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# ***Moringa oleifera* in South Africa: A review on its production, growing conditions and consumption as a food source**

*Moringa oleifera* (moringa) trees excel mainly in tropical and sub-tropical regions and are known to thrive in a wide range of soil types. The recent rise in moringa production in various agro-ecological zones of South Africa could be attributed to its multiple benefits, including nutritional and medicinal properties. Since its introduction as a cultivated crop, there has been a growing interest from farmers, researchers and government on various aspects of the tree such as its morphology, chemistry, growing conditions, production, processing and utilisation. We reviewed the work done on moringa within the South African context in terms of production, growing conditions and cultivation practices. The involvement of government departments on moringa-oriented activities and its consumption as food were also reviewed. In addition, gaps were outlined on its utilisation that need to be addressed, and recommendations provided on what could be done to ensure successful production of moringa in South Africa.

**Significance:**

- This review highlights moringa research that has been done on growing conditions, production and human consumption in South Africa.
- The review further addresses the potential commercialisation of moringa and existing knowledge gaps.

## **Introduction**

Increased demand for food to alleviate hunger and malnutrition has been pertinent over the last few decades among emerging countries across the globe.<sup>1</sup> In mid-2019, the world population reached 7.7 billion and is projected to reach 9.7 billion in 2050.<sup>2</sup> Moreover, the African population was estimated at 1.3 billion<sup>2</sup> and the South African population reached 58.8 million in mid-2019<sup>3</sup>. Thus, ensuring food security for a growing population has become the leading global challenge. For centuries, humans have been dependent on the diversity of plants for food, nutrition, medicine and shelter, as well as for an energy source and for their overall well-being.<sup>4</sup> Of about 390 000 known plant species, only 7000 species are cultivated or collected for nourishment.<sup>5</sup> Furthermore, less than 150 plant species are farmed commercially for food, with 95% of human food being provided by only 30 species.<sup>4,6</sup> Although these cultivated species could fulfil energy requirements, they could not solely meet dietary nutrient requirements.<sup>6</sup> Therefore, it is imperative to diversify and improve the production of less studied, locally adapted plant species that are used in rural communities as food or as a raw material.<sup>7</sup>

*Moringa oleifera* (hereafter referred to as moringa) is native to the sub-Himalayan parts of Northern India, and is widely utilised and known among 13 documented species of the Moringaceae family.<sup>8-10</sup> The plant is propagated by either seeds or cuttings, with seeds planted directly in the field or seedlings raised in nurseries.<sup>11</sup> It is well known for its multitude of uses, including nutrition, medicine, livestock feed, plant growth enhancer, cosmetics, water purification and biofuel production.<sup>12-16</sup> Almost all its parts contain nutrients such as proteins, carbohydrates, vitamins (A, B1, B2, B3, C and E) and minerals.<sup>17-19</sup> Additionally, the leaves and roots are an excellent source of natural antioxidants and contain significant amounts of total phenols, tannins and flavonols.<sup>13,20</sup> According to Marcu<sup>21</sup>, no adverse consequences from the daily intake of moringa leaves have been documented. The leaves and seeds are often eaten raw, cooked or added into food in a powder form for nutritional and medicinal purpose.<sup>12,17,22</sup> As such, moringa has been used in various developmental projects across the globe for malnutrition and poverty alleviation as well as climate change mitigation.<sup>15,23</sup>

Moringa was introduced to rural communities of the Limpopo Province (South Africa) as a cultivated crop in 2006 by the Lammangata moringa project which is based in Tooseng village.<sup>22</sup> Since then, its production and utilisation have been on the rise in various agro-ecological zones of the country.<sup>24-26</sup> Consequently, various stakeholders such as the South African government, farmers and higher education institutions have started flagships with moringa-oriented projects due to growing national interest in the tree. For example, the Agricultural Research Council's Vegetable and Ornamental Plants group in Roodeplaat have done research on moringa propagation, cultivation practices, processing, storage (shelf-life) and analysis on biological activities, safety and phytochemistry. Nationally, moringa has the potential to improve the nutrition, income and livelihood of marginal communities.<sup>18,26-28</sup> Therefore, we reviewed the work done on moringa within South Africa in terms of its production, growing conditions and brief involvement of government departments on moringa-oriented projects. Moreover, we report on its current and prospective consumption by rural communities and potential uses, as well as other aspects that have not yet been explored in the country. To our knowledge, no research work of this nature has been carried out within the South African context.

