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Review

Potentials of the Underutilized Kei-apple (*Dovyalis caffra* L.): Beyond its Nutritional and Functional Value

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Abstract: Kei-apple (*Dovyalis caffra* L) is an indigenous fruit tree of southern Africa. It is currently found in the dry, wooded grassland and forest edges of the arid and semi-arid regions of the world. Existing literature have mainly focused on the medicinal and nutritional as well as phytochemical characterization of Kei-apple. Thus, this review highlights beneficial economic prospects of *Dovyalis caffra* and its contribution to the economic prosperity. It is a drought tolerant plant with diverse uses such as income from the sale of the fruit, cultivated as a fence or to form an impenetrable hedge while the leaves are used for nutrient leaching prevention, fodder and compost making. The trunk of *Dovyalis caffra* serves as a good source of hard wood for fuel, house building and furniture making. It is also a good apicultural fruit tree and an excellent habitat and fertilizer derivation agent for farming activities. Considering the multidimensional effect of poverty and the food insecurity on many rural communities globally, there is a need to explore the potentials by encouraging the cultivation of *Dovyalis caffra* to assist with reducing unemployment, food insecurity and income-poverty problems in the arid and semi-arid areas of the world.

Keywords: economic sustainability; environment conservation; food security; income diversity; indigenous fruit.

1. Introduction

Human depend on plants and their products to survive, this human-plant's intra dependence having resulted in diverse professionals exploring the underutilized crop species in different part of the world to address food security, economic prosperity and environmental sustainability [1-3]. The world economy continues to face significant economic uncertainties and downside risks over changes in the international policy environment, unconventional monetary policy, debt overhang in emerging

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economies and volatile financial flows that indicated the need to move towards an era of prudent conscious, intentional and introspective exploration of the endowed but underutilized resources (The World Economic Situation and Prospects [4]. Amid great plenty, many communities continue to be faced with pervasive poverty, food insecurity, gross inequalities, joblessness and environmental degradation [5].

Changing rainfall patterns, mainly due to climate change, have affected the sustainability of many rural food systems, thereby threatening food and nutrition security of the developing nations in particular [2]. The potential of underutilized plants to contribute under such conditions has been highlighted by several researchers [6-9]. Despite the emerging interest on these underutilized plants, several research gaps still exist. Some of these plants are untapped resources that should be explored during periods of food shortage, with some indigenous plants requiring little water [6], as is the case with the Kei-apple (*Dovyalis caffra* L.), from the family Salicaceae. Given the effects of climate change and its associated food shortage challenge, indigenous plants including Kei-apple, becomes an important resource for an increasing global population.

Powell et al. [10] estimated that 50% of fruit consumed by humans originate from trees, most of which are cultivated, whilst the other 50% is being sourced from bushes and shrubs. However, many fruit trees are still 'wild', 'semi-wild' and or underutilized in natural forest that should be harvested and utilized as an important genetic sources to improve the planted stock [11-14]. In this regard, the potential benefits of the underutilized Kei-apple (*Dovyalis caffra*) as a fruit tree needs to be addressed for issues relating to food security, economic diversification and eliminating barriers that hinder the economic development and growth [15-17]. The cultivation of Kei-apple in the arid and semi-arid area of the world, where they have comparative advantage, will provide a promising alternative for increasing the income of small, medium and large-scale farmers.

This study explored potentials of the Kei-apple (*Dovyalis caffra*) in countries where it has a comparative advantage, with the contention that there is need to articulate a holistic strategy, with priority given to this drought tolerant fruit tree, to enable climate change adaptation and ensure food security, especially in the rural arid and semi-arid areas of the world. Therefore, this review describes the current status of the underutilized Kei-apple tree in terms of its characteristics, present use, its benefits as well as its potential contribution to the national development agenda of arid and semi-arid nations. In particular, it addresses climate change adaptation, food and nutrition security, food sovereignty, as well as employment and wealth creation in rural communities.

1.1. Origin of Kei-apple in the arid and semi-arid regions

Dovyalis caffra is native to the Kei River area, Eastern Cape, South Africa [18]. The plants is also abundant in other provinces such as KwaZulu-Natal and Mpumalanga. It has been introduced in countries such as England Algeria, Australia, Egypt, France, Italy, Jamaica and the United States of America (Fig. 1). In these aforementioned countries, different varieties of Kei–apple have been cultivated, all of which are used in arid and semi-arid regions.

