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INTERACTION EFFECT OF VARIETIES AND PLANT SPACING, UNDER ULTRA HIGH DENSITY SYSTEM, ON GROWTH AND YIELD OF CASHEW (*Anacardium occidentale* L.)

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ABSTRACT

An experiment was conducted at AICRP on Cashew in Bhubaneswar, Odisha, India, during cropping seasons of 2022-23 and 2023-24 to assess the interaction between cashew varieties and planting densities under an ultra-high-density planting (UHDP) system. Three varieties *viz*., 'VRI-3', 'NRCC Selection-2', and 'Balabhadra' were tested at spacing of 2.5 m × 2.5 m, 3.0 m × 3.0 m and 7.5 m × 7.5 m. The results revealed significant differences for yield and yield-related traits among cashew varieties under different plant densities. Adoption of ultra high density planting system significantly decreased trunk cross section area (36.07 cm^2), average canopy spread (2.19 m), crown height (1.56 m), canopy volume (5.08 m^3), total number of laterals m^{-2} (22.29), and number of flowering laterals m^{-2} (12.60) than wider spacing of 178 plants ha^{-1}. The cultivar 'NRCC Selection-2' at 2.5 m × 2.5 m spacing achieved the highest nut yield (0.94 t ha^{-1}), whereas cv. 'VRI-3' at 7.5 m × 7.5 m gave the lowest (0.18 t ha^{-1}). The cultivar 'NRCC Selection-2' exhibited superior performance across all the planting densities, attributed to its genetic potential and enhanced responsiveness to pruning.

Keywords: Cashew, NRCC Selection-2, ultra high density, varieties, yield

INTRODUCTION

The cashew (*Anacardium occidentale* L.) is a highly valuable, export-oriented crop that was first introduced to India by the Portuguese in the 16th century with the primary aim of afforestation and soil conservation. Today, cashew is commercially cultivated in over 33 countries worldwide, with major producers including Ivory Coast, India, Vietnam, Brazil, Tanzania, Nigeria, Ghana, Benin and Indonesia. In India, the total cashew production stands at approximately 7.81 lakh t (tonnes) from an area of 11.92 lakh ha, yielding a productivity of 766 kg ha^{-1}. In Odisha, production reaches around 1.21 lakh t from 2.23 lakh ha, with a lower productivity rate of 655 kg ha^{-1} during 2022-23 (DCCD, 2024). India accounted for 15% export of cashew to different parts of world with total valuation US $ 339.21 million during April 2023 to March 2024 (Ministry of Commerce and Industry, APEDA

Agri. Exchange, 2024). The primary cashew-producing states in India includes Maharashtra, Odisha, Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, Goa and West Bengal. Development in cashew processing industry provides opportunities for processing of 15-20 lakh t of raw cashew annually whereas; domestic production stands between 7-8 lakh t. Since domestic demand for cashew has increased in recent years, India imports nearly 50% of its raw cashew nuts, mostly from African nations, thereby incurred ₹ 8,861.59 crores in 2021-22 to meet this demand (Hubballi, 2023).