## **Overview of moringa production areas**

In South Africa, moringa is produced in six of the nine provinces: Limpopo, Gauteng, Mpumalanga, KwaZulu-Natal, Free State and North West.<sup>24,25</sup> Among these provinces, it is mainly grown in the Limpopo Province by farmers

and at household level.<sup>22</sup> In 2013, the Moringa Development Association of South Africa (MDASA) was formed with a mandate to promote the production, use and commercialisation of moringa. MDASA served as a hub for moringa farmers, product developers and consumers through collaboration with research institutes and organisations for new knowledge and developments. Since its establishment, the number of farmers growing moringa has increased in some parts of South Africa. According to a survey conducted by Mabapa et al.<sup>26</sup>, moringa farmers were found present in all five districts of the Limpopo Province (Capricorn, Mopani, Sekhukhune, Vhembe and Waterberg Districts). Moringa was produced on an area of more than 0.25 ha, with seed yields of 50–100 kg/ha. Furthermore, annual enterprise income was estimated at USD13 000 and a gross margin of USD 6000 through selling moringa leaves.<sup>26</sup>

Tshabalala et al.<sup>29</sup> forecasted that, of South Africa's land area, about 17% (200 837 km<sup>2</sup>) had optimum growing conditions for moringa cultivation, 18% (216 758 km<sup>2</sup>) had suitable conditions, 46% (560 794 km<sup>2</sup>) was less suitable and only 19% (240 699 km<sup>2</sup>) was not suitable. Approximately 80.3% of Limpopo Province's total area had ideal conditions for growing moringa. Furthermore, the ideal conditions were predicted on the eastern coast of the country from KwaZulu-Natal to Eastern Cape as well as some parts of Northern Cape and Western Cape Provinces<sup>29</sup>, thus, suggesting that it could be produced in all nine South African provinces. The production of moringa in South Africa is still at developmental and infant stage<sup>26</sup>, thus, making it difficult to quantify the areas under production and number of hectares dedicated for its cultivation. Therefore, it is necessary to encourage farmers in provinces with suitable cultivation areas to participate in its production and to make them realise its potential benefits. However, cultivating moringa beyond its preferred areas is also possible through manipulation of the growing environment; for instance, growing it under controlled conditions such as greenhouses.

## Government bodies on moringa-oriented projects

In sub-Saharan Africa, moringa is considered as a 'developmental tree' of choice by governments to combat several socio-economic challenges such as poverty, malnutrition and food insecurity.<sup>10,15</sup> Likewise, the government of South Africa has been supporting the production of moringa in some parts of the country with the mission of alleviating malnutrition in disadvantaged communities (Table 1). The Department of Science and Technology (now Department of Science and Innovation; DSI) has made available a substantial amount of funds to support moringa-oriented activities. Moreover, DSI continues to build and support rural community-based infrastructures for growing and processing moringa.<sup>30,31</sup> Since 2010, DSI has funded research projects aimed at value additions on the quality and product development of moringa to encourage the interface of science and indigenous knowledge systems.<sup>29</sup> Similarly, the Department of Agriculture, Forestry and Fisheries (now known as the Department of Agriculture, Land Reform and Rural Development (DALRRD)) has dedicated substantial financial and technical support to emerging moringa farmers.<sup>24</sup> It has listed moringa as the most cultivated and used medicinal plant.<sup>25</sup> The Department of Rural Development and Land Reform (now part of DALRRD) established a moringa agro-processing business at Temotua

farm in Mopani District, Limpopo Province.<sup>32</sup> Consequently, DALRRD continues to encourage several communities to consider moringa as an alternative solution to reduce unemployment. Recently, several studies were carried out on promoting the incorporation of moringa leaf powder in the daily diets of children in school yards.<sup>33,34</sup> These may suggest that the Department of Basic Education supports and recognises the potential use of moringa in schools for alleviating malnutrition among children due to its nutritional benefits.

