

Importance, Genetic Diversity and Prospects for Varietal Improvement of Ginger (*Zingiber officinale* Roscoe) in Burkina Faso

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Abstract Ginger (*Zingiber officinale* Rosc.) is a very important spice for rural and urban communities in Burkina Faso. Cultivation of ginger is mainly practiced by traditional farmers, and its commercialisation offers substantial income to farmers, traders and processors. The tuber contains enormous medicinal and nutritional potential, and can thus contribute to qualitative improvement of the diet of consumers. Despite the many advantages of this plant, it remained underexploited due to insufficient knowledge of cultivation methods, its cycle duration and its water requirement, which confines the crop mainly to the western region of Burkina Faso. Such under-exploitation has been exacerbated due to little attention dedicated to ginger research in the country. Therefore, preservation and improvement of ginger quality represent an important challenge for the various actors of this crop's industry. The present review highlights the importance of ginger, its role in crop diversification, its medicinal and nutritional properties, as well as the future areas of selection and genetic improvement of this species in Burkina Faso.

Keywords: *spice, variability, conservation, breeding, neglected crop*

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1. Introduction

Ginger belongs to the Zingiberaceae family which are perennial monocots. As such, it is a tropical herbaceous plant that is widespread throughout the world [1]. The rhizomes are the consumed parts of the plant [2] and are used as a spice and traditional medicine for various diseases [3,4]. Ginger has the particularity of being able to produce very diverse natural substances of great nutritional value.

Ginger accounts for 5-6% of the spices consumed worldwide [5]. Most of the world's production comes from India which contribute for more than one million tons [6]. In African, Caribbean and Pacific (ACP) countries, Nigeria is the largest producer (349.895 tonnes), before Cameroon, Côte d'Ivoire, Ethiopia and Fiji [6]. Ginger exportations are dominated by China (63%), Thailand (7%), Nepal (6%), the Netherlands (5%) and India (4%). As for imports, Bangladesh (11%), Japan (11%), Pakistan (10%), the United States (9%) and Malaysia (7%) are the top five worldwide [5]. In Burkina Faso, the ever-increasing demand for ginger has led to an increase in its

cultivation in recent years. However, domestic production covers less than 10% of national demand, estimated at about 50.000 tons per year [7]. The gap is then filled by imports (0.01% of the world share) from other countries of the sub-region such as Côte d'Ivoire, Mali, Niger and Nigeria. Although largely below the country's needs, ginger from Burkina Faso seems to be very popular internationally because of its quality and its particular spiciness [7]. Therefore, a promotion of production in Burkina Faso would provide a highly income-generating activity and a source of economic growth for the country.

Although ginger is of great importance, we have overlooked the crop potential for genetic improvement, its medicinal and nutritional benefits in the prevention and treatment of diseases, as well as its potential for sustainable agricultural production. To this extent, little research has been dedicated to the development of ginger in research centres in Burkina Faso, except a pioneering study carried out by [8]. This study made it possible to identify the areas of ginger production and to assess the genetic diversity of cultivated accessions. However, many challenges remain regarding this important but neglected crop, including the promotion of its uses, conservation and evaluation of genetic resources [9,10]. This is necessary to

contribute to the diversification of agricultural production and food sources, and thus potentially improve nutritional security.

This review synthesizes knowledge on the use, conservation, genetic diversity of ginger and the prospects for breeding and varietal improvement of this crop species in Burkina Faso.

2. Botanical Description

The species *Zingiber officinale* is a monocotyledonous plant, perennial herbaceous with aromatic tubers, growing under tropical or subtropical climates, blossoming in shady and humid areas. Its aerial stems are erect and may be sterile (long) or flowering (fertile and short) [11]. The leaves are fragrant, lanceolate and biserial in shape and have parallel veins [12]. The flowers are of various colours, yellow, white or red, depending on the variety. A short axillary spike appearing at the end of a stem covered with scales indicates the end of flowering. These flowers are often sterile, but when mature, they contain the angular black seeds enclosed in trivalve capsules.

The underground stem is the part of the plant that hypertrophies to provide rhizomes [13], which generally present a pale beige skin and flesh of colour varying from yellowish to dark yellow. Rhizomes are elongated in irregular shapes, as tubers with finger-like ramifications, ending with buds. Additionally, rhizomes become more and more fibrous with age and they are typically known for their aromatic smell, sometimes with a hot flavour and a lemony taste that dwindles with drying [7]. It contains nutrients useful for and growing the plant.

