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Tree Intercrop Interference Studies of Ashwagandha (*Withania somanifera* L. Dunal) Varieties with Mandarin and Kinnow Based Agroforestry Systems in South-Eastern Region of Rajasthan, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Ashwagandha or Indian Ginseng (*Withania somnifera*) is a very high-demanded medicinal plant of India which is used in Indian traditional systems of medicine such as Ayurveda, Unani and Siddha. Recently, Ashwagandha is found a novel alternative in the field of oncology due the presence of

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"Withanolide A" and "Withaferin A" alkaloids which have cancer-killing properties, however, it has multifarious uses. In India, there is huge gap between demand (7000 tonnes annual) and supply (1500 tonnes annual) of Ashwagandha which leads to encourage farmers for commercial cultivation. In addition, there are so many Mandarin and Kinnow orchards has been established in the South-Eastern region of Rajasthan and Ashwagandha cultivation in monoculture. Hence, we tried to find out the best suitable Ashwagandha variety under two agroforestry systems for its practical and economical feasibility. This experiment on tree intercrop interference study was conducted at Instructional Farm, College of Horticulture and Forestry, Jhalawar under Agriculture University, Kota, Rajasthan using four improved varieties of Ashwagandha i.e., JA-20, JA-134, RVA-100 and AA-1 (Factor A) and Mandarin and Kinnow based agroforestry systems and sole Ashwagandha cropping system (Factor B) in Factorial Randomized Block Design (FRBD) to know the best tree crop interaction or combination for growth, yield, and quality traits along with economic feasibility. The JA-20 variety was performed better than other three varieties of Ashwagandha for shoot morphological traits, however, JA-134 variety found better than JA-20 variety for root traits as well as yield traits. In case of quality parameters of Ashwagandha, the highest Withanolides content was observed in RVA-100 variety followed by JA-134 variety because of genetic constituent. In case of cropping systems, the Mandarin based agroforestry system proved superior to the Kinnow based agroforestry system for Ashwagandha production. The highest benefit cost (B:C) ratio (5.87) recorded in JA-134 variety of ashwagandha grown under Mandarin based agroforestry system, however it was lowest in RVA-100 variety of ashwagandha grown sole cropping system. The B:C ratio of four varieties ranged from 5.71 to 5.87 under Mandarin based agroforestry system, from 4.00 to 4.11 under Kinnow based agroforestry system and from 2.31 to 2.60 of sole ashwagandha cropping system. JA-134 variety of Ashwagandha is recommended to farmers of South-Eastern region of Rajasthan to grow in Mandarin based agroforestry system. This Agroforestry System will provide annually 5.87-fold economic benefits and around Rupees 5 lacs net return from one hectare land.

Keywords: Withania somnifera; medicinal plant; mandarin; agroforestry systems; ashwagandha variety JA-134; withanolides; economics.

1. INTRODUCTION

Withania somnifera (L.) Dunal (Ashwagandha or Indian Ginseng) is a high-demanded medicinal plant of India which is identified by National Medicinal Plant Board of India as a priority medicinal plant species for production and research [1]. It is one of the most valued shrubby medicinal plants in Indian traditional systems of medicine such as Ayurveda, Unani and Siddha which belongs to the family solanaceae. The genus *Withania* comprises of 23 species which distributed widely in South Asia and the Eastern Mediterranean area, out of these only two (*W. somnifera* and *W. coagulans*) are from India [2]. *Withania coagulans* is a wild species of *Withania*. The word ''Ashwagandha'' or ''Asgandh'' derived from Sanskrit means horse's smell due to the power and aroma of its root similar to the horse [3]. It is a stout shrub upto 170 cm height with fleshy, whitish brown roots. The flowers are greenish in color with orange-red berries or fruits in spherical shape with 6 mm diameter enclosed in an inflated and membranous calyx. The seeds are small in kidney shape with yellowish colour [3]. Ashwagandha root contains 0.4-1.2 per cent alkaloids, 40-65 per cent starch, 40-65 per cent fibers and minor quantity of oil. The important chemical constituents are alkaloids (Withanolides) that are present in roots, leaf and berries [4]. The roots of Ashwagandha contain bioactive compound Withanolides (combination of steroidal alkaloids and lactones) which is useful as a Nervine sedative, Adaptogen, Anthelmintic, Antioxidant, Aphrodisiac, Astringent, Diuretic, Expectorant, Nervine tonic, Rejuvenative Tonic, Reproductive Tonic, Shukrala, Antiinflammatory, Antitumour, Antibacterial, Antispasmodic and used to treat various diseases such as female disorders, stomach and lung inflammation, skin diseases, asthma, emaciation, insomnia, neurological disorders, Parkinson's disease [5-9]. Withanolides are present in roots, leaf and berries used for preparing various drugs. Drugs prepared from Ashwagandha used for stress reliever, to treat senile dysfunction anxiety, depression, phobia, schizophrenia etc. Recently, Ashwagandha is found an emerging and novel alternative in the field of oncology due the presence of "Withanolide A" and "Withaferin A"

