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PHYSICAL COMPATIBILITY OF AGROCHEMICAL TANK MIXTURES COMMONLY USED IN PIGEONPEA (*Cajanus cajan* (L.) Millsp.)

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ABSTRACT

Tank mixing of insecticides, fungicides and fertilizers is a common practice in pigeonpea cultivation to reduce labour, time and application costs. However, information on the compatibility of commonly used agrochemicals is limited. The present study was conducted during 2011–12 at the Regional Agricultural Research Station (RARS), Warangal, India to evaluate the physical compatibility of 25 agrochemicals comprising 20 insecticides (including botanical insecticides), two fungicides and urea, commonly used in pigeonpea crop. The compatibility of the combinations was tested without adding adjuvants. A total of 300 possible combinations were tested under laboratory conditions using the jar test method at their respective recommended doses. Compatibility was assessed based on the occurrence of precipitation, flocculation, layer separation, gelatinization, viscosity changes and exothermic reactions. Among the 300 combinations evaluated, only three combinations *viz.,* NSKE + thiodicarb, NSKE + mancozeb and NSKE + copper oxychloride showed clear evidence of incompatibility due to persistent precipitate formation. Several other combinations exhibited temporary precipitate or supernatant formation, which disappeared or dissolved upon agitation, indicating the need for continuous stirring during field application. Exothermic reactions were not observed in any treatment. The study demonstrated that the majority of commonly used agrochemical combinations are physically compatible for tank mixing. However, further studies on phytotoxicity, biological efficacy and field performance in pigeonpea are required before recommending these mixtures for large-scale use.

Keywords: Agrochemicals, Compatibility, Insecticides, Phytotoxicity, Pigeonpea, Tank mix combinations.

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important legume crop cultivated in semi-arid tropical and subtropical farming systems, providing high-quality vegetable protein, animal feed, and firewood. India accounts for nearly 77% of the global pigeonpea area and 73% of production (FAO, 2024). In India, pigeonpea is predominantly cultivated during the *Kharif* season for both green vegetable and dry seed purposes, either as a sole crop or as an intercrop with maize, castor, sorghum, greengram, soybean and cotton. Owing to the predominantly vegetarian dietary habits of the Indian population, pigeonpea serves as a major source of dietary protein (Mula and Saxena, 2010).

Despite its importance, pigeonpea productivity is constrained by several biotic and abiotic factors. Among the biotic stresses, insect pests and diseases are the major yield-limiting factors. Several insect pests infest the crop at different growth stages, among which the pod borers such as gram pod borer (*Helicoverpa armigera*), spotted pod borer (*Maruca vitrata*), and pod fly (*Melanagromyza obtusa*) cause significant yield losses. More than 50 diseases caused by fungi, bacteria, viruses and nematodes have been reported in pigeonpea. Among them, *Fusarium* wilt (*Fusarium udum*), sterility mosaic disease (SMD) caused by Pigeonpea sterility mosaic virus (PPSMV), and *Phytophthora* blight (*Phytophthora drechsleri* f. sp. *cajani*) are considered major diseases causing severe economic losses.

Besides insect pests and diseases, flower and pod drop is another important physiological constraint limiting pigeonpea productivity. Agronomic interventions such as foliar application of nutrients and growth regulators during critical growth stages have been reported to reduce flower drop and improve yield. Ganapathy *et al*. (2008) reported that foliar application of nutrients and growth regulators at pre-flowering and flowering stages reduced flower drop in greengram. Similarly, foliar application of macronutrients during flower initiation enhanced pigeonpea productivity under rainfed conditions (Fanish *et al.,* 2022). Jayabal *et al*. (1999) also observed that foliar application of macro and micronutrients at critical crop stages improved nutrient absorption and translocation to developing pods, resulting in a higher number of filled pods.

Management of insect pests and diseases in pigeonpea largely depends on the application of insecticides and fungicides, often with limited integration

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of non-chemical pest management strategies. Synthetic insecticides continue to play a major role in modern pigeonpea pest management programmes and several compounds provide effective control of major insect pests under field conditions. During simultaneous occurrence of insect pests and diseases, farmers frequently adopt tank mixing of insecticides and fungicides to save time, labour, and operational costs. In some cases, two insecticides are mixed together to manage multiple pest species or to obtain broader-spectrum control. Farmers also commonly mix fertilizers such as urea with pesticides in spray solutions.

