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Review Article

EFFICACY OF COIR PITH AS A CARRIER FOR MICROBIAL FORMULATIONS IN AGRICULTURE: A REVIEW

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ABSTRACT

A superior formulation should provide the optimum number of beneficial microbes in good state to the soil or rhizosphere or the plant. Currently, a rising trend has been observed in the application of biological alternatives to lessen the lethal effects of chemical fertilizers and pesticides. In this regard, several beneficial microbes such as mineral solubilising bacteria (viz. KSB, PSB, ZSB etc.) and plant growth promoting rhizobacteria (PGPR) have played a huge role. But these microbes cannot be used directly. In search of efficient microbe delivering solutions, a number of organic and inorganic carriers have emerged in due course of time that act as vectors for the microbial inoculant and constitute the main bulk of any carrier based bioformulation. This review will highlight the multifarious uses of coir pith in diverse fields ranging from industries to agro- horticulture and emphasise on its potential use as a suitable carrier for microbial formulations.

INTRODUCTION

From the commercial point of view, efficacy of beneficial microbes in the field of agriculture lies in its attainability to develop it into a formulation on an appropriate carrier or substrate. Usually, a formulation is a mixture of an active ingredient with inert (inactive) ingredients where the other ingredient can be a solvent, carrier, adjuvant or any other compound which is intentionally added (Label Review Manual, 1998). A suitable carrier material is generally inert, assists the growth of active ingredient or living cells, assures their easy establishment in and around the root microcosm of the plant and increases the likelihood of enhancing plant growth or disposing target pests (Arora *et al.*, 2016). In order to be functional, a biocontrol agent must be vigorous enough to endure formulation and storage, and must be a competitive and persistent colonizer after inoculation (Beatty and Jensen, 2002; Selim *et al.*, 2005). Formulation of biocontrol agents helps in alleviating the organisms during production, distribution and storage, assist in the management and application of the product, protect the inoculants from external agents and improve their activity (Burges & Jones, 1998). Implementing several antagonists showing different modes of action may improve biocontrol efficacy of any product under a broad range of environmental situations (Pal and McSpadden Gardener, 2006). Nevertheless, the availability of high-quality formulations of bioeffector agents largely determines the success of biocontrol methods of plant diseases (Ashofteh *et al.*, 2009). While the development and use of bioformulations with these beneficial microorganisms have seen an upward trend in the last few years, in a broader viewpoint, the growth has not been up to mark, predominantly in the developing countries.

Microbe-based formulations or bioformulations are more efficient than their synthetic or chemical counterparts in the sense that a single microbe based formulation product may undergo direct interactions with pathogens, and take part in disease suppression and plant growth promotion through numerous mechanisms (Mendes *et al*. 2011). As pointed out by Jayaraj *et al*. (2005), the use of talc or bentonite combined with bacterial antagonists may improve its effectiveness in suppressing *Fusarium* induced tomato damping off disease. Works of Ardakani *et al*., (2010) showed that the efficacy of bentonite and peat based carrier formulations were more effective (between 1.42 to 1.92 fold) than commercial carboxin-thiram fungicides in reducing damping off of cotton seedlings. Microbe based biofertilizers are usually prepared as carrier-based inoculants that hold the effective microorganisms, either from a single strain or as a consortium. The nature of the

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carrier material determines the success of application of a biofertilizer since incorporation of microorganisms in the carrier material enables easy handling, long-term storage and high effectiveness of biofertilizers (Tensingh Baliah *et al*., 2015). Examples of such successful formulations include those of *B. subtilis* and *P. fluorescens* which are now commercially available (Jayaraj *et al*., 2005). Up till now, dry bioformulations made from different carriers such as peat and talc harbouring many beneficial microbes have been marketed (Mathivanan *et al*., 2005; Gnanamanickam, 2009). Various kinds of carrier material formulations are widely used in biological control in different ways such as solid form (granules), flour and suspension (Sridhar *et al*., 1993; Ardakani *et al*., 2009). To be an effective carrier, it must be economical and readily available for formulation development (Jeyarajan and Nakkeeran, 2000; Arora *et al*., 2016). Before developing a biofertilizer it should be kept in mind that the carrier material to be selected should be a cheap one, otherwise it may not be popular among the farmers in poor countries. Several commercial formulations, especially, *Trichoderma* prepared using inert carriers for plant disease control are costly and have short shelf life (Mohanan *et al*., 2013). Various plantation crop wastes and by-products such as coir pith, coffee husk, tea waste, areca nut leaf sheath and dried husk, cocoa pod husk and bean shell that are cheap as well as easily available were found to be suitable carriers for microbial inoculants (Kousalya and Jeyarajan, 1990; Ponmurugan and Baby, 2005).