alkaloids which have cancer-killing properties [10].

Ashwagandha mainly grown in the Sub-tropical and Semi-temperate regions of India upto 1,700 m elevation. It is also grown as commercial medicinal crops under rainfed condition in South-Eastern region of Rajasthan. It was cultivated at 30 cm × 30 cm spacing within agroforestry trees such as Peach, Grewia and Morus at Solan, Himachal Pradesh in 2005-07 [11]. Koshle [12] intercropped of Ashwagandha at 60 cm × 30 cm spacing between *Pongamia pinnata* trees at Raipur (C.G.) in 2016-17. Agarwal *et al.* [13] reported the longest roots at closer spacing (20 cm x 5 cm) compared to wider spacing (25 cm x 7.5 cm) at Jobner on loamy sand soil condition. Commercial cultivation of Ashwagandha in India is accomplished more than 5,000 ha of land in Madhya Pradesh, Rajasthan, Punjab, Haryana, Gujarat, Maharashtra, Andhra Pradesh, Uttar Pradesh, Himachal Pradesh and Jammu [14,9]. In Rajasthan, it is cultivated in Baran, Jhalawar, Kota, Chittorgarh and Pratapgarh districts [9]. In India, the estimated annual root production of Ashwagandha is around 1500 tonnes and the annual requirement is 7000 tonnes [15]. The increase gap between demand and supply of Ashwagandha has led to an increase in cultivation area in India to fulfil the demand. Intercropping of Ashwagandha can provide substantial yield advantages as compared with sole cropping systems [16]. However, the success of intercropping system depends mainly on selection of suitable intercrop as well as interaction with fruit crops such as Mandarin and Kinnow [17]. Hence, there is ample scope to cultivate it on commercial scale as well as intercrop in the South-Eastern region of Rajasthan because intercropping is one of the best techniques of proper land utilization for optimum production [18]. Therefore, four improved varieties of Ashwagandha i.e., Jawahar Ashwagandha-20 (JA-20), Jawahar Ashwagandha-134 (JA-134), Ashwagandha-100 (RVA-100) and Aanand Ashwagandha-1 (AA-1) introduced in the Mandarin and Kinnow based agroforestry systems in the Jhalawar region of Rajasthan.

In India, citrus has gained a prominent place among popular fruit is being extensively grown under tropical and subtropical conditions. This fruit have significance after mango and banana. The most important commercial citrus species in India are the mandarin (*Citrus reticulata*), sweet orange (*Citrus sinensis*) and acid lime (*Citrus aurantifolia*) sharing 41, 23 and 23 % respectively of all citrus fruits produced in the country. In India, Mandarin and Kinnow are widely cultivated major fruit crops. Mandarin (*Citrus reticulata* Blanco) is one of the important fruits grown in central India, occupying 40 % of the total area under citrus cultivation. Oranges are mostly grown in the states of Maharashtra, Madhya Pradesh, Tamil Nadu, Assam, Orissa, West Bengal, Rajasthan, Nagaland, Mizoram, Arunachal Pradesh [19]. Kinnow (*Citrus reticulata* Blanco) is a man-made hybrid between King mandarin (*Citrus nobilis* Lour.) and Willow leaf mandarin (*C. deliciosa* Tan.) and cultivated in Northern part of India due to increased demand in both domestic as well as in international markets. It has become one of the most important commercial crops and extensively grown in semi-arid regions of Punjab, Haryana, northwestern parts of Rajasthan and Uttar Pradesh [20]. The farmers of South-Eastern region of Rajasthan established extensive plantations for economic benefits. Therefore, Mandarin and Kinnow orchards were established at Instructional farm, Fruit Science, College of Horticulture and Forestry, Jhalawar in 2008. These horticultural crops has been chosen for intercropping of Ashwagandha to maximise the land use, diversify crop and additional income from the same land for sustainable agriculture.

