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Physiological performance and competitive ability in kale (*Brassica oleracea* var. *acephala* 'Manteiga da Georgia') intercropped with important aromatic species and herbs

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Abstract

The effectiveness of intercropping depends on the complementarity or the adaptive capacity of species during the period of coexistence. Kale is a plant that displays differing responses to environmental factors, and may therefore display different behaviour when grown with other species. The aim of this study was to analyse the physiological behaviour and competitive ability of kale when intercropped with the Welsh onion, coriander, basil and parsley. The experiment was carried out under field conditions, in a randomised block design with nine treatments and five replications. The following were evaluated: net photosynthesis, stomatal conductance, CO_2 concentration of the sub-stomatal chamber, transpiration rate, ratio between the CO_2 concentration of the sub-stomatal chamber and the CO_2 concentration of the environment, instantaneous carboxylation efficiency, aggressivity index, and the competitive and compensation ratios. The kale plants intercropped with coriander displayed values for net photosynthesis (A) and instantaneous carboxylation efficiency (A/Ci) of 18.75 µmol CO_2 m^{-2} s^{-1} and 0.060 respectively, the lowest values for all the treatments under evaluation. The kale displayed less competitive ability. The more aggressive crops were the Welsh onion (2.25) and coriander (2.08). The parsley displayed the lowest competitive effect, having no effect on yield in the kale. The conclusion is that the coriander was prejudicial to the photosynthetic performance of the kale. The intercropping system with parsley was the most advantageous, due to the balance seen in interference between species for productive resources.

Keywords: *Allium fistulosum; Brassica oleracea* var. *acephala; Coriandrum sativum*; interspecific competition*; Ocimum basilicum*; *Petroselinum crispum*; photosynthetic efficiency.

Introduction

The species, *Brassica oleracea* L., originally domesticated in the coastal region of the Mediterranean, today presents botanical varieties, grown around the world, which adapt to a wide range of climatic conditions (Rodriguez et al., 2015). Among these varieties, kale (*B. oleracea* L. var. *acephala* DC) is the most widespread in Brazil, with a significant share in domestic vegetable production (Fernandes et al., 2009; Resende et al., 2010). Kale is a sturdy crop that adapts well to different environmental conditions (Vilar et al., 2008). It is also responsive to management techniques, and can be grown under various levels of technology and cropping systems, with its own differing response mechanisms to environmental variables, even when under conditions of stress (Rodriguez et al., 2015). Among the systems for growing vegetables, intercropping is an alternative production system based on such ecological principles as diversity, where two or more species are planted together in a given area (Willey, 1979; Albuquerque et al., 2012). To get the greatest biological diversity, intercropped species generally differ in height, leaf architecture, root system and other morpho-physiological characteristics, which can lead to plants competing for nutrients, water and light energy (Flesch, 2002). However, considering that in the commercial cultivation of intercropped vegetables, both water and nutrients should be abundantly available to the crops, the greatest attention must be given to incident radiation, since this can act as a limiting factor to plant growth under conditions of excessive shading between the intercropped species. Baumanna et al. (2002) report that under light stress, the morpho-physiological characteristics of intercropped species are a result of the effects of this interspecific competition, which may be harmful to one or both of the cultivated crops. Such competition affects the efficient use of environmental resources, as well as the quantity and quality of the final product, i.e. crop yield. The component species of an intercropping system have different capacities for competing with each other, with those of greater competitive ability being more prominent, especially when they have the ability to tolerate or produce allelopathic effects (Pinto and Pinto, 2012), or to self-regulate by changing their morpho-physiological charcteristics in response to the environmental conditions to which they are submitted (phenotypic plasticity) (Taiz and Zeiger, 2013). It is therefore evident that there is a need for studies into physiological performance and the competitive relationship between intercropped species, as a basis for the selection of species that are complementary in their use of productive resources (Willey, 1979; Pinto and Pinto, 2012). However, such investigations are rarely the focus of research into crops under a system of intercropping.

