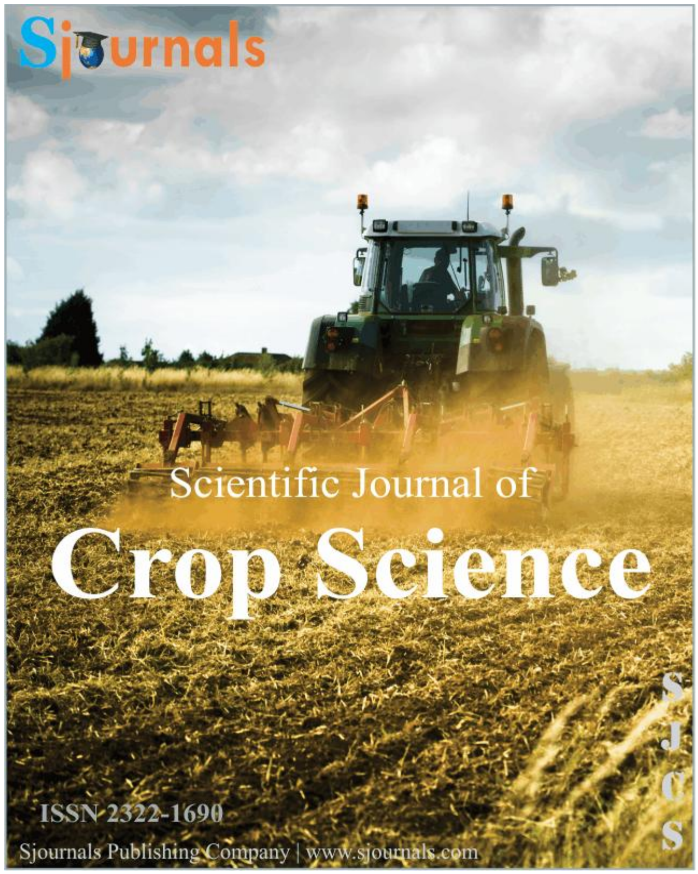
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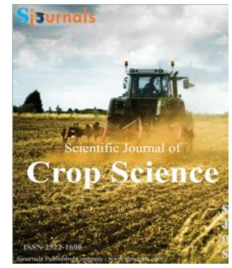

Original article

Yield and yield components of safflower as influenced by genotype and plant density grown in the semi-arid conditions of Botswana

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A B S T R A C T

Two field experiments were carried out at the Botswana University of Agriculture and Natural Resources in Southern Region of Botswana to evaluate the effects of plant density and genotypes on yield and yield components of safflower. The treatments were five safflower genotypes (Kiama composite (local), Sina-PI 537598, Gila -PI 537 692, PI 537 636 and PI 527 710 and plant density (62,500, 83,333, 100,000, 125,000, 166,666 and 200,000). Increase in plant density from 62,500 to 100,000 plants/ha significantly ($p < 0.0001$) increased vegetative growth, yield components and seed yield of safflower. As plant density increased above 100,000 plants/ha vegetative growth, yield and yield components significantly ($p < 0.0001$) decreased in all genotypes both in winter or summer grown safflower. It was concluded that there is variation in the performance of safflower genotypes in response to increasing plant density and growing season, but optimum plant density to maximize safflower seed yield under Botswana conditions was 100,000 plants/ha (Botswana is 40 cm x 25 cm).

1. Introduction

Safflower (*Carthamus tinctorius* L.) is one of the underutilized industrial crops in the African continent with diverse versatile uses, ranging from medicinal, herbal, industrial, cosmetic, food and livestock feed. The plant has a long tap root (2-3 m) which draw moisture from deeper root levels of the sub soil (Mündel et al., 2004; Emongor, 2010) and an extended growing season which gives it a significant drought tolerance (Esendal, 2001). Safflower is drought, heat, cold and saline tolerant (Kaya et al., 2003; Dorclas and Sioulas, 2008). Safflower seed and oil yield varies depending on varieties, environment and management practices. According to FAO (2013), optimal yields under rainfed cultivation ranges between 1 to 2.5 ton ha^{-1} compared to irrigated safflower which ranges between 2 to 4 ton ha^{-1}. In Botswana, under irrigated cultivation, safflower yields ranges from 1500-4400 kg ha^{-1} and 900-2900 kg ha^{-1} in winter and summer, respectively, depending on plant density (Emongor et al., 2013). A study done in 2003 in Mexico showed seed yield peaks of 2503 kg/ha, while in India the average seed yield is 660 kg ha^{-1} (Nimbkar, 2008). The world production is about 908,000 tons, but India produces more than 50% mainly for vegetable oil market (Li and Mundel, 1996).