Nevertheless, Agroforestry practices in the tropics has been increased vigorously with regards to its potential for optimizing land use. Agroforestry is defined as a complete land use system that incorporates trees into farming systems which allows for the production of trees and crops or livestock from the same piece of land in order to obtain economic, environmental, ecological and cultural benefits [21]. Its primary aim is the maximum production of food, timber, fuel, medicinal and aromatic plants per unit area [22]. It also necessary for environmental conservation and rehabilitation of soil resources needed for future production [23]. It is very good supportive to achieve the mission “doubling the farmers income in India” after coming Agroforestry policy in 2014. The farmers carried out the large-scale plantations for fruit, fodder, timber and raw material for industries to meet out their requirements. The interspaces of these plantations also used for the cultivation of agricultural crops, cash crops, medicinal and aromatic plants (MAPs). In the climate change era, the risk of crop failure/famine is more in crop-based agriculture than in tree-based agroforestry system. The total benefit received

from agroforestry-based system is high as compared to crop-based farming system or block plantations (monoculture). Species-level biodiversity in the subtropics are better maintained with partial canopy cover in the over story [24,25] compared to monocultures [26]. Furthermore, Agroforestry technologies are also improving the nutrient cycling [27], understory temperature extremes [28] and enhance soil water balance while reducing erosion [29]. The present research study was formulated to find out the best agroforestry system and variety of Ashwagandha on the basis of yield and economics. Therefore, different agroforestry systems and different varieties of Ashwagandha and their interactions or combinations were tried to know the growth and yield performance of Ashwagandha along with quality parameters under Mandarin and Kinnow based agroforestry systems in Jhalawar region of Rajasthan.

2. MATERIALS AND METHODS

2.1 Experimental Site and Treatment Details

Present experiment was conducted at Instructional Farm, College of Horticulture and Forestry, Jhalawar under Agriculture University, Kota, Rajasthan. The climate of Jhalawar is typically sub-humid and characterized by extremes of temperature both summer and winter with high rainfall and moderate relative humidity. The average annual rainfall in the region is about 954.7 mm. Four different varieties of Ashwagandha viz. Jawahar Ashwagandha-20 (JA-20), Jawahar Ashwagandha-134 (JA-134), Rajmata Vijayrajya Ashwagandha-100 (RVA-100) and Aanand Ashwagandha-1 (AA-1) grown under three different cropping systems i.e., Mandarin based agroforestry system, Kinnow based agroforestry system and sole Ashwagandha. Seven years old plantations of Mandarin (*Citrus reticulata* Blanco.) and Kinnow (*Citrus nobilis* Lour.× *Citrus deliciosa* Tan.) grown at 6 m x 6 m spacing were used for present intercropping study. The factorial randomized block design (FRBD) with three replications used to conduct field trail and layout of the experiment was presented in Fig. 1. Ashwagandha were sown at 60 cm x 60 cm spacing in 4 m x 4 m net plot area. All the standard cultural practices followed for the cultivation of Ashwagandha.

2.2 Data collection

The shoot and root morphological traits were measured using wooden scale and digital calliper at the harvesting stage (180 DAS). The yield of root and seed weighed using weighing balance. The quality parameters viz., Withenoides content, starch content and fibre content were measured using HPLC as per described by Chauhan *et al.* [30]. Benefit Cost Ratio was calculated on the basis of net return (Rs.) to the total cost of production (Rs.). The market price of dry roots of Ashwagandha ranged Rs. 200-300 per kg, price of seeds of Ashwagandha ranged Rs. 100-150 per kg, price of fruits of Mandarin ranged Rs. 30-35 per kg and price of fruits of Kinnow ranged Rs. 35-40 per kg.