Accordingly, considering that the association between crops involves specific biological interactions and competitive relationships, which may have a negative impact on crop performance and the efficiency of intercropping systems, the aim of this study was to analyse the physiological behaviour and competitive ability of kale under an intercropping system that includes aromatic plants and herbs: Welsh onion (*Allium fistulosum* L.), coriander (*Coriandrum sativum* L. cv. 'Verdão'), Italian basil (*Ocimum basilicum* L.) and parsley (*Petroselinum crispum* (Mill.) Nym).

Results and Discussion

Physiological performance of kale

Differences were seen between the monocropped and intercropped kale for the variables net photosynthesis (A) (P=0.0001), transpiration rate and (E) (P=0.031) and instantaneous carboxylation efficiency (A/Ci) (P = 0.001). The other physiological parameters did not differ between treatments (Table 1).

No studies were found into the physiological behaviour of kale under intercropping. Information on the photosynthetic aspects of brassicas, even as monocrops, is scarce. Important among the related works is that of Rodriguez et al. (2015), who found stomatal conductance (gs) varying from 0.2 to 0.8 mol H_2O m^{-2} s^{-1} in kale plants grown under temperatures of 12°C and 32°C respectively. For canola (*B. napus* L.), Jensen et al. (1996) observed an average photosynthetic rate of 29 µmol CO_2 m^{-2} s^{-1}, stomatal conductance of between 1 and 1.5 mol H_2O m^{-2} s^{-1} 1, and Ci/Ca of 0.82 in plants subjected to a temperature of 22°C. Some of these results are close to those obtained in this work. For net photosynthetic rate, transpiration rate and carboxylation efficiency, the greatest values were seen in treatments T_1, T_3, T_4 and T_5, which did not differ between themselves (Table 1). These results can mainly be explained by the greater luminous radiation incident on the kale plants. The energy of solar radiation absorbed by plants is a key factor in photosynthesis (Caron et al., 2003). Therefore, with high levels of radiation intercepted by the leaves, there is an increase in the rate of net photosynthesis (CO_2 assimilation) which, when combined with a lower stomatal resistance (Costa and Marenco, 2007), indicates an increase in instantaneous carboxylation efficiency. In T_2, net photosynthesis, instantaneous carboxylation efficiency and transpiration rate in the kale plants were on average 24, 28.5 and 5% lower respectively than in the other treatments (Table 1). The lower photosynthetic performance can be attributed to uneven interception of the radiation on the kale plants caused by the coriander. This can be explained by the rapid early growth of the coriander seen in the field, coupled with a slower return to growth of the kale after transplanting, which led to the early closure of the spaces between rows, and the consequent shading of the kale plants. The effect of this was etiolation of the plants, with greater elongation of the stem at the expense of biomass accumulation (Taiz and Zeiger, 2013) as a strategy to avoid shading. In fact, under intercropping systems, the taller species can reduce solar radiation onto the lower species (Flesch, 2002), leading to competition for light. In general, under unfavourable light intensities, the plants do not normally receive the necessary amount of light, especially in the red and blue bands (Messinger et al., 2006); or changes occur in the balance of radiation between the red and far red (Taiz and Zeiger, 2013), resulting in such morphological and physiological changes as: 1) reduction in the stomatal index (number of stomata.mm^{-2}) (Morais et al., 2003); 2) greater chlorophyll content; 3) fall in Rubisco activity (ribulose-1,5-bisphosphate carboxylase/oxygenase) (Niinemets et al., 1998); 4) increase in leaf area for greater light interception; and 5) reduction in respiration rate, with a lowering of the light compensation point (Taiz and Zeiger, 2013). These adjustments lead to reduced stomatal conductance and transpiration, with a reduction in net photosynthesis (Morais et al., 2003; Dalastra et al., 2014), and in CO_2 consumption in the sub-stomatal chamber (Van Loon et al., 2014).