3. Importance of Ginger

3.1. Socio-economic Importance

Ginger is a useful and important crop. Ginger is an important commercial crop cultivated for its aromatic rhizomes, which are used both as a spice and for organoleptic and medicinal purposes [14,15]. The intensification of cash crops, especially ginger, offers farmers the opportunity to obtain a complementary financial resource, allowing them to improve their living standards.

The species represents an added value to global trade as it is consumed all over the world [16]. While India dominates the production and import of ginger, then come the United States (19.035 tonnes), the United Kingdom (10.337 tonnes), Saudi Arabia (8.248 tonnes), Singapore (7.566 tonnes), Malaysia (7.652 tonnes), Korea (6.805 tonnes), the Netherlands (6.981 tonnes), and Canada (4.680 tonnes) [16].

3.2. Nutritional Properties

Ginger has been used worldwide as a spice, dietary supplement and in traditional medicine for centuries [17]. This spice is appreciated for its delicate aroma and somewhat hot flavour for the preparation of many dishes. Traditionally, dried ginger is used both for cooking and in the confectionery industry. Indeed, it is used as flavour

ingredient in many culinary recipes ranging from bakery products (gingerbread, cakes, sweets, cookies) to alcoholic and non-alcoholic beverages (tea, juice, ale and ginger beer), all of which are highly appreciated in global food industries [6,18]. Also, it is used in the preparation of curry powder in fresh, diced, candied or dried forms [19].

3.3. Therapeutic Properties

Ginger is known as medicinal species providing multiple health benefits. It is renowned for its anti-nausea, antiemetic, antidiabetic, anti-inflammatory, antimicrobial and antioxidant properties due to its long history of medicinal use and its richness in bioactive constituents such as gingerols, paradols, shogaols and essential oil [20-26]. Used pure in capsules, powder, herbal teas, fresh or syrup or in combination with other species, ginger is widely recommended for the treatment of headaches, colds, coughs, and constipation [17,27,28]. Also, it proved to have properties such as promoting digestion, stimulating appetite, and improving blood circulation. To this extent, various cosmetic products, some toothpastes, and food supplements contain some ginger. Recognised for its aphrodisiac and tonic properties, ginger seem to improve sperm quality [29]. Additionally, studies have proven that ginger extracts have beneficial and calming effects on oxidative stress, hyperglycemia and hyperlipidemia. By increasing the catabolism of fats in skeletal muscles and energy expenditure, ginger consumption can reduce obesity; whereas the application of its essential oil on the skin kills pain [30].

Many other suspected virtues of ginger exist but the scientific evidence is insufficient. These include a promising effect of this spice as a soother of arthritis-related pain [31] and a therapeutic agent in the treatment of certain types of cancer, including prostate cancer [32], breasts [33], kidneys [34], pancreas [31,35], colon and rectum [36,37], of the cervix [38,39]. The anti-cancer properties are attributed to the activity of 6-gingerol which prevents the proliferation of tumour patches in cancer cells and minimises side effects of cancer treatments [33].

4. Biochemical Composition of Ginger Rhizome

Phytochemical studies have shown that ginger rhizomes contain a wide variety of active compounds, which concentrations vary depending on geographical origin, growing season, harvest period and level of maturity of rhizomes at harvest [40,41,42]. These compounds also vary depending on the variety, agronomic practices, and especially drying and storage conditions [20].

More than 400 different compounds have been found in ginger. The main constituents of rhizomes (Table 1) are carbohydrates, fats, proteins, amino acids, vitamins (thiamine, riboflavin, niacin, vitamin A and C), minerals (iron, calcium, phosphorus, zinc, copper), terpenes and polyphenolic compounds [20,43]. According to [41], ginger contains 194 types of volatile oils, 85 types of gingerol and 28 types of diarylheptanoid compounds. Aromatic constituents are zingiberene and bisabolene, whereas oleoresin confers the pungent trait [41,43,44].

Therefore, oleoresins are very important compounds for the hot and lemony flavour of ginger. Some of these compounds belong to the vanilloid family and also known as gingerols [45,46]. Thus, the characteristic aroma and flavour of ginger are due to volatile oils essentially rich in gingerols and shogaols [44,45]. It appears that gingerols, a series of chemical homologs differentiated by the length of their unbranched alkyl chains, have been identified as the main hot components of ginger oleoresin from fresh rhizomes, with [6]-gingerol being the most abundant. However, shogaols are products generated through the dehydration of gingerols during long-term storage or heat treatment [17]. Therefore, shogaols predominate hot constituents of oleoresin in dried ginger.