Safflower seeds contain 13-46 % oil and approximately 90 % of this oil is composed of unsaturated fatty acids (Guan et al., 2008). Safflower oil consists of mainly 70-87% linoleic acid (polyunsaturated fatty acid) and/or 11-80% oleic acid (monounsaturated fatty acid) (Murthy and Anjani, 2008; Aghamohammadreza et al., 2013). Linoleic acid has been shown to offer nutritional and therapeutic benefits such as prevention of coronary heart disease, arteriosclerosis, high blood pressure and hyper lipaemia (Wang and Li, 1985). The contents of oleic and linoleic fatty acids is higher than in sunflower oil (Dajue and Mündel, 1996), soybean, peanuts or olive oils (Corleto et al., 1997). According to Isigigur et al. (1995), fatty acid composition of a vegetable oil determines its best commercial uses. Currently safflower oil is utilized as premium edible oil due to its high fatty acid levels which is essential for reducing blood cholesterol level (Nagaraj, 1993) including its consistency and stability even at low temperatures (Smith, 1993). This shows that safflower has great potential to be utilised as a raw material for vegetable oil production on a large scale in future (Isigigur et al., 1995).

The cultivation of safflower which is drought and saline tolerant and highly nutritive in semi-arid and arid regions of the world can cause diversification of the economies and bridge the gap of edible oil shortage. However, introduction of a new crop to a regional cropping system requires information on its performance under local agronomic and environmental conditions. According to Mazumdar et al. (2007) and Oad et al. (2002) proper plant population densities with appropriate row and plant distance adjustment are the most essential factors for increased safflower grain yield. Different authors have reported variation in response of safflower genotypes to varying plant density in different agro-ecological zones and made recommendations ranging from 74,074 to 1,000,000 plants ha^{-1} (Emongor et al., 2015; Emami et al., 2011; Oad et al., 2002; Dajue and Mündel, 1996). Navabicalat et al. (2004), further reported that plant density significantly affected plant height, the height of the first branch from the ground, auxiliary branch number, head number, seed number per head and seed yield. Variation in population density influences different agronomic traits resulting in various yield responses per unit area (Kouchaki, 1996; Emongor et al., 2013). Plant population density among safflower cultivars has a significant influence on soil moisture availability, radiation distribution, photosynthetic activity (Mohamadzedeh, 2011) and mineral absorption from the soil to the plant (Ahmadian et al., 2011). Therefore, the objective of this study was to evaluate the effect of plant density and genotypes on yield and yield components of safflower.

2. Materials and methods

2.1. Experimental site

Two field experiments were carried out in the Botswana University of Agriculture and Natural Resources in Botswana (24°33'S, 25°54'E, 994 m above sea level) during winter and summer. The soils are shallow, ferruginous tropical soil, mainly consisting of medium to coarse grain sandy loams with a low water holding capacity, and deficient in nitrogen and phosphorus (De Wilt and Nachtengale, 1996; Emongor and Mabe, 2012). The mean rainfall ranges between 250-650 mm per annum. While the evapotranspiration is between 1800-3000 mm per annum (Burgess, 2006). In winter (mid-May until mid-August) temperature ranges from -1 °C (morning) to 30 °C (afternoon). In summer (mid- September to late mid-May) temperature ranges between 20 °C (morning) to 37 °C (afternoon) (Burgess, 2006).

2.2. Experimental design

The experiment was laid in a randomized complete block design (RCBD) under split-plot arrangement with three replications. Treatments included five safflower genotypes Kiama composite, Sina-PI 537598, Gila-PI 537 692, PI 537 636 and PI 527 710 allocated to main-plots and six plant densities 62,500 (40 cm x 40 cm), 83,333 (40 cm x 30), 100,000 (40 cm x 25 cm), 125,000 (40 cm x 20 cm), 166,666 (30 cm x 20 cm), and 200,000 (25 cm x 20 cm) plantsha^{-1}] as sub-plots. The treatments were randomized within the experimental blocks. Safflower was planted in single rows in experimental units measuring 5 m x 5 m. Seeds were sown at a depth of 4.5 cm.

2.3. Cultural practices

The land was cleared, ploughed followed by disc harrowing to a fine soil tilth before planting was done. Soil was sampled to determine mineral composition prior to planting. Fertilizer was applied at 60 kg/ha nitrogen (N), 30 kg/ha phosphorus (P) and 20 kg/ha potassium (K) (FAO, 2013). All necessary management practices including fertilizer application, pest, disease and weed control was undertaken to enhance good growth and development. The amount of water applied was according to crop water requirements (ETm) as related to reference evapotranspiration.