The lower photosynthetic performance seen in the kale plants in T_2 probably resulted in the greatest internal concentration of CO_2 in the sub-stomatal chamber (312.98 - an insignificant value in relation to the other treatments), despite the low stomatal conductance (0.540) (Table 1). It is known that under normal conditions for a typical C3 plant such as kale, greater stomatal activity is accompanied by higher levels of CO_2 in the sub-stomatal chamber, and consequently, a greater increase in photosynthesis (Long and Bernacchi, 2003; Costa and Marenco, 2007). This is because opening of the stomata allows increased CO_2 into the sub-stomatal cavity, always replacing the CO_2 used in the synthesis of photoassimilates. In this way, there are increases in the instantaneous carboxylation efficiency. However, there may be an increase of CO_2 in the sub-stomatal chamber, even where reductions in stomatal conductance of the plants may be found, as seen in this study. According to Machado et al. (1999), this increase in Ci can be explained by the fall in activity of enzymes related to the process of CO_2 fixation, and may also be associated with lower light interception, and consequently, a reduction in the photochemical efficiency of photosystem II, with increased fluorescence and a lower flow of chemical energy (ATP and NADPH) for CO_2 assimilation, thereby promoting a lower consumption of this substrate.The results demonstrate that the coriander was more efficient at intercepting light when grown together with the kale, whereas the physiological changes seen in the kale plants probably indicated an adaptive capacity of the species to receiving less light during growth. On the other hand, the Welsh onion, basil and parsley did not interfere with light interception by the kale, which may be explained by the greater spatial balance between their canopies. Such a correlation agrees with Costa and Marenco (2007), who state that opening the stomata is a simultaneous response to a set of factors (such as luminosity and air humidity) that interact in a coordinated and complex way. A relatively stronger correlation was also seen between net photosynthesis and transpiration (r = 0.51), which may indicate that plants under high rates of photosynthesis show greater transpiration activity (Fig. 1B). Despite this evidence, the way the photosynthetic process relates to transpiration may be influenced by stomatal response to the environmental stimuli to which the plants are submitted. The higher the photosynthetic rate, the greater tends to be the CO_2 demand in the sub-stomatal chamber, which requires continuous CO_2 assimilation by the plant, i.e. there is a tendency for the plant to open the stomata further, stomatal conductance increases and allows greater CO_2 diffusion to the interior, which in turn generates a more intense water loss through transpiration.

Table 1. Net photosynthesis (A), stomatal conductance (gs), CO_2 concentration of the sub-stomatal chamber (Ci), transpiration rate (E), ratio between the CO_2 concentration of the sub-stomatal chamber and the CO_2 concentration of the environment (Ci/Ca), and instantaneous carboxylation efficiency (A/Ci) in kale grown as a monocrop, and intercropped with aromatic plants and herbs, at 28 days after transplanting. Fortaleza, Ceará, Brazil, 2015.

Treatment	A		gs		Ci		E		Ci/Ca		A/Ci	
T_1	25.69	a[1]	0.594	a	291.99	a	0.0086	a	0.739	a	0.088	a
T_2	18.75	b	0.540	a	312.98	a	0.0076	b	0.790	a	0.060	b
T_3	27.17	a	0.682	a	298.33	a	0.0087	a	0.756	a	0.092	a
T_4	26.37	a	0.620	a	292.82	a	0.0087	a	0.741	a	0.091	a
T_5	25.37	a	0,586	a	292.39	a	0.0086	a	0.744	a	0.088	a
Mean	24.67		0.604		297.7		0.0080		0.754		0.084	
CV (%)	9,07		16.8		4.54		6.68		4.48		12.81	

T1 = monocropped kale; T2 = intercropped kale and coriander; T3 = intercropped kale and Welsh onion; T4 = intercropped kale and parsley, and T5 = intercropped kale and basil. [1]Mean values followed by the same letters in a column do not differ by Scott-Knott test at a significance level of 5%.