Several groups of beneficial bacteria, especially PSB, KSB and PGPR are considered as efficient microbial competitors in the soil-root zone. Moreover, the use of these microbes for reducing the impact of agro chemicals is a highly important issue as they have gained world-wide significance and recognition for sustainable agricultural benefits. Globally, the application and commercialization of PGPR for sustainable agriculture is a fast growing and demanding market. However, availability of these microbes for the use of common farmers is still inadequate. The main disadvantage in achieving the agricultural sustainability has been the failure of PGPRs to be commercialized effectively due to several factors including climatic, environmental as well as plant-microbe-soil interactions that may be species-specific or niche-specific (Maheshwari *et al*., 2015). The indigenous naturally available eco-friendly substrate and carrier materials for microbial formulation are urgently needed in the field of agriculture. Currently, there is an active and growing group of researchers working on their fundamental and applied aspects. This review will focus on the feasibility of using coir pith as a carrier with microbial inoculants for marketable use and biocontrol of plant pathogens in future, as seen from an industrial formulation-development perspective.

Coir pith as a carrier

Coco peat, also known as coir pith, coir fibre pith, coir dust, or simply coir, is obtained from coconut husk that surrounds the shell of the coconut. Coir pith is collected during the extraction of coir husk, which form the largest by product of coconut industries. Coco peat primarily consists of the coir fibre pith or coir dust which is obtained by processing coconut husk and removing the long fibres. Following proper processing, coir pith is composted to reduce the bulkiness as well as its lignin, cellulose and C: N content. The composted coir pith thus obtained can hold large quantities of water like a sponge, thereby aiding in moisture retention and relieve the plants from excessive dehydration. Thus it can be used as a replacement for traditional peat in soil mixtures, or, as a soil-less substrate for plant cultivation in horticultural and agricultural practices. Coco peat is widely applied in seed germination, nursery beds, cultivation of stem propagated plants, hardening of tissue cultured plants, lawn making, soil amelioration, easy initiation of rooting in plants, and so on. (Bavappa and Gurusinghe, 1978; Karun *et al*., 1999, Rao, 1999). Experiments of Offord *et al*. (1998) with some native Australian plants like *Pultenaea parviflora*, *Brachyscome* sp. and *Callicoma* sp. led to the observations that coir pith can be used as a suitable alternative to peat. They prepared propagating mixes from peat, coir, perlite and sand with peat-perlite-sand as control and coir-perlite-sand as treatment for stem propagation of the aforesaid plants. Results obtained after a 14-month trial indicated that the growth parameters viz., plant dry weight, number of branches and leaves, growth of root and shoot were similar in both coir based and peat based mixtures, thereby proving their equivalent efficacies.