2.4. Data collection

Plant height was determined using ten plants selected randomly from each replication at physiological maturity. Plant height was determined by measuring plant length from the ground to apical meristem using a metre ruler and expressed in centimeters (cm). The number of primary branches per plant was determined by counting primary branches of ten plants selected randomly per replication. The capitula number/plant was determined by counting the capitula (flowers)/plant. Twenty capitula/plant were used to determine the number of seed/capitula. Biological yield (kg/ha) was determined using above ground plant material which was air dried in the sun, sampled per 4 m^2 and weighed. Thousand seed weight was determined by weighing 1000 representative seeds/ treatment/replication and expressed in grams (g). Seed/grain yield (kg/ha) was estimated from an area of 4 m^2. The seed from the safflower capitula were threshed and winnowed manually, after winnowing seed yield per unit area was determined by weighing the seed using a digital balance.

2.5. Statistical analysis

Analysis of variance was performed on the data collected using general linear model (Proc Glm) procedure of the Statistical Analysis System (SAS) program package. Multiple comparisons among means was done using the Protected Least Significant Difference (LSD) at P = 0.05.

3. Results and discussion

3.1. Vegetative growth

There was a significant ($P < 0.0001$) interaction between genotype and plant density of safflower for all the variables studied in winter or summer growing seasons. Plant height significantly ($P < 0.0001$) increased with increase in plant density from 62,500 to 100,000 plants/ha, thereafter plant height reduced as plant density increased from 125,000 to 200,000 plants/ha across the different genotypes irrespective of season (Figure 1, 2). Plant density of 100,000 plants/ha produced the tallest plants, irrespective of genotype, but the genotype Sina recorded the tallest plants of 172.63 cm in winter (Figure 1) and 122.22 cm in summer (Figure 2). Safflower plants grown in winter were significantly ($P < 0.0001$) taller than summer plants with seasonal plant height differences of 29.20%, 40.06%, 46.25%, 37.77% and 39.22% for the genotypes Sina, Gila, Kiama, PI-527 710 and PI-537 636, respectively (Figure 1, 2).

3.2. Yield components

The capitula number per plant significantly ($P < 0.0001$) increased with increase in plant density from 62,500 to 100,000 plants/ha across genotypes and seasons, then decreased when plant density was increased above 100,000 plants/ha (Table 1, 2). The genotype Sina had the highest capitula number/plant compared to other genotypes irrespective of plant density or season (Table 1, 2). All genotypes produced more capitula number/plant in winter than summer with exception of PI-527710 which had a higher capitula number/plant in summer than winter (Table 1, 2). As plant density increased from 62,500 to 100,000 plants/ha, seed number/capitulum significantly (P < 0.0001) increased, thereafter decreased as plant density increased across genotypes and seasons (Table 1, 2). There was a 34.43, 39.40, 26.62, 38.80, 40.73% reduction in seed number/capitulum as plant density increased from 125,000 to 200,000 plants/ha for Sina, PI-527710, PI-537636, Kiama and Gila, respectively, in winter (Table 1). While in summer seed number/capitulum decreased by 25.43, 26.79, 3517, 28.36 and 32.51% when plant density increased from 125,000 to 200,000 plants/ha for Sina, PI-527710, PI-537636, Kiama and Gila, respectively (Table 2).

The results showed that increasing plant density from 62,500 to 100,000 plants/ha significantly (P < 0.0001) increased thousand-seed weight (Table 1, 2). The increase ranged between 17.42-45.62% in winter and 15.37-31.55 % in summer in all the genotypes under study (Table 1, 2). As plant density increased above 100,000 plants/ha, thousand-seed weight decreased by 34.43, 39.40, 26.62, 38.80 and 40.73% in winter in all genotypes (Table 1). While in summer thousand-seed weight decreased by 25.43, 26.79, 35.17, 28.36, 32.51% for Sina, PI-527710, PI-537636, Kiama and Gila, respectively (Table 2). Among genotypes, PI-537636 had highest thousand-seed weight of 53.33 g in winter (Table 1), while in summer Sina had a thousand-seed weight of 45.40 g as the highest weight compared to other genotypes (Table 2). The biological yield followed the same trend as the other variables already described (Table 1, 2). Increasing plant density from 62,500 to 100,000 plants/ha significantly (P < 0.0001) increased safflower biological yield across all genotypes under study and growing seasons (Table 1, 2). However, as plant density increased above 100,000 plants/ha, biological yield significantly (P < 0.0001) decreased both in winter and summer grown safflower (Table 1, 2). The biological yield was significantly (P < 0.0001) higher in winter than summer, with variations ranging between 7.43-15.16 % from winter to summer across genotypes (Table 1, 2).