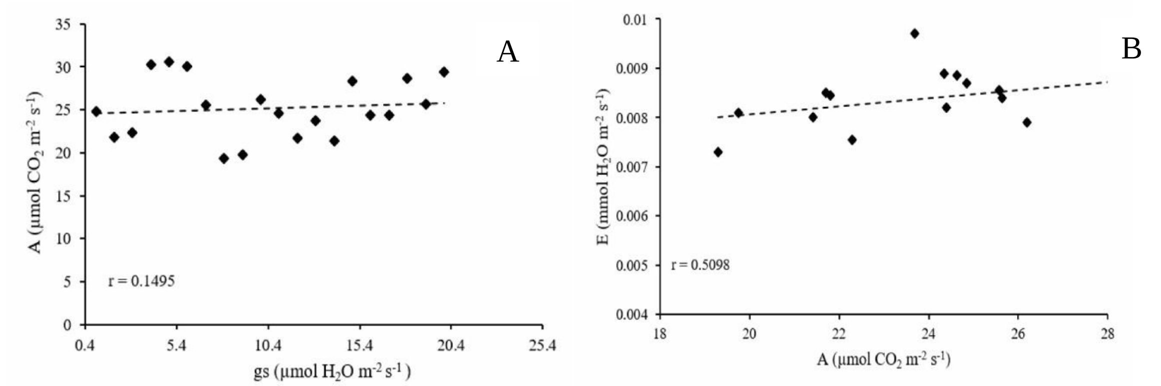

Fig 1. Relationships between stomatal conductance (gs) and net photosynthesis (A) (gs x A; A), and between net photosynthesis (A) and transpiration (E) (A x E; B). Fortaleza, Ceará, Brazil, 2015.

Table 2. Indicators of competitive ability, aggressivity (Ag), competitive ratio (CR) and compensation ratio (RCo) in kale, Welsh onion, coriander, basil and parsley, grown as both monocrops and intercrops. Fortaleza, Ceará, Brazil, 2015.

Treatment	Ag		RC		RCo	
	Kale	Companion	Kale	Companion	Kale	Companion
T_1	-	-	-	-	-	-
T_2	-2.08	2.08	0.33	3.02	-3.38	53.74
T_3	-2.25	2.25	0.19	5.29	2.16	3.60
T_4	-0.87	0.87	0.72	1.39	-2.69	-29.61
T_5	-0.62	0.62	0.31	2.68	0.08	9.48
T_6	-	-	-	-	-	-
T_7	-	-	-	-	-	-
T_8	-	-	-	-	-	-
T_9	-	-	-	-	-	-

T1 = monocropped kale; T2 = intercropped kale and coriander; T3 = intercropped kale and Welsh onion; T4 =intercropped kale and parsley; T5 = intercropped kale and basil; T6 = monocropped coriander; T7 = monocropped Welsh onion; T8 = monocropped parsley and T9 = monocropped basil.

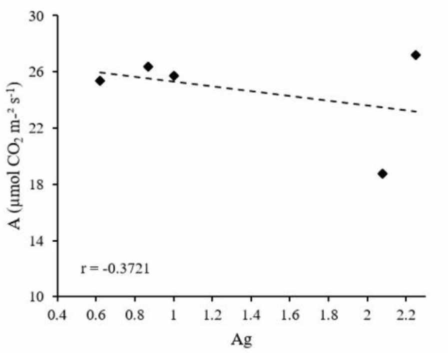

Fig 2. Relationship between agressivity in the companion species (Ag) and net photosynthesis (A) in kale, under intercropping systems. Fortaleza, Ceará, Brazil, 2015.

