"Tree Intercrop Interference Studies of Ashwagandha (*Withaniasomanifera*L. Dunal) Varieties with Mandarin and Kinnow based Agroforestry Systems in South-Eastern Region of Rajasthan"

ABSTRACT

Ashwagandha or Indian Ginseng (*Withaniasomnifera*) 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 "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. There are so many Mandrin and Kinnow orchards established in the South-Eastren region of Rajasthan. Therefore, an experiment on tree intercrop interference research study was laid out 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) andMandrin and Kinnow based agroforestry systemsand sole Ashwagandha cropping system (Factor B) in Factorial Randomized Block Design (FRBD) to know the best tree crop interaction or combination for growth, yield, 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. The Mandrin based agroforestry system was better than Kinnow based agroforestry system for the good production of Ashwagandha. The highest benefit cost 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. Hence, JA-134 variety of Ashwagandha was recommended that farmers of South-Eastern region of Rajasthan can grow this variety under Mandrin based agroforestry system to get 5.87-fold economic benefits and net return around Rupees 5 lacs from one hectare landannually.

Comment [A1]: Should be Mandarin

Comment [A2]: Please rewrite the sentence more clearly. Eg:The Mandarin-based agroforestry system proved superior to the Kinnow system for Ashwagandha production

Comment [A3]: Better not to use abbreviations in abstract. If you are using any please explain it at the first use

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Keywords:*Withaniasomnifera,* Mandarin, Agroforestry Systems, Ashwagandha Variety JA-134, Withanolides, Economics.

INTRODUCTION

Withaniasomnifera(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 (Singh *et al.* 2018). It is one of the most valued shrubby medicinal plant 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 (Kumar *et al.* 2007). *Withaniacoagulans* is a wild species of Withania. It is a native herb of India as well as Africa. 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 (Kumari *et al.* 2017). 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 (Kumari *et al.* 2017). Ashwagandha root contains 0.4-1.2 pecent 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 (Gupta *et al.* 2006). The roots of Ashwagandha contain bioactive compound Withanolides (combination of steroidal alkaloids and lactones) which is useful as Nervine sedative, Adaptogen, Anthelmintic, Antioxidant, Aphrodisiac, Astringent, Diuretic, Expectorant, Nervine tonic, Rejuvenative Tonic Reproductive Tonic, Shukrala, Antiinflammatory, Antitumour, Antibacterial, Antispasmodic, several female disorders, stomach and lung inflammation, skin diseases, asthma,

emaciation, insomnia, neurological disorders, Parkinson's disease (Bhattacharya *et al.* 1987; Singh and Kumar, 1998; Scartezzini*et al.* 2007; Gardner and Level, 2015; Chauhan *et al.* 2018). 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 (Malik *et al.* 2007).

The plant grows widely in the Sub-tropical and Semi-temperate regions of India upto 1,700 m elevation and one of the commercial medicinal crops under rainfed condition. 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 (Thakur *et al.* 2014). Koshle (2017) intercropped of Ashwagandha at 60 cm × 30 cm spacing between *Pongamia pinnata* trees at Raipur (C.G.) in 2016-17. Agarwal *et al.* (2004) 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 (Kothari *et al.* 2003; Chauhan *et al.* 2018). In Rajasthan, it is cultivated in Baran, Jhalawar, Kota, Chittorgarh and Pratapgarh districts (Chauhan *et al.* 2018). In India, the estimated annual root production of Ashwagandha is around 1500 tonnes and the annual requirement is 7000 tonnes (Shinde *et al.* 2014). 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 (Verma and Thakur, 2010). However, the success of intercropping system depends mainly on selection of suitable intercrop as well as interaction with fruit crops such as Mandrin and Kinnow (Din *et al.* 2012). 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 (Bhatnagar *et al.* 2007). 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 Mandrin 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. The fruits occupy 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 (Anon., 2018). 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 **(**Ahmad and Siddiqui, 2015**).** Therefore, Mandarin and Kinnow orchards were established at Instructional farm, Fruit Science, College of Horticulture and Forestry, Jhalawar in 2008.

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 (Thevathasan*et al.* 2004). Its primary aim is the maximum production of food, timber, fuel, medicinal and aromatic plants per unit area. It also necessary for environmental conservation and rehabilitation of soil resources needed for future production (Dhaka *et al.* 2024). It is very good supportive to achieve the mission "doubling the farmers income in India" after coming Agroforestry policy in 2014. The farmers carry 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 (Perfecto *et al.* 1996, De Foresta and Michon, 1997) compared to monocultures (Gallina *et al.* 1996). Furthermore, Agroforestry

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technologies are also improving the nutrient cycling (Nair *et al.* 1999), understory temperature extremes (Barradas and Fanjul, 1986) and enhance soil water balance while reducing erosion (Rao *et al.* 1998). 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; and to find out the economic feasibility of these proposed agroforestry systems in Jhalawar region of Rajasthan.

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MATERIALS AND METHODS

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 VijayrajyaAshwagandha-100 (RVA-100) and Aanand Ashwagandha-1 (AA-1) grown under three different cropping systems i.e., Mandrin 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 figure 1.