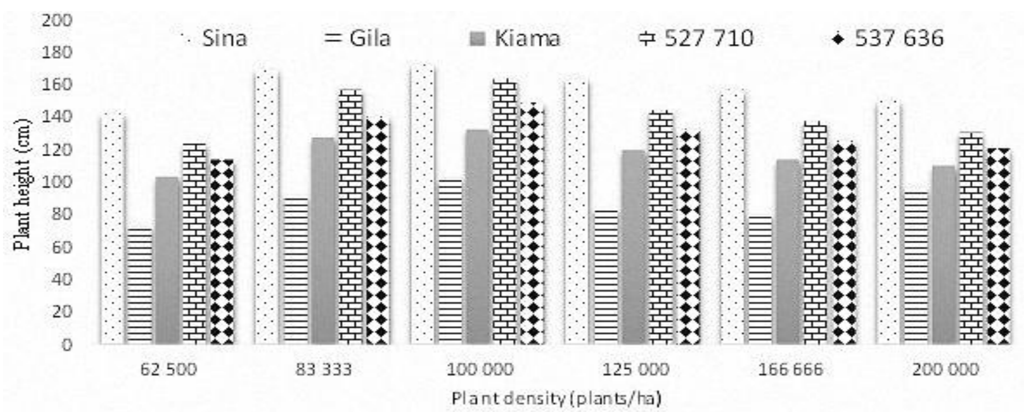

Fig. 1. Effect of plant density on plant height of safflower genotypes grown in winter.

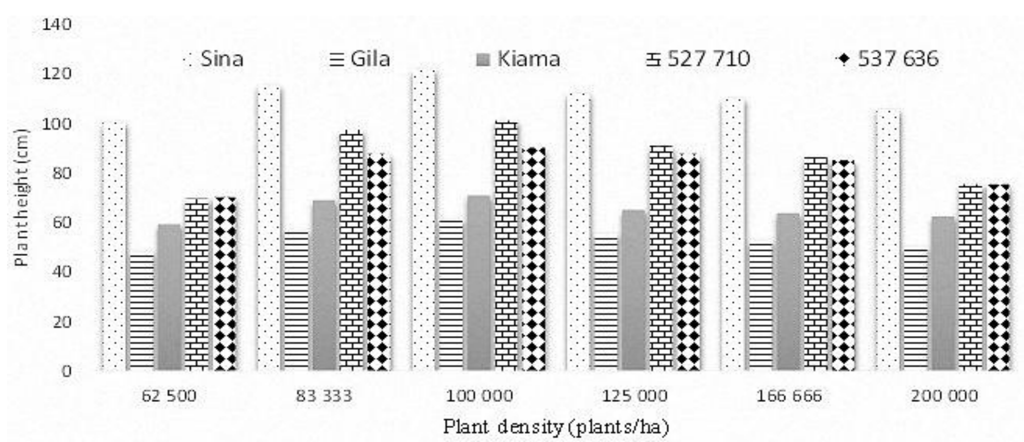

Fig. 2. Effect of plant density on plant height of safflower genotypes grown in summer.

3.3. Seed yield

There was a significant interaction between plant density and safflower genotypes as they affected seed yield (Figure 3, 4). Seed yield significantly ($P < 0.0001$) increased as plant density increased from 62,500 to 100,000 plants/ha (Figure 3, 4). However, as plant density increased above 100,000 plants/ha, safflower seed yield significantly ($P < 0.0001$) decreased among all genotypes and between seasons (Figure 3, 4). The genotype Sina out yielded all the other genotypes under study in both winter (5568 kg/ha) and summer (5107 kg/ha) (Figure 3, 4). While the genotype Gila significantly ($P < 0.0001$) produced the lowest seed yield among the other genotypes with maximum seed yields of 4103 and 3551 kg/ha in winter and summer, respectively (Figure 3, 4). There was also significant ($P < 0.0001$) differences between winter and summer grown safflower with respect to seed yield (Figure 3, 4). Winter grown safflower significantly ($P < 0.0001$) produced higher seed yield than summer among all genotypes under study (Figure 3, 4).