Competitive ability of crops

All the aromatic plants and herbs displayed a more competitive performance than the main crop (Table 2). The results showed positive values for aggressivity in the companion crops, which were characterised as dominant, while the kale always displayed negative values, indicating less competitive capacity, and therefore considered subdominant. Accordingly, it is believed that the greater aggressivity of the companion species may have interfered in the use of resources by the kale. For light, a weak negative correlation (r = - 0.37) was found between aggressivity and net photosynthesis in the kale (Fig. 2), indicating that the competitive ability of this species to use light for photosynthesis decreases as more aggressive companion species are used under intercropping systems.

The Welsh onion was the crop with the highest aggressivity index (Table 2). Despite having no morphological characteristics or type of growth which would clearly point to some kind of competition for the productive resources of the area, the Welsh onion seems to have exerted a negative allelopathic effect on the kale plants. Resulting, in this case, in a reduction in the production of both crops in T_3, when compared to their respective monocrops (T_1 and T_7) (data not shown). The effect of the greater aggressivity of the Welsh onion was reflected in its greater competitiveness, approximately five times that of the kale. This result suggests that the Welsh onion used growth resources more efficiently in the intercrop. Despite the fall in yield of the Welsh onion, the yield in numerical terms offset the production losses in the kale. The compensation ratio of the Welsh onion was around three times the productive result of the kale.

The coriander also displayed high aggressivity, as was expected due to the effects on the kale of the increased competition for light (Table 2). This condition promoted a greater advantage in the capture of environmental resources for the companion crop in relation to the main crop, with the expected yield of the kale in T_2 (at least equal to that of the monocrop) not being reached. The values for competitive ratio found in the intercrop of coriander and kale, established a competitive ability for the first crop around three times greater than for the second. In this case, the intrinsic characteristics of coriander (initial rapid growth) and the period the intercrop was set up, reduced the spatial complementarity of the crops, intensifying interspecific competition.

As a result, there was a fall in yield of the kale in T_2, while the coriander achieved substantial gains in productivity in relation to its monocrop. This condition allowed compensation of the production losses in the kale by the high rate of compensation of the coriander (53.7) being mainly a result of the two crops that occurred during the cycle of the main crop. It is believed that the production efficiency of this intercrop can be increased through minimising competition between the species over time by adjusting the period of seeding. In the first production cycle, seeding a later form of coriander is therefore recommended.

The parsley, despite being more aggressive than the kale, interfered little in the growth and production potential of the main crop (Table 2). This more balanced interference resulted in fewer competitive effects (1.39) with the crops achieving consequently satisfactory gains in productivity for the intercrop (T4) when compared to the monocrops (T_1 and T_8). The explanation given for this advantage is that the crops may have been more effective in capturing growth resources (complementarity in time and/or space) resulting therefore in no negative effects on crop yields. The production of the kale and parsley when intercropped was greater than expected, a relationship of mutual cooperation between the species being evident in this case. Compensatory effects were therefore not required between the crops (negative compensation ratios).

The basil was the least aggressive of the species under study, even with such morpho-physiological characteristics as larger size, denser canopy and faster growth, which at any moment could contribute to a greater competitive ability in relation to the kale. In this case, the reduction in population density of the basil in the intercrop, around 50% less than of the monocrop, minimised competition between crops. Even with the lower aggressivity, the basil proved to be almost three times more competitive than the kale, leading to a reduction in yield of the main crop, presumably the consequence of a possible allelopathic effect. However, the level of basil production achieved in T_5 compensated, in numerical values, for the fall in yield of the kale.

Finally, it should be pointed out that the differences between the competitive ability of the kale and the aromatic and herbal crops were decisive, so that: in the T_3 and T_5 intercrops, the production potential was reduced by a possible antagonism between the crops; in T_2, the management, especially the time the intercrop was set up, favoured the growth of the more competitive crop; and in T_4, complementarity in exploiting the environmental resources resulted in greater production efficiency in the intercrops in relation to the monocrops.