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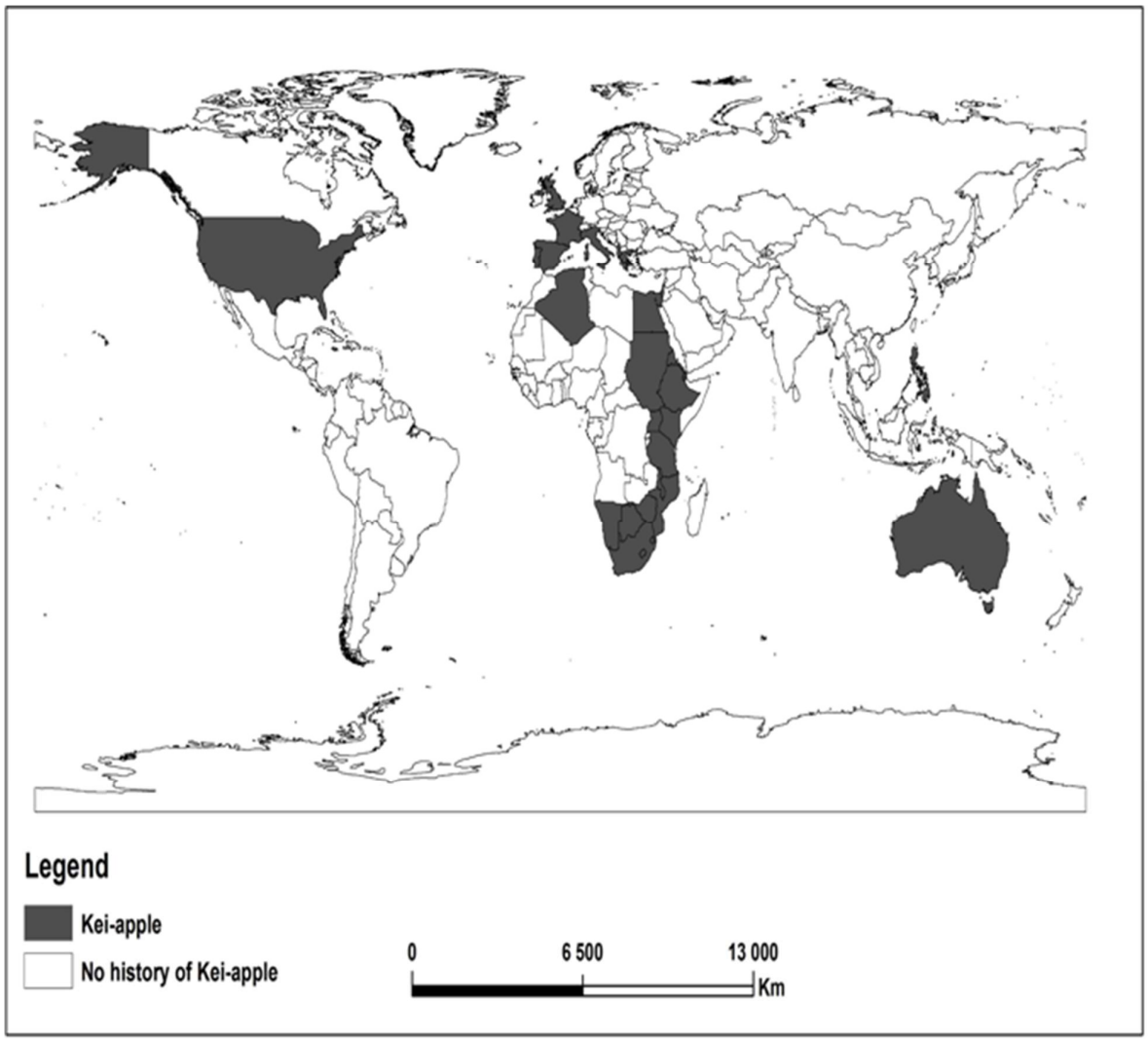