The idea of using coir pith as a carrier for effective microorganisms can be traced back to as early as 1956 when *Rhizobium* inoculated coir pith was applied in the legume cover crops of rubber plantations in the Rubber Research Institute of Malaysia (Prabhu and Thomas, 2002). Later, many researchers (John, 1966; Iswaran, 1972; Faizah *et al*., 1980; van Nieuwenhove *et al*., 2000) working with coir pith agreed to its feasibility and confirmed this finding. As per the findings of Prabhu and Thomas (2002), research at CPCRI has led to the observation that composted coir pith can be utilised as a good carrier material of beneficial microbes such as *Beijerinckia, Azospirillum, Herbaspirillum, Arthrobacter* and *Bacillus* during the preparation of biofertilizers. Malliga *et al*. (1996) reported that N_2 fixing cyanobacteria *Anabaena azollae* inoculated to coir pith sporulated profusely, and hence it can be used as an inexpensive cyanopith fertilizer in paddy fields. The development of economically feasible and efficient bio-control product using locally available agricultural by-products like coir pith, for the application of appropriate microorganisms to the ecosystems is an important component of bio-control programme as well as for the effective utilization of agricultural wastes. The native microflora in coir pith that includes *Aspergillus niger*, *Streptomyces* sp., *Penicillium* sp., *Trichoderma* sp. and *Bacillus* sp. provide NPK enrichment on pot culture experiments and also facilitate easy movement of roots, thereby increasing growth of plants (Soumya, 2011).

Advantages of coir pith over conventional carriers and its contribution to plant growth

Coir pith, if used after proper composting, can be a source of many desirable characteristics making it a highly potential carrier. Coir pith has very high moisture retention capacity, high organic matter content, high cation exchange capacity (CEC), high contents of lignin, cellulose, hemicelluloses, high contents of exchangeable P, K, Na, Ca and Mg and a high capacity to retain large amounts of nutrients. (Verhagen and Papadopoulos, 1997; Evans *et al*., 1996; Abad *et al*., 2002). Although raw coir pith may not be a rich source of nutrients, proper composting and addition of specific nutrients and cultures of beneficial microbes may render it functional by enhancing the availability of nutrients. Such enrichment techniques can have manifold effects on enhancing the quality of coir pith compost, thereby influencing plant growth and soil conditions (Prabhu & Thomas, 2002). Apart from using organic sources such as cowdung slurry, green manure and coffee husk (Vijayalakshmi *et al*., 1989; Moorthy *et al*., 1996; Anand *et al*., 1999) enrichment of coir pith is also possible by addition of effective microbes like *Trichoderma, Azotobacter* and phosphate solubilising bacteria or PSBs (Moorthy and Rao, 1997) for achieving an improved biofertilizer. These techniques increase the effectiveness of using coir pith as a carrier over conventional carrier materials and this can be supported by the works of various researchers.

Table 1 Some common carrier based formulations investigated in relation to microbial disease management in plants.

Carrier (organic/ inorganic)	Microbes inoculated	Plant species	Disease suppressed	References
Bentonite, talc, rice bran and peat	*Pseudomonas fluorescens*	Cotton (*Gossypium* spp.)	Damping off of seedlings by *Rhizoctonia solani*	Ardakani *et al*., 2010
Skimmed milk	(i) *Candida oleophila* (ii) *Pseudozyma flocculosa*	(i) Citrus plants, apples, pears (ii) Greenhouse roses and cucumbers	(i) Postharvest decay caused by *Penicillium* sp. and *Botrytis* sp. (ii) Powdery mildew	(i) Droby *et al*., 1998 (ii) Punja and Utkhede, 2003
Talc and peat	(i)*Pseudomonas fluorescens* (ii) *Pseudomonas fluorescens* A506 (iii)*Pseudomonas syringae* ESC-100	(i) Chick pea (ii) Apple, almond, cherry (iii) Citrus and pome fruit yielding plants	(i) Wilt caused by *Fusarium oxysporum* (ii) Bacterial and fungal postharvest decay	(i)Vidhyasekaran and Muthamilan, 1995 (ii) Stockwell and Stack, 2007
Neem and chitin	*P. fluorescens* pf1 and *Bacillus subtilis*	Chilli	Fruit rot and dieback caused by *Colletotrichum capsici*	Bharathi *et al*., 2004
Vermiculite and sawdust	*P. aeruginosa* KRP1 and *B. licheniformis* KRB1	Indian mustard	Wilt caused by *Fusarium oxysporum* and cottony rot by *Sclerotinia sclerotiorum*	Maheshwari *et al*., 2015
Talcum and vermiculite	*P. fluorescens* R62, R81and *Piriformospora indica*	Tomato	Wilt caused by *Fusarium oxysporum*	Sarma *et al*., 2011
Talc	*P. fluorescens* Pf1	Groundnut	Leaf spot by *Cercosporidium personatum* and rust by *Puccinia arachidis*	Meena *et. al*., 2002
Talc, lignite, fly ash, bentonite, polyethylene glycol, gelatine-glycerin	*Trichoderma harzianum* M1	Tomato	Damping-off by *Pythium aphanidermatm*	Jayaraj *et. al*., 2006
Talc and kaolin	(i) *Metschnikowia pulcherrima* and *Pichia guilliermondii* (ii) *P. fluorescens* SP007	(i) Citrus plants (ii) Rice	(i) Post harvest decay caused by *Penicillium* sp. and *Geotrichum* sp. (ii) Dirty panicle disease caused by *Alternaria* sp., *Cercospora* sp., etc.	(i) Kinay et. al., 2008 (ii) Prathuangwong et al., 2013
Wood flour	*Bacillus* spp. and *P. fluorescens*	Cantaloupe	Root rot by *Fusarium solani*	Sallam Nashwa *et. al*., 2013
Talc and rice bran	*Trichoderma* spp. and *Fusarium concolar*	Cantaloupe	Damping off by *Fusarium semitectum*	Sallam Nashwa *et. al*., 2014
Vermicompost	*Streptomyces sannanensis*	Tea	Bird's eye spot caused by *Cercospora theae*	Gnanamangai and Ponmurugan, 2012

