

1 **Induction of embryogenic callus in cashew**  
2 **(*Anacardium occidentale* L.) by cotyledon, nucellus**  
3 **and testa with antioxidants effect**

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18 **ABSTRACT**  
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**Aims:** This work aims to evaluate the influence of different growth regulators combined with antioxidants on the induction of callus with different explants in cashew.

**Materials and Methods:** Nucellar tissues, cotyledons and testa from elite tree nuts are cultured on media that differ in their concentration of 6-Benzylaminopurine (BAP: 0 mg/l; 0.25 mg/l; 0.5 mg/l) and Acid 2,4 dichlorophenoxyacetic (2,4-D: 0 mg/l; 0.8 mg/l). Therefore, for the control of the browning of the explants, the effect of activated charcoal and polyvinylpyrrolidone was tested. The amount of callus formed is evaluated after 28 days and after 90 days by simple observation according to a given scale.

**Results:** Analysis of variance of callus formation 28 days after the culture of explants shows that the interaction between growth regulators and antioxidants significantly influences ( $p < 0.05$ ) the induction of callus. The combination BAP 0.25mg/l and 2,4-D 0.8mg/l produces on average more callus ( $0.47 \pm 0.00$ ). There is a very significant difference ( $P < 0.05$  to  $p < 0.001$ ) in the effect of growth regulators and antioxidants on obtaining callus after 90 days of cultivation. The 0.25 mg/l combination of BAP and 0.8 mg/l of 2,4-D still appears to be the best combination of growth regulators for callus with 58% of callus formed. Cotyledons in the presence of PVP respond better than activated charcoal. The nucellus are the explants that respond better in the presence of activated charcoal. The test for Least Significant Difference reveals that PVP significantly promotes ( $p < 0.05$ ) the production of a large number of calli (77%) unlike activated charcoal (9%) after 90 days of culture.

**Conclusion:** Summary, for obtaining viable and embryogenic callus in cashew, the combination of BAP at 0.25 mg/L and 0.8 mg/L of 2,4-D is the best and this in the presence of PVP with cotyledons.

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21 *Keywords: Anacardium occidentale, callus, 6-Benzylaminopurine, antioxidant, embryogenesis*  
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26 **1. INTRODUCTION**  
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28 *Anacardium occidentale* L. is an agriculturally important crop in several tropical regions such as Asia, Africa, India and  
29 Latin America. The cashew is highly valued for its edible nuts and shell. Conventional plant breeders and biotechnology  
30 programmes to improve productivity are giving it great interest. The growing demand for cashew kernels has led to an  
31 increase in the cultivation of this plant. However, current propagation methods have become a limiting factor in the supply  
32 of adequate planting material [1]. Conventional methods of vegetative propagation, namely layering, grafting or cutting,  
33 are not fast to meet the needs of elite varieties in a timely manner. The technology for commercial-scale propagation of  
34 plants is mainly based on micropropagation. Micropropagation, especially somatic embryogenesis protocols, aims at rapid  
35 multiplication of seedlings true to the parent material [2]. Although the successes of somatic embryogenesis have been  
36 documented for some highly productive forest and fruit species, there are still barriers to the implementation of somatic  
37 embryogenesis on an operational scale in forestry and agroforestry [3]. Among other constraints to cashew  
38 micropropagation, explant browning and the type of growth regulator are the main factors to be controlled in the induction  
39 of somatic embryogenesis [4]. In *in vitro* culture, cashew, like other Anacardiaceae, is very recalcitrant and only limited  
40 success has been achieved [4,5]. Several studies have shown in cashew and mango that 2,4-D is the essential  
41 component of the induction phase of somatic embryogenesis in several species. However, the prolonged presence of 2,4-  
42 D in the induction medium inhibits the growth of somatic embryos beyond the globular stage [6,7]. Recent studies in  
43 mango [8], a species of the same family as cashew, have shown that improved embryo production is observed when the  
44 concentration of nitrogen in the medium, especially ammonium salts, is low and 2,4-D is replaced by BAP at low  
45 concentration (0.25 mg/l). Furthermore, cashew is rich in phenolic compounds. Mantell et al [5] report that secondary  
46 metabolites are released in the phloem vessels of all cashew organs. Indeed, the wounds caused during the cutting of  
47 explants favour the oxidation of these phenolic compounds, whose exudation leads to the browning and then the necrosis  
48 of the calyxes. Thus, a low rate of calli is obtained at the end of the induction. Establishing an effective protocol to control  
49 browning is therefore a challenge. Cultivation of explants with antioxidants such as 0.3% Polyvinylpyrrolidone (PVP) [9]  
50 combined with frequent subculturing and dark incubation [10], addition of activated charcoal to the basal medium [11],  
51 minimises the effect of phenolic exudations and consequently, explant necrosis. Thus, the aim of this work is to evaluate  
52 the effect of BAP and 2,4-D in combination with PVP or activated charcoal in the formation of pro-embryogenic calli in  
53 order to obtain somatic embryos capable of germinating and regenerating the whole plant of *Anacardium occidentale in*  
54 *vitro*.