Table 1

Effect of plant density on yield components of safflower genotypes grown in winter.

Treatments	Branch number/plant	Capitula number/plant	Seed number /capitula	1000-seed weight	Biological yield
Sina+62 500	19.00kjl	99.33gf	58.33gf	38.33ef	4956.7l
Sina+83 333	34.33b	148.33b	74.67b	51.67a	7020b
Sina+100 000	42.33a	159.33a	82.00a	52.33a	7177.7a
Sina+125 000	31.00c	127.33c	70.00c	50.33a	6520.3d
Sina+166 666	24.67fg	108.00e	64.00d	45.00b	6083.7e
Sina+200 000	21.67njl	102.00f	61.00ef	41.00cd	5483.3ij
527710+62 500	9.33q	32.33r	32.33q	21.67o	4776.7m
527 710 +83 333	18.67kl	70.30po	45.00m	30.67mlkj	6520.3d
527 710 +100 000	21.00kjl	82.00mn	48.33l	32.33ikj	6891.3c
527 710 +125 000	15.67nm	67.00p	35.33p	25.00n	6060.7fe
527 710 +166 666	12.67po	52.33q	35.33p	25.00n	5421.7j
527 710 +200 000	12.33po	36.00r	34.67qp	22.67on	5055.7l
537 636+62500	11.00pq	81.00n	37.00p	29.33ml	4430n
537 636+83 333	22.67hgi	97.00gh	51.67ikj	35.00hg	6066fe
537 636+100 000	24.67fg	102.67f	52.33ihj	53.33ihj	6514 d
537 636 +125 000	19kjl	93.67ih	48.67l	33.00ihj	5843.3g
537 636 +166 666	14.33nmo	89.67kj	44.67m	31.00mikj	5554ih
537 636 +200 000	13.00npo	85.33ml	41.33n	29.00m	4307o
Kiama +62500	16.33ml	91.33ij	51.00lkj	32.67ihj	4277o
Kiama +83 333	30.33dc	122.33d	65.00d	43.33cb	5811g
Kiama +100 000	34.00b	130.67c	70.33c	45.33b	5983.3f
Kiama +125 000	27.00fe	119.33d	60.67ef	42.00c	5537.7i
Kiama +166 666	24.00hg	99.67gf	56.00gh	39.33ed	5048l
Kiama +200 000	19.67kj	81.33n	50.67lkj	37.33efg	4517n
Gila+62500	15.00nmo	80.00n	41.33n	30.00mlk	3527.3q
Gila +83 333	21.00kjl	109.67e	60.00f	37.67ef	5418j
Gila+100 000	28.00de	119.67d	63.33ed	41.67cd	5639h
Gila +125 000	18.67kl	101.67f	54.00ih	36.33fg	5202.7k
Gila +166 666	15.67nm	86.00kl	50.67ljk	33.33ih	4510n
Gila +200 000	13.67npmo	73.67o	45.00m	31.67lkj	4055.7p
Significance	****	****	****	*****	****
Stderr	0.94	1.33	1.02	0.091	35.21

Significance: * 0.05, ** 0.01, *** 0.001, **** 0.0001; Means with the same letter are not significantly different from each other. Stderr: standard error.

Table 2
Effect of plant density on yield components of safflower genotypes grown in summer.