## Growing conditions and cultivation practices

### Work done on climatic conditions

Amongst all climatic factors that affect plant growth, temperature is one of the most important factors governing natural geographical plant distribution, tree performance, physiology and productivity.<sup>12</sup> Studies conducted at the University of Pretoria's experimental farm in Gauteng Province revealed that among three evaluated night/day temperature regimes (10/20 °C, 15/25 °C, 20/30 °C), 20/30 °C was the most suitable for germination and plant growth of moringa seedlings (Table 2). Furthermore, it was confirmed that tropical and sub-tropical conditions with hot summers and mild winters are ideal for cultivation.<sup>13,35</sup> According to Manduwa et al.<sup>36</sup>, the performance of the reproductive phase of moringa depends on temperature. Temperatures of between 30 °C and 35 °C encouraged fruit set whereas low temperatures ( $\leq 15$  °C) reduced fruit set during bloom. Although high temperatures are well suited for moringa growth, decreased but satisfactory growth and yields could still be attained in below-optimal climates.<sup>36</sup> This is attributed to the ability of moringa to withstand lower temperatures through physiological adaptation by thickening of leaves when under temperature stress.<sup>37</sup> Successful moringa cultivation in cooler climates would greatly increase its production; however, the effect of growing it under such conditions should be well understood before planting.

These sun- and heat-loving plant species grow best with an annual rainfall of between 250 mm and 1500 mm.<sup>11</sup> Photosynthesis, growth and respiration are processes controlled by metabolic pathways and are affected by temperature and seasonal changes.<sup>39</sup> Gaseous exchange was affected by seasonal change in a study conducted at NTL Baraka Eco-farming, Limpopo Province.<sup>40</sup> In summer, an increase in sub-stomatal carbon dioxide (CO<sub>2</sub>) was observed while stomatal conductance transpiration and photosynthetic rate were all reduced. Moringa plants reduced these parameters as an adaptation mechanism and increased water use efficiency under low rainfall and extreme temperature. This is due to the capability of the plant to store carbon in its succulent parts during growing periods.<sup>40</sup> According to Gandji et al.<sup>41</sup>, the rate at which moringa trees absorb CO<sub>2</sub> is about 55 times higher when compared to Japanese cedar trees and 20 times higher than that of typical vegetation. Subsequently, cultivation of moringa in parts of South Africa could contribute to national climate change mitigation and adaptation plans.<sup>42</sup> Moringa trees are highly susceptible to frost and cold conditions.<sup>11</sup> This suggests that the southwestern parts of South Africa, which are characterised by cold winters with rainfall<sup>43</sup>, may not be suitable for its cultivation during the winter season. Alternatively, moringa seedlings are usually grown inside greenhouses for overwintering and transplanted shortly after winter in temperate zones of South Africa.<sup>44,45</sup>

**Table 1:** Participation of various government departments in moringa production

Government department	Programmes/activities	References
Department of Agriculture, Forestry and Fisheries (DAFF)	Included moringa on the list of medicinal plants in South Africa	DAFF <sup>24,25</sup>
Department of Science and Technology (DST)	Offered financial support for moringa-oriented activities	DST <sup>30,31</sup>
Department of Rural Development and Land Reform (DRDLR)	Established agro-processing business at Temotua farm	DRDLR <sup>32</sup>
Department of Basic Education	Allowed research on the incorporation of moringa in the daily diets of school children	Ntila et al. <sup>33</sup> ; Zungu et al. <sup>34</sup>

**Table 2:** Temperature requirements proposed by various studies conducted within South Africa for growth and development stages and storage of moringa

	Required temperature	References
Germination and seedling growth	20/30 °C (night/day)	Muhl et al. <sup>13,35</sup>
Fruit set	30–35 °C	Manduwa et al. <sup>36</sup>
Seed storage	Between -19 °C and 4 °C	Du Toit et al. <sup>38</sup>

### Soil, nutrient and water requirements

Studies elsewhere report that moringa is well adapted to a wide range of soil types and thrives in poor soils with little or no fertilisation.<sup>46</sup> According to Price<sup>11</sup>, moringa trees prefer well-drained sandy loam soils due to their susceptibility to waterlogged conditions. Within South Africa, Mashela<sup>47</sup> assessed its response to loam, sandy, clayey and calcareous soils collected from Madisha-Ditoro and Moletlane villages (Limpopo Province). Moringa seedlings grown on clay and sandy soils produced slightly similar above-ground biomasses that were higher than those produced in calcareous and loam soils. Comparatively, plants grown in clay soils had both higher above-ground biomass and root length, whilst those in sandy soils also had higher above-ground biomass but with reduced below-ground biomass. Additionally, it was demonstrated that calcareous soils with their high pH reduced growth of seedlings.<sup>47</sup>

