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REVIEW ARTICLE

RESEARCH FOR SISAL (*AGAVE SP.*) FIBRE PRODUCTION IN INDIA

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ABSTRACT

Sisal (*Agave sp*) is an important leaf fibre yielding plant grown extensively in Brazil and in African countries (Kenya, Tanzania, Madagascar etc.). It was introduced in India long ago and grown by tribal people of central plateau zone for fibre and live fence, by quasi-organized planters for fibre and by some state departments mainly for soil conservation purpose. In spite of its huge potential and demand of fibre in the country, adequate effort has not been given based on findings of research on sisal for commercial fibre production from sisal. Although some good amount of research have been conducted on various aspects of this crop in India, but there was no comprehensive documentation of research on sisal fibre production. Therefore, the present paper summarized 60 years of research findings on sisal fibre production in India classified into different chapters such as soil & climatic requirement, sisal types for different geographical areas, propagation technique, planting system, macro-micro nutrient management, water and weed management, intercropping, disease management, harvesting & extraction, fibre quality & grading, uses, economic and social benefits.

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INTRODUCTION

Sisal is a xerophytic, monocarp, semi-perennial leaf fibre producing plant. The plant has short stem bears rosette of leaves that are sessile, linear lanceolate attains a length of 1-1.5 m or more. The leaves are thick, fleshy and often covered with waxy layer, typical characteristics of xerophytic plants. A healthy sisal plant produces about 200-250 leaves during its 10-12 years life span, after which it produces a long flowering axis called 'pole'. Different species of *Agave* (Aaparagaceae family) namely *A. sisalana, A. cantala, A. vera-cruz, A. amaniensis, A. angustifolia* and *A. fourcryodes* can produce hard fibre from its leaf. However, among the different species, *A. sisalana* contributes nearly 85% of the total sisal fibre production of the World. *A. sisalana* is a native of the Yucatan area of Mexico where the fibre had been used by the native Mexican people for centuries. Later, around 1836, sisal was introduced to Florida. Other than Mexico, wide cultivation of sisal was started in Tanzania, where it was introduced by Dr. Richard Hindorf, an Agronomist from Germany. In the present world, major sisal producing countries are Brazil, Kenya, Tanzania, Madagascar, China, Mexico and Haiti (Table 1). In the modern world, sisal/ agave was extensively studied by Howard Scott Gentry (1903-1993) who was an American botanist recognized as the world's leading authority on the agaves. Sisal fibre is very commonly used in the shipping industry for mooring small craft, lashing, and handling cargo. Besides, it has several other domestic to industrial uses including high strength requiring long-lasting geo-textile and speciality composites. Sisal is also an excellent CDM (Clean Development Mechanism) crop for bioethanol as well as for afforestation over poor quality arid lands giving both permanent carbon credits of forestry for carbon sequestration (Kant, 2010). In general sisal is not much infested by many disease and insect pest; and therefore, sisal plantation does not produce pesticide load to the environment. Besides, sisal plants reduce soil erosion through its extensive root system and contributes positively to watershed management (Sarkar, 2015). Sisal has several distinguishing characteristics which makes sisal a 'speciality crop' for conservation agriculture (Sarkar *et al*., 2010). Research conducted in different aspects of sisal fibre production in India are summarized here.

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Climatic requirement

Agave, in general, is well adapted to arid environments as the species is xerophytic in nature. It can withstand a maximum temperature near 50°C and grows well with evenly distributed rainfall of 60-125 cm. Excessive rains (causing water stagnation) and very low temperature causing frost tend to damage the plantation (Sarkar *et al*., 2010).

Cytological/ chromosomal studies

Cytological studies on somatic chromosomes of Agave revealed that the base chromosome number is 30 and the 2n

chromosome numbers are 90 for *A. tequilina*, 120 for *A. americana*, 150 for *A. sisalana* and 180 for *A. decipiens* (Banerjee and Sharma, 1989).

Sisal types and germplasm in India

In India the only field repository of sisal germplasm are maintained at Sisal Research Station (a regional Research Station of ICAR-CRIJAF) located at Bamra in Sambalpur district of Odisha. At present there are 86 sisal germplasm collected all parts of India. The programme wise collection categorization are given in Table 1 and the detail of collected germplasm is given in partial list in Table 2.

Table 1. Programme-wise sisal germplasm collection

Collection programme	Collection year	No. of germplasm
NATP Collection	2002-2004	36
NE Collection	2007	6
MP-UP Collection with NBPGR	2007	3
Central Indian Collection	2010	29
South India Collection	2012-13	12
TOTAL		86

Sisal, in general is prone to attack by zebra disease. Out of the total germplasm of sisal, 58 germplasm were tested for understanding susceptibility towards zebra disease. Out of the tested germplasm, 11 were resistant, 12 were moderately resistant and 35 were susceptible to highly susceptible in reaction towards zebra disease (Anonymous, 2015). So the identified 11 resistant lines may be considered as one of the resistance source parent for any breeding programme aimed at developing resistant hybrid of sisal.

Sisal types for different geographical zones of India

In India different species of sisal are available and grown. In 1952 it was reported that in India 4 species of sisal were available for cultivation. They were (a) *Agave sisalana* – the smooth-leaved variety, (b) *Agave cantala* or Bombay aloe fibre, (c) *Agave veracruz* with thick fleshy, bluish leaves yielding commercial aloe fibres and (d) *Agave wightii* (the dwarf) aloe used in south India (Ray, 1952). Several researchers evaluated different species of sisal for varied agro-climatic conditions of India and found some kind of association between a definite region and the performance of a