Treatments	Branch number /plant	Capitula number/ plant	Seed number/ capitula	1000- seed weight	Biological yield
Sina+62 500	27.33f	79.67j	54.33hi	33.30ef	6076.9e
Sina+83 333	34.67b	99.33b	72.67b	44.00ba	6411.58ba
Sina+100 000	38.33a	102.67a	75.67a	45.40a	6516.82a
Sina+125 000	31.67d	96.00c	69.33c	39.43c	6267.82bcd
Sina+166 666	33.33c	91.67d	60.00d	36.17d	6173.95ecd
Sina+200 000	30.33e	85.00gf	60.33fe	35.83d	6103.48ed
527710+62 500	23.33i	77.67k	54.00hi	28.73ikhj	5407.67hgi
527 710 +83 333	29.67e	89.00e	66.00d	38.43c	6311.85bc
527 710 +100 000	32.67dc	91.00d	71.00cb	41.97b	6414.46ba
527 710 +125 000	27.67f	85.33f	61.67e	36.00d	6213.76ecd
527 710 +166 666	25.67gh	83.33gh	58.00fg	34.83ed	6115.75ed
527 710 +200 000	25.33h	82.33ih	56.00hg	31.90gf	5562.74g
537 636+62500	18.67nm	69.00n	44.00op	26.38ml	5152.40ikj
537 636+83 333	25.33h	79.67j	61.67e	32.46gf	5822.25f
537 636+100 000	26.67gf	81.00ij	65.33d	35.91d	6035.96e
537 636 +125 000	25.00h	76.67k	59.00f	30.85gh	5811.33f
537 636 +166 666	22.67ji	74.67l	49.67lk	29.16ihj	5386.16hgi
537 636 +200 000	20.33h	71.67m	48.33lm	27.53iklj	5249.84ji
Kiama +62500	14.33o	34.00x	41.67qp	25.11m	4750.59m
Kiama +83 333	23.67i	57.00p	55.00p	29.67ih	5334.80hji
Kiama +100 000	25.67gb	60.67o	60.33fe	32.36gf	5440.04h
Kiama +125 000	21.00lk	55.00q	52.33ji	27.26klj	5268.57hji
Kiama +166 666	20.67lk	52.00r	47.67lnm	26.61mlk	4965.78kl
Kiama +200 000	18.33nm	51.67r	47.00nm	26.59mlk	4843.06ml
Gila+62500	10.33p	49.00t	38.67r	17.01o	4122.22o
Gila +83 333	20.33l	49.67st	51.00jk	29.54ih	4502.51n
Gila+100 000	21.67jk	51.00sr	54.33hi	32.09gf	4896.75ml
Gila +125 000	19.00m	46.67u	49.00lkm	26.41ml	4410.53n
Gila +166 666	17.67n	42.33v	45.33on	22.52n	4204.15o
Gila +200 000	15.33o	38.33w	41.00qr	21.42n	4059.87o
Significance	****	****	****	*****	****
Stderr	0.354	0.674	0.896	0.757	66.00

Significance: * 0.05, ** 0.01, *** 0.001, **** 0.0001; Means with the same letter are not significantly different from each other. Stderr: standard error.

There were significant ($P < 0.0001$) positive correlations between seed yield and capitula number/plant, branch number/plant, plant height, seed number/capitulum, thousand-seed weight and biological yield (Table 3,4). This implied that an increase in grain/seed yield under both winter and summer grown safflower was significantly ($P < 0.0001$) attributed to increase capitula number/plant, branch number/plant, plant height, seed number/capitulum, thousand-seed weight and biological yield (Table 3, 4).

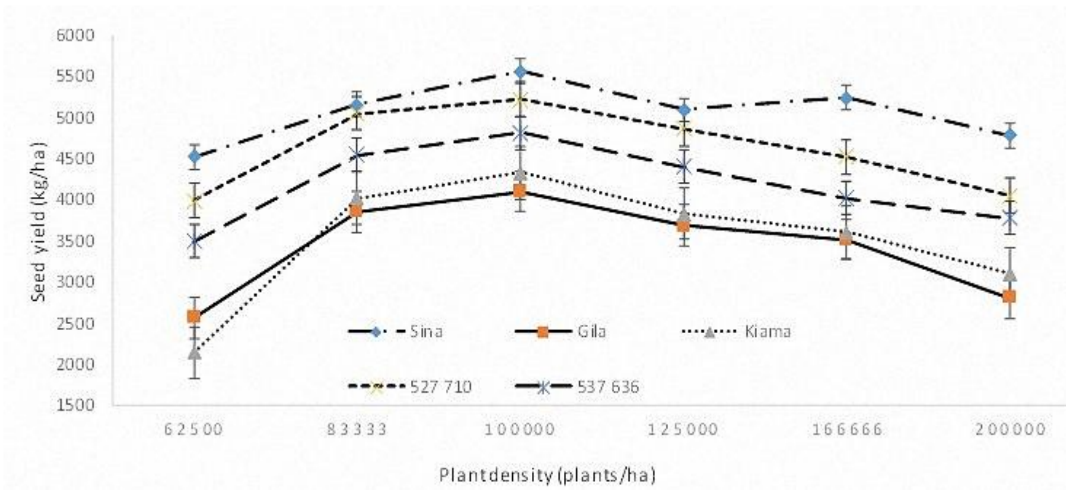

Fig. 3. Effect of plant density on seed yield of safflower genotypes grown in winter.

