account the challenges faced by the nuclear industry today.

With safety of the nuclear plants being a major public concern, are there safer options to the present-generation power plants? The GEN-IV project is an international initiative by the nuclear industry to specifically address this issue. While India has not been a participant in this initiative so far, the recent developments certainly open the doors for India's participation. Fusion power has always been seen as a safer option to harness nuclear power, but has not yet matured in spite of several decades of research. The international ITER project is a collective effort to take a step forward in this technology. Thanks to the Indo-US deal, India is now a formal member of the ITER team. Accelerator-driven sub-critical reactors (energy amplifiers) is yet another concept that has been in the blackboards of research laboratories for a couple of decades. These systems are inherently safe compared to the traditionl reactors (controlled bombs). Fuelled by thorium, they also have unique advantages in spent fuel processing. Unfortunately, their engineering aspects, and more importantly, their commercial aspects are totally unexplored. India has a rich experience in handling thorium fuel with one U-233 reactor in operation and one power reactor in an advanced design stage. India has also been participating in several high-energy accelerator facilities across the world and collaborating with several accelerator laboratories. With India's commitment to thorium utilization for electricity, I believe that it is time for the country to launch a time-bound technology demonstration project on thorium-fuelled accelerator-driven sub-critical system for electricity generation and invite international partners.

Let me end with a little bit of day-dreaming. It has been suggested (by Buckminster Fuller) several decades ago that interconnection of electric power networks between regions and continents into a global energy grid (a worldwide web of electricity) can be an effective strategy to address the common aspiration of electricity on demand anywhere, anytime. While this suggestion was made in the context of tapping the abundant renewable energy resources across the globe, there exists a strong justification for integrating nuclear power into such a global electricity grid. This will of course call for international cooperation on an unprecedented scale, as well as, putting all nuclear assets under an international consortium.

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Essential oils of traditionally used aromatic plants as green shelf-life enhancers for herbal raw materials from microbial contamination and oxidative deterioration

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This commentary deals with recommendation of essential oils of selected traditionally used aromatic plants as shelf life enhancer of herbal raw materials in view of their efficacy to protect them from microbial and mycotoxin contaminations and oxidative deteriorations during post-harvest processing. Such documentation of pharmacological efficacy of traditionally used aromatic plants would be also helpful in bioprospection of plant diversity against the act of biopiracy.

India is a megabiodiversity country enriched with about 18,500 angiospermic species, out of which 9000 are of medicinal value. Such a large percentage of medicinal plant species is not found in any other mega biodiversity-rich countries. Use of herbal drugs in India is an age-old practice. Knowledge of ancient Indian herbal species was disseminated to the world through different routes like trade relationship with Mesopotamia, Gulf countries and Iran; cultural relationship with Arabia, Tibet and China; sites of knowledge like Nalanda and Taxila University; external scholars like Fahiyan, Ywan Chwang and Al Baruni, and also through invaders. According to a report by the World Health Organization, the present market of herbal drugs is 14 billion USD, which would reach approximately 5 trillion USD by 2050. People are getting attracted continuously towards herbal drugs because of their lesser side-effects, and frequent reports on the development of resistance against single molecule-based antibiotics. India's share in the world market of medicinal plants and products is a merely 2.5%. The main reason for this low percentage share in global herbal market is unscientific harvesting practices which have led to degradation in both quality and quantity of raw herbal drugs. In addition, tropical geography of the country is conducive for microbial growth and due to improper post-harvest processing, there are chances of microbial contamination of the herbal raw materials. The Indian forests, which are the major suppliers of herbal drugs, also act as nursery of phyto-pathogens. During post-harvest processing a number of pathogenic fungi and bacteria get associated with herbal raw materials, which consequently degrade them. Moulds produce hydrolytic enzymes: lipases, proteases and carbohydrases, as well as some volatiles such as dimethyl disulphide, geosmin, and 2-methyliso-borneol, which are responsible for the deterioration of sensorial properties of the raw materials resulting in loss of their quality. Host–pathogen interaction also adversely affects the active principle of the medicinal plants; sometimes the beneficial component gets converted into a harmful one[1].

Most of the storage fungi are toxigenic and the mycotoxins secreted by them significantly degrade the quality of raw herbal drugs causing serious health hazards to the consumers. Among different mycotoxins, aflatoxin B_1 possesses highest potency to cause mammalian toxicity. In developing countries about 4.5 billion people are systematically exposed to aflatoxins, which cause aflatoxicosis resulting into abnormal liver chemistry, carcinogenesis, reduced immune response and even death. The conditions like high temperature, high moisture content, poor storage practices, prolonged storage and traditional processing methods are conducive for fungal attack. Among different fungi, the dominance of aspergilli, particularly *Aspergillus flavus*, is of much importance due to secretion of high levels of aflatoxins. Drug formulation from aflatoxin-contaminated raw materials would be equally harmful as aflatoxins. Aflatoxin and its metabolites, particularly aflatoxin B_1 (AFB1)-8, 9-exoepoxide, also give rise to oxidative stress resulting in an increase of toxic reactive oxygen species leading to lipid peroxidation and cellular damage in herbal raw materials[2]. Hence, during storage herbal raw materials face the risk of lipid peroxidation, resulting in the generation of enumerable free radicals into the system. Lipid peroxidation is a complex phenomenon occurring in aerobic cells and reflects interaction between oxygen and polyunsaturated fatty acids, thereby reducing the shelf life.