Reducing or withholding fertilisers tends to slow the overall growth of moringa.<sup>48</sup> Thus, it is advisable to apply fertilisers for improving its growth and yield in areas with low rainfall and extreme temperatures.<sup>49</sup> Moringa is capable of surviving dry seasons and tolerates drought conditions mainly due to its long tuberous taproot that grows very deep into the soil to absorb water and minerals from the sub-soils.<sup>50</sup> The effects of three irrigation intervals (300, 600 and 900 mm per annum) were evaluated on flowering and fruit development of moringa in Gauteng Province. Low irrigation treatment (300 mm/annum) resulted in high bud initiation; however, fruit set was delayed. Therefore, it is necessary to limit water supply to enhance flower initiation prior to floral initiation, but this should be followed by sufficient irrigation to ensure pollination, fruit set and yield.<sup>51</sup>

### Planting density, biomass and storage conditions

Mabapa et al.<sup>49</sup> investigated the effect of four plant densities (c. 435 000, c. 300 000, c. 200 000 and c. 100 000 plants/ha) on above-ground biomass of moringa at Syferkuil and Ofcolaco farms (Limpopo Province). Their results showed that the highest planting density of c. 435 000 plants/ha led to the highest biomass of 527–2867 kg/ha on both sites with different agro-climatic conditions.<sup>49</sup> The study carried out at NTL Baraka Eco-farming indicated that various planting densities (c. 1250, c. 1667, c. 2500 and c. 5000 plants/ha) did not influence gaseous exchange parameters such as stomatal conductance, and photosynthetic and transpiration rates. It was recommended that a planting density of c. 5000 plants/ha should be used for moringa cultivation in many parts of the province with favourable conditions, for enhancing the livelihoods and well-being of farmers.<sup>40</sup> Therefore, lower planting density may be used for seed production while high density is ideal for optimum leaf

production. Flower and fruit development stages of moringa were affected by pruning intensity in a study carried out at the University of Pretoria. Moderate (2 m) pruning above the soil surface (pollarding) was found to be an ideal practice for moringa production rather than severe (1 m), light (3 m) or no pruning under sub-optimal conditions.<sup>52</sup> In order to ease mechanical harvesting, moringa can be harvested at a height of 0.5 m above the soil surface when the stem is relatively soft (Table 3).<sup>49</sup>

Storage, temperature, moisture content and seed aging are the main factors affecting seed viability and quality of moringa.<sup>38,53</sup> According to Fotouo-M<sup>53</sup>, moringa seeds can be stored inside paper or aluminium bags for up to 6 months; beyond this period, they should be stored in sealed containers at temperatures of between -19 °C and 4 °C. Farmers are advised to store their seeds at temperatures below 20 °C in paper bags for up to 12 months, given that the seeds' moisture content remains below 8%.<sup>38</sup> Another method of seed storage includes storing them in their fruits under cool and dry conditions for up to 12 months. Alternatively, one can dry the seeds for 30 days before storing them in airtight containers to ensure high-quality seeds.<sup>54</sup> Moringa leaves may be transported and consumed throughout the year without losing nutrient quality.<sup>55</sup>

### Moringa consumption for nutrition

Moringa has been included in some diets to combat malnutrition, especially among infants and breastfeeding women in developing countries.<sup>19,56</sup> Interest in moringa consumption among South Africans is expected to rise. Farmers in the Limpopo Province use moringa as a nutritional source, an income source and for health purposes.<sup>26</sup> The dried moringa leaves of South African ecotypes were found to have the following nutrients: crude protein (30.3%), calcium (3.7%), phosphorus (0.3%), magnesium (0.5%), iron (490.0 mg/kg), sodium (0.6%), zinc (13.0 mg/kg), potassium (1.5%), copper (8.3%), manganese (86.8 mg/kg), sulfur (0.6%) and selenium (363 mg/kg). Additionally, the leaves contained 19 amino acids, 17 fatty acids and high concentrations of vitamin E and beta-carotene.<sup>18</sup> The findings of Pakade et al.<sup>57</sup> revealed that moringa leaves collected from Limpopo (Tooseng village) and Gauteng (Atteridgeville) provinces did not contain metals and were thus safe and suitable for human consumption. Their results also showed that moringa leaves had higher concentrations of calcium and magnesium than locally sourced vegetables such as spinach (*Spinacia oleracea*), cabbage (*Brassica oleracea* var. *capitata*), peas (*Pisum sativum*), cauliflower (*Brassica oleracea* var. *botrytis*) and broccoli (*Brassica oleracea* var. *italica*). The concentrations of other major nutrients in moringa leaves were similar to those of the vegetables<sup>57</sup>.