One of the main constraints in Indian cashew industry is the limited availability of domestic raw materials and dependence on African countries for import of raw cashew to meet nation's demand which mostly accounted for the low productivity of 766 kg ha^{-1}, attributed to factors like senile and unproductive orchards, insufficient plant populations $unit^{-1}$ area, inadequate canopy management and limited adoption of improved cultivation practices. In recent years, the demand for cashew has been rising steadily in both domestic and global markets. In India, cashew consumption has surged about 5.5 times over the past decade, with projections indicating continued growth in the coming years. The domestic demand for raw cashew nuts is expected to reach approximately 50 million t or more by 2050 (Saroj and Nayak, 2016). To meet this escalating demand, it is crucial to enhance productivity $unit^{-1}$. One effective solution is the adoption of ultra-high-density and high-density planting techniques, which can significantly boost yield efficiency. Several crop management techniques can be utilized to enhance both the yield and quality of various crops. These strategies encompass aspects like crop husbandry practices (e.g., seed rate, spacing, planting density, sowing time, fertilizer application, etc.); stress factors, including abiotic stresses (like drought, salinity, temperature, and day length) and biotic stresses (like pests and diseases), external chemical treatments, intercropping, and genetic traits of the crop itself. Among these factors, planting arrangement and spacing play a crucial role in optimizing the use of natural resources while managing competition among neighboring plants (Li *et al*., 2020). Plant density i.e. the number of plants $unit^{-1}$ area, significantly impacts the efficiency of resource utilization. An ideal plant population enhances the crop canopy's ability to capture essential environmental resources such as sunlight, water and nutrients (Shi *et al*., 2016). However, an increase in plant density intensifies competition for these resources, which can lead to depletion of limited resources (Jiang *et al*., 2013). Furthermore, a well-structured canopy can contribute to an optimal leaf area index, thereby enhances photosynthetic efficiency through better solar radiation interception (Wang *et al*., 2015). While higher plant densities often lead to increased overall productivity, lower densities tend to produce larger fruits, which fetch higher prices in fresh markets (Qiu *et al*., 2013). Research has shown that implementing a high-density planting (HDP) system with 500 plants ha^{-1} can increase yield by 2.2 times as compared to the conventional planting density of 156 plants ha^{-1} (8 m x 8 m) during the first ten years (Janni *et al*., 2022). Varietal selection plays a pivotal role in the success of high-density planting systems. In India, over 50 cashew varieties are cultivated across diverse agro-ecological zones (Janni *et al*., 2022). Due to significant differences in morphological and yield traits among these varieties, optimizing planting density for each cultivar is essential to maximize productivity. The studies in other fruit crops such as guava, mango, mandarin and apple have demonstrated that HDP systems are more economically viable than conventional systems (Gaikwad *et al*., 2017; Barman and Mishra, 2018; Ladaniya *et al*., 2021; Mir *et al*., 2022). Considering the above facts, the present study was undertaken to evaluate the interaction effect of varieties and plant spacing under ultra high density system on growth and yield of cashew with objective of enhancing cashew productivity and maintaining soil health.

MATERIALS AND METHODS

A field experiment was carried out at the AICRP on Cashew, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha (India) during 2022-23 and 2023-24 cropping seasons located at 20.27° N latitude and 85.84° E longitude, with an average elevation of 45 m masl. The experiment was laid out in split plot design with three planting density of S_1: (2.5 × 2.5 m^2), S_2: (3 × 3 m^2) and S_3: (7.5 × 7.5 m^2) as main plots and three varieties *viz.*, V_1: 'VRI-3', V_2: 'NRCC selection-2' and V_3: 'Balabhadra' as subplot and were replicated thrice. The variety 'VRI-3' was collected from RRS, Vriddhachalam, Tamil Nadu; while 'NRCC Selection-2' and 'Balabhadra' were procured from DCR, Puttur, Karnataka and AICRP on Cashew, OUAT, Bhubaneswar, respectively. The grafted cashew plants of these varieties were planted during 2020. Uniform cultural practices were implemented across all treatments following the recommended standard cultivation practices (Nayak *et al*., 2020). However, in ultra-high-density planting system, severe pruning (heading back) was conducted to control plant height effectively. In contrast, light pruning was applied in the normal density planting system, where crisscross and overcrowded branches were removed during the month of June to ensure better canopy management.

The observations were recorded for growth traits *viz.*, canopy height, canopy spread, canopy volume, tree trunk cross sectional area (TCSA), total number of laterals m^{-2}, total number of flowering laterals m^{-2}. Panicle morphology *viz.*, panicle girth, panicle length, panicle width, number of rachis $panicles^{-1}$ and yield traits *viz.*, kernel length, kernel width, kernel weight, kernel thickness, yield (t ha^{-1}). Then the volume of canopy and trunk cross-sectional area were, respectively, calculated by using the following formula of Thorne *et al*. (2002) and Kumar *et al.* (2008):

$$\text{Volume of canopy } (m^3) = 2/3\ \pi\ H\ (A/2 \times B/2)$$

Where, H = Plant height (m); A = Canopy spread (E-W) (m) and B = Canopy spread (N-S) (m)

$$\text{Trunk cross-sectional area (TCSA)} = G^2 / 4\pi\text{); where, } G = \text{Girth}$$

The experimental pooled data of two years recorded for various parameters under study were subjected to statistically analyze using split plot design procedure (Panse and Sukhatme, 1985). The Pearson correlation coefficient was calculated for vegetative traits and yield parameters using KAUGRAPES software (Gopinath *et al.*, 2020).