Table 2. Partial list of sisal germplsm maintained in India

Collector No.	IC No.	Species	Month and year of collection	Collected from	
				District	State
KBA-207	329859	*A. miradorensis*	11/2001	Udaipur	Rajasthan
NM-02-34	333531	*A. miradorensis*	01/2002	Tirunelveli	Tamil Nadu
NM-02-39	333536	*A. angustifolia*	01/2002	Tirunelveli	Tamil Nadu
NM-02-68	333565	*A. angustifolia*	01/2002	Kanyakumari	Tamil Nadu
NM-02-71	333568	*A. nirvana*	01/2002	Kanyakumari	Tamil Nadu
NM-02-106	333603	*A. gigantia*	01/2002	Thrissur	Kerala
YMG-307	-	*A. angustifolia*	11/2002	Banas Kantha	Gujarat
YMGP-335	-	*A. angustifolia*	11/2002	Narmada	Gujarat
YMGP-347	-	*A. angustifolia*	11/2002	Dang	Gujarat
NLA-03-08	374414	*A. americana*	01/2003	Coimbatore	Tamil Nadu
NLA-03-27	374433	*Agave sp.*	01/2003	Coimbatore	Tamil Nadu
NLA-03-28	374434	*Agave sp.*	01/2003	Coimbatore	Tamil Nadu
NLA-03-37	374443	*Agave sp.*	01/2003	Nilgiri	Tamil Nadu
NA-03-42	374448	*Agave sp.*	01/2003	Nilgiri	Tamil Nadu
NA-03-43	374449	*Agave sp.*	01/2003	Nilgiri	Tamil Nadu
NA-03-44	374450	*Agave sp.*	01/2003	Nilgiri	Tamil Nadu
NA-03-52	374458	*Agave sp.*	01/2003	Mysore	Karnataka
NA-03-53	374459	*Agave sp.*	01/2003	Mysore	Karnataka
NA-03-63	374469	*Agave sp.*	01/2003	Mysore	Karnataka
NA-03-65	374471	*Agave sp.*	01/2003	Mysore	Karnataka
AD-03-06	399989	*A. americana*	04/2003	Birbhum	West Bengal
AD-03-11	399994	*A. sisalana*	04/2003	Birbhum	West Bengal
AD-03-19	400002	*A. americana*	04/2003	Birbhum	West Bengal
AD-03-23	400006	*A. americana*	04/2003	Birbhum	West Bengal
AD-03-32	400015	*A. sisalana*	04/2003	Purulia	West Bengal
SBC-1/16	-	*A. americana*	12/2003	South 24 Parganas	West Bengal
SBC-1/24	-	*A. americana*	12/2003	South 24 Parganas	West Bengal
SBC-1/102	-	*A. sisalana*	12/2003	South 24 Parganas	West Bengal
AMDJ-04/15	-	*A. americana*	10/2004	Buldana	Maharashtra
AMDJ-04/21	-	*A. americana*	10/2004	Aurangabad	Maharashtra
AMDJ-04/29	-	*A. americana*	10/2004	Ahmednagar	Maharashtra
AMDJ-04/30	-	*A. americana*	10/2004	Ahmednagar	Maharashtra
AMDJ-04/32	-	*A. sisalana*	10/2004	Ahmednagar	Maharashtra
AMDJ-04/35	-	*A. sisalana*	10/2004	Ahmednagar	Maharashtra
AMDJ-04/48	-	*A. sisalana*	10/2004	Nasik	Maharashtra
AMDG-04/56	-	*A. americana*	10/2004	Jalgaon	Maharashtra
MB-6	-	*A. miradurensis*	07/2007	Barpeta	Assam
MB-9	-	*Sansivera sp*	07/2007	Barpeta	Assam
MB-19	-	*Agave sp*	07/2007	West Garo Hills	Meghalaya
MB-20	-	*Sansivera sp*	07/2007	West Garo Hills	Meghalaya
MB-21	-	*Sansivera sp*	07/2007	West Garo Hills	Meghalaya
MB-28	-	*Agave sp*	07/2007	East Garo Hills	Meghalaya
KC/AK/DS-17	558422	*A. americana*	12/2007	Jhansi	Uttar Pradesh
KC/AK/DS-18	558423	*A. miradurensis*	12/2007	Jhansi	Uttar Pradesh
KC/AK/DS-27	558432	*A. sisalana*	12/2007	Datia	Madhya Pradesh

specific Agave species. Some efforts were given in 1967 and 1968 to comprehend about the possibility of growing sisal economically in the lateritic area of West Bengal namely west Midnapore division. Two geographic type of *Agave sisalana* (Keleghai provenance and Sambalpur provenance) and *Agave cantala* were tried. *Agave cantala* gave better performance in west Midnapore as compared to both the *A. sisalana* provenance (Banerjee, 1972). Three species of sisal namely *A. americana*, *A. veracruz* and *A. sisalana* were evaluated in Mettupalayam area of Coimbatore district in Tamil Nadu. It was revealed that *A. sisalna* gave the highest fibre recovery (5.1%), better fibre colour (golden yellow) and produced higher profitability (Suresh *et al*., 1992). Performance of 3 agave species in degraded hillock sites in Karnataka was evaluated. Growth and yield was the best in *A. sisalana* followed by *A. americana*, whereas, performance of *A. cantala* was poor (Swaminath and Ravindran, 1990). Field experiment conducted for 10 years in Bijapur area of Karnataka proved that *Agave americana* was most suitable for that area as it recorded higher leaf number, leaf length and fibre yield (17.04 t/ha). Whereas, *Agave sisalana* yield was 8.42-8.71 t/ha (Devaranavadgi *et al*., 2010). Singh (1984) reported that a sisal hybrid (*A. amaniensis* x *A. angustifolia*) produced about 70-80% more fibre yield as compared to the most popular *A. sisalana* in trials conducted at Odisha, Bihar, Madhya Pradesh and West Bengal. For Garwal Himalaya areas *A. americana* showed bright prospect to check soil erosion and industrial fibre use (Teneja *et al*., 1994). In Doon valley on the bouldery riverbed wasteland, seven species of Agave were tried for their stability with economic yield. Among the species considered, *Agave sisalana* was found to be the only stable species for growth characters and higher fibre yield at Doon valley. Hence *A. sisalana* was recommended for mass adoption on bouldery riverbed wastelands of Doon valley (Gupta *et al*., 1997). The suitable sisal species for different zones of India are given in Table 3.

Soil with higher water table, having slight to moderate erosion, high water holding capacity, medium to slightly acidic soil reaction (pH 5.6 to 7.3), deep (>0.45 cm) and sandy loam to sandy clay loam texture was placed under '*well suitable*' for sisal cultivation. '*Moderately suitable*' class of soil for sisal had characteristics of moderately well drained with 3-5% slope, medium water holding capacity. Soil with imperfectly drained, more than 5% slope, moderate to severe erosion, moderate to highly alkaline reaction, higher clay content was considered as '*poorly suitable*' class. Whereas, soil with very poor drainage, high water table, alkaline reaction and shallow soil depth was considered '*unsuitable*' for sisal cultivation. It was also reported that sisal can be grown on even iron-ore mined-out areas. In such condition *A. americana* grew and survived well (Prasad and Dhuria, 1989). In Anantapur district of Andhra Pradesh sisal was first tried during 1962 with the plantlets collected from Nildungri Sisal Estate of Sambalpur. They opined that sisal came up well in the red and loamy soils than on the alkaline and shallow soils of Anantapur (Reddy, 1966). Adivasi populated northern plateau region of Odisha grows non-remunerative upland rice, where diversification of farming by substituting upland rice by sisal was suggested to improve socio-economic condition of the people (Sahu, 1979).

