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RESEARCH ARTICLE

DOUBLE-ROW ARRANGEMENT INCREASES COMPETITIVENESS IN SORGHUM-GREEN GRAM INTERCROPPING SYSTEM IN DRYLAND AREAS OF KENYA

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ABSTRACT

Recurrent droughts have threatened crop yields and livelihoods of many small-scale farmers in dryland areas of Kenya. An evaluation of sorghum [*Sorghum bicolor* (L.) Moench] and green gram [(*Vigna radiata* (L.) Wilezek] intercropping was conducted to determine the yield and competitiveness among the green gram varieties and crop arrangements. Two field experiments were performed simultaneously during the 2022 short rain season in two dryland areas of southeastern Kenya. Four green gram varieties (N26, KS20, Biashara, and Karembo) and three crop arrangements (sole crop, double row, and single row) and control of both sole crop green gram and sorghum were used. Treatments were placed in a randomized complete block design with a split-plot arrangement where a crop arrangement system formed the main plots while the green gram variety assumed the subplots and was replicated three times. Data collected were soil fertility status at the start of the trials, nodulation, plant height, and yield of green gram and sorghum. Competition ratio was used to assess the intercropping systems. Green gram variety N26 outperformed the other varieties, irrespective of crop arrangement. Competition ratios (CR) between the two crops showed that the CR of green gram was >1, thus legume(s) were more aggressive in affecting the growth of sorghum. The study findings indicate that green gram was more aggressive than sorghum and the double row planting of N26 enhances competitiveness and productivity of sorghum-green gram intercropping systems in dryland areas. This crop arrangement can improve land use efficiency, increase grain yields, and contribute to improved food security in arid and semi-arid regions of Kenya. Further studies are proposed to screen for green gram varieties that are compatible with sorghum to provide optimal intercropping productivity in different agro ecological zones.

KEYWORDS

Competition ratio, double row, intercropping, plant arrangement, single row, sole crop

1. INTRODUCTION

Modern agricultural production in arid and semi-arid lands (ASALs) requires crops that are climate resilient (Hou et al., 2019). Farmers in these areas are food insecure due to low and poorly distributed rainfall, and low adoption of improved green gram varieties (Hakim et al., 2022; Okeyo et al., 2020). Considering these factors, a sustainable system such as intercropping is required (Gilani et al., 2021). Intercropping is a practice where two or more crops are grown on the same piece of land and performs well in less resource-endowed conditions (Yumbya et al., 2024; Wang et al., 2020). Therefore, sorghum-green gram intercropping can be the best management option for increasing productivity and food security (Gong et al., 2020; Saha et al., 2022). This system would therefore play an important role in both subsistence and commercial production through the provision of diversified foods in dryland areas (Musyimi et al., 2022).

Globally, the area under green gram is 6 million hectares with a mean production of 0.73 t ha^{-1} (Muchomba et al., 2023). Kenya's annual consumption is 600 million metric tonnes whose deficit of 61% is filled by imports from Uganda and Tanzania (Kilimo Trust, 2017; Muchomba et al., 2023). Despite the release of high-yielding green gram varieties with different yielding potential, the crop has a low productivity rate of 0.5 t ha^{-1} while its demand and consumption have doubled over the last ten years (Wambua et al., 2017; Kiponda et al., 2023). Green gram is one of the most important drought-tolerant short-duration legumes that is grown in ASALs of Kenya (Yumbya et al., 2025). Green gram has the potential to generate income for rural communities, create employment, and attain food security (Kung`ala et al., 2026). Green gram contains 31% protein without flatulence, 4% fibers, 1.5% oil, 5% ash, and 10% water (Mulika et al., 2019). Sprouted green grams provide vitamins retinol, riboflavin, thiamine, ascorbic acid, and niacin (Mebrahtom and Selam, 2021; Mulika et al., 2019). Additionally, it is a good source of carbohydrates (62%) and amino acids such as tryptophan, lysine, methionine, leucine, and isoleucine (Mugo et al., 2020). Green gram grains are rich in minerals such as zinc, potassium, phosphorus, sodium, magnesium, and calcium (Mebrahtom and Selam, 2021; Muchomba et al., 2023). In addition, green gram can fix about 35% N per hectare through biological nitrogen fixation that can be used by the subsequent crop (Zammurad Iqbal Ahmed, 2006). Many green gram varieties have been developed, but differ in growth habit, canopy architecture and maturity period, characteristics that can affect their competitive interactions with intercropped components (Karimi et al., 2019).