## 2. MATERIALS AND METHODS

### 2.1. Materials

Immature seeds (2-3 weeks after fertilization) collected on selected cashew trees from the municipality of Bassila retained by previous studies were surface sterilized for 5 min in 70% (v/v) ethanol, followed by 50% sodium hypochlorite (4% active chlorine) solution with a few drops of Tween-20 for 30 minutes; and then rinsed three times in sterile distilled water. Ovules were removed from cashew nut under sterile conditions and bisected longitudinally [12]. The nuts were cut open under sterile conditions in a laminar hood, the ovules were dissected out, cut in half. The immature seed was taken out using sterile forceps and to allow removal of the embryo and nucellus. Thick and fleshy seed coat explants, nucelli and cotyledon were cultured on Modified Gamborg's B5 major salts, MS minor salts, iron source and organics with varying hormone concentrations [8]. The explants were placed on the various media with either their convex (dorsal) or concave (ventral, cut end) side in contact.

### 2.2. Methods

The medium supplemented with 6% sucrose, 400 mg/L L-glutamine, 500 mg/L casein hydrolysate, 80 mg/l adenine sulphate and, with 0.8 mg/L 2,4-dichlorophenoxy-acetic acid (2,4-D) alone, or in combination with BAP at 0.25 mg/l or 0.5 mg/l (Table 1) giving five treatments in all 2.5 g/l of activated charcoal or PVP. For callus induction, 10–15 explants were used per treatment (explant x media), with three replicates in a randomized block design. All the experiments were repeated twice.

Cultures were incubated in the dark at  $25^{\circ} \pm 1^{\circ}\text{C}$  for 12 weeks, and callus formation was observed each week. The numbers of explants showing callus and pro-embryonic calli (PEC) initiation as well as the number of days taken for callusing and PEC formation were recorded after 28 and 90 days.

**Table 1** : Media compositions for the induction of calli from the various types of explants

Media	BAP (mg/l)	2,4-D (mg/l)	PVP (g/l)	Activated charcoal (g/l)
C0P	0	0.8	2.5	0
C1P	0.25	0	2.5	0
C2P	0.5	0	2.5	0
C3P	0.25	0.8	2.5	0
C4P	0.5	0.8	2.5	0
C0ch	0	0.8	0	2.5
C1ch	0.25	0	0	2.5
C2ch	0.5	0	0	2.5
C3ch	0.25	0.8	0	2.5
C4ch	0.5	0.8	0	2.5

80 The amount of callus is evaluated using the scale: no callus = 0 cal; slight callus = 1mm cal; moderate callus = 2 to 5mm;  
81 profuse callus = 5 to 8mm; highly profuse callus = 8 to 10mm) is noted after 4 weeks and after 90 days by simple  
82 observation.

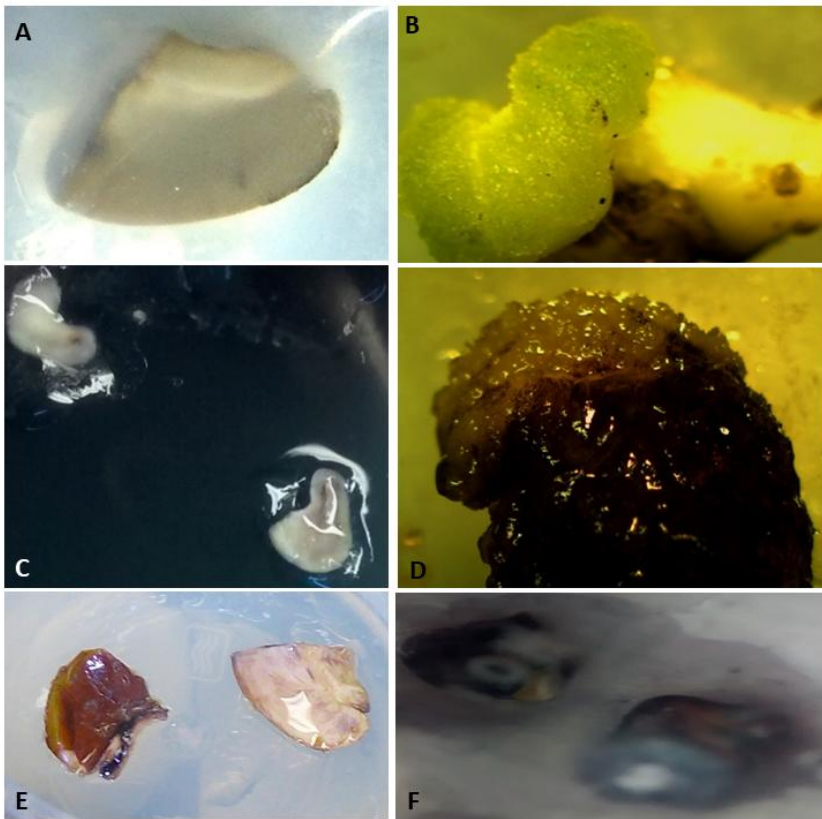
### 83 **2.3. Statistical analysis**

84 The data collected after 28 and 90 days were entered and processed with the Excel spreadsheet. These data were then  
85 subjected to a two and three-way analysis of variance (ANOVA) using the PROC GLM procedure of the Statistical  
86 Analysis System (SAS) software version 9.2. Data for the amounts of calli after four weeks were subjected to a three-way  
87 ANOVA (growth regulators, antioxidants and explants) while the data taken after 90 days were subjected to a two-way  
88 ANOVA (growth regulators and antioxidant). Multiple means comparisons were made with the test for the least significant  
89 difference (LSD) at the 5% level [13].  
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## 91 **3. RESULTS**