Materials and Methods

Plant materials

The Welsh onion, coriander and parsley were sown directly into planting furrows, the ground having been previously turned and fertilised eight days before transplanting the kale. The coriander gave two successive crops due to its short life cycle when compared to the kale. The basil was transplanted three days before transplanting the kale. Seedlings of the basil and kale were produced in plastic trays (polypropylene) of 162 cells, filled with a substrate based on earthworm humus (80%) and vermiculite (20%). The seedlings were transplanted at 20 and 23 days after sowing (DAS), for the basil and kale respectively. The cultivars used were: for the kale '*Manteiga da Georgia*'; for the coriander '*Verdao*'; for the Welsh onion '*Todo Ano*'; for the parsley '*Grauda Portuguesa*' and for the Italian basil '*Genovese*'.

The amount of fertiliser applied when planting was 12 $kg.m^{-2}$ of organic compost (a result of the decomposition of cattle manure and vegetable waste) on the day the experiment was set up in the field (sowing of the Welsh onion, coriander and parsley). A topdressing of fertiliser was carried out every two weeks, at doses of 0.3 $kg.plant^{-1}$ for the kale and basil, and 0.3 kg.linear $metre^{-1}$ for the other crops. The plants were irrigated locally by micro spray. Weeding was performed periodically. Pesticides were not applied during the experiment.

The kale was harvested at 41, 56 and 70 days after transplanting (DAT), collecting the leaves from the four plants of each plot. For the basil, the branches of the two plants from rows in the working area were harvested at 36, 51 and 70 DAT. For the other crops, a 0.30 x 0.30m frame was used, with plants contained within that area being harvested. The parsley was harvested at 55 DAS, and the Welsh onion at 70 DAS. The coriander was harvested at 35 and 36 DAS, for the first and second crop, respectively.

Characterisation of the study area

The field experiment was carried out from August to November 2015, in Fortaleza, in the State of Ceará, Brazil (03º44'24" S, 38º34'35" W). According to the Köppen classification, the climate in the region is type As, defined as a tropical climate, having dry summers, average annual temperatures greater than 26°C and rainfall around 1,450 mm (Alvares et al., 2014). During the study, the average temperature was 28.1°C, the relative humidity was 66.6% and the accumulated rainfall was 11 mm.

The soil used for setting up the experiment has a history of vegetable cultivation, with the following chemical properties in the 0-20 cm layer: pH ($_{water}$) = 6.3, P = 215.3 mg.dm^{-3}, K^+ = 310.0 mg.dm^{-3}, Ca^{2+} = 12.7 cmolc.dm^{-3}, Mg^{2+} = 7.6 cmolc.dm^{-3}, Al^{3+} = 0.0 cmolc.dm^{-3}, (H+Al) = 1.9 cmolc.dm^{-3}, SB = 21.7 cmolc.dm^{-3}, CTC = 23.8 cmolc.dm^{-3}, V = 92.0% and OM = 65.8 g.kg^{-1}.

Experimental design and treatments

The experimental design was of randomised blocks with nine treatments and five replications. The treatments consisted of kale, both as a monocrop and intercropped with aromatic vegetables and herbs: T_1 (monocropped kale), T_2 (intercropped kale and coriander), T_3 (intercropped kale and Welsh onion), T_4 (intercropped kale and parsley), T_5 (intercropped kale and basil), T_6 (monocropped coriander), T_7 (monocropped Welsh onion), T_8 (monocropped parsley) and T_9 (monocropped basil).