Figure 1: Global occurrence and distribution of Kei-apple (*Dovyalis caffra*)

2. Characteristics and botanical description of the Kei-apple (*Dovyalis caffra*)

Kei-apple is an evergreen tree which produces fruits that resemble little golden apples. The tree becomes bespangled with fruit, whose thin, tough skin shelters a yellow and juicy pulp with a lively aroma [19]. It is a moderately hardy subtropical plant, being a drought and frost hardy shrub or small tree [20]. Its heights range from 3-8m with rich green foliage that provides a year round screen and shade (Fig. 2a). The bark is smooth on young branchlets, and fissured and flaky to corky on old branches and stems (Fig. 2b). The young branches are usually armed with thorns of 40-70 mm, while the stem has few thorns and the tree crown is much branched (Fig. 2c). The plant does well in almost every soil but cannot tolerate damp locations or a high water table [21].

The leaves of Kei-apple are simple, often in tight clusters on its dwarf lateral branches, which alternates on the leaves, having a dark green coloration with a waxy luster, with approximately 35 prominent veins from the base on both sides, narrowly to broadly obovate-elliptic, 2-5.5 by 0.5-3 cm [22]. The leaf apex is round but occasionally notched, and base tapering to narrow round with margin

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and slightly rolled under, with a petiole up to 5 mm long [23,24]. Male flowers are 3 mm long in dense clusters of 5-10 flowers, while the female flowers are found in groups of up to three on stalks 4-10 mm long in leaf axils. The fruits are up to 60 mm in diameter and are yellowish-orange in color [25], rounded in shape and 2.5-4 cm in diameter [26]. The fruit bears 5-15 seeds arranged in double rings at the center, and are flat, pointed and surrounded by threadlike fibers. During ripening, the tough skin turns from green to yellow-orange (Fig. 2d), and boasts a fuzzy coat, similar to that of a peach, and with a very acidic flavor that needs to be sweetened prior to consumption.

3. Current uses and potentials of the Kei-apple (*Dovyalis caffra*)

Cultivation of Kei-apple trees has a potential benefit as a critical component of rural-urban landscape and infrastructure if it can be successfully incorporated into the physical and social fabric of towns and cities. In the developing nations of the world, there is a need for availability of quality tree planting material such as that of Kei-apple plant to support afforestation. A vision which involves farmers, governmental and non-governmental organizations should be emphasized in the blue prints of most nation's forest act. The following are ways in which the Kei-apple is being used or can be used:

3.1. Home /domestic uses

a. Kei-apple for aesthetic and fencing: Kei-apple has strong aesthetic and landscaping potential, which is intensive tree management/ornamental use, its attributes seldom being exploited, and mainly used to beautify. As a boundary, barrier or support, Kei trees can be spaced close together to form an impenetrable hedge around homesteads, gardens and croplands to keep out unwanted animals due to it long thorns [27,11, 28]. Kei-apple plants in home gardens are an important part of some traditional/subsistent farming systems, which should be encouraged in developing countries that are characterized by high population densities and the decreasing availability and accessibility of arable crop farming lands. As a result, Kei-apple home gardens could be cultivated more intensively to provide additional subsistent food and income, provide shade and a nursery environment and habitat for crops [16].

b. Kei-apple for fuel and furniture material provision: With increasing food prices, a lack of adequate livelihood for many people, and the recognition of the threats of climate change and other global challenges to agricultural production, the importance of both food and nutritional security, and the roles of forests and farms in securing them, have come to the fore [29]. As a result, a greater understanding of how forests and tree-based production systems support food security and nutrition, both directly and indirectly, is needed [30,31,10,12]. Kei-apple tree-based production is important in the value added from home garden produce, i.e. by changing from producing only fruit to including fire wood from the pruned branches for heating and cooking. Kei-apple could also be an excellent furniture material, as the tree is a hard wood.

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Figure 2: Morphology of Kei-apple (*Dovyalis caffra*). (A) Fruiting Kei-apple tree (B) Kei-apple tree showing potential of usefulness for furniture and fuel purposes (C) Kei-apple tree with thorny branches as a good fencing material (D) Ripe Kei-apple fruits.