**Table 3:** Cultivation practices and storage conditions as suggested by studies conducted within South Africa

Production practices	Description	References
Planting density	Minimum = 5000 plants/ha; maximum = 450 000 plants/ha	Mabapa et al. <sup>40,49</sup>
Harvesting/cuttings	50 cm above the soil surface to facilitate mechanical harvesting	Mabapa et al. <sup>49</sup>
Irrigation	Bud initiation = 300 mm/annum; fruit set = 600–900 mm/annum	Muhl et al. <sup>51</sup>
Pruning	Moderate (2 m) pruning above soil surface is ideal for moringa production	Du Toit et al. <sup>52</sup>

Incorporation of moringa should be encouraged in meals that contain these vegetables for enhancing their nutritional value.<sup>58</sup> Furthermore, incorporating moringa into common dishes could promote awareness of moringa as a food source nationally rather than being limited only to medicinal uses.<sup>25</sup> Table 4 shows various consumption patterns of moringa by communities that were reported within the South African context.

Over a decade ago, the acceptability test outcomes of dishes prepared with moringa revealed that moringa was well accepted and recommended as an additional food ingredient to enhance the nutritional value of diets among Bapedi communities in Limpopo Province.<sup>27</sup> Subsequently, few studies have since been carried out to evaluate its acceptability in complementary foods. The acceptability and perceptions of soft white maize porridge modified with different levels of moringa leaf powder (MLP) were evaluated in Hammanskraal (Gauteng Province) and Lebowakgomo (Limpopo Province) townships.<sup>33</sup> Increased levels of MLP added in the porridge led to a decrease in its acceptability among caregivers, and this was due to the bitter taste, making it undesirable to children.<sup>33</sup> Therefore, it is imperative to consider low quantities of MLP in foods prepared for children to increase its acceptance. According to Ntila et al.<sup>59</sup>, increasing levels of MLP (0–3%) in maize soft porridge contained higher amounts of nutrients, phenols and antioxidant activities. Moreover, it was emphasised that foods mixed with MLP are likely to be unacceptable to consumers due to the unfamiliar taste and colour. The addition of MLP in *mahewu* (non-alcoholic cereal grain beverage) led to a substantial increase in the nutrient content of the beverage.<sup>60</sup> However, its acceptability by the Ntambanana community (KwaZulu-Natal Province) declined with an increasing percentage of MLP. This was ascribed to sensory attributes of unfamiliar change in colour and aroma. Subsequently, 2% MLP supplemented *mahewu* was more acceptable than 4% and 6%.<sup>60</sup> Another study in KwaZulu-Natal Province assessed nutritional composition and acceptability of MLP-based chip snacks and it was found that the snack containing 1% MLP was almost as acceptable as the untreated snacks. Moreover, 1% MLP snacks had a higher concentration of crude protein and minerals with less fat compared to untreated snacks.<sup>34</sup> Incorporation of MLP in snacks could significantly improve nutrition among children and could lead to a reduction in the intake of unhealthy snacks which pose a health threat. Indeed, these recent studies show that the use of moringa-based products could have a positive impact on the nutritional status of South Africans, particularly malnourished children.