The experimental plots of both the monocropped and intercropped kale consisted of two rows, each with four kale plants, giving eight plants per plot, at a spacing of 0.6 x 0.6 m. In the intercropped treatments, the companion vegetables were placed between the kale plants transversely to the crop rows. The Welsh onion, coriander and parsley were grown in three rows between the kale plants, totalling nine rows per plot. For the coriander and parsley, the spacing used between crop rows was 0.20 m, with 4 grams of seed used per linear metre; for the Welsh onion, there was 0.20 m between crop rows, with 0.10 m between plants. The kale was at a distance of 0.10 m from the external rows of coriander, parsley and Welsh onion. The basil was grown in a single row between the kale plants (three rows per plot), at a spacing of 0.6 m between rows and 0.25 m between plants, at a distance of 0.30 m from the kale, totalling 12 plants per plot. For the monocrop treatments of Welsh onion, coriander and parsley, each plot consisted of 10 crop rows. In the Welsh onion, the spacing between rows was 0.20 m with 0.10 m between plants. The coriander and parsley were grown with 0.20 m between crop rows, and with 4 grams of seed distributed per linear metre of surface furrow. The basil was arranged in six rows spaced 0.30 m apart, with 0.25 m between plants (four plants per row), totalling 24 plants per plot.

Analysis of physiological performance

The physiological evaluation was made only of the kale, using leaves that were fully expanded and exposed to light, preferably located on the upper third of the plant. A portable infrared gas analyser (IRGA) was used, model LI-6400XT from LI-COR Biosciences, Lincoln, Nebraska (USA), and the following physiological factors were determined: 1) Net photosynthesis (*A* – µmol CO_2 m^{-2} s^{-1}); 2) Stomatal conductance (*g*s - µmol H_2O m^{-2} s^{-1}); 3) CO_2 concentration of the sub-stomatal chamber (Ci - µmol CO_2 mol^{-1}); 4) Transpiration rate (*E* - mmol H_2O m^{2} s^{-1}); 5) Ratio between the CO_2 concentration of the sub-stomatal chamber and the CO_2 concentration of the environment (Ci/Ca) e 6) Instantaneous carboxylation efficiency (*A*/Ci).

The physiological evaluation was made 28 days after transplanting the kale, between 08:00 and 11:00 on a clear day, using artificial lighting of 1200 µmol m^{-2} s^{-1} (photosynthetic photon flux density) in the evaluation chamber of the equipment, in order to maintain similar environmental conditions during the evaluations. The two plants at the centre of the plot were evaluated.

Analysis of competitive ability

The competitive ability between the components of the intercropping systems was obtained by calculating the aggressivity index (Ag), the competitive ratio (CR) and the compensation ratio (RCo). Aggressivity (Ag) measures the interspecific competition of the intercrop by means of the crop-yield index. The index was proposed by McGilchrist and Trenbath (1971):

$$Ag_{ab} = \frac{Yab}{Yaa * Zab} - \frac{Yba}{Ybb * Zba} \text{ and } A_{ba} = \frac{Yba}{Ybb * Zba} - \frac{Yab}{Yaa * Zab}$$

where:

Yab: yield of species 'a' (kale) intercropped with species 'b' (companion);

Yaa: yield of species 'a' as a monocrop;

Zab: planting proportion of species 'a' mixed in with species 'b';

Yba: yield of species 'b' mixed in with species 'a';

Ybb: yield of species 'b' as a monocrop;

Zba: planting proportion of species 'b' mixed in with species 'a'.

This index indicates how much one crop in an intercropping system is superior in productivity to the other. When A is equal to zero, both crops are equally competitive; whereas when the value of Ag is not equal to zero, with $Ag_{ab} > 0$, the competitive ability of crop 'a' exceeds 'b' in the intercrop, i.e. 'a' is dominant. However, when $Ag_{ba} > 0$, the competitive ability of crop 'b' is greater than 'a' in the intercrop, i.e. b is dominant. Whenever a crop displays a positive sign, it is considered dominant, the crop presenting a negative sign being subdominant. The larger the numerical value, the greater the difference between the species with regard to competitive capacity (Pinto and Pinto, 2012).