However, preparation of tank mixtures requires adequate knowledge regarding the compatibility of the components involved. Using incompatible mixtures may result in overdosing due to combined concentrations of diluents, leading to field-level problems such as phytotoxicity (Rodriguez *et al*., 2002). Tank mixtures may alter the absorption, translocation, metabolism and toxicity of pesticides within plants, thereby influencing their biological efficacy. Interactions among agrochemicals may be additive, synergistic, antagonistic, or potentiating in nature. Chemical incompatibility may also occur due to deactivation or degradation of active ingredients. Such incompatibilities can result in reduced pest control, increased injury to non-target plants, phytotoxicity and other adverse effects (Regupathy and Ramasubramanian, 2004). Physical incompatibility is generally observed as precipitation or improper mixing of spray solutions, whereas chemical incompatibility may involve breakdown or undesirable chemical reactions among components, resulting in partial or complete failure of the mixture.

Although tank mixtures are economical and convenient for managing multiple pests, diseases and nutrient deficiencies simultaneously, information on the compatibility of commonly used insecticides, fungicides and nutrients in pigeonpea is limited. Therefore, studies on compatibility are essential to identify safe and effective agrochemical combinations that do not adversely affect crop health or pesticide efficacy. Keeping this in view, the present investigation was undertaken to evaluate the physical compatibility of insecticides, fungicides and urea in all possible tank mixtures commonly used in pigeonpea to identify incompatible combinations.

MATERIAL AND METHODS

The present experiment was conducted at Regional Agricultural Research Station, Warangal, Acharya N.G. Ranga Agricultural University, Andhra Pradesh (now under Professor Jayashankar Telangana State Agricultural University, Telangana), India. Twenty five agrochemicals (17 chemical insecticides, 2 neem based insecticides, 2 fungicides and urea) commonly used in pigeonpea ecosystem (Table 1) were tested under laboratory conditions during 2011-12, for their physical compatibility.

Physical compatibility of the 25 test agro chemicals in all the possible 300 combinations, at their respective recommended doses, was tested using Jar test method. Adjuvant was not used while testing for compatibility. Freshly prepared distilled water was used for the study and the experiment was conducted in lab under room temperature conditions. A clear glass jar with lid of 250 ml capacity was taken, in which 100 ml of water was taken. The test chemicals were added to the jar depending on the recommended dilution factor/ dose of the chemical. Order of mixing of the chemicals for compatibility was WP, WG, SC, SP, SL and EC. The mixture in the jars was stirred gently after each addition by closing the jars tightly, by turning the jars 10 times. Later, the jars were kept aside for 15 minutes. The outer surface of the jars was examined for any increase in temperature indicating a possible exothermic reaction. If so, the mixture may be undergoing a chemical reaction and the pesticide combination was considered as incompatible.

The jars were kept aside for another 15 minutes (total 30 minutes) and checked for incompatible phenomena like non homogeneity, layer suspension, precipitation, change in viscosity, aggregation, flocculation, clump formation and gelatinization of the mixture, which cause clogging of nozzle and uneven spray distribution in the field. If no such phenomena are seen, the combination was considered as 'compatible'.

Even if incompatible phenomena were observed within half an hour after mixing, the mixture was turned upside down 3 times. If the phenomena disappeared, such combination also was considered as 'compatible' and can be used, provided if it is shaken well during application in the field.

Table 1. Agrochemicals tested in combinations for studying physical compatibility

S. No.	Test Agro- chemical	Recommended Dose (g/ml L^{-1})
Insecticides		
1	Endosulfan 35 EC	2.0
2	Monocrotophos 36 SL	1.6
3	Quinalphos 25 EC	2.0
4	Chlorpyriphos 20 EC	2.5
5	Acephate 75 SP	1.5
6	Dimethoate 30 EC	2.0
7	Spinosad 45 SC	0.3
8	Indoxacarb 14.5 SC	1.0
9	Acetamiprid 20 SP	0.2
10	Fipronil 5 SC	2.0
11	Flubendiamide 39.35 SC	0.2
12	Dichlorvos 76 EC	1.0
13	Novaluron 10 EC	1.0
14	Thiodicarb 75 WP	1.5
15	Profenophos 50 EC	2.0
16	Imidacloprid 200 SL	0.25
17	Rynaxypyr 20 SC	0.3
18	Emamectin benzoate 5 SG	0.4
19	Thiamethoxam 25 WG	0.25
20	Thiacloprid 21.7 SC	1.0
21	NSKE 5%	50.0
22	Azadirachtin 1500 ppm (0.15 EC)	5.0
Fungicides		
23	Mancozeb 75 WP	2.5
24	Copper oxychloride 50WP	3.0
Fertilizer		
25	Urea	20.0

RESULTS AND DISCUSSION

The physical compatibility of 25 agrochemicals commonly used in the pigeonpea production system was evaluated under laboratory conditions by testing all possible 300 binary tank-mixture combinations at their recommended field doses using the jar test method. The study revealed that the vast majority of the agrochemical combinations were physically compatible, indicating that they can be mixed safely without causing immediate physical instability (Table 2).