An ideal preservative should have antimicrobial, antiaflatoxigenic and antioxidant properties for preventing quantitative and qualitative spoilage; it should also possess a favourable safety profile. Physical treatments such as heat therapy, low-temperature storage and radiations have their own limitations. The application of synthetic preservatives to control fungal propagation would not be appreciated by consumers, pharma industries and regulatory authorities due to their negative health issues, residual toxicity and safety concerns. Benzoic acid, sulphur dioxide, sodium nitrite, sorbates, ethylenediaminetetraacetic acid, citric acid and butylated hydroxytoluene (BHT) are some of the examples of synthetic preservatives commonly used for enhancing the shelf life of edible materials, but their full compatibility with the human system is still in question. Moreover, sulphur dioxide causes breathing difficulties; sodium nitrite[3] and BHT[4] are reported to be carcinogenic. Hence, due to their side-effects synthetic preservatives are not suitable for enhancing the shelf life of herbal raw materials. In recent years, safe natural preservatives are thought to be better alternatives.

Traditionally, herbal drugs were utilized in the form of mixture of different plants. Some of these plants act synergistically as bioenhancers for elevating bioactivity of the herbal drugs, resulting into accelerated efficacy. Some plants protect their degradation with the help of compounds like phenolics, flavonoides, quinones, tannins and terpenes, which are produced by them during different metabolic activities. This principle of utilizing plant products for plant health itself may be adopted during post-harvest processing of medicinal plants against the deteriorating microbes. Plant-based preservatives are biodegradable, renewable, safe for non-target organisms and have diverse biological effects, thereby providing less chance of resistance development to microbes. Such plant-based preservatives were in common use before 1940s, but their utilization decreased due to emergence of highly effective and cheaper synthetic preservatives. However, the present time demands some green options for preservation of pharma products and food items. A spectrum of plant-based antimicrobial compounds, viz. pyrethrum, sabadilla, carvone, rotenone[5], limonene and, most importantly, neem products is currently being used in agro-industries. Different essential oils (EOs) extracted from plants play the same role but warrant extra attention as preservatives in the form of fumigants due to their volatile and ephemeral nature, less chance of residual toxicity and their activity in vapour phase instead of direct contact.

Essential oils are one of the major secondary metabolites of plants having broad antimicrobial, antifungal and antimycotoxic actions. Some of the plant EOs, viz. thyme, turmeric, sage, oregano, clove, tulsi, musk, cumin, lemon grass, etc. show biological activity against pathogenic bacteria, moulds, viruses, insect and oxidative deterioration[6]. Raw herbal drugs may be fumigated during storage by the EOs, which may be easily removed by simple sun-drying during formulation. Different EOs of higher plants have been used in flavouring, seasoning and sometimes as preservatives, around the world, especially in biodiversity-rich countries. EOs have long been considered to possess antimicrobial properties and have been effectively used in the indigenous systems. Since the Middle Ages, EOs have been widely used for bactericidal, virucidal, fungicidal, antiparasitical, insecticidal, medicinal and cosmetic applications. In addition, they have been reported to possess strong antioxidant property which prevents the loss of herbal raw materials through lipid peroxidation[7]. In the last few decades different pharmaceutical, sanitary, cosmetic, agricultural and food industries have paid attention towards EOs in place of synthetic oils to improve shelf life and quality of their products because of their potent antimicrobial and antioxidant activities[8,9]. Being natural in origin, EOs and their components are considered environment-favourable, user-friendly and are generally exempted from toxicity data requirements by the US Environment Protection Agency.

Most of the plant EOs are kept in 'generally regarded as safe' category by US Food and Drug Administration which validate their use as preservative in consumable items. A large number of EOs and their combinations, viz. *Citrus sinensis*, *Citrus maxima*[10], *Aegle marmelos*[11], *Thymus vulgaris*, *Ocimum canum*, *Apluda mutica*, *Ocimum sanctum*[12], *Cymbopogon khasans*, *Cymbopogon martini* and *Ceasullia axillaris*[7] have already been recommended as shelf-life enhancers of herbal raw materials. In the last few decades some EOs-based industries have been established in the European countries and researchers have introduced some EO-based preservatives like 'DMC Base natural' (50% EO from rosemary, sage and citrus and 50% glycerol) and carvone, a monoterpene of EO of *Carum cavi*. Efforts have also been made for enhancing practical applicability of EOs through their microencapsulation with different polymers to prevent them from oxidative damage as well as to facilitate their controlled release during storage. This technique also reduces the dose of EO as preservative. Regarding antifungal mode of action of EO, the major site of action is the plasma membrane as confirmed through various analyses, including transmission electron microscopy[13]. Being lipophilic in nature, EO accumulates in the plasma membrane, causes swelling of the membrane and makes the membrane proteins inefficient due to increased membrane disorder. This ultimately causes leakage of cell contents and inhibition of cell growth[13].

Based on favourable safety profile and organoleptic parameters, the EOs of selected traditionally used aromatic plants have potential in value addition of herbal raw materials and as a possible bioresource to protect them from microbial and oxidative deteriorations, and in the enhancement of their shelf life in view of antimicrobial, antimycotoxin and antioxidant activities. India is country of rich traditional knowledge on ethnobotanty which has not been properly recorded. The documentation of pharmacological efficacy of traditionally used aromatic plants would be helpful in bioprospection of plant diversity against the act of biopiracy.

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