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most economically important cereal crop worldwide, with production above 60 metric tonnes per annum where Kenya produces about 35% (Moi, 2021). Sorghum is used as human food, animal feed, alcohol, firewood, and is rich in minerals such as iron and zinc (Temeche et al., 2022). It is adapted to dry areas due to its extensive root system and waxy leaves that reduce transpiration rate (Njagi et al., 2019).The common varieties grown in Kenya are KARI Mtama 1, KARI Mtama 2, Seredo, Serena, Sila, and Gadam (Yumbya et al., 2024). Despite their importance, productivity of these crops in dryland areas

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remains low due to erratic rainfall, declining soil fertility, pests, diseases, weeds, bird damage, and low adoption of high-yielding varieties and poor crop management practices (Okeyo et al., 2020).

Cereal-legume intercropping is practiced by small scale farmers to enhance land use efficiency, stabilize yields and reduce production risks (Li et al., 2021; Maitra et al., 2021). The success of the intercropping system depends on crop variety, plant density, agricultural practices, and crop arrangement patterns (Yumbya et al., 2024).

However, the performance of intercropping systems is strongly influenced by spatial arrangement and varietal selection, as these factors determine the degree of competition or complementarity between component crops (Gilani et al., 2021). Traditional single-row intercropping may intensify interspecific competition, limiting potential yield advantages (Arina et al., 2021).

There is limited evidence on the effects of row arrangement and varietal choice on crop competitiveness under dryland conditions. Understanding these interactions is essential for identifying optimal intercropping strategies that minimize competition and maximize productivity in dryland systems. Therefore, an early maturing crop such as green gram can be intercropped with sorghum to decrease the risk of crop failure and provide subsistence food in ASALs (Temeche et al., 2022). However, despite the potential of both crops, the use of sorghum-green gram intercropping is limited in the dry areas of southeastern Kenya (Yumbya et al., 2025).

This has led to very low yields of the two crops at the farm level as worsened by poor intercropping patterns. The objectives of this study were to: (i) determine the effect of competition among different green gram varieties in intercropping systems and; (ii) establish competition ratio of different crop arrangement patterns in southeastern Kenya. The findings are expected to provide practical guidance for improving crop productivity, resource use efficiency, and sustainability in dryland farming systems of Kenya.

2. MATERIALS AND METHODS

2.1 Experiment sites

The two trials were conducted in the farmers' fields during the 2022 short rains season in Katangi and Mwala sites (Figure 1). Katangi is geographically positioned at latitude 1°26´13´´S and longitude 37°48´18´´E, an elevation of 1051 m above sea level. This site lies in the drier low midland 4 (LM 4) with a mean temperature range of 17-35 °C. The soils are ferralsols, ferric luvisoils, and acrisols which have low organic matter, Nitrogen and Phosphorus (Namoi et al., 2014). Mwala, positioned at an altitude of 1252 m above sea level, features acrisols and ferralsols lying in low midland 3 (LM 3) within the coordinates 1°21´29´´S and, 37°27´41´´E and exhibits air temperature spanning from 18 °C to 29 °C (Karuma et al., 2014). The two sites receive bimodal rainfall patterns where long rains begin in March and cease in May while short rains begin in October and cease in December. The mean annual rainfall is 600-700 mm with short rains being more reliable (Yumbya et al., 2024).