According to the works of Ramalingam & Ranganathan (2001), the shelf life of *Azospirillum* was higher in composted coir pith followed by vermicompost. Among the different tested formulations, coir pith formulation significantly increased the plant fresh weight, dry weight, root length, leaf chlorophyll, free amino acid and protein content, followed by vermicompost formulation and least in lignite formulation. Works of Kumar and Marimuthu (1994) and Ramamoorthy *et al*. (1999) suggest antifungal activities of coir pith and indicate towards its importance in the field of integrated pest management in the future. Combined effect of basal and foliar application of coir pith based cyanobacterial biofertilizer had positive impact on the growth, stem circumference, number of leaves, flowers and branches of *Basella rubra* L. (Abraham Christopher, *et al*., 2007). As per the experimental results of Bagyalakshmi and Balamurugan (2012), three day old cultures of *Azospirillum lipoferum*, *Pseudomonas putida* and *Burkholderia cepacia* were colonised well in coir pith formulation when compared to vermicompost. During incubation period, PGPR organisms started to establish in both carrier materials gradually and they reached the maximum population on 30th day of incubation. After that the population of PGPRs started reducing gradually with the increase of incubation period. Furthermore, coir pith formulation supported maximum growth of *P. putida* than other PGPRs (38 x 10^7 CFU g^{-1}). Works of Meerow (1994) indicated that growth index, shoot and root dry weights of *Pentas* sp. and *Ixora* sp. were significantly better in coir based medium than sedge-peat based medium. According to the observations of Noguera *et al* (1997), pot experiments conducted with *Calendula officinalis* and *Coleus blumei* showed better growth and increased shoot fresh weight when grown in coir based medium as compared to *Sphagnum* peat and vermuiculite based potting mixture. Manoharan *et al*., (2010) reported that the application of coir pith based cyanobacterial biofertilizer can increase the growth and biochemical parameters of *Amaranthus dubius.* Saravanan *et al*., (2012) conducted nursery experiments to assess the effect of *Frankia, Azospirillum* and *Phosphobacterium* in decomposed coir pith as substrate on the growth performance of *Casuarina equisetifolia* seedlings and observed enhanced growth and biomass, protein, chlorophyll and nutrient content.