Propagation techniques

In Indian condition, *A. sisalana* flowers in 8-10 years and produce bulbils (Chaudhari and Goel, 1993). The main plantation of sisal is raised either from reared bulbils from the nursery after one year or by suckers available from older sisal plantation. Experiments conducted to ascertain the better choice of planting material for sisal plantation concluded that there is no significant difference in growth and yield of sisal if grown from mature bulbils or suckers of similar size. Therefore, choice of propagating material would be either one

Table 3. Suitable sisal species for different zones of India

Region/ state	Suitable agave species	Reference
Odisha	*A. sisalana* and hybrid sisal	Singh, 1984
West Bengal (West Midnapore)	*A. cantala*	Banerjee, 1972
Karnataka (degraded hillock)	*A. sisalana*	Swaminath and Ravindran, 1990
Karnataka (Bijapur)	*A. americana*	Devaranavadgi *et al*., 2010
Tamil Nadu	*A. sisalana*	Suresh *et al*., 1992
Garwal Himalaya	*A. americana*	Teneja *et al*., 1994
Doon valley (riverbed wasteland)	*A. sisalana*	Gupta *et al*., 1997

Table 4. Price of sisal planting materials in India

Sisal types	(Rate in INR per thousand pieces)		
Agave sisalana	2006-2009[a]	2010-2011[b]	2012-2014[c]
Bulbil	400	600	700
Sucker	800	1500	2500
Agave cantala			
Bulbil	300	500	600
Sucker	700	1200	2000
Agave hydrid			
Bulbil	500	700	800
Sucker	900	2000	3000

Source: [a]CRIJAF, Barrackpore Letters No. 11-8/P&S/06-07/8594; dated 10.11.2006; [b]No. 11-01/P&S/10-11/13309-11; dated 18.11.2010; [c]No. 11-01/P&S/2012-13/5022-25; dated 22.08.2012.

Soil suitable for sisal plantation

Generally accepted that sisal plantation is carried out for utilizing the soil which is neither fit for agricultural crops nor tree plantation (Sen and Jha, 1988). Detailed study on the land suitability for sisal was studied by Sahu and Mishra (1994).

as per availability in the locality (Dhyani and Geo Paul, 1974a). The experiment in Andhra Pradesh reported that planting by bulbils caused 9% mortality and planting from suckers caused minimum mortality of the sisal plantlets (Reddy, 1966). Bigger sized bulbils are produced on the sisal pole (inflorescence stalk) when lopped due to wind or cut by

human. The giant sized bulbils could be directly planted in the main field by skipping nurseries. Cut poles having maximum 3 branches produce such giant bulbils having superior planting value than others (Dhyani *et al*., 1971). Bulbils, the propagating material of sisal is obtained only once after 12 years of life cycle of the sisal plant. The produced bulbils might be inadequate to meet the huge requirement of planting materials. Attempt was made to develop mass multiplication method of *A. sisalana* by splitting the bulbils into pieces and application of rooting hormone. It was reported that splitting of bulbils into 4 pieces and application of IBA 2500 ppm could produce large number of propagules (344 bulbils from 100 whole bulbils) having 100% rooting, 1.89 ± 0.22 root numbers and 6.08 ± 1.02 cm root length within 45 days after treatment and raising (Takawale *et al*., 2004). Sisal bulbils are tended for about a year in nursery before planting in the field for fibre production. It was reported that application of 60 kg N, 30 kg P_2O_5 and 30 kg K_2O/ha in the nursery produced the healthiest sisal plantlets (green weight of 203 g/bulbil) which is 5.6 times higher plantlet weight as compared to no fertilizer application (Jain *et al*., 1965). Appropriate care is essentially required for raising sisal bulbils in the nursery as the miniature sisal plantlets require moisture for growth. To conserve soil moisture in the sisal nursery, mulching with black alkathane film (150 gauge) produced more number of leaves (21.16/plant) and longest bulbils (51.59 cm). Although paddy straw mulch also exerted some good impact on the growth of sisal bulbils (Singh *et al*., 1985). Price of planting materials of sisal was also increased considerably over the years. During 2006-08, for a hectare sisal plantation, the cost of planting materials were 3,600/- for *A. sisalana* and 4,050/- for hybrid sisal. Within 7-8 years, the cost of planting materials for *A. sisalana* increased 3 times and more than 3 times for hubrid sisal as compared to 2006-08 price level (Table 4).

Micro-propagation studies

Being vegetatively propagated, sisal planting materials are in short supply. Researcher from India given concentrated efforts for regeneration of sisal plantlets through different methods like somatic embryogenesis, micropropagation, organogenesis etc. Part of rhizomes and immature leaves were used. No response was obtained with leaf explants. But rhizome culture with SH medium (with little modifications) produced plantlets and 80-90% rooting was developed within 30 days. The rooted plants showed 70-80% survival in the field (Das, 1992). Nikam (1997) reported that callus culture of *A. sisalana* for rhizome and stem explants on defined medium produced sufficient shoots and the same rooted steadily within 21-35 days. The callus was remained active to produce shoots for about 32 months. The rooted plants adapted to the field conditions and grown well. The regenerated sisal plants were morphologically similar to the mother plants. In another study, it was reported that callus was initiated from in vitro grown mature leaf and ex vitro grown mature leaf and rhizome explants of *A. sisalana* on MS medium. Light was essential for callus formation. Micro shoots developed on MS medium containing BA and GA_3 finally rooted on MS medium containing IAA. The acclimatized rooted agave plantlets grown satisfactorily in ex vitro (Hazra *et al*., 2002). Researcher developed protocol for somatic embryogenesis and plant regeneration of *A. sisalana*. Embryonic callus culture were initiated from young shoots raised in vitro from the stem portion of bulbil on definite medium. After 28 days a maximum of 76% germinated embryos were obtained. Plantlets regenerated from embryos were transferred to the field where about 100% survival rate was recoded (Nikam *et al*., 2003).

Planting method

Double row planting was found superior over 1.0 m and 0.6 m spacing of single row in *A. sisalana* (Singh and Bisaria, 1994). The most suitable double row spacing is 3m + 1.0m x 1.0 m and the optimum plant population is 5000 plants/ha (Dhyani, 1967).