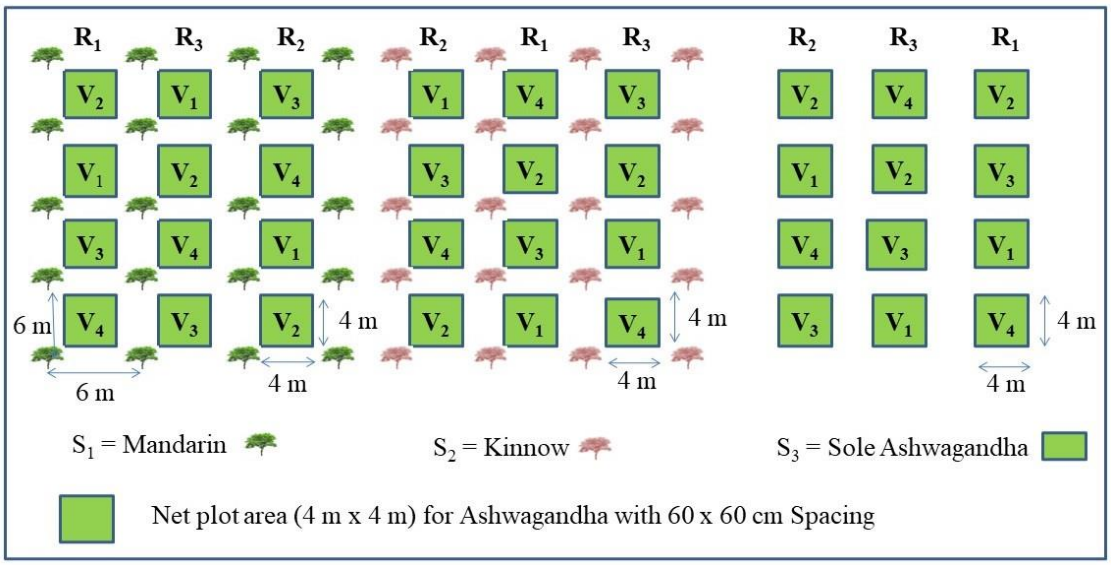

Fig. 1. Layout plan of treatment combinations in the experimental field

Statistical analysis: The data obtained from the experiment were subjected to R statistical software in factorial randomized block design (FRBD) with three replications to analysis of variance (ANOVA). The treatment means were compared using critical difference test at 5 % level of significance as per procedure described by Gomez and Gomez [31].

3. RESULTS AND DISCUSSION

The tree crop interaction experiment was carried out in two agroforestry systems viz., Mandarin based agroforestry system (S_1), Kinnow based agroforestry system (S_2) and sole cropping system of ashwagandha as Factor A. In Factor B, four different of ashwagandha i.e. Jawahar Ashwagandha-20 (JA-20), Jawahar Ashwagandha-134 (JA-134), Ashwagandha-100 (RVA-100) and Aanand Ashwagandha-1 (AA-1) were introduced to find the best interaction or combinations for growth, yield, quality traits of Ashwagandha. The benefit cost ratio was also carried out to know the economic feasibility of different agroforestry systems with four varieties of ashwagandha. The result of present experiment was described in the four followings heads and discussed with the relevant scientific literature.

3.1 Shoot Morphological Traits Of Ashwagandha

The data presented in Tables 1, 2 and 3 indicates that both different cropping systems and different varieties significantly influenced on the plant height, collar diameter and number of branches per plant of the ashwagandha crop. The highest values of plant height (80.77 cm), collar diameter (0.90 mm) and number of branches per plant (6.61) of the ashwagandha were observed in the sole cropping system (S_3) followed by Mandarin (S_1) based agroforestry system. Among all the varieties of ashwagandha, JA-20 (V_1) performed best with a mean height of 78.12 cm, mean collar diameter of 0.85 mm and 6.26 branches per plant followed by JA-134 (V_2) variety of ashwagandha. There was a non-significant variation among all the interactions of cropping systems and varieties of ashwagandha for all the shoot traits in the present experiment.