The factor, competitive ratio (CR), was obtained from the aggressivity index (Willey and Rao, 1980), and calculated based on the equation:

$$RC_a = \frac{\dfrac{Yab}{Yaa * Zab}}{\dfrac{Yba}{Ybb * Zba}} \text{ and } RC_b = \frac{\dfrac{Yba}{Ybb * Zba}}{\dfrac{Yab}{Yaa * Zab}}$$

Where;

Yab and Yba: represent the yield of crop 'a' (kale) and crop 'b' (companion) in the intercrop;

Yaa and Ybb: yield of crop 'a' and crop 'b' as monocrops;

Zab and Zba: planting proportion of species 'a' to species 'b' in the intercrop.

This index indicates the number of times that one species is more competitive than the other, i.e has a greater ability to use productive resources. Interpretation of the competitive ratio (RC) is given by: RC < 1, there is a positive benefit and the crop can grow in association; if RC > 1, there is a disadvantage to the other crop, and its cultivation in association is not indicated (Pinto and Pinto, 2012). In any situation, both crops will have the same numerical value, but the sign of the dominant species will be positive and that of the subdominant species will be negative.

The compensation ratio (RCo) was calculated as per Ntare and Williams (1992), and is expressed by the equation:

$$RCo_a = \frac{Yab}{Ybb - Yba} \text{ and } RCo_b = \frac{Yba}{Yaa * Zab}$$

where:

Yab e Yba: yield of crop 'a' (kale) and 'b' (companion) in the intercrop;

Yaa e Ybb: yield of the monocrops 'a' and 'b'.

This index shows whether the yield of the most competitive crop offsets any competitive effect on the subdominant species. When $RCo_a > 1$, the competitive effect of species 'a' on species 'b' is offset by the substantial gain in species 'a'. When $RCo_b > 1$, the competitive effect of species 'b' on species 'a' is balanced by a substantial gain in species 'b' (Pinto et al., 2012). Whereas $RCo_a = 1$ indicates that a reduction in the yield of species 'b' intercropped with species 'a' is similar to the yield of species 'a' intercropped with species 'b', with no compensation occurring. When $RCo_a < 1$, this indicates that there is no competitive effect from species 'a' on species 'b', as the yield of species 'b' intercropped with species 'a' is maintained equal to that of the monocrop, or the yield of species 'b' intercropped with species 'a' is higher than in the monocrop, with no need for compensation.

Crop production yields in the kale were estimated based on the fresh weight of the commercial-grade leaves (length of 25-30 cm and no damage from pests or diseases), and on the fresh weight of the shoots in the other crops, determined with the help of a precision balance. The values for production yield were estimated for one hectare.

Statistical analysis

The physiological evaluation of the main crop (kale) considered all the treatments that included the crop, i.e. five treatments (T_1-T_5). For evaluation of the competitive ability of each crop, both the intercrops and their respective monocrops were considered. In this case, in addition to the five treatments that included the kale mentioned above, the monocrops of the secondary species (T_6-T_9) were also considered as treatments. The results of the physiological responses of the kale were subjected to analysis of variance (F-test, $p \leq 0.01$ and $p \leq 0.05$) and when a significance was found, the data were submitted to means comparison by the Scott-Knott grouping test ($\alpha = 0.05$). The analyses were carried out using the GENES Genetics and Statistics software (Cruz, 2013). Correlation analyses were used to examine relationships between stomatal conductance (gs), transpiration rate (E), aggressivity (Ag) and net photosynthesis (*A*).

Conclusion

The kale displayed lower competitive ability compared to the aromatic crops under study, especially when intercropped with coriander. Parsley, due to its slower vegetative growth when intercropped, used the resources in a complementary way to the kale, and stood out as the most advantageous species for exploiting intercropping systems that employ kale. Despite a greater sensitivity to interaction with companion plants, the ability of kale to adjust its physiology in the face of increased plant density in the growing area makes it viable for use by farmers when intercropping. However, the use of kale in intercropping systems should be with species that have less competitive effects on productive performance, or when management practices are adopted that benefit kale when this is the main crop.

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