Nutrient management

Field studies conducted at Sambalpur (Odisha) determined the optimum dose of fertilizers as 100 kg N, 50 kg P_2O_5 and 100 kg K_2O per hectare. Application of the total amount of N fertilizer through popular source like calcium ammonium nitrate (or urea) might not be feasible for common farmers; whereas, it was reported that application of 50% N through popular source and remaining 50% N through nitrogen enriched coal was helpful in producing more number of leaves resulting higher fibre yield (Dhyani and Geo Paul, 1974c). Field experiments conducted in western Odisha showed that N:P:K @ 60:30:60 kg/ha along with 20 t sisal waste could able to increase the leaf number by 67.9% and leaf length by 29.2%, and therefore, considered as the acceptable nutrient management option for sisal plantation in India (Sarkar, 2010). As regards micronutrient, sisal has a high boron requirement, followed by manganese and zinc (Chaudhari and Goel, 1993). Studies showed that soil application of zinc sulphate @ 20kg/ha along with borax @15 kg/ha (in combination with drip irrigation) produced the longest leaf (97.2 cm), maximum number of harvested leaves (1.48 lakh/ha) and the highest fibre yield of 1546 kg/ha (Anonymous, 2015).

Irrigation/ drainage management

Sisal being a xerophytic plant can survive and produce economic fibre even in water stress and drought-like situation. However, it responds well to applied water through irrigation, preferably in the form of drip. It was reported that drip irrigation with a discharge rate of 4 l/h for 2 hours at 2 week interval during the dry period had significant effect on leaf length, number of harvested leaves, fibre yield with the maximum water use efficiency of 3.91 kg fibre/ha-mm (Kundu *et al*., 2013; Anonymous, 2015). In sisal growing western Odisha area, during June – September, the rainfall (1094 mm) is much excess to the ETc demand during the period (337.76 mm) for sisal and therefore, care is to be taken to remove the excess water from the sisal field having little natural slope for achieving better growth and fibre yield (Sarkar *et al*., 2013).

Weed management

In sisal nursery, planting is done with the onset of monsoon and therefore, the chance of weed infestation is always more. One hectare of sisal nursery requires at least 150 labourers in total for manual weeding 2-3 times for which huge wage expenditure is involved. Weed competition for the first 45 days is very critical for sisal nursery, as heavy competition from weeds during this period reduce emission of new leaves drastically. It was established that in sisal nursery, s-metolachlor @ 0.5 kg/ha at 1 DBP can control the weeds (89.2%) upto 45 days; and beyond that point only two manual weeding gave the highest WEC of 92.3 (45 DAP) and 71.8%

(60 DAP), respectively. Hand weeding twice produced the most robust type of sisal plantlets (13.9 g/plant) followed by the plantlets obtained with sisal waste (13.3 g/plant). All the tested herbicides reduced the biomass of sisal bulbils as compared to hand weeding in the order of trifluralin (14.7%) > pretilachlor (22.1%) > s-metolachlor (35.9%) > quizalofop ethyl (39.2%) (Sarkar *et al*., 2014). In another experiment it was found that in sisal nursery application of glyphosate @ 1.5 kg/ha could achieve 87.2% weed control efficiency at 3 weeks and produced the healthiest bulbils (4.74 g/bulbil) at 7 week after planting. Any dose of glyphosate higher than 1.5 kg/ha was detrimental to sisal bulbils as it reduced survival rate and biomass accumulation in the bulbils (Sarkar and Abdullah, 2010). Removal of weeds is quite important in sisal especially during the first 3 years in main plantation (Dhyani, 1967). It was opined that it is not always necessary to clean the field when the weeds are below the canopy of sisal plants but all the brushwood and shrubs should be removed before they top the sisal plants (Chaudharui and Goel, 1993).

Intercropping

During early 90's it was opined that although sisal grows well as a pure crop but some cash crops can be grown in sisal field for initial few years (Chaudhari and Goel, 1995). Appropriate technology for growing annual legume intercrops during kharif season in the vacant space in between the double rowed sisal plantation for the initial 3 years has been developed and popularized among the tribal sisal farmers of Odisha and adjoining areas. Annual legumes like short duration pigeon pea (cv. ICPL 87), cowpea (cv. VRCP-4), blackgram (cv. Pant Urd 31) and greengram (cv. Pant Mung 5) produced good economic return resulting higher sisal equivalent yield from the system (Sarkar *et al*., 2015). Some medicinal and aromatic plats were also tried as intercrops in sisal. Safed musli gave the highest net return, however, the maximum benefit: cost ratio (2.9) was recorded in vettiver (Anonymous, 2015). In a long-term study on growing sisal in the intercropping environment with forest trees, two types of sisal (*A. sisalana* and Hybrid sisal cv. Bamra hybrid-1) were planted in double row system in between two rows of teak or gamhar in all possible combinations. From the study it was ascertained that *sisalana* sisal can be grown by utilizing space in between rows of gamhar planted with a population of 470 trees/ha and it is not advisable to grow hybrid sisal with teak or gamhar (Sarkar *et al*., 2010). Attempt had been made to determine the economic raising of sisal with Bhabar (*Eulaliopsis binata*) in the degraded riverbed lands of Doon valley containing more than 80% boulders and pebbles. It was observed that in such situation 50% harvest intensity of sisal leaves with Bhabar grass is recommended for better economic viability (Gupta *et al*., 1989).

Effect of shade / partial light on sisal

Being a xerophytic and C_4 plant, sisal may have affinity towards higher ambient light intensity. So, field experiment was conducted to get some idea on the effect of partial shade on the fibre yield in two commercial types of sisal (*Agave sisalana* and hybrid sisal No. 11648) at Sambalpur, Odisha. It was observed that *A. sisalana* produced more fibre in full ambient light (FAL) condition (13.0-53.7 g/leaf) than partial shade condition (8.8-46.3 g/leaf). Similar observations were also recorded in case of hybrid sisal also, where FAL produced more fibre (23.7-53.0 g/leaf) than partial shade (50% FAL) condition (7.3-44.0 g/leaf). Among the two types of sisal considered in the study, on an average, hybrid sisal yielded more (36 g/leaf) than *Agave sisalana* (32.8 g/leaf) in light condition; whereas, the reverse was observed in partial shade condition. In such situation, *Agave sisalana* produced more fibre (24.7 g/leaf) than hybrid sisal (23.3 g/leaf). In both the types of sisal, the partial shade condition reduced the fibre yield. The yield reduction due to partial shade was more pronounced in case of hybrid sisal (35.5%) than *Agave sisalana* (24.7%). Therefore, to incorporate sisal in any intercropping or agri-silvicultural system, out of the two important sisal types, *Agave sisalana* need to be given preference over the hybrid one (Sarkar and Kundu, 2014). In the sisal plantation in Madras (now Chennai) railway tracts, it was recorded that in some places between Coimbatore and Erode where the agave was overgrown with creepers, the sisal plants were week and unhealthy; in other places (near Tudiyalur) sisal plantation shaded by tamarind, neem and other trees were stunted. Sisal plantation in open space with full sunlight were rich in leaf number and luxuriant in growth (Thurston, 1894).