Table 1. Plant height (cm) of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	78.45	77.95	74.32	76.77	76.87
Kinnow (S_2)	72.90	71.57	69.82	70.28	71.14
Sole Crop (S_3)	83.00	80.55	79.42	80.10	80.77
Mean (V)	78.12	76.69	74.52	75.72	
Factors	CD				
Factor (S)	0.68				
Factor (V)	0.79				
Factor (S×V)	NS				

Note: NS= non-significant

Table 2. Collar diameter (mm) of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	0.86	0.84	0.81	0.82	0.83
Kinnow (S_2)	0.79	0.77	0.75	0.76	0.77
Sole Crop (S_3)	0.92	0.91	0.87	0.90	0.90
Mean (V)	0.85	0.84	0.81	0.83	
Factors	CD				
Factor (S)	0.01				
Factor (V)	0.01				
Factor (S×V)	NS				

Note: NS= non-significant

Table 3. Number of branches per plant of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	6.28	6.15	6.01	5.80	6.06
Kinnow (S_2)	5.68	5.55	5.41	5.20	5.46
Sole Crop (S_3)	6.83	6.70	6.56	6.35	6.61
Mean (V)	6.26	6.13	6.00	5.78	
Factors	CD				
Factor (S)	0.11				
Factor (V)	0.13				
Factor (S×V)	NS				

Note: NS= non-significant

Plant height of ashwagandha ranged from 46.63 cm to 65.90 cm, number of branches per plant ranged from 7.61 to 10.77 in the integrated nutrient management experiment carried out at College of Horticulture, Mandsaur, MP [32]. Ahirwar *et al.* [33] reported plant height (47.50-54.38 cm) and number of branches per plant (4.72-5.35) of ashwagandha under different intercropping systems at Jabalpur, MP. Growth of ashwagandha under different agroforestry systems was studied at Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh [11]. The plant height ranged between 36.71 to 38.21 cm under different agroforestry systems which was lower than our experiment because the natural habitat of ashwagandha was favorable in the South-Eastern part of Rajasthan and MP. The plant height (57.13 cm) and number of branches (7.33) of JA-20 ashwagandha variety was recorded at College of Horticulture, Arabhavi, Karnataka [34] which was comparable to the results of present experiment. Anjanidevi *et al.* [35] also reported plant height growth (55.05 cm) of JA-134 variety of ashwagandha grown at Rajendranagar, Hyderabad. Thus, variety JA-20 and JA-134 performed best under Mandarin based agroforestry system after solo cropping pattern of ashwagandha due to more photosynthesis activity which is responsible for shoot growths in the light demander plant species.

3.2 Root Morphological Traits of Ashwagandha

All the root traits of the ashwagandha crop were significantly affected by both cropping systems and different varieties of ashwagandha (Tables 4, 5 and 6) in this experiment. The longest root (25.97 cm), widest root diameter (0.78 cm) and maximum number of roots per plant (2.05) were observed in the sole cropping system followed by Mandarin based agroforestry system. Among all the varieties of ashwagandha, the maximum values were recorded for mean root length (22.35 cm), mean root diameter (0.72 cm) and number of roots per plant (1.94) in JA-134 variety of ashwagandha followed by JA-20 variety. There was significant variation among all the interactions of cropping systems and varieties of ashwagandha for root length and diameter. The longest root (27.42 cm) and widest root diameter (0.83 cm) were recorded in S_3V_2 (JA-134 variety in sole cropping system) followed by in S_3V_1 (Tables 4 and 5). However, number of roots per plant found non-significant for all the interactions (Table 6).