Research should be conducted to fully document and assess local knowledge on consumption patterns of moringa as a food source among individuals living in populations in which its use is established. Despite their nutritional benefits, moringa foodstuffs in southern Africa are at times categorised as ‘famine food’ eaten during periods of food shortage and are often associated with a lower social class.<sup>61</sup> As such, moringa products are still underutilised and yet to be fully exploited. There is, therefore, a need to promote awareness on the nutritional importance of moringa among marginal communities of South Africa. Moreover, guidance and training on its processing and incorporation in foods is necessary.<sup>33</sup>

## Prospects of moringa within South Africa

### Promotion of production and commercialisation

Studies should be conducted to record the total number of major moringa production areas in provinces across South Africa, as well as the number of hectares dedicated to its cultivation. Such surveys could easily be conducted with the help of the government departments involved in moringa production and the MDASA. Although moringa food products are available in local markets in a few areas of South Africa, its production is still insufficient and unstable.<sup>26</sup> Furthermore, its commercialisation is still in its infancy, which makes it challenging to quantify the hectares under production, the volume and product value nationally.<sup>22,29</sup> Hence, it is necessary to shift from small-scale, backyard production into commercial economies of scale. This would necessitate the formation of an inclusive value chain starting from cultivation to postharvest. However, access to adequate and reliable markets is the main constraint.<sup>26</sup> Subsequently, the selling price of leaf powder and other moringa products varies widely due to the lack of formal markets and price control. Lots of work and funding are required to support moringa production. Government bodies involved in moringa activities should assist farmers in attaining reliable markets for their produce. One practical way to publicise its production and consumption is by organising workshops and conferences that aim at discussing its nutritional, medicinal, and other various benefits. For example, the *Second International Symposium on Moringa* held in Pretoria (10–13 November 2019) brought together moringa experts, researchers, farmers, product producers and entrepreneurs from all over the world. The symposium offered an opportunity for sharing, networking and increasing knowledge. The display of various moringa products in those workshops and conferences could also increase its interest and acceptance among the public. In order to extend the audience, information about the potential benefits of moringa should be broadcast on television, radio and influential social platforms such as Twitter, Instagram and Facebook. The distribution of free or low-cost seeds/seedlings to potential farmers would also assist in popularising its production. Currently, there are varieties of foodstuffs such as moringa spice, *mahewu*, tea leaves, ice tea, peanut butter, energy drinks and yoghurts (Table 5).<sup>22,26</sup>

Nutritional analysis of moringa food products could be prerequisites to marketing as these are important in offering quality assurance and integrity to consumers. Despite limited documentation on safety, there are currently no reported adverse effects of moringa products and extracts in human use.<sup>62</sup> However, quality assurance should be addressed because Dar<sup>63</sup> stated that moringa leaf powder could lead to gastrointestinal disorders in consumers due to poor sanitation standards during production and postharvest handling. Indeed, this could improve the market value of moringa food products as it would increase the confidence of traders as well as consumers and this would be a big step in its commercialisation in the country.

**Table 4:** Consumption patterns of moringa for nutritional purposes in South Africa

Moringa part	Consumption pattern	References/source
Leaves	Grounded moringa leaf (leaf powder) used as a spice in common dishes; fresh leaves added in salads or cooked as a vegetable; dry leaf powder added to meals for children; moringa tea prepared by adding one spoon of leaf powder to boiled water	Pakade et al. <sup>58</sup> ; Lekgau <sup>22</sup> Mabapa et al. <sup>26</sup> ; personal observation
Seeds	Seeds are eaten like groundnut; grounded seeds used as a spice in food	Personal observation and communication
Roots and other parts	Uses of moringa roots and other parts as a food source are currently unknown and undocumented	

**Table 5:** Moringa-based food products in markets (formal and informal) within South Africa

Food products	Description	References
Capsules	The capsules are manufactured using moringa dry leaf powder and used as a nutritional supplement	Pakade et al. <sup>57,58</sup> ; Mabapa et al. <sup>26</sup>
Energy drinks	Made from moringa leaf extracts or powder	Tshabalala et al. <sup>29</sup>
Flavoured peanut butter	Addition of moringa in peanut butter to increase its nutritional value	Tshabalala et al. <sup>29</sup>
Ice tea	Made from moringa leaf extracts or powder	Tshabalala et al. <sup>29</sup>
Moringa juice	Extracts from either fresh or dry leaves	Mabapa et al. <sup>26</sup>
Moringa leaf powder	Dry leaves are grounded into powder	Mabapa et al. <sup>26</sup>
Soft porridge	Incorporation of moringa leaf powder in soft maize porridge	Ntila et al. <sup>33</sup>
Tea leaves/bags	Made from dry moringa leaf powder	Lekgau <sup>22</sup> ; Mabapa et al. <sup>26</sup>
Yoghurt	Made from either dry or fresh leaf extracts	Tshabalala et al. <sup>29</sup>
<i>Mahewu</i>	Incorporation of moringa leaf powder in a non-alcoholic beverage commonly known as <i>mahewu</i>	Olusanya et al. <sup>60</sup>
Chip snacks	Incorporation of moringa leaf powder in chip snacks	Zungu et al. <sup>34</sup>