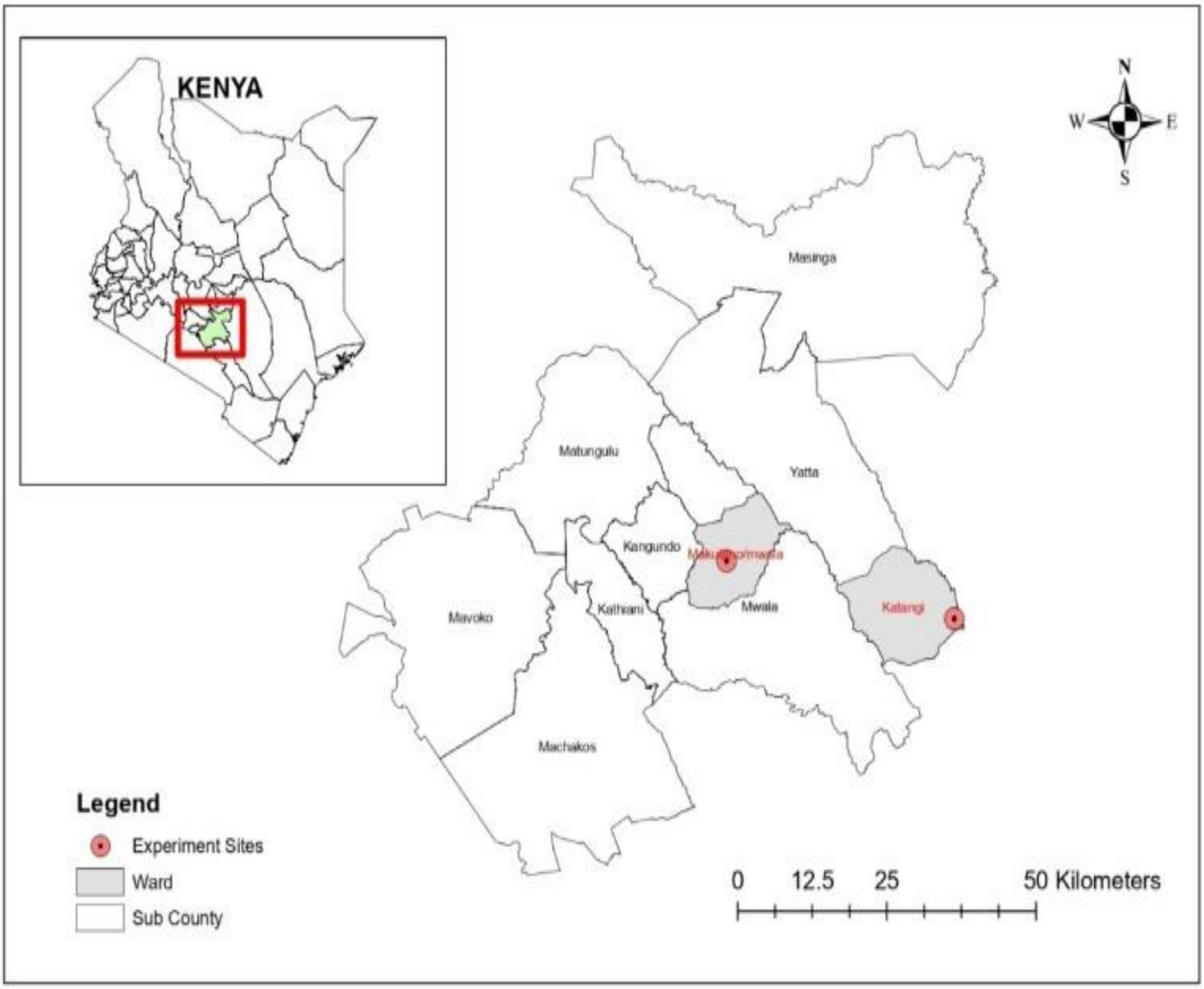

Figure 1: Map of Machakos County showing the experiment sites (Source: Yumbya et al., 2024).

2.2 Planting materials

Table 1 shows the four green gram varieties (N26, KS20, Karembo, and Biashara) which are early maturing, tolerant to aphids, resistant to powdery mildew, and high yielding were used for the field experiment (Karimi et al., 2019; Yumbya et al., 2024). The intercrop used was sorghum, a variety of Seredo that can survive in harsh conditions, tolerate birds due to the high tannin content in the grain, and is high yielding (4 t ha^{-1}) (Njagi et al., 2019; Moi, 2021). These seeds used in this trial were obtained from Kenya Agricultural and Livestock Research Organization (KALRO) Katumani and local agro-dealers.

2.3 Treatments and experiment design

The experiments were laid out in split plots arranged in a randomized complete block design with three repetitions. The four green gram varieties were contained in the subplots while the three crop arrangements (sole crop, single row, and double row) were assigned to the main plots. The sole green gram and sole sorghum were used as controls.

Table 1: Key traits and yield potential of green gram used in the study

Variety	Days to flowering	Days to maturity	Pod colour	Grain colour	Yield potential (t ha^{-1})
N26	45	80-90	Black	Shiny green	0.8-1.2
KS20	45	65-75	Cream	Large dull green	1.6-1.8
Karembo	42	65-75	Large and brown	Large shiny green	1.6-1.8
Biashara	45	65-75	Large and cream	Large shiny green	1.6-1.8

Source: Yumbya et al*.,* 2024

2.4 Field management practices

The land was ploughed before sowing to a fine tilth and plots of 11.5 m x 6 m prepared with a 0.5 m alley between the plots. Sole green gram followed a spacing of 0.50 m by 0.15 m (13 plants m^{-2}) while sole sorghum followed a spacing of 0.6 m by 0.20 m (8 plants m^{-2}). In the single row, sorghum row alternated with a single row of green gram which was separated by 0.30 m. In the double row, the two sorghum rows were separated by a 0.90 m strip reserved for green grams planted at 0.30 m apart.

Both the single row and double row registered the same population density of 11 green gram plants m^{-2} and 8 sorghum plants m^{-2} whose seeds were sown on the same day. 4 t ha^{-1} of Farmyard manure (FYM) and 250 kg ha^{-1} of N.P.K 23:23:0 were incorporated in the plots during planting based on soil analysis and recommendations. Manual weeding was done on the second week and after every three weeks to ensure the field was weed-free. Sorghum was top dressed with calcium ammonium nitrate (26% N) at the rate of 75 kg ha^{-1} at stem elongation and anthesis.