RESULTS AND DISCUSSION

Vegetative parameters

Planting density significantly influenced various vegetative growth parameters (Table 1). The maximum TCSA (46.70 cm^2), average canopy spread (2.70 m), crown height (1.92 m), canopy volume (9.85 m^3), total number of laterals m^{-2} (26.35 m^{-2}) and the number of flowering laterals (15.89 m^{-2}) were observed in 7.5 m x 7.5 m spacing (S_3), while minimum was observed in 2.5 m x 2.5 m spacing (S_1). Additionally, significant differences were noticed in three cashew varieties studied under different spacing. Among these, variety 'Balabhadra' had maximum TCSA (43.35 cm^2), average canopy spread (2.47 m), crown height (1.76 m), canopy volume (7.53 m^3), while total number of laterals (28.80 m^{-2}) and number of flowering laterals (19.48 m^{-2}) were highest in 'VRI-3' variety.

Variety x spacing interaction on TCSA and crown height (m) depicted no significant differences in this UHD system of cashew. While the interaction effect of spacing and variety on average canopy spread, canopy volume (m^3), total number of laterals m^{-2} and number of flowering laterals had a significant difference. Highest canopy volume (10.83 m^3) and average canopy spread (2.80 m) was maximum in S_3V_2 treatment, while crown height was maximum in S_3V_3 treatment (2.02 m). Highest number of total laterals (30.42 m^{-2}) and flowering laterals (20.90 m^{-2}) was recorded in S_3V_1 treatment. These results clearly indicated that normal planting density had higher vegetative growth than closer spacing. The vegetative growth of cashew under ultra-high density planting is influenced by genotype and environmental conditions (Tripathy *et al*., 2015; Nayak *et al*., 2020; Janani *et al*., 2022). The larger trunk cross-sectional area observed with wider spacing may be attributed to the reduced competition for natural resources, nutrients, and photosynthates. The reduced canopy spread, height and volume in ultra-density planting, as compared to conventional spacing, are primarily due to regular pruning, which is necessary to prevent branch overlap (Nayak *et al.*, 2020). Similar observation has been reported by Nayak *et al.* (2020) and Janani *et al.* (2022) in cashew; Tharanika *et al.* (2024) and Yallesh *et al.* (2024) in banana.

Table 1: Effect of spacing and varieties on vegetative growth in cashew plantation

Treatments	TCSA (cm^2)	Average canopy spread (m^2)	Crown height (m)	Canopy volume (m^3)	Total No. of laterals m^{-2}	No. of flowering laterals m^{-2}
Plant spacing						
S_1:2.5 m x 2.5 m	36.07	2.19	1.56	5.08	22.29	12.60
S_2: 3 m x 3 m	38.02	2.37	1.61	6.21	23.80	13.92
S_3: 7.5 m x 7.5 m	46.70	2.70	1.92	9.85	26.35	15.89
SE(m) ±	2.43	0.025	0.029	0.290	0.201	0.186
$CD_{0.05}$	7.95	0.081	0.094	0.946	0.655	0.608
Varieties						
V_1:VRI 3	42.07	2.35	1.58	6.26	28.80	19.48
V_2: NRCC Sel.2	35.37	2.43	1.74	7.36	22.41	12.06
V_3: Balabhadra	43.35	2.47	1.76	7.53	21.22	10.87
SE(m) ±	1.523	0.016	0.018	0.082	0.154	0.095
$CD_{0.05}$	4.446	0.046	0.053	0.238	0.449	0.276
Interactions						
S_1V_1	37.42	2.13	1.48	4.53	27.40	18.67
S_1V_2	30.49	2.14	1.57	4.98	20.58	10.05
S_1V_3	40.29	2.30	1.62	5.72	18.88	9.08
S_2V_1	35.78	2.34	1.51	5.83	28.59	18.89
S_2V_2	35.41	2.35	1.67	6.26	21.87	12.25
S_2V_3	42.88	2.42	1.65	6.55	20.95	10.63
S_3V_1	53.02	2.58	1.76	8.41	30.42	20.90
S_3V_2	40.21	2.80	1.99	10.83	24.80	13.88
S_3V_3	46.88	2.71	2.02	10.31	23.84	12.89
SE(m) ±	3.48	0.032	0.036	0.163	0.308	0.189
$CD_{0.05}$	ns	0.092	ns	0.477	0.899	0.553