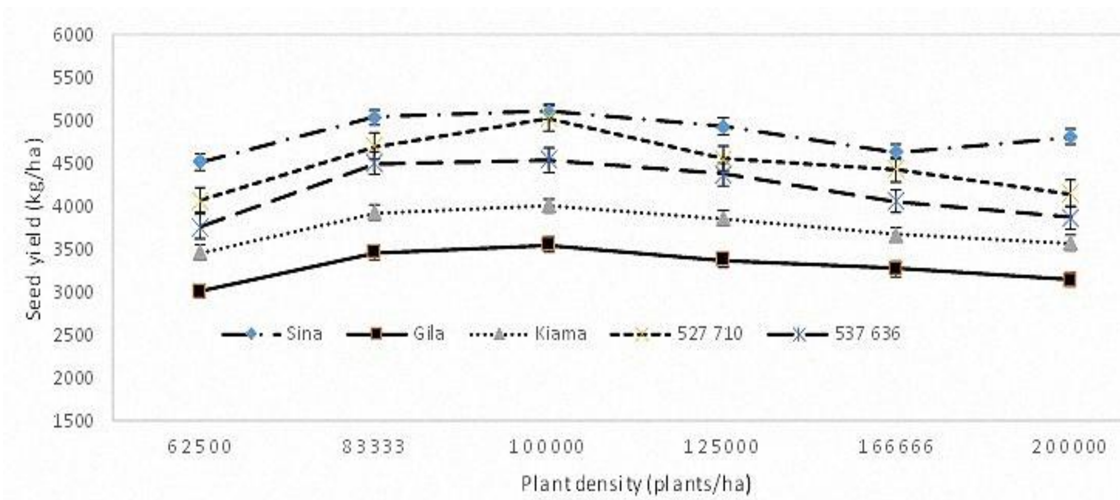

Fig. 4. Effect of plant density on seed yield of safflower genotypes grown in summer.

Table 3
Correlation among yield and yield components of safflower under winter conditions.

Variables	Seed yield	Capitula number per plant	Branch number per plant	Plant height	Seed number per capitulum	Thousand seed weight	Biological yield
Seed yield	1.00000						
Capitula number per plant	0.89497****	1.00000					
Branch number per plant	0.84348****	0.87711	1.00000				
Plant height	0.89975****	0.93054	0.80130	1.00000			
Seed number per capitulum	0.95040****	0.94184	0.89932	0.94825	1.00000		
Thousand seed weight	0.92415****	0.91983	0.90303	0.91362	0.95472	1.00000	
Biological yield	0.89410****	0.89497	0.89184	0.78140	0.89596	0.86469	1.00000

Significance: * 0.05, ** 0.01, *** 0.001, **** 0.0001

Table 4
Correlation among yield and yield components of safflower under summer conditions.

Variables	Seed yield	Capitula number per plant	Branch number per plant	Plant height	Seed number per capitulum	Thousand seed weight	Biological yield
Seed yield	1.00000						
Capitula number per plant	0.95522****	1.00000					
Branch number per plant	0.93597****	0.90665	1.00000				
Plant height	0.95937****	0.94736	0.93349	1.00000			
Seed number per capitulum	0.90908****	0.85918	0.94461	0.87340	1.00000		
Thousand seed weight	0.91790****	0.88043	0.94277	0.89277	0.89405	1.00000	
Biological yield	0.96531****	0.94848	0.90340	0.93307	0.87753	0.89485	1.00000

Significance: * 0.05, ** 0.01, *** 0.001, **** 0.0001

Increasing plant density from 62,500 to 100,000 plants/ha increased vegetative growth, yield components and seed yield of safflower in all genotypes and between seasons. The increase in vegetative growth, yield components and seed yield of safflower with increase in plant density up to 100,000 plants/ha was attributed to lack of competition for essential growth factors such as light, nutrients and water. Suggesting that the optimum plant density for safflower under the semi-arid conditions of Botswana was 100,000 plants/ha (40 cm x 25 cm). A further increase in plant density above 100,000 plants/ha resulted in significant decrease in vegetative growth, yield components and seed yield of safflower. This was attributed to inter and intra-row plant competition for essential growth factors such as light, nutrients, water and photo assimilates (Emongor et al., 2015; Marschner, 2003). Emongor et al. (2013) reported similar findings with safflower genotype 'Kiama composite', where increasing safflower plant density above 100,000 plants/ha decreased vegetative growth, yield components, seed yield, oil content and yield. Khajepour (2004) reported that very high plant densities resulted in shading of lower parts of the canopy leading to reduced photosynthesis and high respiration rate hence a reduction in crop growth, development and yield. Ghanem and Ash-Shormillesy (2007) in Egypt reported a decreasing trend of safflower seed yield and yield components as plant density increased. Yau (2009) observed that plant height decreased with increasing plant densities while Sharikian and Babaeian (2000) confirmed that capitula number/plant, seed number/plant and seed number/capitulum significantly decreased with increasing plant density per unit area. Other researchers have reported that as plant density increases up to a certain limit, reduction in vegetative growth, yield components and yield and yield occurs due to severe intra-specific competition which depressed the amount of metabolites synthesized by the plant hence reduction in plant dry matter accumulation (Bassal, 2003; Sedghi et al., 2008). Different studies conducted from various regions of the world on plant density of safflower genotypes showed that altering row patterns and plant population aims to improve radiation use efficiency and hence increasing crop growth and yield (Andrade et al., 1993; Cirilo et al., 1994; Sarmadinia and Kouchaki, 2009). The increase in seed yield of every genotype at a spacing of 40 cm x 25 cm (100,000 plants/ha) was attributed to significant increase in plant height, branch number per plant, thousand seed weight, number of capitulum per plant and seeds per capitula at this density. This is due to a significantly positive correlation between seed yield and other yield components.