2.5 Data collection

2.5.1 Weather data and soil sampling

Weather data recorded at the experiment site during the study period were rainfall amount, air temperature, and relative humidity. Daily rainfall amount (mm) was obtained from meteorological stations located near the experiment sites. Furthermore, air temperature and relative humidity were obtained from onsite measurements using ANENG HS-1 weather station thermometer and hygrometer respectively and measured at 2 m above grass canopy in clear sky between 1100 and 1300 hours. Before the trial establishment, composite soil samples were collected using the zigzag method at a depth of 0-30 cm. Soil samples were randomly scooped using a soil auger and dried under shade, crushed, and sieved over a 2 mm sieve to get a representative sample of 0.25 kg which was analyzed.

Soil pH was determined using a pH meter in a soil-water suspension of 1g:2.5mL. The Walkley-Black (wet oxidation) method was used to determine the organic matter (Spertus, 2021). The Kjeldahl method was used to measure the total nitrogen while extractable soil phosphorus was measured by Olsens' method, and the flame spectrophotometer was used to determine the amount of potassium (Okalebo et al., 2002; De Silva et al., 2015; Potdar et al., 2021). Magnesium, sodium, calcium, and iron were determined using the Mehlich-1 double acid extractable method. The diethylene triaminepentaacetic acid extraction method was used to estimate the amount of copper and zinc in the soil sample (Abbas et al., 2021).

2.5.2 Green gram nodulation and grain yield

Nodulation in green gram was evaluated at branching, flowering, and podding stages where five green gram plants were randomly selected, watered, and dug up using a hoe, and then roots lifted carefully. All the roots were put in a basin with water where nodules were washed and counted to determine the number of nodules per plant and the average was calculated. Green gram plants were harvested at maturity in the net plots measuring 1.9 m x 4 m (7.6 m^2) for sole green gram, while single row and double row net plots measured 1.9 m x 4.8 m (9.12 m^2) for grain yield determination. The total grain yield (t ha^{-1}) was extrapolated from the net plot area after harvesting, threshing, winnowing, and drying the grains for at least a week to 12.5% moisture content.

2.5.3 Sorghum plant height and yield

Five sorghum plants in the middle of each plot were randomly sampled for plant height and measured from the base of the soil surface to the tip of the central leaf of the plants using a meter rule from the second to the tenth week. The total grain yield (t ha^{-1}) of sorghum was extrapolated from the net plot area measuring 8.4 m x 3.6 m and border rows were excluded. After threshing and winnowing the grains, the grains were sun-dried to 12.5%, sorted, and weight determination was done using a digital electronic weighing scale to evaluate the grain yield.

2.6 Intercropping system assessment using competition ratio

Competition ratio (CR) is the measure of the competitive ability (inter-specific competition) of component species in an intercropping system. If the CR of green gram is less than 1, then green gram is less competitive than sorghum and if the CR of green gram is more than 1, then green gram is more competitive than sorghum (Doubi et al., 2016). Following a study, the competition ratio for sorghum and green gram was computed as shown in Equation 1 and Equation 2 respectively (Abbas et al., 2021).

$$CR\ Sorghum = \frac{La}{Lb} x\ \frac{Zba}{Zab} \quad (1)$$

$$CR\ Green\ gram = \frac{Lb}{La} x\ \frac{Zab}{Zba} \quad (2)$$

Where La is the LER of sorghum while Lb is the LER of green gram

Zba is the proportion of sorghum in the sorghum-green gram intercrop while Zab is the proportion of green gram in the sorghum-green gram intercrop.

2.7 Data analysis

The data collected on various parameters were subjected to R software version 4.3.3.0 (R core team, (2022), Vienna, Austria) using a two-way analysis of variance. All significant effects of crop arrangement, variety, and their interactions were separated using Fisher's least significant difference (LSD) at P ≤ 0.05. All data were expressed as means ± standard error of the mean (SEM).

3. Results and Discussion

3.1 Weather data and soil characteristics

The weather conditions across the sites are shown in Figure 2. The total rainfall received in Mwala was 227 mm while in Katangi was 191 mm. This amount is about 90% of the long-term average for the short rain seasons in each site hence both crops did not experience significant moisture stress. The rainfall amount was below the estimated 250 mm which is the critical amount required to maximize grain yield for green gram and 300 mm for sorghum (Mugo et al., 2020; Moi, 2021). The mean air temperature range was 21-31 °C while relative humidity was similar across the test sites ranging from 47-72%, which is typical of the growing season (Figure 2). The initial soil fertility analysis before the crop establishment showed that samples were moderately acidic with pH (5.7-7.2) which was in the range for crops' normal growth. However, the total nitrogen (0.8-1.5 g kg^{-1}) and phosphorus (13-26 mg kg^{-1}) were low in the two sites while organic carbon was low in Mwala (9.8-17.6 g kg^{-1}) but moderate in Katangi. Potassium, calcium, magnesium, manganese, iron, and sodium were adequate for green gram and sorghum production in both sites. Copper and zinc were enough in Katangi but low in Mwala. Additionally, the soil bulk density (1.08-1.37 g cm^{-3}) was within the root zone and hence did not restrict root growth across all the environments.