Diseases and its management

In total 11 species of agave species maintained at Sisal Research Station (Odisha) were tested under natural epiphytotic condition for reaction to zebra disease, the most common and dreaded disease of sisal. Only one species (*A. miradorensis*) showed moderately resistant reaction and 3 species (*A. cantala*, *A. angustifolia* and *A. amanuensis*) showed moderately susceptible and the rest 7 species showed susceptible to highly susceptible reaction (Jha *et al*., 2014; Anonymous, 2015). The main economic fibre yielding species *Agave sisalana* and Agave hybrid (Bamra 1) are affected by zebra disease caused by *Phytophthora nicotianae* var. *parasitica*. The pathogen causes damage to the leaves which results in dark black water soaked lesion with concentric wavy rings. Small spots coalesce to form bigger spots (Jha and Sarkar, 2011). The disease is endemic in nature and losses caused by the disease in Odisha is about 10-20% or even more. The hybrid sisal is more susceptible to zebra disease (15.4 to 33.1%) as compared to *A. sisalana*. Weather variables like minimum temperature, mean temperature and minimum relative humidity have effect on the occurrence and severity of zebra disease in sisal. Out of the weather variables, minimum temperature showed the highest negative correlation (-0.92 to -0.93), so has the maximum effect on the disease severity (Anonymous, 2015). To overcome the disease, fungicide schedule like mancozeb 0.2%, metalaxyl 8% + mancozeb 0.2% and their combinations need to be followed (Roy *et al*., 2011). Breeding efforts to get resistance genes from *A. decipens* for making *A. sisalana* resistant to zebra disease was also suggested (Osborne and Singh, 1980). In Himachal Pradesh, sisal (*A. americana*) leaves of 90-95% plants were affected by *Alternaria alternate* (Gautam, 2013). This disease decreases the quality of fibre, so need attention.

Sisal as live hedge/ fence

Late 19th century sisal was extensively planted as a protective hedge along the Madras (now Chennai) railway tract (Thurston, 1894). Agave showed the highest survival percentage (78-83%) as live hedge operative within 3-4 years and for erecting live hedge, *A. sisalana* costs minimum in Maharashtra (Pendke and Gitte, 2004). In 1949 West Bengal

Forest Department was growing sisal as hedge plants on the mounds of cattle proof trenches but no concentrated plantation was established for production of fibre during that time (Banerjee, 1972). In Madhya Pradesh sisal was hardly grown for fibre, but *A. cantala*, *A. veracruz* and *A. wightii* were grown as hedge plants (Ray, 1952). For north-eastern ghat of Odisha different shrubs were studied for live hedge. Agave showed higher survival percentage but recorded comparatively lower plant height as compared to other species namely Lawsoma (Mishra *et al*., 2000). Govt. of Kerala encouraged and assisted live fencing by sisal (*A. sisalana*) in various tribal settlements and other human habitations along the forest fringes across the state to ward off wild elephants' attack on human life and property (Anonymous, 2012).

Harvesting

Attaining maturity, sisal leaves are harvested manually by cutting from the leaf base with a sharp specialized crescent like knife having long handle. First cutting, in general, starts at 3 ½ years crop age. However, in intensive cultivation programme with appropriate care, first harvest can start at 2 ½ years of age also. At first cutting 16 leaves and in each subsequent cutting 12 leaves are left on the plant. Harvesting during November to February is advised considering several factors like comparatively lower temperature, minimum rain hindrance, restricted active growth and economy in harvesting and extraction operation. After cutting, the leaves are bundled (say 50 numbers) and the same are transported to the extraction unit. Extraction of fibre is done on the same day or preferably next day as early as possible (Sarkar *et al*., 2010). Experiments conducted at Dehradun had shown that early commencement of leaf cuttings gave better yield and higher fibre percentage in subsequent cuttings (Chaudhari and Goel, 1993).

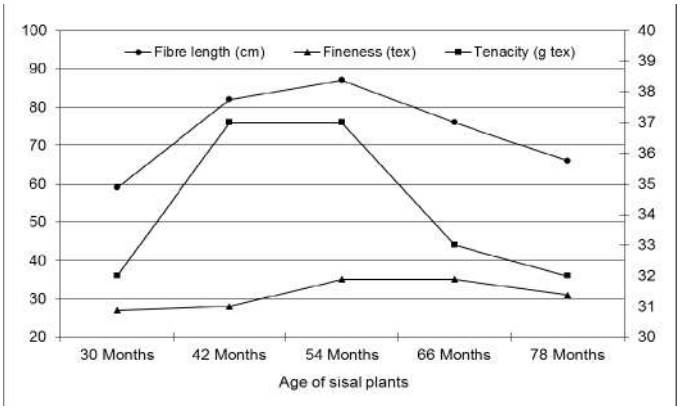

Fig. 1. Relation between harvesting age and fibre quality in sisal

It was observed that age of sisal plant has effect on quality of fibre produced (Fig 1). In general, it was recorded that fibre length, coarseness and tenacity of fibres increase with age of sisal plant upto 4½ years (54 months) beyond which the quality decreases (Dhyani and Geo Paul, 1974b).