Ahirwar *et al.* [33] reported root length found in the range of 12.18-13.08 cm and root diameter between 2.60-2.89 cm of ashwagandha under different intercropping systems grown at Jabalpur, MP. The root length (12.93 cm) and root diameter (7.65 mm) of JA-20 ashwagandha variety was recorded higher than JA-134 variety (root length-11.12 and diameter-6.64 mm) grown at College of Horticulture, Arabhavi, Karnataka [34]. The root length, root diameter and number of secondary roots of JA-134 ashwagandha variety recorded 15.96 cm, 1.83 cm and 4.85 numbers, respectively [35] which was competitive to the results of present experiment. Thus, the interaction of JA-134 variety within Mandarin based agroforestry system performed better than Kinnow based agroforestry system due to more photosynthesis activity as well soil nutrients availability and their interactions which is responsible for the root growth of ashwagandha varieties.

Table 4. Root length (cm) of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	20.25	22.43	18.18	19.13	20.00
Kinnow (S_2)	16.91	17.19	15.23	16.20	16.38
Sole Crop (S_3)	26.85	27.42	24.25	25.35	25.97
Mean (V)	21.33	22.35	19.22	20.23	
Factors	CD				
Factor (S)	0.45				
Factor (V)	0.51				
Factor (S×V)	0.89				

Table 5. Root diameter (cm) of Ashwagandha varieties under Mandarin and Kinnow based Agroforestry Systems and Sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	0.69	0.70	0.65	0.66	0.68
Kinnow (S_2)	0.61	0.62	0.52	0.53	0.57
Sole Crop (S_3)	0.80	0.83	0.73	0.77	0.78
Mean (V)	0.70	0.72	0.63	0.66	
Factors	CD				
Factor (S)	0.01				
Factor (V)	0.02				
Factor (S×V)	0.03				

Table 6. Number of roots per plant of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	1.86	1.90	1.79	1.82	1.84
Kinnow (S_2)	1.75	1.77	1.71	1.73	1.74
Sole Crop (S_3)	2.09	2.14	1.95	2.03	2.05
Mean (V)	1.90	1.94	1.82	1.86	
Factors	CD				
Factor (S)	0.04				
Factor (V)	0.04				
Factor (S×V)	NS				

Note: NS= non-significant

3.3 Yield Traits of Ashwagandha

All the yield traits of the ashwagandha crop were significantly affected by both cropping systems and different varieties of ashwagandha (Tables 7, 8 and 9) in the present experiment. The highest values of fresh root yield (12.90 q/ha), dry root yield (5.20 q/ha) and seed yield (95.15 kg/ha) of the ashwagandha were observed in the sole cropping system followed by Mandarin based agroforestry system. Among all the varieties of ashwagandha, the highest yield of mean fresh root (12.44 q/ha), mean dry root (4.97q/ha) and mean seed (88.03 kg/ha) recorded in JA-134 variety followed by JA-20 variety. There was a non-significant variation among all the interactions of cropping systems and varieties of ashwagandha for the fresh root yield and dry root yield (Tables 7 and 8). However, seed yield found significant for all the interactions with the maximum seed yield (99.70 kg/ha) in S_3V_2 (JA-134 variety in sole cropping system) followed by S_3V_1 in this experiment (Table 9).

Table 7. Fresh root yield (q/ha) of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	12.12	12.35	11.79	11.96	12.05
Kinnow (S_2)	11.47	11.61	11.31	11.38	11.44
Sole Crop (S_3)	12.98	13.38	12.51	12.71	12.90
Mean (V)	12.19	12.44	11.87	12.02	
Factors	CD				
Factor (S)	0.20				
Factor (V)	0.23				
Factor (S×V)	NS				

Note: NS= non-significant

Table 8. Dry root yield (q/ha) of Ashwagandha varieties under Mandarin and Kinnow based Agroforestry Systems and Sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	4.81	4.92	4.64	4.73	4.78
Kinnow (S_2)	4.49	4.55	4.41	4.44	4.47
Sole Crop (S_3)	5.24	5.44	5.01	5.11	5.20
Mean (V)	4.85	4.97	4.69	4.76	
Factors	CD				
Factor (S)	0.10				
Factor (V)	0.12				
Factor (S×V)	NS				