### 92 **3.1. Morphological Response**

93 Morphological changes such as swelling, colour change were noticed from the first week of culture. Regardless of the  
94 treatment, 98% of the explants showed morphological responses. After the first week of culture, the cotyledons turned  
95 green and tripled or even quadrupled in size after three weeks of culture. The explants reacted differently and depending  
96 on the composition of the medium. In the cotyledons, calli were observed on the edge and on the outer side. In the  
97 nucellus, calli were observed on the surface above the medium. The testa gave some calli and this on the outer layer. The  
98 testa (Fig. E) rapidly turned brown and necrotic (Fig. F). The cotyledons and the nucellus were the best explants to obtain  
99 the callus. The nucellar callus **was** brown (Fig. D), while the cotyledonary callus **was** snow white, translucent, white  
100 crystals or green (Fig. B).  
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A: Cotyledon explant; B: Calli from Cotyledon; C: Nucellar explant; D: Calli from Nucellar; E: Testa explant; F: Necrosis of testa explant

**Figure: 1** Morphological response of different explants on the medium

### 3.2. Callus formation

The three-factor analysis of variance considering media, antioxidants and explants on callus formation after four weeks of cultivation revealed (Table 2) that there was no significant difference ( $p > 0.05$ ) between plant growth regulators and antioxidants with respect to callus formation. However, the interaction between hormone composition and antioxidants significantly ( $p < 0.05$ ) influenced callus induction. Table 3 shows the results of the smallest significant difference test. From this table it can be seen that the testa did not significantly ( $p > 0.05$ ) induce callus formation compared to the nucellus and cotyledon, which did induce callus and even of medium size. Activated charcoal appeared to be the antioxidant that significantly ( $p < 0.05$ ) promoted callus formation in the medium with only 2,4-D at 0.8 mg/l (C0) and the medium with BAP at 0.25 mg/l and no 2,4-D (C1). The medium (C1) was less favourable for callus formation. However, media C0 where BAP was zero (0mg/l) and 2,4-D 0.8mg/l; then C3 where BAP was low (0.25mg/l) and 2,4-D 0.8mg/l produced significantly ( $p < 0.05$ ) more callus ( $0.47 \pm 0.00$  on average) according to the Smallest Significant Difference test. In general, C0, C4 and C3 media were the best for obtaining average callus with 46%, 37% and 23% average callus respectively. It was also noted that activated carbon gave more callus on media C0 and C1. In general, it was found that media C0 where BAP was zero (0mg/l) and 2,4-D 0.8mg/l; then C3 where BAP was low (0.25mg/l) and 2,4-D 0.8mg/l produced more callus ( $0.47 \pm 0.00$  on average).

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**Table 2.** F-values and level of significance from three-way Analysis of Variance (ANOVA) of callus formation regarding plant growth regulators (PGR), antioxidant and explant after 28 days

Source of variation	Degree of freedom	F-values				
		Callus formation after 28 days				
		No callus	slight callus	moderate callus	Profuse callus	Highly profuse callus
<b>PGR</b>	4	0.85 <sup>ns</sup>	0.69 <sup>ns</sup>	1.03 <sup>ns</sup>	2.58 <sup>ns</sup>	0.12 <sup>ns</sup>
<b>Antioxidants</b>	1	0.09 <sup>ns</sup>	0.55 <sup>ns</sup>	0.05 <sup>ns</sup>	0.90 <sup>ns</sup>	0.20 <sup>ns</sup>
<b>Explants</b>	2	3.06 <sup>ns</sup>	0.64 <sup>ns</sup>	1.83 <sup>ns</sup>	1.7 <sup>ns</sup>	0.28 <sup>ns</sup>
<b>PGR * Antioxidants</b>	4	3.63*	0.73 <sup>ns</sup>	3.11*	0.72 <sup>ns</sup>	0.12 <sup>ns</sup>
<b>PGR * Explants</b>	8	0.64 <sup>ns</sup>	0.70 <sup>ns</sup>	0.63 <sup>ns</sup>	1.8 <sup>ns</sup>	0.11 <sup>ns</sup>
<b>Antioxidants * Explants</b>	2	0.50 <sup>ns</sup>	0.72 <sup>ns</sup>	0.34 <sup>ns</sup>	0.62 <sup>ns</sup>	0.28 <sup>ns</sup>
<b>PGR* Antioxidants*Explants</b>	8	2.04 <sup>ns</sup>	0.77 <sup>ns</sup>	1.06 <sup>ns</sup>	1.04 <sup>ns</sup>	0.13 <sup>ns</sup>

ns:  $P > 0.05$  \*:  $P < 0.05$

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**Table 3 :** Effect of growth regulators, antioxidant and explant on callus formation after 28 days (mean ± standard error)