3.2 Grain yield and nodulation of green gram

The results in Table 2 show significant interactions (P < 0.001) between variety and crop arrangement on green gram grain yield. Variety N26 recorded the highest mean yield by 0.56 t ha^{-1} compared with the least variety KS20 (Table 3). The sole crop (0.91 t ha^{-1}) produced the highest mean yield compared with double row (0.75 t ha^{-1}) and single row (0.62 t ha^{-1}). This could be due to the maximum plant population (13 plants m^{-2}) and minimum competition for resources. These findings agree with the results of (Temeche et al., 2022). The average green gram yield was 0.8 t ha^{-1} in Mwala and 0.72 t ha^{-1} in Katangi which were less than the potential yield of 1.8 t ha^{-1} that was reported by (Karimi et al., 2019). This could be due to the uneven distribution of rainfall during the critical period for yield determination (Figure 2). Similarly, a group researcher reported a significant reduction in green gram yield while intercropping green gram and sorghum (Arshad et al., 2020).

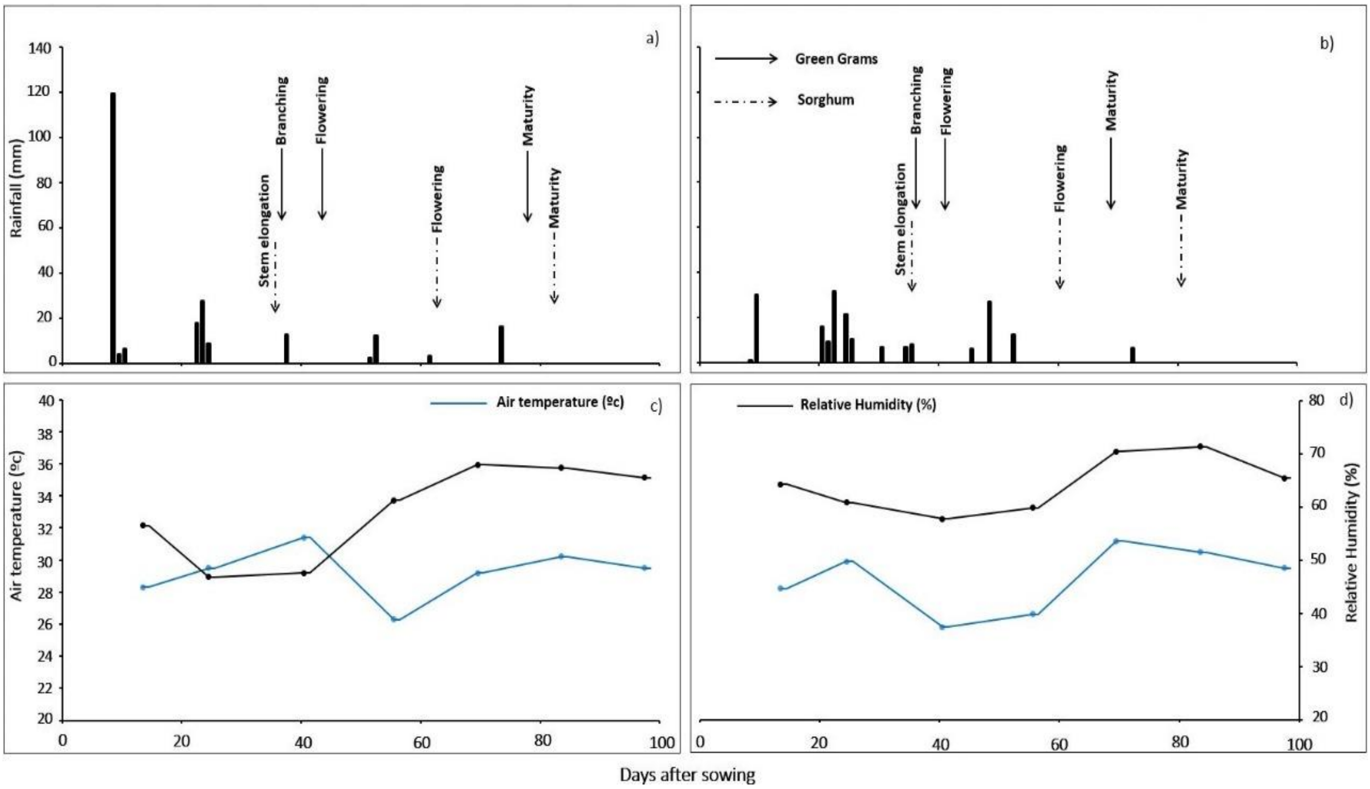

Figure 2: Average weather conditions during growing period at Mwala (a and c) and Katangi (b and d) during 2022 short rains season

Nodulation is a very important factor for plants which is related to the number of pods plant^{-1} and enhances crop productivity (Karimi et al., 2019). Nodulation was significantly (P < 0.001) influenced by variety and crop arrangement (Table 3). Variety N26 and sole crop recorded a superior number of root nodules plant^{-1} (5-22) compared with the other varieties and other crop arrangements respectively. These variations in varieties are genetically controlled (Mulika et al., 2019). Similar results were reported by (Shumet et al., 2022).