Note: NS= non-significant

Table 9. Seed yield (kg/ha) of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	85.40	88.88	78.30	82.70	83.82
Kinnow (S_2)	69.40	75.50	60.20	64.30	67.35
Sole Crop (S_3)	95.50	99.70	91.50	93.90	95.15
Mean (V)	83.43	88.03	76.67	80.30	
Factors	CD				
Factor (S)	1.38				
Factor (V)	1.59				
Factor (S×V)	2.75				

Root biomass of ashwagandha was observed in the range of 4.89 to 7.96 q/ha which was grown at College of Horticulture, Mandsaur, MP [32] under INM trail. Ahirwar *et al.* [33] found root yield in the range of 392-518 kg per hectare under different intercropping systems grown at Jabalpur, MP. However, the lower root biomass (2.30-2.63 q/ha) of ashwagandha under different agroforestry systems was reported by Thakur *et al.* [11] in Himachal Pradesh, than the root yield from the present experiment. The fresh root yield, dry root yield and seed yield of JA-134 ashwagandha variety were recorded 9.83 q/ha, 5.16 q/ha and 3.48 q/ha, respectively [35] which was comparable to the results of present experiment. While seed yield 150 kg/ha was reported by Pandey [36]. Thus, JA-134 variety of ashwagandha performed best under Mandarin based agroforestry system for yield traits after sole cropping system due to lower sown area of ashwagandha under tree crop than open condition.

3.4 Quality Traits of Ashwagandha

Withanolides content in roots of Ashwagandha varieties found significant among varietal factor, whereas it was non-significant among different cropping systems and interactions of systems and varieties of Ashwagandha (Table 10). The highest mean Withanolides content (2.07 mg/g) was recorded in RVA-100 variety followed by JA-134 variety with a value of 1.53 mg/g in roots of Ashwagandha. Starch content and fibre content in roots of Ashwagandha varieties were significantly affected by both different cropping systems and different varieties of ashwagandha (Tables 11 and 12); whereas interactions of cropping systems and varieties was non-significant. The highest mean values of starch content (10.17%) and mean fibre content (27.32%) in the roots of the ashwagandha were observed in the sole cropping system followed by Mandarin based agroforestry system. Among all the varieties of ashwagandha, the highest starch content (11.21%) in JA-134 variety and fibre content (30.98%) in the roots were recorded in JA-20 variety of ashwagandha.

Table 10. Withanolides content (mg/g) in roots of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	1.33	1.54	2.09	1.21	1.54
Kinnow (S_2)	1.27	1.52	2.03	1.17	1.50
Sole Crop (S_3)	1.35	1.54	2.08	1.24	1.55
Mean (V)	1.31	1.53	2.07	1.21	
Factors	CD				
Factor (S)	NS				
Factor (V)	0.09				
Factor (S×V)	NS				

Note: NS= non-significant

Table 11. Starch content (%) in roots of Ashwagandha varieties under Mandarin and Kinnow based Agroforestry Systems and Sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	10.56	11.24	7.58	9.54	9.73
Kinnow (S_2)	10.19	10.41	7.37	9.64	9.40
Sole Crop (S_3)	11.14	11.99	7.75	9.78	10.17
Mean (V)	10.63	11.21	7.57	9.65	
Factors	CD				
Factor (S)	0.58				
Factor (V)	0.67				
Factor (S×V)	NS				

Note: NS= non-significant

Table 12. Fiber content (%) in roots of ashwagandha varieties under mandarin and kinnow based agroforestry systems and sole cropping system

System (S) / Variety (V)	JA-20 (V_1)	JA-134 (V_2)	RVA-100 (V_3)	AA-1 (V_4)	Mean (S)
Mandarin (S_1)	30.40	31.12	26.46	19.79	26.94
Kinnow (S_2)	29.57	29.94	25.63	19.03	26.04
Sole Crop (S_3)	32.97	30.08	25.69	20.52	27.32
Mean (V)	30.98	30.38	25.93	19.78	
Factors	CD				
Factor (S)	1.00				
Factor (V)	1.15				
Factor (S×V)	NS				