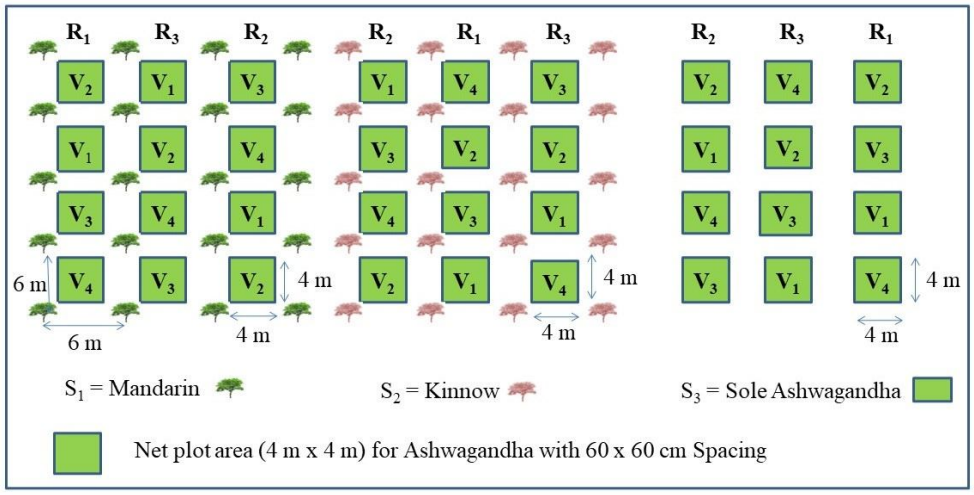

Figure 1: Layout plan of treatment combinations in the experimental field

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. 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.*(2019). 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.

Comment [A9]: Please indicate the measured parameters clearly with the relevant procedures

Statistical analysis: The data obtained from the experiment were subjected to statistical analysis (ANOVA) in R statistical software through the procedure of factorial randomized block design (FRBD) for various traits studied in the present investigation.

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 and 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 scientific literature related to the experiment.

Shoot morphological traits of ashwagandha

The data presented in Table 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 height of 78.12 cm, 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.

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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

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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 nutriment management experiment carried out at College of Horticulture, Mandsaur, MP (Patidar 2013). Ahirwar*et al.* (2019) 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 (Thakur *et al.* 2014). The plant height ranged between 36.71 to 38.21 cm under different agroforestry systems which 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 (Polaiah*et al.* 2013) which was comparable to the results of present experiment. Anjanidevi*et al.* (2022) also reported ~~good~~ 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 Mandrin based agroforestry system after solo cropping pattern of ashwagandha due to the photosynthesis activitywhich is responsible for shoot growths in the light demander plant species.

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Root morphological traits of ashwagandha

All the root traits of the ashwagandha crop were significantly affected by both ~~different~~cropping systems and different varieties of ashwagandha (Table 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, maximum values were recorded for root length (22.35 cm), 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 (Table 4 and 5). However, number of roots per plant found non-significant for all the interactions (Table 6).

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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

Ahirwar*et al.* (2019) reported root length 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 (Polaiah*et al.* 2013). 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 (Anjanidevi*et al.* 2022) which was competitive to the results of present experiment. Thus, the interaction of JA-134 variety within Mandrin based agroforestry system performed better than Kinnow based agroforestry system due to the photosynthesis activity as well soil nutrients availability and their interactions which is responsible for the root growth of ashwagandha varieties.

Yield traitsof ashwagandha

All the yield traits of the ashwagandha crop were significantly affected by both different cropping systems and different varieties of ashwagandha (Table 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 fresh root (12.44 q/ha), dry root (4.97q/ha) and 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 (Table 7 and 8). However, seed yield found significant for all the interactions with a 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 (Patidar 2013) under INM trail. Ahirwar*et al.* (2019) 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.* (2014) 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 (Anjanidevi*et al.* 2022) which was comparable to the results of present experiment. While seed yield 150 kg/ha was reported by Pandey (2022). Thus, JA-134 variety of ashwagandha performed best under Mandrin based agroforestry system for yield traits after sole cropping system due to lower sown area of ashwagandha under tree crop than open condition.

Quality traitsof 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 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 (Table 11 and 12); whereas interactions of cropping systems and varieties was non-significant. The highest values of starch content (10.17 %) and 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 JA-20 variety were recorded in the roots 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.* (2019) 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.* (2019) which was found in the comparable range with the 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 (Anjanidevi*et al.* 2022). 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.

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 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).

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

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 (Verma and Thakur 2010). The highest B:C ratio value of 3.87 was reported by Verma and Thakur (2010) from Morus + Setaria + ashwagandha system on farmers land (financial perspective), while, it was lowest (1.60) from Peach + Setaria + ashwagandha system assuming that the enterprise has been taken on rented land (economic perspective). Anand *et al.* (2014) 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 (Pandey 2022). 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.

CONCLUSION

From the present experiment, it can be concluded that JA-134 variety of ashwagandha should be grown under Mandrin 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 Mandrin orchard can be socially and economically benefited.

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