Compatibility studies of coir pith with fertilizers

Coir pith boosts the survivability of biofertilizers applied to the soil as the addition of coir pith enhances the aeration and moisture holding capacity of the soil, thereby enabling plants to derive more benefits from the association (Prabhu and Thomas, 2002). Results show that the input of *Rhizobium* biofertilizers along with composted coir pith give better nodulation and yield in pulses (Prabhakaran and Srinivasan, 1995; Jayakumar *et al*., 1997).

green manure and bioinoculants were found to be the most effective in increasing the growth and biomass of seedlings. Increase in shoot length, higher concentrations of protein (1.59mg/g),

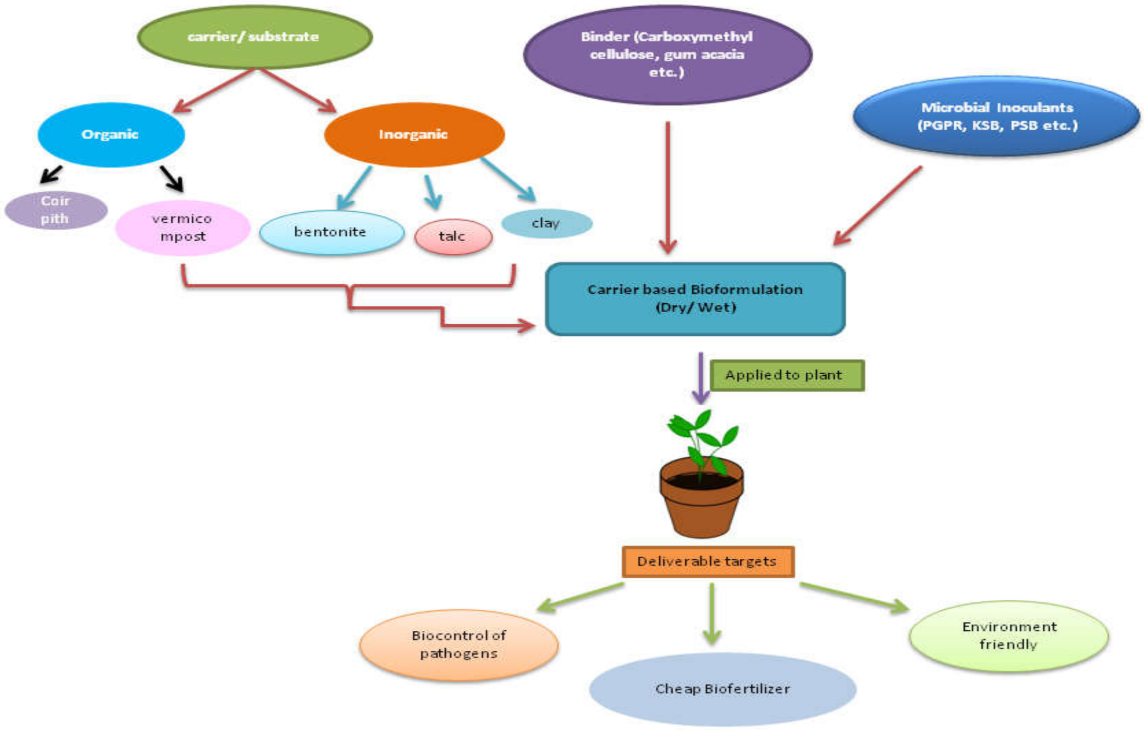

Fig 1 Stepwise preparation of a carrier based bioformulation and its role in supporting plant growth and development.