Note: NS= non-significant

Chauhan *et al.* [30] observed higher withanolides content in RVA-100 variety (2.079 mg/g) followed by JA-134 variety (1.423 mg/g) and JA-20 variety (1.326 mg/g). Similar starch content and fibre content in roots of Ashwagandha was recorded by Chauhan *et al.* [30] which was found in the comparable range with the results of present experiment. The starch content, fibre content and total alkaloid content of JA-134 ashwagandha variety were recorded as 11.93 %, 40.19 % and 0.36 %, respectively [35]. Gulati *et al.* (2017) recorded fibre content (21.7 %), starch content (8.22 mg/g) and total alkaloid content (0.26 %) in RVA-100 variety of ashwagandha grown at CCS Haryana Agricultural University, Hisar. Thus, RVA-100 variety of ashwagandha performed best for the quality parameters which was genetically controlled by the genotype/ variety.

3.5 Economic Feasibility

The average cost of cultivation, gross return, net return and B: C ratio was calculated to know the profitability of the cropping systems and variety used in this experiment. The net return of four different varieties of ashwagandha ranged from Rs. 489140 to Rs. 495865 under Mandarin based agroforestry system, between Rs. 340635 to Rs. 348250 under Kinnow based agroforestry system and between Rs. 76280 to Rs. 85770 of sole ashwagandha cropping system (Table 13). The highest benefit cost ratio (5.87) recorded in JA-134 variety of ashwagandha grown under Mandarin based agroforestry system, however the lowest BC ratio found in RVA-100 variety of ashwagandha grown sole cropping system. The BC ratio ranged from 5.71 to 5.87 under Mandarin based agroforestry system, from 4.00 to 4.11 under Kinnow based agroforestry system and from 2.31 to 2.60 of sole ashwagandha cropping system (Table 13).

The economics of ashwagandha under different agroforestry systems in Mid Hills of Western Himalayas was carried out to know the benefit cost ratio for the highest profitability [16]. The highest B:C ratio value of 3.87 was reported by Verma and Thakur [16] from Morus + Setaria + ashwagandha system on farmers land (financial perspective), while, it was the lowest (1.60) from Peach + Setaria + ashwagandha system assuming that the enterprise has been taken on rented land (economic perspective). Anand *et al.* [37] worked out B:C ratio of the cultivation of JA-134 variety at Krishi Vigyan Kendra, Sonbhadra, Mirzapur (UP) for four consecutive years (2008-09 to 2011-12) which was in the range of 3.31 to 4.43. The B:C ratio 3.18 and 3.06 were observed in JA 20 variety and JA-134 variety of ashwagandha in the sole cropping system [36]. Thus, the highest benefit cost ratio (5.87) was recorded in JA-134 variety of ashwagandha grown under Mandarin based agroforestry system in the present experiment which means we can get 5 Rupees and 87 Paisa from Rs. 1.0 investment.

Table 13. Economic feasibility of ashwagandha varieties cultivation under mandarin and kinnow based agroforestry systems and sole cropping system

Treatment Combinations	Cost of Cultivation (Rs./ha)	Gross Return (Rs./ha)	Net Return (Rs./ha)	B : C Ratio
S_1V_1	84500	573640	489140	5.79
S_1V_2	84500	580365	495865	5.87
S_1V_3	86500	580485	493985	5.71
S_1V_4	85600	578460	492860	5.76
S_2V_1	84000	424635	340635	4.06
S_2V_2	84500	431500	347000	4.11
S_2V_3	87000	435250	348250	4.00
S_2V_4	85600	431220	345620	4.04
S_3V_1	33000	114350	81350	2.47
S_3V_2	33000	118770	85770	2.60
S_3V_3	33000	109280	76280	2.31
S_3V_4	33500	111520	78020	2.33

Note: S_1=Mandarin, S_2=Kinnow, S_3=Sole Crop, V_1=JA-20, V_2=JA-134, V_3=RVA-100, V_4=AA-1

4. CONCLUSION

From the present experiment, it can be concluded that JA-134 variety of ashwagandha should be grown under Mandarin based agroforestry system in the South-Eastern region of Rajasthan to get 5.87-fold profit from the same land. So, JA-134 variety of ashwagandha has more potential cash crop for commercial cultivation in the South-Eastern region of Rajasthan through which farmers of Mandarin orchard can be socially and economically benefited.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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