Table 2: Grain yield (t ha-1) of green gram varieties grown under sole crop or intercropped with sorghum in single and double row arrangement and sorghum grain yield (t ha-1) in Mwala and Katangi during the 2022 short rains experiment season

Site & Variety	Sole crop	Single	Double	Mean	Sorghum grain yield	
N26	1.30 ± 0.01a	0.89 ± 0.01c	1.08 ± 0.01b	1.09 ± 0.01a	Sole crop	3.2 ± 0.03a
Biashara	1.12 ± 0.02a	0.79 ± 0.01c	0.95 ± 0.02b	0.95 ± 0.02b	Single row	2.1 ± 0.04c
Karembo	0.76 ± 0.02a	0.53 ± 0.01c	0.65 ± 0.02b	0.65 ± 0.02c	Double row	2.7 ± 0.05b
KS20	0.60 ± 0.01a	0.36 ± 0.01c	0.49 ± 0.02b	0.48 ± 0.02d	Mean	2.7 ± 0.04
Mean	0.95 ± 0.02A	0.64 ± 0.01C	0.79 ± 0.02B	-	-	-
N26	1.20 ± 0.02a	0.82 ± 0.02c	0.95 ± 0.03b	0.99 ± 0.02a	Sole crop	2.1 ± 0.03a
Biashara	0.89 ± 0.02a	0.66 ± 0.01c	0.80 ± 0.02b	0.78 ± 0.02b	Single row	1.3 ± 0.03c
Karembo	0.74 ± 0.01a	0.52 ± 0.01c	0.62 ± 0.02b	0.63 ± 0.01c	Double row	1.7 ± 0.04b
KS20	0.62 ± 0.01a	0.35 ± 0.03c	0.45 ± 0.02b	0.47 ± 0.02d	Mean	1.7 ± 0.03
Mean	0.86 ± 0.02A	0.59 ± 0.02C	0.71 ± 0.02B	-	-	-

Values are means ± standard error of the mean. Means followed by the same letter are not significantly different from each other by the Fisher's test at a 5% probability level.

Table 3: Nodulation at branching and flowering of green gram varieties grown under sole crop or intercropped with sorghum in single and double row arrangement and sorghum grain yield (t ha^{-1}) in Mwala and Katangi during the 2022 short rains experiment season

Site & variety	Nodulation at branching				Nodulation at flowering			
	Sole crop	Single	Double	Mean	Sole crop	Single	Double	Mean
Mwala								
N26	26.5 ± 0.81a	21.3 ± 0.62c	23.7 ± 0.61b	23.8 ± 0.68a	23.9 ± 0.55a	19.7 ± 0.56b	21.6 ± 0.33b	21.7 ± 0.48a
Biashara	24.7 ± 0.52b	19.8 ± 0.31c	22.2 ± 0.72b	22.2 ± 0.52b	21.7 ± 0.25a	19.3 ± 0.76b	19.8 ± 0.49b	20.3 ± 0.50ab
Karembo	18.5 ± 0.72c	15.7 ± 0.44c	17.8 ± 0.52b	17.3 ± 0.56c	17.9 ± 0.40a	15.2 ± 0.43b	17.3 ± 0.83b	16.8 ± 0.55b
KS20	16.8 ± 0.51d	13.0 ± 0.61c	14.8 ± 0.82b	14.9 ± 0.65d	17.0 ± 0.63a	12.7 ± 0.68b	14.5 ± 0.71b	14.7 ± 0.66b

Table 3 (Cont): Nodulation at branching and flowering of green gram varieties grown under sole crop or intercropped with sorghum in single and double row arrangement and sorghum grain yield (t ha^{-1}) in Mwala and Katangi during the 2022 short rains experiment season