Panicle morphology

The interaction between varieties and spacing showed no significant effect on panicle morphology, including panicle length, width, girth, and the number of rachis panicle^{-1}, across three cashew varieties and spacing treatments (Table 2). The planting density did not significantly affect panicle length, panicle width and number of rachis panicle^{-1} and panicle girth. The wide spacing of 7.5 m x 7.5 m (S_3) resulted in highest values for panicle length (17.5 cm), panicle width (25.5 cm), panicle girth (1.54 cm), total number of rachis panicle^{-1} (8.15). In contrast, narrowest spacing of 2.5 m × 2.5 m (S_1) resulted in lowest values for these variables. Panicle morphology significantly varied among the three test cashew genotypes under different spacing arrangements. The variety 'NRCC Selection-2' showed highest values for panicle width (27.79 cm) and panicle girth (1.67 cm), followed by variety 'Balabhadra'. However, variety 'VRI-3' had highest panicle length (17.63 cm) and total number of rachis panicle^{-1} (8.33), followed by variety 'NRCC Selection-2'. This suggests that the variation in panicle morphology is primarily driven by genetic factors, rather than by planting density or the interaction between genotype and spacing. Similar observations have been reported for panicle girth in previous studies in cashew (Nayak *et al.*, 2020) and mango (Gaikwad *et al.*, 2017).

Table 2: Effect of spacing and varieties on panicle morphology in cashew plantation

Treatments	Panicle length (cm)	Panicle width (cm)	Panicle girth (cm)	No. of rachis panicles
Plant spacing				
S_1:2.5 m x 2.5 m	17.01	24.90	1.51	7.88
S_2: 3 m x 3 m	17.21	25.23	1.52	8.02
S_3: 7.5 m x 7.5m	17.50	25.50	1.54	8.15
SE(m) ±	0.176	0.166	0.014	0.043
$CD_{0.05}$	ns	ns	ns	ns
Varieties				
V_1:VRI 3	17.63	23.52	1.39	8.33
V_2: NRCC Sel.2	17.21	27.79	1.67	8.04
V_3: Balabhadra	16.88	24.33	1.51	7.69
SE(m) ±	0.111	0.112	0.008	0.041
$CD_{0.05}$	0.324	0.328	0.023	0.120
Interactions				
S_1V_1	17.34	23.21	1.38	8.14
S_1V_2	17.02	27.51	1.66	7.91
S_1V_3	16.67	23.98	1.50	7.61
S_2V_1	17.60	23.47	1.39	8.35
S_2V_2	17.16	27.83	1.68	8.06
S_2V_3	16.86	24.39	1.51	7.66
S_3V_1	17.93	23.89	1.42	8.51
S_3V_2	17.44	28.02	1.69	8.15
S_3V_3	17.12	24.61	1.52	7.79
SE(m) ±	0.222	0.225	0.016	0.082
$CD_{0.05}$	ns	ns	ns	ns

Kernel characters

Interaction effect between variety and spacing showed no significant differences in kernel characteristics (Table 3). However, varieties exhibited significant differences for kernel characters. The kernel weight (2.40 g), kernel width (2.03 cm) and kernel thickness (1.47 cm) were maximum in variety 'NRCC Selection 2', while maximum kernel length (2.82 cm) was observed in 'Balabhadra' variety. The minimum kernel weight (2.15 g) and kernel width (1.84 cm) was noticed in variety 'VRI-3', while minimum kernel thickness (1.19 cm) was observed in variety 'Balabhadra'. The influence of spacing on kernel length, kernel weight, kernel width and kernel thickness for different varieties showed no significant difference. The widest spacing of 7.5 m x 7.5 m (S_3) resulted in the highest values for kernel weight (2.33 g), kernel length (2.78 cm), kernel width (1.98 cm) and kernel thickness (1.32 cm). However, kernel weight increased with wider plant spacing, likely due to reduced competition for nutrients and better light penetration as compared to ultra-high and high-density plantings. Similar observations were reported by Nayak *et al*. (2020) in cashew; Mahesh *et al.* (2017) in guava and Mir *et al*. (2022) in apple. The increase in kernel weight with standard spacing may be attributed to the reduced competition for nutrients and other growth resources, as also observed by Kumar *et al.* (2013) in apricots.