## Research gaps on utilising other moringa parts

All the various parts of moringa are known across the world for their multiple uses, including consumption of flowers, seeds and immature pods, fresh leaves as a relish and water purification (seeds).<sup>17,64</sup> However, not all of these uses are recognised in South Africa (i.e. consumption of immature fruits and seeds). Moringa seeds are known to be an important source of essential nutrients and, in other countries, the immature pods are cooked and consumed as food.<sup>65</sup> This practice ought to be adopted in South Africa. Another example is the use of crushed moringa seeds and/or a seedcake for water purification. Many households in rural villages use river water which can be full of suspended matter such as microorganisms, objects and silt particles and such material necessitates elimination prior to water use. This use should be implemented in South Africa as it will be beneficial to rural communities that rely on river water; however, mechanisms involving coagulation by moringa need to be well understood.

In South Africa, moringa leaves are the most researched and utilised part of the tree, whereas little work has been done on the application of other parts of the tree such as seeds, pods and roots. Almost all moringa parts have been researched for use and product development in many countries including India, the Philippines and Nigeria.<sup>15,66</sup> While there are several publications on morphology and chemical composition, there is scant documentation on familiarity and perceptions about moringa in rural communities that make use of the tree. Current studies on moringa consumption and acceptability have been narrowly conducted on caregivers (and/or mothers) and children, and to our knowledge, insufficient research has been done on perceptions and acceptability of moringa in elders, men and youths. Hence, research seems to be gender and age biased. Therefore, there is a need to encourage more intensive and comprehensive utilisation of the plant. In addition, higher education institutions should conduct studies to develop processing techniques and establish a value chain of moringa in South Africa.

## Other knowledge gaps on moringa

Studies conducted in Limpopo Province showed that moringa seedlings were infested by spider mites (*Tetranychus urticae*), which contributed to seedling mortality.<sup>67</sup> There is a scarcity of information on pests and diseases that affect moringa production and yields. Knowledge on this aspect would allow the development of proper management strategies which would be beneficial to the moringa industry. Although research has been done on the application of moringa leaf extracts as growth enhancers on certain crops<sup>68</sup>, its effectiveness has not yet been tested

on a larger commercial scale. Also, the use of seedcakes as biofertiliser and/or organic manure is yet to be researched in South Africa and this could reduce overreliance on chemical fertilisers, which are known to have adverse effects on the environment.

## Conclusion

Over the last decade, moringa has risen from a minor crop to one of the most auspicious multi-use crops in South Africa. Its cultivation has expanded in recent years and a diversity of moringa-based food products is available in rural communities and local markets. Stakeholders such as government departments, farmers and higher education institutions have initiated flagship projects with moringa-oriented activities to ensure successful cultivation, production and utilisation of this miracle tree. Moringa is a perennial, drought-tolerant and resilient crop that is capable of surviving a wide range of environmental and climatic conditions. Considering the predicted climatic changes which are likely to have adverse consequences for farming, moringa can serve as a feasible alternative crop for rural inhabitants. Therefore, promoting its production, food products and consumption would be beneficial for the well-being of people residing in marginal communities. This review highlights research that has been done on growing conditions, production and human consumption, and addresses existing knowledge gaps on these topics within South Africa.

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We declare that there are no competing interests.

## Authors' contributions

C.V.M.: Conceptualisation; writing – the initial draft; writing – revisions; project management. P.N.M.: Conceptualisation; student supervision; writing – review and editing; validation; project leadership. P.J.P.: Conceptualisation; student supervision; writing – review and editing; validation; project leadership. E.E.P.: Conceptualisation; student supervision; funding acquisition; validation; review and editing; project leadership. All authors discussed, read and approved the final manuscript.



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