Media	Antioxidants	Explants	Callus formation					
			No callus	slight callus	moderate callus	Profuse callus	highly profuse callus	
BAP 0mg/l and 2,4-D 0,8mg/l  (C0)	Activated charcoal	Nucellus	0,00±0,00 <b>b</b>	0,00±0,00 <b>a</b>	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Testa	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>b</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Cotyledon	0,00±0,00 <b>b</b>	0,00±0,00 <b>a</b>	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Mean	0,20±0,20 <b>B</b>	0,00±0,00 <b>A</b>	0,80±0,20 <b>A</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>	
	PVP	Nucellus	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Testa	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Cotyledon	0,50±0,28 <b>a</b>	0,00±0,00 <b>a</b>	0,50±0,28 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Mean	0,750±0,16 <b>A</b>	0,00±0,00 <b>A</b>	0,25±0,16 <b>B</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>	
	Mean		0,53±0,00 <b>Y</b>	0,00±0,00 <b>X</b>	0,46±0,00 <b>X</b>	0,00±0,00 <b>X</b>	0,00±0,00 <b>X</b>	
	BAP 0,25 mg/l and 2,4-D 0mg/l  (C1)	Activated charcoal	Nucellus	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
			Testa	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
			Cotyledon	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
			Mean	0,66±0,33 <b>B</b>	0,00±0,00 <b>A</b>	0,33±0,33 <b>A</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>
PVP		Nucellus	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Testa	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Cotyledon	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	
		Mean	1,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>B</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>	
Mean			0,90±0,00 <b>X</b>	0,00±0,00 <b>X</b>	0,10±0,00 <b>Y</b>	0,00±0,00 <b>X</b>	0,00±0,00 <b>X</b>	
BAP 0,5mg/l		Activated	Nucellus	1,00±0,00 <b>a</b>	0,00±0,00	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>

and 2,4-D 0mg/l (C2)	charcoal			<b>a</b>			
		Testa	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
		Cotyledon	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
		Mean	1,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>
	PVP	Nucellus	0,50±0,50 <b>a</b>	0,00±0,00 <b>a</b>	0,50±0,50 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
		Testa	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
		Cotyledon	0,60±0,24 <b>a</b>	0,00±0,00 <b>a</b>	0,20±0,20 <b>a</b>	0,00±0,00 <b>a</b>	0,20±0,20 <b>a</b>
		Mean	0,70±0,15 <b>A</b>	0,00±0,00 <b>A</b>	0,20±0,13 <b>A</b>	0,00±0,00 <b>A</b>	0,10±0,10 <b>A</b>
	Mean		0,78±0,00 <b>X,Y</b>	0,00±0,00 <b>X</b>	0,14±0,00 <b>X,Y</b>	0,00±0,00 <b>X</b>	0,07±0,00 <b>X</b>
	BAP 0,25mg/l and 2,4-D 0,8mg/l (C3)	Activated charcoal	Nucellus	0,00±0,00 <b>b</b>	0,50±0,50 <b>a</b>	0,50±0,50 <b>a</b>	0,00±0,00 <b>a</b>
Testa			1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
Cotyledon			1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
Mean			0,50±0,28 <b>A</b>	0,25±0,25 <b>A</b>	0,25±0,25 <b>A</b>	0,00±0,00 <b>A</b>	0,00±0,00 <b>A</b>
PVP		Nucellus	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
		Testa	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
		Cotyledon	0,20±0,20 <b>a</b>	0,00±0,00 <b>a</b>	0,40±0,24 <b>a</b>	0,00±0,00 <b>a</b>	0,40±0,24 <b>a</b>
		Mean	0,55±0,17 <b>A</b>	0,00±0,00 <b>A</b>	0,22±0,14 <b>A</b>	0,00±0,00 <b>A</b>	0,22±0,14 <b>A</b>
Mean			0,53±0,00 <b>Y</b>	0,07±0,00 <b>X</b>	0,23±0,00 <b>X,Y</b>	0,00±0,00 <b>X</b>	0,15±0,00 <b>X</b>
BAP 0,5mg/l and 2,4-D 0,8mg/l		Activated charcoal	Nucellus	1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>
	Testa		1,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>	0,00±0,00 <b>a</b>

(C4)	Cotyledon	1,00±0,00a	0,00±0,00 a	0,00±0,00a	0,00±0,00a	0,00±0,00a
	Mean	1,00±0,00A	0,00±0,00 A	0,00±0,00A	0,00±0,00A	0,00±0,00A
PVP	Nucellus	0,00±0,00a	0,00±0,00 a	1,00±0,00a	0,00±0,00a	0,00±0,00a
	Testa	0,00±0,00a	0,00±0,00 a	0,00±0,00a	0,00±0,00a	0,00±0,00a
	Cotyledon	0,33±0,33a	0,00±0,00 a	0,66±0,33a	0,00±0,00a	0,00±0,00a
	Mean	0,25±0,25A	0,00±0,00 A	0,75±0,25A	0,00±0,00A	0,00±0,00A
	Mean	0,62±0,00X,Y	0,00±0,00 X	0,37±0,00X,Y	0,00±0,00X	0,00±0,00X

142 *Within column, means followed by letters of same characters are not significantly different ( $P > 0.05$ ) according to the test for the Least*  
143 *Significant Difference.*