Table 1. Dietary value of ginger rhizome (USDA data)

Nutrients	Composition per 100g of the rhizome
Energy	80 cal
Carbohydrates	18 g
Protein	1.82 g
Lipids	0.8 g
Saturated fatty acids	2.2 g
Fat	0.75 g
Sugars	1.7 g
Dietary fiber	2 g
Mineral elements	
Calcium	16 mg
Iron	0.6 mg
Magnesium	43 mg
Phosphorus	34 mg
Potassium	415 mg
Zinc	0.34 mg
Vitamins	
Thiamin (vitamin B1)	0.025 mg
Riboflavin (vitamin B2)	0.034 mg
Vitamin B3 (Niacin)	0.075 mg
Vitamin B5 (Pantothenic Acid)	0.203 mg
Vitamin B6 (Pyridoxine)	0.2 mg
Vitamin B9 (Folic Acid)	11 µg
Vitamin C	5 mg

5. Ginger Production in Burkina Faso

Ginger is a promising crop with high economic potential. Its production remained marginal in Burkina Faso, compared to major food crops and cash crops [47]. The average annual production was estimated below 5.000 tons per year, which meets less than 10% of the domestic demand, estimated at around 50.000 tons per year [7]. The production fluctuated from year to year, but with overall an increasing trend in recent years [47]. This evolution of the production reflects the growing interest of farmers in this crop due to an increasing market demand.

Ginger cultivation has been adopted by many farmers as an option of income diversification and thus provides them with substantial revenues. Diversification of crops contributes significantly to farmers' resilience to climate change and offers economic benefits to alleviate poverty and food insecurity [48].

However, farmers dedication to large scale production is constrained by the tediousness of the work, the lack of

labour and agricultural equipment and the long duration of ginger production cycle. In a survey we conducted in the crop production areas, most of the producers we met testify that ginger is the first crop to plant with early rains, well before even major food and other cash crops (cereals, cotton, groundnut, sesame, etc.). Yet, ginger is one of the last to be harvested. However, it is not known whether this schedule is a season planning option of farming activities or a requirement of the species to complete its cycle. Therefore, future research should clarify whether ginger can be produced in shorter duration.

Furthermore, the most common agricultural practice for ginger cropping is planting on ridges, although often flat sowing is also used. These practices are implemented along with mulching for soil moisture conservation, soil fertility improvement, and seedling protection from excessive sunlight [49].

Such methods are important to sustain ginger cultivation, which seems to deplete soil noticeably [1]. Thus, several soil fertility management practices, such as crop rotation and association, have been applied to minimise soil depletion over years.

Ginger is mainly produced in western regions of Burkina Faso, such as the *Cascades*, the *Hauts Bassins* and the *Sud-Ouest* (Figure 1). These regions are the most humid and their pedoclimatic conditions are very conducive to ginger cultivation. Whilst men are predominant in the production activities, ginger processing and commercialisation are generally entitled to women. The business related to this spice proved to be beneficial all actors, including producers, traders and processors [47].

Subsequently, ginger appears as a cash crop with high market value, which is dragged by the crop's proven or recognized nutritional and medicinal properties [50,51]. However, although its cultivation is increasingly gaining interest, little research is being undertaken on ginger in order to better guide producers and develop successful and adapted cultivars in Burkina Faso.

6. Conservation of Ginger Rhizomes

6.1. Traditional Methods of Preserving Rhizomes

Successful conservation is a key factor in the preservation of species' genetic resources, in varietal improvement programmes and in commercial quality maintenance. This is even truer with ginger, which is vegetatively propagated and the conservation of seed rhizomes from one crop year to the other can be a big challenge for farmers. Traditionally, ginger is conserved in three main conditions [51,52]: (i) on-site conservation in the field. In this case, the rhizomes are not harvested but are rather kept underground and then covered with straw to minimize the sun's impact; (ii) the heap storage conservation under shade with adequate mulching, or in a straw-covered hut; finally (iii) conservation in pits covered with earth and straw. The duration of the conservation is dependent on the farmers urge to sell his produce to face variable financial needs (children school fees, social events) or to use them as seeds for the next cropping season.