Among the 300 combinations evaluated, only three combinations, namely NSKE + thiodicarb, NSKE + mancozeb, and NSKE + copper oxychloride, exhibited clear physical incompatibility. In these mixtures (without compatibility adjuvant), visible precipitation was developed within five minutes of mixing (Figures 1 and 2), indicating poor suspension stability. Such precipitation can hinder uniform spray application by causing sedimentation and nozzle blockage, thereby reducing field efficiency. The incompatibility is likely to be associated with interactions between the suspended botanical constituents of NSKE and the insoluble particles present in wettable powder formulations such as thiodicarb, mancozeb and copper oxychloride. Addition of a detergent considerably reduced the extent of precipitation, suggesting that improved dispersion of suspended particles enhanced mixture stability. Nevertheless, these combinations should not be

Table 2. Physical compatibility of combinations of different agrochemicals (without adjuvant) used in pigeonpea ecosystem at RARS, Warangal

Test chemical	Endosulfan 35 EC	Monocrotophos 36	Quinalphos 25 EC	Chlorpyriphos 20 EC	Acephate 75 SP	Dimethoate 30 EC	Spinosad 45 SC	Indoxacarb 14.5 SC	Acetamiprid 20 SP	Fipronil 5 SC	Flubendiamide 39.35 SC	Dichlorvos 76 EC	Novaluron 10 EC	Thiodicarb 75 WP	Profenophos 50 EC	Imidacloprid 200 SL	Rynaxypyr 20 SC	Emamectin benzoate 5 SG	Thiamethoxam 25 WG	Thiacloprid 21.7 SC	NSKE 5%	Azadirachtin 1500 ppm (0.15EC)	Mancozeb 75 WP	Copper oxy chloride 50 WP	Urea
Endosulfan 35 EC	-																								
Monocrotophos 36 SL	√	-																							
Quinalphos 25 EC	√	√	-																						
Chlorpyriphos 20 EC	√	√	√	-																					
Acephate 75 SP	√	√	√	√	-																				
Dimethoate 30 EC	√	√	√	√	√	-																			
Spinosad 45 SC	√	√	√	√	√	√	-																		
Indoxacarb 14.5 SC	√	√	√	√	√	√	√	-																	
Acetamiprid 20 SP	√	√	√	√	√	√	√	√	-																
Fipronil 5 SC	√	√	√	√	√	√	√	√	√	-															
Flubendiamide 39.35 SC	√	√	√	√	√	√	√	√	√	√	-														
Dichlorvos 76 EC	√	√	√	√	√	√	√	√	√	√	√	-													
Novaluron 10 EC	√	√	√	√	√	√	√	√	√	√	√	√	-												
Thiodicarb 75 WP	√	√	√	√	√	√	√	√	√	√	√	√	√	-											
Profenophos 50 EC	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-										
Imidacloprid 200 SL	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-									
Rynaxypyr 20 SC	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-								
Emamectin benzoate 5 SG	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-							
Thiamethoxam 25 WG	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-						
Thiacloprid 21.7 SC	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-					
NSKE 5%	√	√	√	√	√	√	√	√	√	√	√	√	√	x	√	√	√	√	√	√	-				
Azadirachtin 1500 ppm (0.15EC)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-			
Mancozeb 75 WP	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	x	√	-		
Copper oxychloride 50WP	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	x	√	√	-	
Urea	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	-

Physically compatible x- Incompatible

Table 3. Temporary incompatible parameters observed in combinations of different agrochemicals (without adjuvant) used in pigeonpea