144  
145 Table 4 presents the results of the analysis of variance after 90 days of initial culture of the explants. The analysis of the  
146 table showed that there was a highly significant difference ( $P < 0.05$  to  $p < 0.001$ ) in the effect of growth regulators and  
147 antioxidants on calli production. There was also a significant effect of growth regulators on the achievement of low calli.  
148 The interaction between growth regulators and antioxidants was significant in relation to calli production. Furthermore, it  
149 was observed that the formation of moderately deep, and highly deep callus was not significantly different ( $p > 0.05$ )  
150 between the media and antioxidants. Table 5 shows the effect of growth regulators and antioxidants on callus formation.  
151 The smallest significant difference test revealed that PVP significantly ( $p < 0.05$ ) favoured a large number of calluses  
152 (77%) in contrast to activated carbon (9%) on the medium with BAP 0.25mg/l and 2,4-D 0.8mg/l (C3). Similarly, C3  
153 medium with the combination of BAP 0.25mg/l and 0.8mg/l 2,4-D on the one hand and C4 medium with BAP 0.5mg/l and  
154 2,4-D 0.8mg/l on the other hand appeared to be the best media for obtaining callus with 58% and 45% of callus formed  
155 respectively. In most cases, the combination of 0.25 mg/l BAP and 0.8 mg/l 2,4D (C3) in the presence of PVP was  
156 significantly ( $p < 0.05$ ) better for callus formation.

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**Table 4** : F-values and level of significance from two-way Analysis of Variance (ANOVA) of callus formation regarding plant growth regulators (PGR) and antioxidant after 90 days

Source of variation	Degree of freedom	F-values				
		Callus formation after 90 days				
		No callus	slight callus	moderate callus	Profuse callus	highly profuse callus
<b>PGR</b>	4	5.58 <sup>***</sup>	2.78 <sup>*</sup>	0.80 <sup>ns</sup>	0.75 <sup>ns</sup>	1.85 <sup>ns</sup>
<b>Antioxidants</b>	1	6.43 <sup>*</sup>	0.95 <sup>ns</sup>	0.38 <sup>ns</sup>	0.89 <sup>ns</sup>	1.11 <sup>ns</sup>
<b>PGR* Antioxidants</b>	4	3.43 <sup>*</sup>	1.14 <sup>ns</sup>	0.80 <sup>ns</sup>	0.32 <sup>ns</sup>	1.85 <sup>ns</sup>

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ns:  $P > 0.05$  \* :  $P < 0.05$ ; \*\*\*:  $P < 0.001$

**Table 5** : Effect of growth regulators, antioxidant and explant on callus formation after 90 days (mean  $\pm$  standard error)

Media	Antioxidants	Callus formation				
		No callus	slight callus	moderate callus	Profuse callus	highly profuse callus
BAP 0mg/l and 2,4-D 0,8mg/l (C0)	Activated charcoal	1,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a
	PVP	1,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a
	Mean	1,00 $\pm$ 0,00A	0,00 $\pm$ 0,00B	0,00 $\pm$ 0,00A	0,00 $\pm$ 0,00A	0,00 $\pm$ 0,00B
BAP 0,25mg/l and 2,4-D 0mg/l (C1)	Activated charcoal	1,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a
	PVP	1,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a
	Mean	1,00 $\pm$ 0,00A	0,00 $\pm$ 0,00B	0,00 $\pm$ 0,00A	0,00 $\pm$ 0,00A	0,00 $\pm$ 0,00B
BAP 0,5mg/l and 2,4-D 0mg/l (C2)	Activated charcoal	1,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a
	PVP	0,92 $\pm$ 0,07a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,07 $\pm$ 0,07a	0,00 $\pm$ 0,00a
	Mean	0,94 $\pm$ 0,05A	0,00 $\pm$ 0,00B	0,00 $\pm$ 0,00A	0,05 $\pm$ 0,05A	0,00 $\pm$ 0,00B
BAP 0,25mg/l and 2,4-D 0,8mg/l (C3)	Activated charcoal	0,91 $\pm$ 0,08a	0,08 $\pm$ 0,08b	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a
	PVP	0,23 $\pm$ 0,07b	0,40 $\pm$ 0,09a	0,16 $\pm$ 0,06a	0,20 $\pm$ 0,07a	0,00 $\pm$ 0,00a
	Mean	0,42 $\pm$ 0,07B	0,30 $\pm$ 0,07A	0,11 $\pm$ 0,05A	0,14 $\pm$ 0,05A	0,00 $\pm$ 0,00B
BAP 0,5mg/l and 2,4-D	Activated charcoal	0,88 $\pm$ 0,11a	0,00 $\pm$ 0,00a	0,00 $\pm$ 0,00a	0,11 $\pm$ 0,11a	0,00 $\pm$ 0,00a

0,8mg/l (C4)	PVP	0,50±0,13 <sup>a</sup>	0,07±0,07 <sup>a</sup>	0,00±0,00 <sup>a</sup>	0,21±0,11 <sup>a</sup>	0,21±0,11 <sup>a</sup>
	Mean	0,65±0,10 <sup>B</sup>	0,04±0,04 <sup>B</sup>	0,00±0,00 <sup>A</sup>	0,17±0,08 <sup>A</sup>	0,13±0,07 <sup>A</sup>

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172 *Within column, means followed by letters of same characters are not significantly different (P > 0.05) according to the test for the Least*  
 173 *Significant Difference.*

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### 3.2.1. Effect of the concentration of growth regulators on callus formation

176 Table 6 shows the effect of concentration of growth regulators and type of antioxidant on callus formation. It **was noted**  
 177 that the existence of both growth regulators in the medium is important for callogenesis in cashew. The C3 medium: 0.25  
 178 mg/l BAP and 0.8 mg/l 2,4-D **seemed** to be the most important regulators of callogenesis.