Fibre extraction method

Long ago it was reported that in Coimbatore area in southern India, extraction of sisal fibre was performed by hand and no machinery was used during 1890s. The sisal fibre was extracted by two methods namely (i) scraping and (ii) maceration. In the scraping system, the harvested leaves were split longitudinally in to 4-5 pieces and beaten with wooden mallet and placed on a board held firmly by the toes. The pulp was then removed by means of a bamboo scrapper and the fibre was then dried in sun. In the maceration method, the harvested whole leaf was beaten with wooden mallet and then thrown in bundles in water tank to macerate for 15-20 days until the pulp was decomposed. The fibre obtained by this method was not very clean as in case of scraping technique (Thurston, 1894). Ray (1952) reported that besides mechanical methods, sisal fibre was also extracted in wet method. In the wet method, the harvested sisal leaves are allowed to ret in water, as a result of which soft tissues and gummy materials disintegrate by chemical and bacterial action and the fibre are separated easily. The process was less expensive but it takes long time to complete the operation. Earlier mechanical or machine extraction of sisal fibre from leaf was not in vogue. In late 1960s or later, ramie decorticator available from foreign countries were improvised by modifying desirable adjustments and proved efficient in extracting leaf fibres of sisal. In order to protect the operator from getting injured, a slit feeding window was placed to guard the operator's hands and a hood was fixed over the rotor to protect the operator from the plant tissue, gums and mucilage came out at the time of extraction (Mukherjee and Chakraborty, 1970). The fibre extraction process from sisal leaves by machine is called 'Decortication' and the machine is called 'Decorticator'. It consists of a drum measuring 12 inch (30.48 cm) diameter, on the periphery on which are mounted 12 blades made of angle-iron equally places at 3 inch apart. According to the leaf feeding system in the decorticators, it is classified into two types viz, single feeder (leaves are feed in one mouth by one operator) and double feeder (leaves are fed in two side-by-side mouths by two operators individually). There is a small gap of 0.5 to 1.0 mm between the rotating scrap blades and the fixed scrapper plate through which the decorticated fibre remain intact hold in the hand of the operator. The decorticators run by an air cooled 6.4 h.p. diesel engines having ideal rpm of 1500.

From the observation it was noted that the single feeder decorticator drum rotates with 1467 rpm and the double feeder decorticator drum rotate at 1325 rpm while in full operation. It was observed that the single feeder decorticator requires 4 minutes 5 seconds to decorticate unsorted one standard bundle of 50 leaves and the double feeder decorticator requires only 2 minutes 7 seconds to do the same extraction job. The double feeder machine decorticated 2.04 times more number of leaves than single feeder decorticator which can decorticate only 835 leaves per hour. In terms of fibre yield output, single feeder decorticator is less efficient as it could yield 6.92 kg/hr whereas; on an average double feeder decorticator produced 2.23 times more fibre per hour (Sarkar and Abdullah, 2010).
Due to initial high cost involvement and higher power requirement, such decorticators are not popular among the small and medium sisal planters. There was an urgent need to develop an efficient, portable, cheaper and low energy requiring sisal fibre extraction machine so that ventures on sisal plantation could be taken by the mass in India. Very recently a portable machine for sisal fibre extraction was designed and developed based on the same principal of earlier raspador decorticator. The new machine has a central rotating drum of 40 cm diameter on which 18 angle iron beater knives are spaced equidistant and rotates at 600 rpm. The rotating drum maintains a clearance of 0.5 to 1.0 mm against the base plate for the rasping action. It requires only 3 h.p. single phase electric motor or a 3.5 h.p. diesel engine to run and at the same time noise and vibration is also much less. The main advances

over the earlier one are the higher fibre output (±14 kg/hr), very low extraction loss and obtaining 37% more fibre yield output (Naik *et al*., 2013b). In an attempt to extract sisal fibre other than decortication method, 3 methods namely alkali pre-treatment (NaOH, 8%), acid pre-treatment (H_2SO_4, 99%) and biological pre-treatment (cow dung water mixture 1:3 for 15 days) along with rinse and wash in water were tried. Among the 3 methods, it was observed that pre-treatment of sisal leaves with biomaterial (cow dung) could be a cost effective, eco-friendly, efficient and productive way of fibre extraction from the sisal leaves (Tripathi and Tewari, 2013). The fibre extracted by sisal fibre extractor was more strength, lustrous and finer than retting method. The fibre bundle strength was 32.31 g/tex and the fibre fineness was 4.92. The average cutting energy at butt-end section was 1.31 J/cm^2 (Naik *et al*., 2013a). Comparison between the different methods of sisal fibre extraction was given in Table 5.

Table 5. Yield of sisal fibre under different fibre extraction methods

Method of extraction	Yield/hr	Fibre yield %	Reference
Hand decorticator	1.25-1.50 kg	-	Naik *et al*., 2013b
Raspador decorticator	9-10 kg	2.70%	Mukherjee and Chakraborty, 1970
Single feeder decorticator	6.92 kg	3.0%	Sarkar and Abdullah, 2010
Double feeder decorticator	15.43 kg	3.0%	Sarkar and Abdullah, 2010
Portable decorticator	12-14 kg	3.7%	Naik *et al*., 2013b
Bio material pre-treatment	-	4.65±0.45%	Tripathi and Tewari, 2013

Table 6. Grade designations and definition of quality of Aloe/ Sisal fibre in India

Grade Designation	Maximum limits of tolerance		Special characteristics		General characteristics
	Foreign matter (% by weight)	Harsh fibre (% by weight)	Colour	Minimum length (cm)	
Special	3	5	Creamy white	80	(a) The fibre shall be reasonably soft texture and uniform colour. It shall be clean and reasonably dry.
No. 1	5	10	Pale creamy white	70	
No. 2	8	25	Greyish or brownish white	60	(b) The strands shall be reasonably uniform in length and strength and free from tangling, knot spines and other undesirable materials

Fibre yield

During late 80's, sisal plantation in Palammu area of Bihar could able to produce 150 kg fibre/ha in the first year and in the subsequent years the fibre yield was 300 kg/ha (Sen and Jha, 1988). Later in 1993, it was reported that properly managed sisal plantation can yield 550-1320 kg/ha (Chaudhari and Goel, 1993). The average yield of sisal fibre in India is poor and does not exceed 0.6-0.8 t/ha. But with proper care and attention and by using improved cultivation techniques, the fibre yield could be achieved to 2.0 t/ha (Sarkar *et al*., 2010).

Prediction of fibre yield

Multiple regression equations were fitted to predict the dry fibre yield on the basis of 3 independent agronomic parameters viz. number of 1000 leaves/ha (x_1), green weight (q) of leaves/ha (x_2) and green weight (q) of fibre/ha (x_3). The established yield prediction equation for hybrid sisal was, $Y= -0.2290 -0.0590x_1 +0.0373x_2 +0.2963x_3$ (R2= 0.9670) and for *A. sisalana*, the equation was $Y= 0.2551 -0.0792x_1 +0.0313x_2 +0.3793x_3$ (R2= 0.9865), where Y is the predicted fibre yield in q/ha (Singh and Sasmal, 1994). The yield prediction equation of 1994 was quite complex and often not holding good for presently cultivated types having more fertilizer and micro-irrigation responsiveness. Recently (2017) more simple regression equation using only mean leaf length (LL) and harvestable leaf number (LN) has been developed for fibre yield prediction in sisal. The yield prediction model, Y= -1221.428 + (23.327) x LN + (10.761) x LL + 21.355 (where, Y is the fibre yield in g per plant) estimated the actual fibre yield with > 96% accuracy (Sarkar *et al*., 2017).