Test chemical	Endosulfan 35 EC	Monocrotophos 36 SL	Quinalphos 25 EC	Chlorpyriphos 20 EC	Acephate 75 SP	Dimethoate 30 EC	Spinosad 45 SC	Indoxacarb 14.5 SC	Acetamiprid 20 SP	Fipronil 5 SC	Flubendiamide 39.35 SC	Dichlorvos 76 EC	Novaluron 10 EC	Thiodicarb 75 WP	Profenophos 50 EC	Imidacloprid 200 SL	Rynaxypyr 20 SC	Emamectin benzoate 5 SG	Thiamethoxam 25 WG	Thiacloprid 21.7 SC	NSKE 5%	Azadirachtin 1500 ppm (0.15EC)	Mancozeb 75 WP	Copper oxy chloride 50 WP	Urea
Endosulfan 35 EC																									
Monocrotophos 36 SL																									
Quinalphos 25 EC																									
Chlorpyriphos 20 EC																									
Acephate 75 SP	#		$	@																					
Dimethoate 30 EC	#				@																				
Spinosad 45 SC																									
Indoxacarb 14.5 SC	#		$			#																			
Acetamiprid 20 SP																									
Fipronil 5 SC	#				@	@																			
Flubendiamide 39.35 SC																									
Dichlorvos 76 EC																									
Novaluron 10 EC						@				@															
Thiodicarb 75 WP			$			#				@	#	#	#@												
Profenophos 50 EC					#				#					#											
Imidacloprid 200 SL			$												#										
Rynaxypyr 20 SC										@					#										
Emamectin benzoate 5 SG																									
Thiamethoxam 25 WG										@				#	#										
Thiacloprid 21.7 SC										@					#				#						
NSKE 5%		*			*	*	*	*	*	*	*	*	*		*	*	*		*	*					
Azadirachtin 1500 ppm (0.15 EC)															#										
Mancozeb 75 WP	#		#			#	#	#	#	#@	#	#	#	#	#	#	#		#			#			
Copper oxychloride 50WP	#	#	#		#	#	#	#	#	#@	#	#	#	#	#	#	#			#		#	#		
Urea										@					#										

*NSKE precipitates after 30 min # Chemical/inert matter precipitates after 30 min. @ White powdery supernatant $ Blue supernatant after 5-10 min

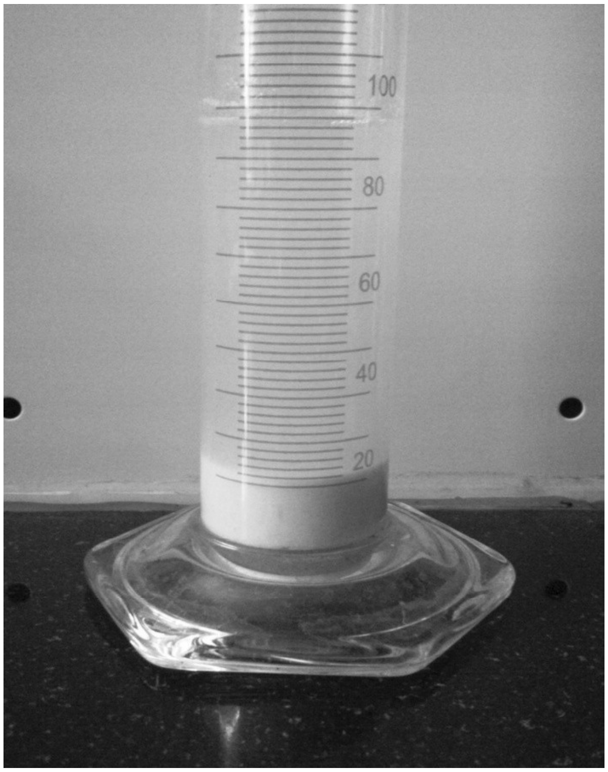

Fig. 1. Precipitation in combination of Mancozeb + NSKE

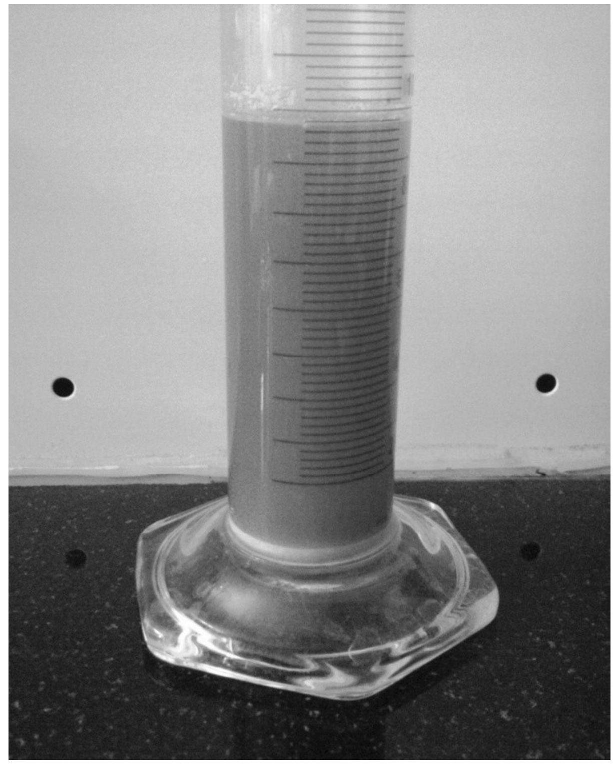

Fig. 2. Precipitation in combination of Copper oxy chloride + NSKE

recommended for direct tank mixing without prior compatibility testing under field conditions.

