±1.30^{a}	12.56±3.54^{bcd}	0.43±0.10^{ab}	0.85±0.20^{abc}	3.83±0.006^{j}
C. 20	51.80±2.25^{a}	0.19±0.12^{a}	5.28±1.30^{a}	16.06±3.54^{bcde}	0.37±0.05^{a}	0.74±0.11^{a}	3.33±0.006^{i}
C. 25	54.37±3.26^{ab}	0.19±0.12^{a}	4.98±1.30^{a}	20.58±3.54^{cdef}	0.61±0.40^{ab}	1.23±0.81^{bc}	5.52±0.006^{l}
C and A	60.23±2.32^{cd}	0.27±0.08^{a}	5.55±1.30^{a}	15.67±4.03^{bcde}	0.52±0.06^{ab}	0.97±0.10^{abc}	0.97±0.007^{e}
C and A10	57.70±2.65^{bc}	0.24±0.08^{a}	5.41±1.30^{a}	15.24±4.36^{bcde}	0.46±0.01^{ab}	0.80±0.01^{ab}	0.80±0.008^{a}
C and A 15	60.30±1.40^{cd}	0.20±0.08^{a}	5.50±1.30^{a}	17.12±6.25^{bcde}	0.47±0.00^{ab}	0.97±0.03^{abc}	0.97±0.006^{e}
C and A 20	57.10±1.78^{abc}	0.19±0.08^{a}	5.19±1.30^{a}	21.62±8.47^{def}	0.58±0.14^{ab}	1.10±0.07^{abc}	1.10±0.006^{f}
C and A 25	55.80±1.40^{abc}	0.19±0.08^{a}	3.82±1.30^{a}	27.56±11.37^{f}	0.52±0.00^{ab}	1.14±0.09^{abc}	1.14±0.007^{g}
C and E 5	64.10±1.40^{de}	0.27±0.08^{a}	5.54±1.30^{a}	16.03±4.14^{bcde}	0.46±0.01^{ab}	0.89±0.01^{abc}	0.89±0.005^{d}
C and E10	58.90±1.40^{bcd}	0.24±0.08^{a}	5.63±1.30^{a}	18.94±5.66^{bcdee}	0.58±0.01^{ab}	1.17±0.01^{abc}	1.17±0.007^{h}
C and E 15	57.77±2.70^{bc}	0.20±0.08^{a}	5.46±1.30^{a}	20.58±7.77^{cdef}	0.47±0.00^{ab}	0.82±0.01^{ab}	0.82±0.006^{b}
C and E 20	61.00±1.40^{cd}	0.19±0.08^{a}	5.18±1.30^{a}	23.09±9.14^{ef}	0.47±0.00^{ab}	1.17±0.01^{abc}	1.17±0.007^{h}
C and E 25	67.93±3.21^{ef}	0.19±0.08^{a}	4.76±1.30^{a}	21.48±8.57^{def}	0.50±0.01^{ab}	0.85±0.01^{abc}	0.85±0.006^{c}

Values are means± standard deviation of three replications. Values within a column with different superscripts are significantly different ($p<0.05$). Keys: C= *Capsicum annuum* in Monoculture, C and A=*Capsicum annuum* and *Acanthospermum Hispidum* in Mixed culture, C and E = *Capsicum annuum* and *Euphorbia heterophylla* in Mixed culture

CONCLUSION

The study concluded that lower salinity generally favours plant growth and development, but at higher concentration negatively affects canopy height, specific leaf area, and yield. Despite variations in plant responses, leaf dry matter content and relative water content remained relatively stable across treatments, suggesting the ability of these crops to maintain physiological balance under saline conditions. Specific leaf area and yield data further suggest that intercropping under moderate salinity conditions can provide a competitive advantage, possibly through resource sharing and stress mitigation.

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