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**Table 6 :** Effect of growth regulators on callus formation after 90 days of culture (mean ± standard errors)

Amount of callus formed	BAP 0mg/l et 2,4-D0.8mg/l (C0)	BAP 0.25 mg/l et 2,4-D0mg/l (C1)	BAP 0.5mg/l et 2,4-D0mg/l (C2)	BAP 0.25mg/l et 2,4-D0.8mg/l (C3)	BAP 0.5mg/l et 2,4-D0.8mg/l (C4)
No callus	1.00±0.00 <sup>a</sup>	1.00±0.00 <sup>a</sup>	0.94±0.05 <sup>a</sup>	0.42±0.07 <sup>b</sup>	0.65±0.10 <sup>b</sup>
Slight callus	0.00±0.00 <sup>b</sup>	0.00±0.00 <sup>b</sup>	0.00±0.00 <sup>a</sup>	0.30±0.07 <sup>a</sup>	0.04±0.04 <sup>b</sup>
Moderate callus	0.00±0.00 <sup>a</sup>	0.00±0.00 <sup>a</sup>	0.00±0.00 <sup>a</sup>	0.11±0.05 <sup>a</sup>	0.00±0.00 <sup>a</sup>
Profuse callus	0.00±0.00 <sup>a</sup>	0.00±0.00 <sup>a</sup>	0.05±0.05 <sup>a</sup>	0.14±0.05 <sup>a</sup>	0.17±0.08 <sup>a</sup>
highly profuse callus	0.00±0.00 <sup>b</sup>	0.00±0.00 <sup>b</sup>	0.00±0.00 <sup>b</sup>	0.00±0.00 <sup>b</sup>	0.13±0.07 <sup>a</sup>

181 *The means followed by the same alphabetical letter of the same character and for the same factor are not significantly different (P>*  
 182 *0.05) according to the test for the Least Significant Difference*

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### 3.2.2. Combined effect of 2,4-D and antioxidants polyvinylpyrrolidone (pvp) and activated charcoal on the formation and survival of callus

185

186 2,4-D was able to induce callus from cotyledons on both activated charcoal and polyvinylpyrrolidone. On the activated  
 187 charcoal medium, the nucellus also formed **ed** calli. However, callus formation **was** observed 28 days after the initial culture  
 188 and the calluses did not last over time. Activated charcoal appeared **red** to be the antioxidant that significantly (p <0.05)  
 189 **favoured** callus formation on the medium with only 2,4-D at 0.8 mg/l (C0).

190

191 **Table 7** : Combined effect of 2,4-D and antioxidants polyvinylpyrrolidone (pvp) and activated charcoal on callus formation  
 192 and survival (mean ± standard errors)  
 193

<i>Explants</i>	<i>Antioxidants</i>	<i>28 days</i>	<i>90 days</i>
Nucellus	Activated charcoal	1.20±0.32a	0.00±0.00a
testa	Activated charcoal	0.00±0.32b	0.00±0.00a
Cotyledon	Activated charcoal	0.50±0.36a	0.00±0.00a
Nucellus	polyvinylpyrrolidone	0.00±0.32b	0.00±0.00a
testa	polyvinylpyrrolidone	0.00±0.32b	0.00±0.00a
Cotyledon	polyvinylpyrrolidone	1.00±0.36a	0.00±0.00a

194 *The means followed by the same alphabetical letter of the same character and for the same factor are not significantly different (P>*  
 195 *0.05) according to the test for the Least Significant Difference*  
 196

197 **3.2.3. Effect of BAP at 0.25 mg/l on callus formation and survival**

198 Only the cotyledons yielded calli with both activated charcoal and polyvinylpyrrolidone with BAP at 0.25 mg/l. These calli  
 199 appeared after 28 days of initial culture but did not survive.

200 **Table 8**: Effect of BAP at 0.25 mg/l and antioxidants polyvinylpyrrolidone (pvp) and activated charcoal on callus formation  
 201 and survival (mean ± standard errors)  
 202

<i>Explants</i>	<i>Antioxidants</i>	<i>Callus after 28 days</i>	<i>Callus after 90 days</i>
Cotyledon	polyvinylpyrrolidone	0.800±0.283a	0.00±0.00 a
Nucellus	polyvinylpyrrolidone	0.000±0.00a	0.00±0.00 a
Testa	polyvinylpyrrolidone	0.000±0.00a	0.00±0.00 a
Cotyledon	Activated charcoal	0.800±0.00a	0.00±0.00 a
Nucellus	Activated charcoal	0.000±0.00a	0.00±0.00 a
Testa	Activated charcoal	0.000±0.00a	0.00±0.00 a

203 *The means followed by the same alphabetical letter of the same character and for the same factor are not significantly different (P>*  
 204 *0.05) according to the test for the Least Significant Difference*  
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206 **3.2.4. Combined effect of BAP at 0.5mg/l and antioxidants (polyvinylpyrrolidone and activated charcoal) on the**  
 207 **formation and survival of callus from various explants**

208 BAP at 0.5 mg/l produced callus from nucellus and cotyledons but only with polyvinylpyrrolidone as antioxidant (Table 9).  
 209 The calli that were produced from the cotyledons lasted up to 90 days, but the rate had halved. On the other hand, with  
 210 activated charcoal, no callus production was noted for any explant.