Apart from these incompatible combinations, several tank mixtures exhibited temporary physical instability after standing for approximately 30 minutes (Table 3). Precipitation of inert matter was observed in mixtures involving NSKE with monocrotophos, acephate, dimethoate, spinosad, indoxacarb, acetamiprid, fipronil, flubendiamide, dichlorvos, novaluron, profenophos, imidacloprid, rynaxypyr, thiamethoxam and thiacloprid. Similar temporary precipitation was also recorded in numerous combinations involving mancozeb and copper oxychloride with several insecticides. Endosulfan, dimethoate, profenophos and thiodicarb also produced temporary precipitates when mixed with selected agrochemicals.

Formation of a white powdery supernatant was observed in combinations of acephate with chlorpyriphos; dimethoate with fipronil and novaluron; and several combinations involving fipronil with dichlorvos, novaluron, imidacloprid, emamectin benzoate, urea, thiamethoxam, thiacloprid, mancozeb and copper oxychloride. Likewise, a blue-coloured supernatant was developed within 5–10 minutes in mixtures of quinalphos with acephate, indoxacarb, thiodicarb and imidacloprid. However, these changes disappeared completely after gentle agitation of the mixtures, restoring a homogeneous suspension. These observations indicate that the instability was reversible and represented temporary settling of suspended particles rather than permanent incompatibility. Therefore, continuous agitation of spray solutions during field application is essential to maintain uniform distribution of active ingredients and ensure effective spray coverage.

No increase in temperature or other evidence of exothermic reactions was observed in any of the agrochemical combinations tested. This indicates that none of the mixtures underwent rapid visible chemical reactions immediately after mixing under the laboratory conditions employed in the present study.

The results demonstrate that formulation type plays an important role in determining physical compatibility. Most emulsifiable concentrate (EC), soluble liquid (SL), soluble powder (SP), suspension concentrate (SC) and water-dispersible granule (WG) formulations remained physically stable when mixed according to the recommended order of addition (WP $\rightarrow$ WG $\rightarrow$ SC $\rightarrow$ SP $\rightarrow$ SL $\rightarrow$ EC). Following this sequence likely facilitated proper dispersion of individual formulations before the addition of subsequent components, thereby minimizing the risk of incompatibility. The findings emphasize the importance of adhering to the recommended mixing order during preparation of spray solutions.

Tank mixing has become a common practice in pigeonpea cultivation because it reduces labour requirements, application costs and the number of field operations while enabling simultaneous management of insect pests, diseases and nutrient deficiencies. However, inappropriate mixtures may result in precipitation, nozzle clogging, poor spray distribution, reduced biological efficacy or phytotoxicity. The present investigation indicates that most commonly used insecticides, fungicides and urea are physically compatible and can be mixed safely except combinations involving NSKE with thiodicarb, mancozeb and copper oxychloride which showed precipitation without an adjuvant. Temporary precipitation and supernatant formation observed in several combinations indicate physical instability rather than complete incompatibility.

Although the majority of the mixtures were physically compatible, physical compatibility alone should not be considered as evidence of biological compatibility or field performance. A physically stable tank mixture may still exhibit synergistic or antagonistic interactions affecting pest control, persistence of active ingredients or crop safety. Similarly, the present investigation evaluated only the immediate physical behaviour of freshly prepared mixtures and did not assess degradation of active ingredients during prolonged storage, phytotoxicity or pesticide efficacy. Therefore, further studies under field conditions are required to validate the biological effectiveness, crop safety and long-term stability of compatible tank mixtures before they are recommended for large-scale use.

Overall, the study demonstrated that 297 of the 300 agrochemical combinations evaluated were physically compatible under laboratory conditions. The information generated provides a valuable scientific basis for selecting suitable tank mixtures in pigeonpea and contributes to safer, more efficient and economical crop protection practices.

CONCLUSION

Among the 300 agrochemical combinations evaluated, only three combinations involving NSKE with thiodicarb, mancozeb, and copper oxychloride exhibited clear physical incompatibility due to precipitation. The results indicate that most commonly used agrochemicals can be tank mixed safely in pigeonpea; however, phytotoxicity, biological efficacy and long-term field performance of these mixtures require further investigation.

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