3.2. Natural environment

a. Kei-apple for evolution: Kei-apple tree nurseries in the rural and urban centres of the developing world provides wide advantages that are needed in the rural-urban forests, not only to guard against incidences of plant pests and diseases, but also to "put the right tree in the right place" as the evolution of our cities and suburbs creates new settings for tree planting [32]. Kei-apple husbandry has the potential to supply Kei-apple seedlings and cuttings. Most of fruit trees are propagated either by seed and/or vegetative structures which could both serve as a good means of income to local communities.

b. Kei-apple as an air recycler to combat global warming: Tree planting is increasingly being viewed as providing ecosystem services, including environmental benefits and sustainability [33-35]. Kei-apple trees produce oxygen and sequester carbon in the atmosphere. Transitioning to a perennial agriculture system based on trees can help to combat global warming. This is obtained from

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physiological processes such as transpiration of trees which reduces atmospheric temperature and increase relative humidity.

3.3. Soil nourishment

a. Kei-apple for compost making: Compost is an organic fertilizer that can be made on the farm or in a garden at very low cost, the main input being labour. Compost is decomposed organic matter, such as crop residues and/or animal manure, and can include materials such as Kei-apple leaves and pruned branches to improve the soil [36-38].

b. Kei-apple as a mulch: Mulch is a layer of decaying organic matter on the ground, often referred to as 'soil blanket, which occurs naturally in wooded areas. Mulch is a nutrient rich, moisture absorbent bed of decaying forest tree leaves that includes twigs and branches, providing an optimal environment for fungal, microbial and insect life [39]. Natural mulch serves as a 'nutrient bank', storing the nutrients contained in organic matter and slowly making them available to plants. Mulching improves nutrient and water retention in the soil, encourages favorable soil microbial activity and worms, and suppresses weed growth. When properly executed, mulching can significantly improve the well-being of plants and reduce the maintenance required for bare soil culture. Mulched plants have better vigour and therefore have improved resistance to pests and diseases. Kei-apple tree could be used as a mulching device on the surface of the soil so as to conserve soil moisture and prevent leaching of nutrients, improve soil fertility and soil health status. Kei-apple's leaf as a mulch are organic in nature [39,40] .

c. Kei-apple as an excellent habitat and fertilizer derivation: The more the trees such as Kei- apple cultivation on the landscape, the greater the diversity of wildlife in dry and arid landscapers where few trees grow [41]. This increased vegetation in such regions provide shelter for animals and birds, whose excrete provides one of the best sources of phosphate, thereby increasing the surrounding soil fertility.

3.4. Agriculture

a. Kei-apple as animal fodder: The Food and Agricultural Organization [42] estimated that the world food requirement by the year 2050 will be double that of 2010, with a significant part expected to come from the developing countries due to their rapidly increasing populations, disposable incomes and urbanization. For livestock products, approximately two-thirds of the increased demand will need to be met by improving the production efficiency of feed, fodder, both forages and concentrate feeds [42, 43]. However, in addition to shortage of feed, imbalanced nutrition is a major factor responsible for low livestock productivity. Kei apple is rich in compounds such as ascorbic acid, pectin, alanine, arginine, aspartic acid and glutamic acid which results to balanced nutrition that contributes to improving animal output as well as reducing both the cost of production and the emission of greenhouse gases per unit of animal product. In this regard, Kei-apple leaves serve as a fodder for goat, cattle and wild game [43].

b. Kei-apple for bee production: Honey bees are found to be associated with forests globally, the flowers providing nectar and the trees shelter for a swarm or bee hive [44]. Kei-apple trees, with

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their prolific flowers, provide good nectar for the honey production by bees. Beekeeping is an incentive for planting new and protecting existing trees, with these being very important for bees and beekeepers [29]. However, to gain optimum benefit from honey bees, Kei-apple screening and adapting of the well performing multipurpose species is essential to increase honey production [45].

c. Kei-apple production for erosion control/wind breaker and mixed tree/crop systems: Incorporating Kei-apple trees on farms could assist with controlling the increasing erosion problems that farmers experience in arid and semi-arid regions due to climate change by intercropping them with millet, maize, beans, sorghum and sunflower or other local crops.

d. Kei-apple planting as farmers' incentive: An understanding of how and when the Kei-apple trees can best be exploited by farmers is essential for national and global forestry programmes geared to improving household's food security. Kei-apple tree growing practices indicate that this trees is often grown in situations where labour, capital and physical resources are limited, where it can play the following overlapping roles:

(1) Help maintain land productivity in situations of scarce capital, supplement purchased inputs of fertilizer and herbicides, and investments in soil and crop protection practices.