Fibre composition, quality and grading

Sisal fibre varies widely in physical quality and moderately in chemical composition. The variation in chemical composition is because of its different sources, age, extraction methods etc. It was indicated that sisal fibre contains 78% cellulose, 10% hemicellulose, 8% lignin, 2% waxes and about 1% ash by weight. But others found that sisal contains 43-56% cellulose, 7-9% lignin, 21-24% pentosan and 0.6-1.1% ash. It was also reported that the cellulose and lignin contents of sisal vary from 49.62-60.95% and 3.75-4.40%, respectively, depending on the age of the plant (Mwaikambo, 2006). From India, it was mentioned that the sisal fibre is composed of cellulose (78%), hemicellulose (10%), lignin (8-10%), wax (2%) and 1% ash. In general, the physical properties of sisal are, 0.6-1.2 m length, 0.05-0.2 mm diameter, 1.35 g/cm^3 density; the mechanical properties are tensile strength 500-660 MPa, Tensile module 30-40 GPa and 2-3% elongation (Mitra, 2009). There is no universal standard of grading sisal fibre in different countries in which it is produced. Different countries have their own system of fibre grading. Internationally the most important 3sisal fibre grades definitions are – (A) East African sisal fibre grade, (B) Madagascar sisal fibre grade and (C) Brazil sisal fibre grade. The grade definitions are presented here in tabulated form.

In Brazil grades, sisal fibre is also classified based on fibre length; the classification is Extra-long (>110 cm), Long (90-110 cm), Medium (70-90 cm) and Short (60-70 cm). In India no definite and universally acceptable fibre grading system has been defined but India may adopt east African sisal grading system for Indian industries (Chaudhari and Goel., 1993). In India the BIS authority follow 'Aloe Fibre Grading and Marking Rules, 1975' as in the country fibre obtained from the botanical species of *Agave cantala*, and *A. Vera-cruz* are commercially called 'Aloe' fibre. The grade designation and definition of quality of sisal/ Aloe fibre are as follows (The Aloe fibre grading and marking rules, 1975; Table 6).

Definition of Terms: 'Foreign matter' includes dust, lumps of earth, sticks, tangled mass of very short and weak pieces of

strand and skin waste and any other impurity; 'Harsh Fibre' means fibre which has become very hard or harsh due to improper extraction.

Uses of sisal

The main use of sisal fibre is for manufacturing of ropes and twines and other forms of cordage; although, considerable

A. East African sisal fibre grades

Grades	*Fibre length*	*Colour*	*Other features*
Grade 1	≥ 90 cm	Creamy white to cream	It should be free from defective decortication and be properly brushed. Free of undecorticated barks, harshness, knots, tousled and bunchy ends. It should be free of tows.
Grade 2	75-89 cm	Creamy white to cream	It should be free of defective decortication and be properly brushed. Free of undecorticated barks, harshness, knots, tousled and bunchy ends. It should also be free of tows.
Grade 3L	≥ 90 cm	Mixture of whitish and yellowish	It should be free of defective decortication and be properly brushed. Free of undecorticated barks, harshness, knots, tousled and bunchy ends. It should also be free of tows.
Grade 3S	60-89 cm	Mixture of whitish and yellowish	It should be free of defective decortication and be properly brushed. Free of undecorticated barks, harshness, knots, tousled and bunchy ends. It should also be free of tows.
Grade UG	≥ 60 cm	Brownish and spotted due to damaged leaf or greenish	Black coloured fibre is not allowed in this grade because this shows that it is in the process of rotting (or rotten). Moreover, fibre should be properly brushed, free of undecorticated barks, harshness, knots, tousled and bunchy ends. It should also be free of tows.
Grade SSUG	≥ 60 cm	Yellowish to more dark and blemished	This is the fibre that does not conform to standard UG grade but can be exported as line fibre.
Grade Tow No. 1	-	Creamy white to cream	This is fibre which has been cut and thrown behind the brushing machines during the process of brushing. It should be free of undecorticated barks, knots, dusts and sweepings and should not contain fibre of other mentioned grades.
Grade Tow No. 2	-	Brownish, spotted, yellowish or greenish	This is fibre which has been cut and thrown behind the brushing machines during the process of brushing. Moreover, fibre should be free of undecorticated barks, knots, dusts and sweepings and should not contain fibre of other mentioned grades.
Uncarded Flume Tow	-	Breamy white to light brown	Devoid of undecorticated strips of sisal leaf, rotten fibre and foreign materials. It should be properly dried with a moisture content similar to other grades. Dust content not to exceed 15% when extracted by hand.
Carded Flume Tow	-	-	It should be the same as uncarded flume tow, except the total dust content not to exceed 10%.
UHDS	-	-	Unwashed hand decorticated sisal, non-Estate produced fibre.

B. Madagascar sisal fibre grades

Grade	*Fibre length*	*Colour*	*Other features*
Grade 3L	≥ 90 cm	Mixture of whitish and yellowish	It should be free of defective decortication and be properly brushed. Free of undecorticated barks, harshness, knots, tousled and bunchy ends. It should also be free of tows.
Grade R	60-90 cm	Brownish and spotted due to damaged leaf or greenish due to insufficient water during decortication. Black coloured fibre is not allowed	Fibre should be properly brushed, free of undecorticated barks, harshness, knots, tousled and bunchy ends. It should be free of tows.
Grade D	≥ 60 cm	-	Fibres ranging from blemished to very blemished. Some undecorticated parts. Some fibre measuring less than 60cm.
Etoupe No. 1 (Tow No. 1)	-	Creamy white to cream	This is fibre which has been cut and thrown behind the brushing machines during the process of brushing. It should be free of undecorticated barks, knots, dusts and sweepings. It should not contain fibre of other mentioned grades.
Carded Etoupe	shorter than E1 Tow	Most part of the fibre is white	Carded means having passed through a carding machine to eliminate the majority of the fluff from the brushing. For the most part fibre is white but shorter than E1 Tow.