Nut yield

Maximizing cashew nut yield per unit area is the primary goal of cashew farmers. The plant spacing significantly affected nut yield. The normal spacing of 7.5 m x 7.5 m (S_3) gave lowest yield (0.19 t ha^{-1}), while less spacing 2.5 m × 2.5 m (S_1) resulted in highest yield (0.85 t ha^{-1}). Among the various spacing options, the highest yield was found at plant spacing of 2.5 m × 2.5 m as compared to wider spacing, mainly attributed more number of plants per unit area. The results are supported by Nayak *et al*. (2020) in cashew and Kumar *et al.* (2013) in apricot. The genotypes significantly impacted nut yield with

Table 3: Effect of spacing and varieties on kernel characters and yield in cashew plantation

Treatments	Kernel weight (g)	Kernel length (cm)	Kernel width (cm)	Kernel thickness (cm)	Yield (t ha^{-1})
Plant spacing					
S_1: 2.5 m x 2.5 m	2.21	2.71	1.89	1.27	0.85
S_2: 3 m x 3 m	2.27	2.75	1.92	1.29	0.67
S_3: 7.5 m x 7.5 m	2.33	2.78	1.98	1.32	0.19
SE(m) ±	0.015	0.011	0.007	0.009	0.021
$CD_{0.0}$	0.050	0.035	0.022	0.030	0.068
Varieties					
V_1:VRI 3	2.15	2.67	1.84	1.22	0.54
V_2: NRCC Sel.2	2.40	2.74	2.03	1.47	0.63
V_3: Balabhadra	2.28	2.82	1.93	1.19	0.53
SE(m) ±	0.013	0.008	0.005	0.005	0.015
$CD_{0.05}$	0.037	0.024	0.014	0.016	0.045
Interactions					
S_1V_1	2.08	2.63	1.80	1.20	0.84
S_1V_2	2.34	2.72	1.99	1.43	0.94
S_1V_3	2.22	2.79	1.90	1.17	0.76
S_2V_1	2.13	2.68	1.84	1.23	0.60
S_2V_2	2.39	2.75	2.02	1.47	0.74
S_2V_3	2.30	2.81	1.91	1.17	0.66
S_3V_1	2.23	2.71	1.87	1.24	0.18
S_3V_2	2.47	2.77	2.09	1.51	0.21
S_3V_3	2.32	2.85	1.97	1.22	0.19
SE(m) ±	0.026	0.017	0.010	0.013	0.031
$CD_{0.05}$	ns	ns	ns	ns	ns

highest yield found in variety 'NRCC Selection 2' (0.63 t ha^{-1}), and lowest yield in variety 'Balabhadra' (0.53 t ha^{-1}). The highest yield was observed in 'NRCC Selection 2' as compared to the other varieties, primarily due to its positive response to intensive pruning under ultra-density planting. These findings are in agreement with Kumaresh *et al.* (2023), Janani *et al.* (2022) and Nayak *et al*. (2020). The spacing and varieties interaction insignificantly affected the nut yield. However, among the interactions, the highest yield was seen in S_1V_2 combination (0.94 t ha^{-1}), followed by S_1V_1 (0.84 t ha^{-1}), and lowest yield in S_3V_1 (0.18 t ha^{-1}).