(2) Ideal in situations where labour and capital are scarce, as the trees require low input and management.

(3) Are a good provider of income earning opportunities, especially when the size of landholdings or the productivity of land falls below the level at which the household's basic food needs can be met from their on-farm food production or subsistent farming activities.

(4) Enhances farmers to spread their risk by diversifying their farm outputs, evening the seasonal spread of inputs and outputs, and building up a stock of capital in the form of mature trees that can be harvested and sold for cash during emergencies.

e. Kei-apple planting as herbicide: Herbicides are commonly known as weed killers, they are chemical substances used to control unwanted crops from the field in any agricultural enterprise. It has been said that Kei apple have herbicide potentials if explored. The extracts from this fruit tree can be used to kill any plant material with which they come into contact with. According to Orwa et al. [23], if the Kei-apple fruit is soaked in water and allowed to ferment, the liquid drained off has herbicidal properties which can be used on the farm to control weeds.

3.5. Economics

a. Kei-apple as an off-farm income source: As land holding sizes decline in many developing countries, farmer's income is increasingly sought from diverse off-farm employment opportunities. Trees such as the Kei-apple require low labour inputs and can serve as a main component allowing farmers to cultivate their land and then leave it while they work off the farm [46].

b. Kei-apple trees as cash crops: Farmers in developing nations can grow Kei-apple trees to sell wood as a cash crop on land previously used for agriculture, as it can thrive on soil with limited fertility [47, 80]. Money can be made through their ability to meet basic food needs/subsistence

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through their regular arable crop production, which usually force the vulnerable farmers to earn an income off the farm [48, 49]. In these situations where the farmer has unproductive land and little time for crop production, low input Kei-apple trees may be a sound way of using the land [50-52, 81].

c. Kei-apple as a rational economic investment: Kei-apple tree cultivation also requires little labour, which is important for agribusiness enterprises, specifically in developing countries, as there is wide-spread rural-urban migration of young men seeking off-farm employment, which is causing a shortage of household farm labour. In areas where markets for tree products are good, returning to work on farms for Kei-apple production could become an important employer of younger family members [53, 54].

d. **Kei-apple as a viable source of saving:** Kei-apple tree farming forms a good source of savings which could be drawn upon by harvesting the trees at a time of their choice [55]. In most parts of the developing nations that are subject to drought, Kei-apple trees are seen as plants with less chances to fail, thus reducing investors' uncertainty. The potentials of Kei-apple tree growing in developing countries may lead to an increase in income, improved livelihood and invariably, which improves household food security status. This plays out as follows:

(1) There is lower or reduced labour inputs needed with Kei-apple trees, which reduces the cost of hired labour and the problems of labour management.

(2) There are minimal annual operating costs requirement once the Kei-apple trees are properly established.

(3) There are lower water requirements from the outset and even when the trees are established, they are drought resistance, which has the potential of reducing the risk of crop failure.

(4) Kei-apple tree cultivation has a good potential of being a low-risk capital asset.

(5) Kei-apple enterprise requires little technical and financial input to establish and run successfully.