Rajalingam and Kumar (2001) evaluated the effects of digested coir pith compost and biofertilizers on the quality of tea soil and yield percentage of three cultivars of tea viz., Assam Jat, China Jat and ATK clone. Treatments were incorporated using composted coir pith at 3 and 6 tonnes/ha alongwith biofertilizers, namely PGPR (*Azospirillum lipoferum*), Phosphobacteria (*Bacillus megaterium*) and VAM fungus (*Glomus fasciculatum*), each at 40 kg/ha in addition to commercial fertilizers. Results revealed higher green leaf yield in different treatments containing composted coir pith and biofertilizers either alone or in combination with full or reduced dose of commercial fertilizers. The study indicated that co-inoculation of composted coir pith and biofertilizers may be helpful in improving the green leaf yield and also the physical, chemical and biological properties of tea soil. Reghuvaran and Ravindranath (2010) conducted pot experiments on some medicinal plants (*Bacopa monnieri*, *Andrographis paniculata*, *Phyllanthus niruri* and *Piper longum*) using a composted mixture of coir pith, *Pleurotus sajor caju*, *Acetobacter*, *Azospirillum* and urea. Results revealed that plants grown in pots containing higher percentage of coir pith had increased root and shoot length. Similar results were obtained in terms of total carbohydrate and chlorophyll content. Higher concentrations of carbohydrate and chlorophyll were noted in the coir pith-bioinoculant-urea based mixture when compared to control. Murugesan *et al*. (2016) recorded the growth performance and biomass data of *Eucalyptus* seedlings grown in coir pith and vermiculite based potting media and observed that the co-composting of coir pith and vermiculite based media with farmyard manure, vermicompost, effluent compost, carbohydrate (1.78mg/g), chlorophyll (1.41mg/g), N (0.22mg/g), P (0.76mg/g), K (3.98mg/g) and phenols (4.73mg/g) were estimated in the leaves of the *Eucalyptus* seedlings grown in the coir pith based potting media, as compared to vermiculite based media and control.

Current Status and Future Prospects

Owing to increasing price of chemical fertilizers coupled with environmental hazards related to their use as well as with the gradual shift towards green farming, a rising interest has been seen during recent years to utilize coir pith in agriculture (Prabhu and Thomas, 2001). Composted coir pith being rich in aromatic polyphenols may find utilities in integrated pest management as composts having a good percentage of tannins and polyphenols are known to suppress phytopathogenic nematodes (Mian and Rodriguez-Kabana, 1982). According to Baskaran and Saravanan (1997), absolute coir pith used as a potting medium showed considerable increase in water holding capacity of potting mixture when tomato plants were grown on coir pith based potting substrate. Besides being an excellent soil conditioner it is rich in plant nutrients like Ca, K, Mn, Fe, Mg, Zn etc. and is currently used in a vast extent as a soil-less medium. A mixture of coir dust and soil has been used as a potting substrate for orchids in many nurseries and green houses of India. Due to its high porosity and mineral content, it can be used as an alternative substrate for cultivation of edible mushrooms. Although extensive efforts are being made for the commercialization of coir pith based bioformulations, it is yet to attract widespread industrial adoption. Certain factors inhibiting the widespread industrial application of the bioformulation technology as noted by various researchers (Nakkeeran *et al*., 2005, Jeyarajan and Nakkeeran, 2000, Duffy *et al*., 1996, Guetsky *et al*., 2001) working in this field include:

1. Slow commercial availability and difficulty in obtaining a reliable supply of inexpensive bioformulations.
2. Lower shelf life of the bioformulations.
3. Non specificity and non selectivity of the microorganisms to the carrier.
4. Difficulty in maintaining effective number of microbes in the formulation.
5. Negative effects of co-existing microbes on bioformulation capacity.

Bioformulation development in the current scenario requires rigorous collaborative research effort of microbiological as well as technological aspect (Arora, 2015). For example, if immature coir pith is applied to soil, it will undergo decomposition by taking up nutrients after entering into the soil, thereby affecting the standing crops. Furthermore, the carrier material determines the shelf life and survival of a particular microbial inoculum in the soil. The survival of the microorganism is very important in the field of biofertilizer production and application because the inoculant should have the most favourable population in the root region of target crops for optimal growth of the plants. Therefore, it is important to note that prior to formulation development and application, it is necessary to understand the ecology of the PGPR-host-pest interaction (Barea, 2015).

CONCLUSION

The success rate of application of biofertilizers is mainly dependent on the delivery system or nature of carrier material as it determines the positive efficacy of the inoculants present in it. Beneficial microbes have gained widespread popularity in the agriculture sector owing to their remarkable ability in improving plant growth and development and thus have surfaced as the rising trend amongst modern agro techniques for sustainable development. Though immensely beneficial with a huge potential for wide applicability, rapid commercialization has been lacking due to unavailability of appropriate carriers and formulations. It is, therefore, the need of the hour to initiate and develop new research ideas and come up with better solutions for an integrated biocontrol and ecologically safe technology.

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