Safflower plants grown in winter were significantly taller than plants grown in summer. The difference in safflower plant height due to growing season was attributed to the difference between night and day temperatures (DIF). On average the DIF during the elongation phase of safflower in May-June (winter) and November-December (summer) in Botswana is 20.7 and 14°C, respectively, explaining the difference in plant height between winter and summer grown safflower plants (Emongor et al., 2013). Changes in day and night temperatures have morphological effects on the stem extension (Went, 1944). The use of DIF to control the height of plants has been demonstrated on a wide range of species (Myster and Moe, 1995). The higher the DIF, the greater the stem elongation (Berghage and Heins, 1991; Erwin et al., 1989 a, b; Karlsson et al., 1989). DIF increases internode elongation for many plant species (Berghage and Heins, 1991; Myster and Moe, 1995). The high positive

DIF in winter could have promoted biosynthesis of gibberellins which are known to promote cell and internode elongation hence explaining the increase in safflower plant height (Emongor et al., 2015). The higher vegetative growth, yield components and seed yield of safflower grown in winter than summer was attributed to a longer drying period in winter (140 days after emergence) than summer (114 days after emergence) hence more accumulation of biological yield or dry matter (Emongor et al., 2013). Significant variation in phenology, growth and yield across safflower genotypes and seasons has also been reported in different studies (Isoda et al., 2011; Hassan et al., 2015; Tahmasebpour et al., 2016). The seasonal variations among genotypes was mainly attributed to difference in environments, temperature and sunshine (Emongor et al., 2013; Hassan et al., 2015; Tahmasebpour et al., 2016). Ritche and NeSmith (1991) and Kaleem et al. (2009) confirmed that temperature and photoperiod regulates plant growth and development processes, while Shabana et al. (2013) and Orchard (1975) emphasized that phenological development of safflower is largely dependent on temperature rather than photoperiod. This has a great impact on crop yield and yield attributes especially during seed development and maturation (Orchard, 1975).

In the current study, there was a significant ($P < 0.0001$) positive correlation between seed yield and capitula number/plant, seed number/capitulum, thousand-seed weight, biological yield, plant height and branch number/plant. This implies that plant height, branch number/plant, seed number/capitulum, seed number/plant, capitula number/plant and biological yield can be used as yield components of safflower. Karimi et al. (2013) reported positive significant correlations of 1000-seed weight, number of seed/capitulum, number of seed/plant, biological yield, oil content, seed yield, plant height, harvest index, days to flowering and days to physiological maturity in safflower. Kedikanetswe (2012) reported that the yield components of safflower were capitula number/plant, capitula size, number of achenes (seed)/capitula, and achene weight (100-seed weight). Gonzalez et al. (1994) had earlier reported that the primary yield components of safflower were number of capitula (flowers) per plant, number of achenes per capitulum and achene weight. Mozaffari and Azari (2006) and Omidi (2002) reported similar findings in their studies on spring safflower cultivars. Significant positive correlations between seed yield and plant height have also been reported (Ramachandran, 1983; Kumar et al., 1982; Shakeri-Amoughin et al., 2015). Even though yield components are under genetic control, they do respond with various degrees of flexibility to plant density (Gonzalez et al., 1994).

4. Conclusion

Safflower is well adaptive and high yielding crop for cultivation in Botswana under irrigated conditions. From the findings of this study it was concluded that there is variation in the performance of safflower genotypes in response to increasing plant density and growing season, but optimum plant density to maximize safflower seed yield under Botswana conditions was 100,000 plants/ha (Botswana is 40 cm x 25 cm).

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