Correlation between genotypes and spacing on vegetative traits, panicle morphology and yield attributes

A Pearson correlation coefficient analysis on pooled data revealed relationships among vegetative traits, panicle morphology and yield attributes of cashew under varying genotypes and spacing (Table 4). Vegetative traits like TCSA, canopy spread, crown height, and canopy volume showed negative correlation with yield per hectare and panicle morphology. This negative relationship may be due to the increasing plant density from 178 to 1600 trees ha^{-1} which significantly impacted the growth parameters, panicle morphology and yield attributes of cashew trees. Under ultra-dense planting, heavy pruning is required to regulate growth parameters, leading to reduced growth. Conversely, wider spacing promotes enhanced plant growth due to greater space availability, reduced competition for natural resources and improved conditions for growth, panicle development and yield attributes (Tripathy *et al.*, 2015; Nayak *et al*., 2020). TCSA showed positive correlations with canopy spread, crown height, canopy volume, total laterals m^{-2}, flowering laterals m^{-2}, panicle length, rachis panicle^{-1}, and kernel length, but negatively correlated with panicle width, panicle girth, kernel weight, kernel width, and kernel thickness. Canopy spread, crown height, and canopy volume were found positively

Table 4: Correlation of interactions between genotypes and spacing on vegetative traits, panicle morphology and yield attributes

Traits	YH	TCSA	ACS	CH	CV	TL	TFL	PL	PW	PG	NRP	KW	KL	KB	KT
YH	1.0000														
TCSA	-0.7858	1.0000													
ACS	-0.9430	0.6490	1.0000												
CH	-0.8379	0.5400	0.9306	1.0000											
CV	-0.9307	0.6082	0.9856	0.9692	1.0000										
TL	-0.5204	0.5574	0.2478	0.0096	0.2047	1.0000									
TFL	-0.3782	0.4684	0.0957	-0.1331	0.0563	0.9828	1.0000								
PL	-0.5379	0.3676	0.3156	0.1103	0.2986	0.8562	0.8071	1.0000							
PW	0.0271	-0.4216	0.1939	0.3501	0.2538	-0.6043	-0.6666	-0.1317	1.0000						
PG	0.0358	-0.3754	0.2238	0.4100	0.2802	-0.7359	-0.8028	-0.3269	0.9718	1.0000					
NRP	-0.3472	0.1727	0.1344	-0.0669	0.1155	0.7793	0.7462	0.9693	-0.0634	-0.2797	1.0000				
KW	-0.2521	-0.1065	0.5142	0.6508	0.5506	-0.6051	-0.7036	-0.2526	0.8876	0.9398	-0.2823	1.0000			
KL	-0.3829	0.3430	0.5779	0.6863	0.5721	-0.4713	-0.5648	-0.5307	0.2253	0.4182	-0.6740	0.6181	1.0000		
KB	-0.2588	-0.1632	0.5059	0.6551	0.5570	-0.5733	-0.6796	-0.1928	0.9182	0.9506	-0.2060	0.9832	0.5414	1.0000	
KT	-0.0320	-0.4305	0.1907	0.2920	0.2494	-0.3711	-0.4356	0.1335	0.9509	0.8571	0.2222	0.7555	-0.0224	0.8226	1.0000

YH - Yield (t ha^{-1}), TCSA - Trunk cross sectional area, ACS - Average canopy spread, CH - Crown height, CV - Canopy volume, TL - Total number of laterals m^{-2}, TFL - Total number of flowering laterals m^{-2}, PL - Panicle length, PW - Panicle width, PG - Panicle girth, NRP - Number of rachis per panicle, KW - Kernel weight, KL - Kernel length, KB - Kernel breadth, KT - Kernel thickness

correlated with kernel traits. Panicle morphology showed complex correlations such as panicle length correlated positively with rachis $panicle^{-1}$ but negatively with kernel traits, while panicle width and girth correlated positively with kernel traits but negatively with rachis $panicle^{-1}$. Weight, length and width of cashew kernel were positively interrelated, while kernel thickness had varied correlations.

Conclusion: The study revealed a significant interaction effect of varieties and plant spacing for most of the growth traits (TCSA and average canopy spread) and yield, while panicle and kernel characteristics were insignificantly affected. Among the varieties tested, 'NRCC Sel. 2' showed superior performance under ultra-high-density planting conditions in terms of nut yield ha^{-1}, suggesting that it is highly suitable for ultra-high-density planting in the Eastern Ghat region. However, for long-term sustainability and enhanced productivity, development of dwarf cashew varieties may further optimize and facilitate the adoption of ultra-high-density planting systems in cashew cultivation.

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Conflict of interest: The authors declare that there is no conflict of interest between authors.

Data availability: The data used to support the findings of the study are included within the article.

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