C. Brazil sisal fibre grades

Grades	*Fibre colour*	*Impurities*	*Other features*
Type 1	Whitish/ soft cream	Impurities level ≤ 1%	Humidity maximum 14% without knots.
Type 2	Cream/ yellowish	Impurities level ≤ 3%	Humidity maximum 14% without knots.
Type 3	Cream/ yellowish	Impurities level ≤ 5%	Well brushed, humidity maximum 14%, without knots.
Refuge (Reject)	Brownish/ green	High % of impurities	Humidity maximum 14%, presence of knots and
Bucha (Tow)	Yellowish/ brownish	Very high level of dust	Humidity maximum 14%, presence of knots and a

amount of fibre are also utilized for padding and upholstery and mats as well as for bags and sacking. More uses includes sausage casings, reinforced plastics and building boards, carpets, crafts and speciality papers, different types of nets and brushes, straps of different use, ladies fancy purses and belts. Microcrystalline cellulose (MCC) derived from sisal are as good as other industrial MCCs used in medicine industry. Sisal plant parts contain 0.05-0.14% hecogenin, a glycoside of commercial importance (Sarkar *et al*., 2010). The most important use of sisal fibre is in manufacturing of binder-twines. In Madhya Pradesh, aloe fibre was used in jails for manufacture of *newar*, tat beds, pile rugs etc. In Bombay (now Mumbai) area, sisal fibre were used for manufacture of loosely woven bags for transportation of seed cotton to the market or ginning factory (Ray, 1952). Central Coir Research Institute, Kerala shown that sisal can be blended with coir in 80:20% ratio to make coir more useful in diversified products. It was reported that normal coir gave an average of 240 m of coir yarn a kg, while the coir-sisal blend produced 1300 m a kg; so this made the yarn fine and light for application in new areas (Anonymous, 2007). Corrugated fibre board boxes can be made from sisal which is cheaper (3.50/per box of 220 x 110 x 180 mm dimension) than wooden packs (5.75) (Ambrose and Devadas, 2009). The hydrolysed and filtered extract of agave leaves containing *Zymomonas mobilis* could be used for production of 5% ethanol (Murugan and Rajendran, 2013).

Sisal (*A. americana*) roots have a very good soil binding factor for the abandoned limestone mines of Dehradun than number of trees and shrubs available in Dehradun. So, sisal can be one of the suitable species for soil conservation in order to rehabilitate degraded mine sites (Dadhwal and Singh, 1993). In recent past (2000-2003) experiment conducted in Bellary district of Karnataka showed that *Agave sisalana* is efficient in reducing runoff by 34.6%, soil loss by 61.9% and conserve 16.4% more soil moisture over control (Math *et al*., 2006). Plant extract of *A. americana* was effective in reducing mycelial growth of the fungi (*Fusarium* and *Pythium*) causing yellows and rhizome rot disease of ginger (Sharma, 1998). It was reported from Maharashtra that *A. cantala* leaf extract was found to be beneficial in controlling downy mildew infection of grape leaves (Naik and Bartakke, 2009). Some preliminary experiments reported that Agave leaf extract could able to resist termite and borer attack in bamboo, but found to be ineffective in preventing growth of mould fungi (Lepcha and Kumar, 2008). It was reported that for developing strategy for conservation of biodiversity, afforestation with multi-utility plants such as *Agave sisalana* (and some others) need to be considered because of all its virtues and popularity among people for its usefulness (Kawalekar, 2014).

Economic benefits

In case of sisal plantation, out of the total cost of cultivation, 50% goes to harvesting, decortication and extraction followed by fertilizer (24%), land preparation & weeding (12%), planting material (6%), fibre processing (5%) and fertilizer application (3%). In a field experiment conducted for 12 years cycle of sisal plantation (from 1967-68 to 1978-79) in Odisha revealed that the average net profit was 1107/ha/year during that time (Singh, 1983). It was reported that for an 8 years period of sisal plantation, the net profit at the end of 8th year might be in the range of 27034 to 44290/ha (Singh and Bisaria, 1994). Roy (1958) reported that sisal (*A. sisalana*) if properly exploited can bring good income for the farmers of specific region of West Bengal (most arid areas). It was also opined that more arid areas of India can be put under sisal with profit. During sixties, sisal (*A. sisalana*) plantation was established in the Latehar area of Bihar. From a 10 year cycle it was revealed that cultivation of sisal commends itself as a very attractive economic proposition for that area of Bihar (Shah, 1974). If proper strategy is adopted by the concerned agencies involving Government departments, bankers with participation of NGOs and people themselves, sisal plantation can improve the impoverished economy of people by generating primary as well as supplementary income/ employment opportunities (Karmakar, 2002).

Social benefits/ employment opportunity

Sisal generates a 3-tier system of work opportunities for work-force, in the field for sisal crop production, second in the sisal fibre extraction stage and thirdly in manufacturing. Growth and processing of sisal by tribal people and their assured market at attractive prices by entrepreneurs with extraction units, appears to be a better avenue for both tribal farmers and entrepreneurs (Karmakar, 2002). During sixties, sisal (*A. sisalana*) plantation was established in the Latehar area of Bihar. The study also opined that the degraded and deteriorated forest land can be put to a productive and profitable use by growing sisal on it, decrease unemployment and better manage under-employment and increase earnings of the weaker section of the society (Shah, 1974). Sisal plantation activity alone has an employment potential of about 113 man days/ha for the rural poor. Moreover, it was suggested that if only 20% of the wasteland of Madhya Pradesh is used for sisal plantation, enormous employment potential of 339 million man-days could be generated from cultivation and fibre extraction (Srinivasakumar *et al*., 2013).

Conclusion

Sisal fibre has a bright prospect for its versatile nature encompassing eco-friendliness, suitability for moderate waste lands, apt for changing climatic situation due to low water requirement, high water use efficiency (CAM plant), survival & economic output even in very high ambient temperature; it puts minimum pesticide load to the environment through its cultivation process, being semi-perennial and lower agro-activity it conserves soil. Sisal is the most viable option for employment opportunity and rural economic development in the tribal dominated and socio-economically less developed parts of the country; vast arena of sisal based composites with targeted characteristics, sisal based geotextiles having edge over others due to presence of higher strength and waxy material impregnated and a bunch of engineering applications and many more. If the full potential of agave plantation is utilized, it will be of immense help in uplifting the economic conditions of the tribals living around the forest areas in India (Chaudhari and Goel, 1993).

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