Site & variety	Nodulation at branching				Nodulation at flowering			
	Sole crop	Single	Double	Mean	Sole crop	Single	Double	Mean
Mean	21.6 ± 0.64A	17.5 ± 0.50C	19.6 ± 0.67B		20.1 ± 0.46A	16.7 ± 0.61B	18.3 ± 0.59B	
Katangi								
N26	23.6 ± 0.62a	17.1 ± 0.42c	18.9 ± 0.64b	19.9 ± 0.56a	26.9 ± 0.27a	19.0 ± 0.63b	22.9 ± 0.51b	22.9 ± 0.47a
Biashara	19.5 ± 0.52a	16.6 ± 0.61c	17.3 ± 0.42b	17.8 ± 0.52b	24.5 ± 0.29a	18.7 ± 0.74b	20.7 ± 0.66b	21.3 ± 0.20ab
Karembo	15.9 ± 0.41a	12.9 ± 0.81c	15.1 ± 0.32b	14.6 ± 0.51c	18.4 ± 0.69a	15.5 ± 0.87b	15.8 ± 0.54b	16.6 ± 0.70b
KS20	14.9 ± 0.61a	7.8 ± 0.53c	11.8 ± 0.52b	11.5 ± 0.55d	15.7 ± 0.80a	6.6 ± 0.54b	10.6 ± 0.75b	11.0 ± 0.70b
Mean	18.5 ± 0.54A	13.6 ± 0.59C	15.8 ± 0.48B		21.4 ± 0.51A	15.0 ± 0.70B	17.5 ± 0.62B	

Values are means ± standard error of the mean. Means followed by the same letter are not significantly different from each other by the Fisher's test at a 5% probability level.

3.3 Grain yield and plant height of sorghum

Sorghum grain yield and plant height were significantly (P < 0 .01) influenced by crop arrangement (Table 2). The sole sorghum yielded more (2.2 t ha^{-1}) than double row (2.2 t ha^{-1}) and single row (1.7 t ha^{-1}). This significant yield decline in intercropping patterns was probably due to interspecific competition for resources between intercrop components. Similar results were documented by (Kiponda et al., 2023; Hailu and Geremu, 2021). Plant height is an agronomic attribute that shows vegetative growth behavior which is mainly controlled by plant genetic makeup and environmental factors (Shumet et al., 2022). Figure 3 revealed that sole sorghum recorded the highest mean plant height of 122.3 cm at 10 weeks after planting (WAP) while single row reduced plant height by 8.3% followed by double row system which was reduced by 12.2%. This could be due to the optimum space that was available for sole sorghum plants to grow taller. These results are consistent with (Shumet et al., 2022).

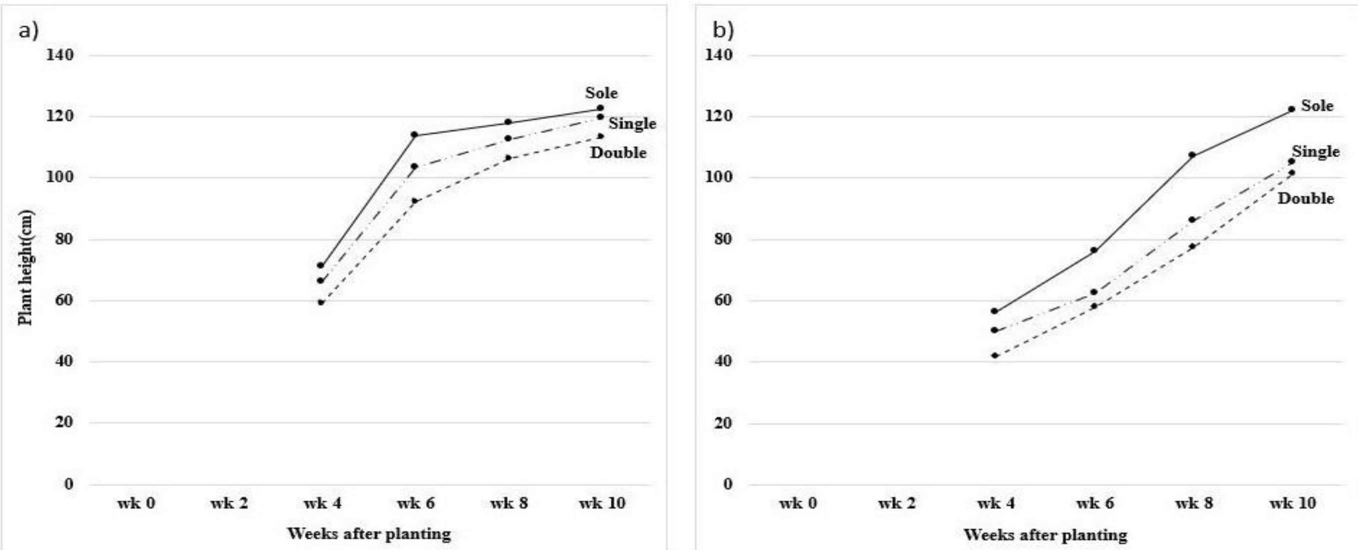

Figure 3: Plant height of sorghum grown as sole, single row, and double alternate rows at 4, 6, 8, and 10 weeks after planting in Mwala a) and Katangi b) during the 2022 short rains season

3.4 Competition ratio

Intercropping competition is highly affected by inadequate water acquisition, therefore, plants that are competitive in an intercrop system could alleviate drought stress and conserve moisture in dryland areas (Wang et al., 2020). Competition ratio (CR) was used to determine the competitive ability of crops in an intercrop system and differed among the varieties and crop arrangement patterns. The higher value of CR of green gram indicated its superior ability to competition than that of sorghum.