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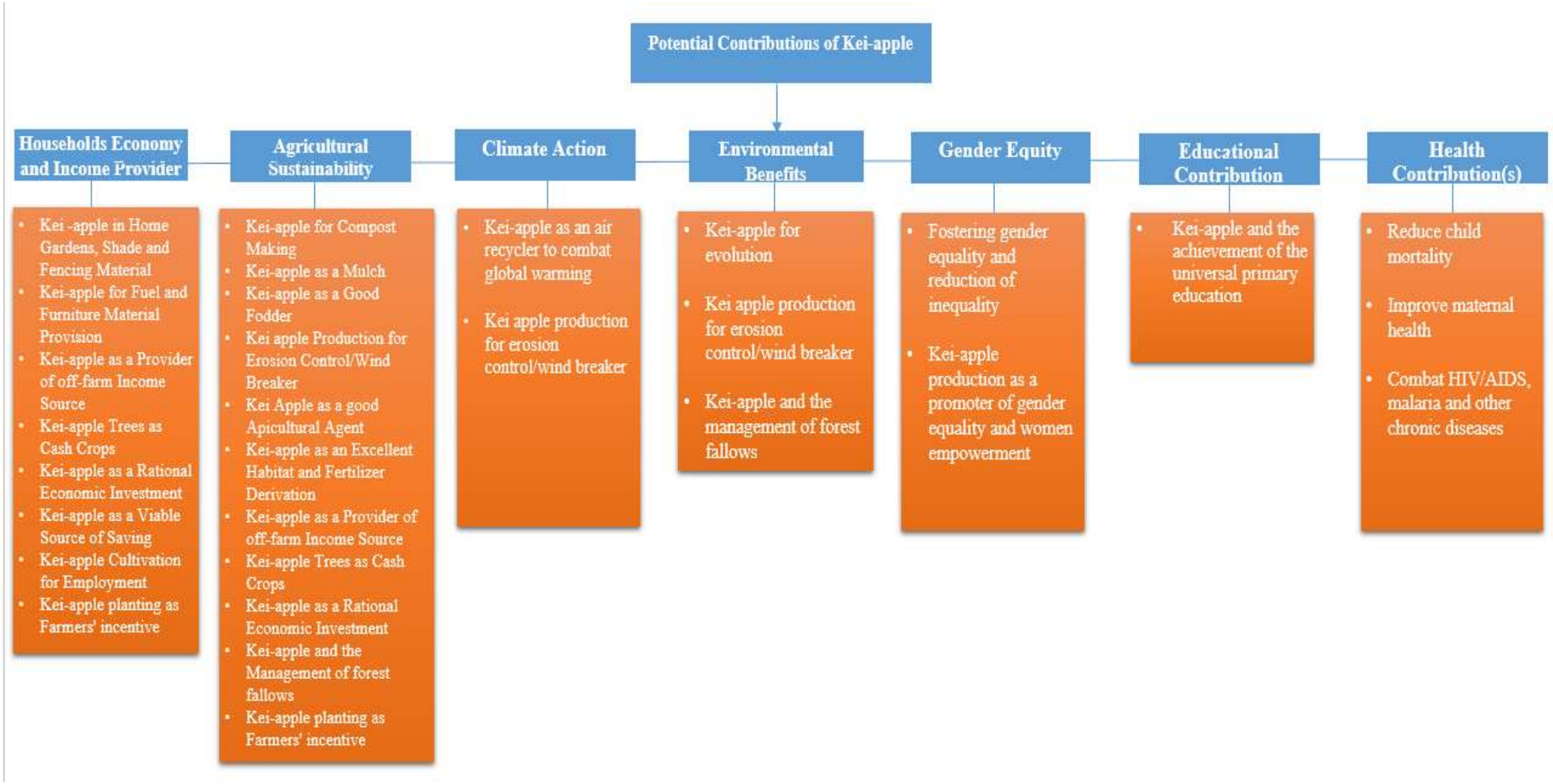

Figure 3: Uses and benefits of Kei-apple (*Dovyalis caffra L.*)

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4. Benefits of the Kei-apple (*Dovyalis caffra*)

There are many benefits that could be derived from the cultivation and domestication of Kei apple, some of such benefits are highlighted below:

4.1. Kei-apple and the achievement of the Universal Primary Education: Promoting early child-care and development to ensure a 'right start' to education is a key achievement of the United Nations Children's Fund (UNICEF). Children's learning capacities are severely restricted if they are hobbled by malnutrition or developmental delays. Micronutrient deficiencies impair cognitive and psychomotor skills, particularly in young children [56]. These deficiencies can be alleviated through the incorporation of fruits including Kei-apple. With consumption of this fruits, children's cognitive and psychomotor skills can be enhanced. Children who learn more and do well in school are more likely to want to stay in school and their parents are more likely to see the financial benefits of supporting their children's education [57, 58].