211 **Table 9**: Effect of BAP at 0.5 mg/l and antioxidants polyvinylpyrrolidone (pvp) and activated charcoal on callus formation  
 212 and survival (mean ± standard errors).  
 213

<i>Explants</i>	<i>Antioxidants</i>	<i>Callus (28 days)</i>	<i>Callus (90 days)</i>
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Cotyledon	polyvinylpyrrolidone	1.20±0.36a	0.60 ± 0.24a
Nucellus	polyvinylpyrrolidone	0.40±0.36a	0.00± 0.00a
Testa	polyvinylpyrrolidone	0.00±0.00b	0.00± 0.00a
Cotyledon	Activated charcoal	0.00 ±0.00b	0.00± 0.00a
Nucellus	Activated charcoal	0.00±0.00b	0.00± 0.00a
Testa	Activated charcoal	0.00±0.00b	0.00± 0.00a

The means followed by the same alphabetical letter of the same character and for the same factor are not significantly different ( $P > 0.05$ ) according to the test for the Least Significant Difference

### 3.2.5. Combined effect of BAP at 0.25mg/l; 2,4-D at 0.8 mg/l and antioxidants polyvinylpyrrolidone and activated charcoal on the formation and survival of callus from various explants

The analysis in Table 10 showed that the combination of BAP at 0.25 mg/l and 2,4-D at 0.8 mg/l produced callus that survived even beyond 90 days. Cotyledons in the presence of polyvinylpyrrolidone produced 2.40±0.29 callus that survived even beyond 90 days after the initial culture. Whereas with activated charcoal, callus formation did not occur after 28 days but we noticed it after 90 days. Nucellus, on the other hand, gave callus in the presence of both antioxidants with a high rate in the presence of activated charcoal (0.60±0.29). Moreover, these calli survived even beyond 90 days.

**Table 10:** Combined effect of BAP at 0.25mg/l, 2,4-D and antioxidants polyvinylpyrrolidone (pvp) and activated charcoal on callus formation and survival (mean ± standard errors).

Explants	Antioxidants	Callus (28 days)	Callus (90 days)
Cotyledon	polyvinylpyrrolidone	2.40±0.29a	2.40±0.29a
Nucellus	polyvinylpyrrolidone	0.20±0.00b	0.20±0.00a
Testa	polyvinylpyrrolidone	0.00±0.00b	0.00±0.00a
Cotyledon	Activated charcoal	0.00±0.00b	0.40±0.29a
Nucellus	Activated charcoal	0.60±0.29b	0.60±0.29a
Testa	Activated charcoal	0.00±0.00b	0.00±0.00a

The means followed by the same alphabetical letter of the same character and for the same factor are not significantly different ( $P > 0.05$ ) according to the test for the Least Significant Difference

### 3.2.6. Combined effect of BAP at 0.5mg/l, 2,4-D and antioxidant on the formation and survival of callus

Table 11 showed that the presence of 0.5 mg/l BAP, 0.8 mg/l 2,4-D and 2.5 g/l polyvinylpyrrolidone increased the amount of callus with cotyledons. The combined presence of BAP and 2,4-D growth regulators increased the amount of callus formed. On the other hand, with activated charcoal, no callus production was noted for any explant except for nucellus which produced 0.20±0.00 callus after 90 days.

235 **Table 11:** Combined effect of BAP at 0.5mg/l, 2,4-D; polyvinylpyrrolidone (pvp) and activated charcoal on callus formation  
 236 and survival (mean  $\pm$  standard errors).  
 237

Explants	Antioxidants	Callus days)	(28 Callus days)	(90 days)
Cotyledon	polyvinylpyrrolidone	0.80 $\pm$ 0.25a	3.00 $\pm$ 0.23a	
Nucellus	polyvinylpyrrolidone	0.40 $\pm$ 0.25a	0.00 $\pm$ 0.00b	
Testa	polyvinylpyrrolidone	0.00 $\pm$ 0.00b	0.00 $\pm$ 0.00b	
Cotyledon	Activated charcoal	0.00 $\pm$ 0.00b	0.00 $\pm$ 0.00b	
Nucellus	Activated charcoal	0.00 $\pm$ 0.00b	0.20 $\pm$ 0.00b	
Testa	Activated charcoal	0.00 $\pm$ 0.00b	0.00 $\pm$ 0.00b	

238 *The means followed by the same alphabetical letter of the same character and for the same factor are not significantly*  
 239 *different (P> 0.05) according to the test for the Least Significant Difference*  
 240