The highest competition ratio (CR) value of green gram was recorded as 1.45 in variety N26 under double row (Table 4). The results showed that green gram relative to sorghum showed higher competitive ratios which were more than unity (CR > one), indicating legume dominance except for a single row under KS20 (Table 4). This corroborates with who stated that legumes when intercropped with finger millet showed greater competition (Sowmya et al., 2023). The CR showed the green gram variety N26 was dominant in the intercrops with sorghum. In contrast, the KS20 variety was dominated in the intercrop with sorghum in a single row.

Table 4: Competition ratio of green gram varieties grown under sole crop or intercropped with sorghum in single and double row arrangement in Mwala and Katangi during the 2022 short rains experiment season

Site & variety	Green gram competition ratio			Sorghum competition ratio		
	Single	Double	Mean	Single	Double	Mean
Mwala						
N26	1.00 ± 0.01cd	1.45 ± 0.04a	1.28 ± 0.03a	1.01 ± 0.01ab	0.74 ± 0.04e	0.87 ± 0.03b

Table 4 (Cont): Competition ratio of green gram varieties grown under sole crop or intercropped with sorghum in single and double row arrangement in Mwala and Katangi during the 2022 short rains experiment season

Site & variety	Green gram competition ratio			Sorghum competition ratio		
	Single	Double	Mean	Single	Double	Mean
Biashara	1.15 ± 0.02bc	1.39 ± 0.01a	1.20 ± 0.02a	0.91 ± 0.04bc	0.72 ± 0.02e	0.83 ± 0.03c
Karembo	1.11 ± 0.04bc	1.37 ± 0.02ab	1.24 ± 0.03a	0.88 ± 0.02cd	0.71 ± 0.01e	0.80 ± 0.02d
KS20	0.94 ± 0.03d	1.37 ± 0.02ab	1.16 ± 0.03b	1.07 ± 0.03a	0.79 ± 0.02de	0.93 ± 0.03a
Mean	1.05 ± 0.03B	1.40 ± 0.02A	1.23 ± 0.03	0.97 ± 0.03B	0.74 ± 0.03A	0.86 ± 0.03
Katangi						
N26	1.05 ± 0.02cd	1.44 ± 0.02bc	1.30 ± 0.02a	0.96 ± 0.02b	0.82 ± 0.02cd	0.89 ± 0.02b
Biashara	1.16 ± 0.03bc	1.23 ± 0.05a	1.14 ± 0.04a	0.87 ± 0.03bc	0.71 ± 0.04e	0.79 ± 0.04d
Karembo	1.08 ± 0.04c	1.34 ± 0.02ab	1.21 ± 0.03a	0.92 ± 0.04bc	0.76 ± 0.03de	0.84 ± 0.03c
KS20	0.87 ± 0.01d	1.13 ± 0.01c	1.00 ± 0.01b	1.16 ± 0.01a	0.90 ± 0.01bc	1.03 ± 0.01a
Mean	1.04 ± 0.03A	1.29 ± 0.03A	1.17 ± 0.03	0.98 ± 0.03A	0.80B ± 0.03	0.89 ± 0.03

Values are means ± standard error of the mean. Means followed by the same letter are not significantly different from each other by the Fisher's test at a 5% probability level.

4. Conclusion

The study demonstrated that planting arrangement and varietal selection significantly influenced the performance and competitiveness of sorghum-green gram intercropping systems in dryland areas of Kenya. The double row planting arrangement enhanced crop complementarity and resource utilization leading to improved productivity compared with traditional single-row arrangement. Among the green gram varieties evaluated, N26 outperformed the other varieties, irrespective of the crop arrangement. The results further showed that, double row arrangement of N26 produced the highest competition ratio, indicating a stronger competitive advantage and better ability to utilize available resources within the intercropping system.

This suggests that N26 is well adapted to intercropping with sorghum and can effectively contribute to increased system productivity. In conclusion, from the results of significant interaction between green gram varieties and crop arrangement system, the double row planting of N26 enhances competitiveness and productivity of sorghum-green gram intercropping systems in dryland environments. Adoption of this planting arrangement can therefore improve land use efficiency, increase grain yields, and contribute to improved food security in arid and semi-arid regions of Kenya. Further research is essential to screen for green gram varieties that are compatible with sorghum to provide optimal intercropping productivity in different agro-ecological zones for wider adoption.

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COMPETING INTERESTS

There are no conflicts of interest in this work.

AUTHORS' CONTRIBUTIONS

The author prepared the manuscript, read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support findings of this study are available from the corresponding author upon reasonable request.

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