4.2. Kei-apple production as a promoter of gender equality and women empowerment: Kei-apple production have the potential of providing women of the developing nations of the world with diverse economic opportunities since women are known to be the principal producers of most horticultural crops in developing countries and are predominantly involved in the value addition activities from production to marketing [59,56, 60]. Considering women empowerment through Kei apple cultivation and production in the developing nations of the world can lead to a greater improvement in poverty alleviation, this is supported by the report of the International Food Policy and Research Institute [61, 79], that enhanced social and economic status of women, for example can be achieved through Kei apple production which have the potential to lead to a greater households' food and nutrition security. In addition to the financial benefits of Kei apple production, increasing women's access to Kei apple cultivation by themselves and their families, will improve their health and work performance, thereby contributing to higher income(s).

4.3. Reduce child mortality: Globally, the majority of child and young adolescent deaths occur at the young ages. The United Nations Inter-agency Group for Child Mortality Estimation [62] estimated that 85% (5.4 million) of the 6.3 million deaths in 2017 occurred in the first five years of life and about half (47%) of the under-five deaths in 2017 occurred in the first month of life. Malnutrition remain one of the major causes of, or is a significant contributing factor to, child mortality in developing countries [63, 64]. The link between horticulture through Kei-apple cultivation and child mortality is indirect, but very important. The absence of essential micronutrients exacerbates poor children's vulnerability to disease [65]. Improving access to fruits such as Kei-apple in children's diets may reduce mortality and morbidity of infants and children under five years old, particularly in rural areas of the world.

4.4. Improve maternal health: Maternal health depends on having achieved food security during childhood as well as a diet rich in micronutrients during conception, pregnancy and the first few months after childbirth [66, 77]. The health of women before conception directly impacts their health during pregnancy and child birth. The majority of pregnant women in developing countries suffer

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from anaemia and other micronutrient deficiencies. This affects both their productivity during pregnancy and can lead to complications for the foetus during and after childbirth. Encouragement of Kei-apple cultivation and consumption can benefit maternal health directly by improving the quality of women's diets [67, 76]. Kei-apple fruits is one key appropriate source of micronutrients in the diets of these women.

4.5. Combat HIV/AIDS, malaria and other chronic diseases: Healthy, well-nourished people are able to resist many infectious diseases and have better resources to be able to fight infections [56,68, 69]. The human body's immune system relies on a balanced diet, rich in micronutrients, to be effective. Chemicals in fruits can bolster the body's immune system, helping it to resist HIV/AIDS, malaria, diarrhoea, tuberculosis and many other infectious diseases [70,71, 78]. Fruits are also considered by FAO and WHO as the primary nutritional tools to prevent non-communicable and micronutrient deficiency related diseases [72-75].

5. Conclusion and future prospective

Despite the exceptional quality of the Kei-apple, it is still considered as underutilized fruit tree in the arid and the semi-arid regions of the world. *Dovyalis caffra* can be successfully cultivated in any marginal ecosystem of the tropics and the subtropics for food security, poverty alleviation and economic prosperity. This multi-purpose tree tolerates extreme dry droughts with high temperature. It is a drought-tolerant plant that is highly appropriate and thrives in environments where exotic plants can barely survive. Kei-apple has several uses such as sources of income, use for garden fence, fuel use, furniture, fodder use, leaching prevention, compost making and for food security purposes. The tree also renders environmental services such as wind breaker and the release of oxygen to the ecosystem towards the achievement of a sustainable environment.

Dovyalis caffra has the potential to reduce land degradation because it thrives in harsh environments where other variety of trees can hardly survive. Few among many possible ways to increase Kei-apple production are: development of improved hybrids, establishment of new plantations with genotype of proven quality and yield, rehabilitation of old plantations with improved clones or varieties. Future research needs to focus on: improvement in size grades, taste and overcoming spines difficulty problems. In addition, the improvement in harvest and post-harvest handling protocols through extension programmes would in no measure increase global acceptability and elevate purchase prices of Kei-apple fruit. Given that Kei-apple cultivation is economically and environmentally viable, a timely motivation for its integration and incorporation into the national blue prints of the nations of the world is highly recommended for all round sustainability.

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