#### 241 4. Discussion

242 The results of this study showed that nucellus and cotyledons were the best explants for somatic embryogenesis in  
 243 cashew. Cotyledons produced more calli than nucellus. However, the calli of nucellus were embryogenic, while those of  
 244 cotyledons were not all embryogenic. The potential of nucellus as an explant for in vitro studies of woody plants has been  
 245 highlighted by Rangaswamy [14]. Nucellus tissue is of maternal origin, so the desirable traits of the parent are retained in  
 246 the progeny derived from this tissue. Moreover, due to the lack of vascular connection with the parent plant, the nucellar is  
 247 considered pathogen-free, and thus plants with nucellar origin would be disease-free. However, it has been observed that  
 248 the hormone level of the whole grain poorly reflects the levels in the immature embryos since the endosperm constitutes  
 249 the majority of the dry matter of the grain and, as demonstrated by Jiménez and Bangerth [15,16], the hormone levels in  
 250 the endosperm can vary considerably from those in the immature embryos. Some authors believe that the level of  
 251 endogenous phytohormones is very low in immature nut explants [17], which would be related to the days of incubation  
 252 needed to trigger callogenesis. Therefore, in sum, callus formation with nucellus can be observed after 90 days of initial  
 253 culture. The expression of morphogenetic competence *in vitro* is complex and influenced by physiological and genetic  
 254 factors. Thus, the effect of explant type and concentration of BAP and 2,4-D was significant on callus formation, in line  
 255 with other work on *Triticum durum* (durum wheat). Work on mango embryogenesis showed that the combination of 1 mg/l  
 256 2,4-D and 0.25 mg/l BAP was the best for callus formation [8]. It has been reported that culturing explants in 2,4-D  
 257 containing medium, the classical induction treatment for many species, increases the levels of endogenous auxin in the  
 258 explants [18]. It has also been observed that polar transport of auxin is essential for the establishment of bilateral  
 259 symmetry during embryogenesis in dicot somatic plants [19]. Once the stimulus for further development of somatic  
 260 embryos has been given (i.e., by reducing or removing 2,4-D from the culture medium), these levels must be reduced to

261 allow the establishment of the auxin polar gradient. If the levels are extremely low or high, or if they do not decrease after  
262 the induction treatment, the gradient cannot be formed, and somatic embryogenesis cannot be expressed. In all species  
263 reported in the literature where embryogenic and non-embryogenic callus lines could be obtained in the presence of 2,4-  
264 D, it was observed that embryogenic callus contained higher levels of free IAA than non-embryogenic callus. These higher  
265 levels may be important in the establishment of polar auxin transport, which is postulated to be critical in the development  
266 of somatic embryogenesis. In Arabidopsis, high auxin levels have been reported in cotyledon primordia and cotyledons  
267 [20], consistent with the embryogenic competence displayed by the cotyledonary parts of zygotic embryos [21,22].  
268 Sucrose concentration was found to directly influence the uptake of BAP by sunflower explants, and soon afterwards, the  
269 levels of endogenous auxins and cytokinins were altered, triggering an organogenic or embryogenic response [23]. The  
270 majority of woody plants and some herbaceous species grown in vitro show a browning of the medium. If this browning  
271 was extreme, the explants would turn brown to black, necrose and eventually die [24]. In this study, PVP was found to be  
272 almost effective in controlling browning, especially in the cotyledons. This could be due to the specificity of these  
273 chemicals for certain plants and species. The specificity of PVP in controlling browning has also been reported by Vaugh  
274 and Duke [25]. The addition of activated charcoal to liquid and semi-solid media is a recognised practice and its influence  
275 on growth and development can be attributed mainly to the adsorption of inhibitory substances in the culture medium [26-  
276 30], drastically decreasing phenolic oxidation or accumulation of brown exudate [31-33], changing the pH of the medium  
277 to an optimal level for morphogenesis [34] and establishing a darkened environment in the medium and thus simulating  
278 soil conditions [35].

## 279 **5. Conclusion**

280 This study shows that for obtaining viable and embryogenic callus, the combination of BAP at 0.25 mg/L and 0.8 mg/L of  
281 2,4-D is the best and this in the presence of PVP as an antioxidant. The nucellus respond better in the presence of  
282 activated charcoal. A protocol of pro-embryonic calli formation from the nucellus, and cotyledons has been established.  
283 This protocol has as its basal medium: B5 macroelements, MS microelements, vitamins MS and 400mg/l of L-Glutamine,  
284 500 mg/l of casein hydrolysate, 2.5g/L of Polyvinylpyrrolidone (PVP), 6% of Sucrose. The BAP and 2,4-D growth  
285 regulators are associated alone or in combination. As for the type of explant, the testa does not significantly induce the  
286 formation ( $p>0.05$ ) of callus compared to nucellus (12.06%) and cotyledon (20.7%) that induce callus.

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300 **COMPETING INTERESTS**

301 The authors declare that they have no conflict of interest regarding the manuscript. All authors have read and accepted  
302 the manuscript for publication.  
303  
304  
305

306 **AUTHORS' CONTRIBUTIONS**

307 BSAA, BTB, SSH have conceptualized the topic and investigated the work while BSAA, GHTC, BTB have written first  
308 original draft. CA and JD have complementally supervised the work and JAH have reviewed and edited the manuscript for  
309 publication. All authors read and approved the final manuscript.  
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392

## 393 **DEFINITIONS, ACRONYMS, ABBREVIATIONS**

394 AC: Activated Charcoal

395 ANOVA : Analysis of Variance

396 BAP : 6-benzylaminopurine

397 B5 : Gamborg medium

398 °C: Degree Celsius

399 2,4-D: 2,4-Dichlorophenoxyacetic acid

400 g/l: gramme per litre

401 IAA: Indole-3-Acetic Acid

402 LSD: Least Significant Difference

403 mg/l: milligram per litre

404 mm: millimetre

405 MS: Murashige and Skoog, 1962

406 %: Percentage

407 PEC: Pro-Embryonic Calli

408 PGR: Plant Growth Regulators

409 pH: Potential of Hydrogen

410 PVP: Polyvinylpyrrolidone

411 SAS: Statistical Analysis System

412