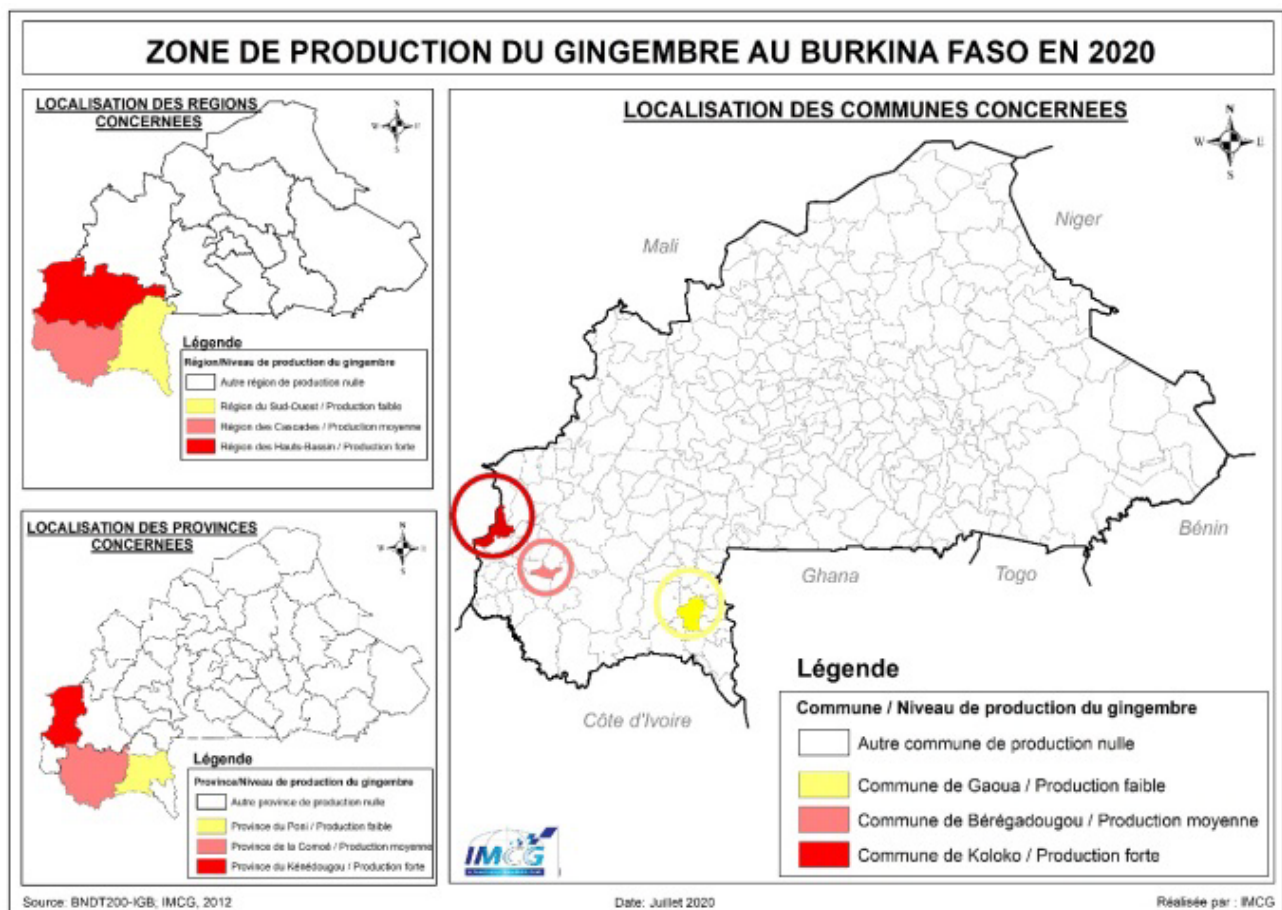


Figure 1. Map showing ginger production areas in Burkina Faso [47]

6.2. Constraints of Conservation and Improvement Strategies

The long-term preservation of ginger is laborious with traditional, rudimentary and not-always effective methods. Indeed, under traditional storage conditions, ginger rhizome may be subject of many serious issues such as quality defects, mould and other attacks of biotic origin (bacteria, fungi, viruses, nematodes) [14], rots, early germination, physiological exhaustion, etc. [16,53,54]. Farmers' conservation techniques do not warrant rhizomes' integrity over a long period of time. Long term conservation in traditional condition leads to gradual degeneration and subsequent weakening of their ability to regenerate. This affects the seed system enormously, which remained informal, due to little involvement of both research institutions and the National Seed Service, because the conservation of rhizomes from one season to the next remains uncertain.

Another setback of the traditional conservation system is the loss of genetic variability of ginger, imposed by a kind of natural selection of genotypes that stand long term conservation. Yet, the crop production and varietal improvement depend greatly on the available diversity [55]. Therefore, there is a need to improve ginger conservation methods to save the maximum of its genetic resources and develop the ginger industry in the country. To the extent of diversity conservation, maintenance and creation of variability, many modern conservation methods exist that could overcome the limitations of traditional approaches. Of these, *in vitro* micropropagation

of buds used as explants has already been shown to be very effective on the related species *Curcuma caesia* [56,57]. Tissue culture is a promising method for the maintenance of collections. This technique, already tested on ginger in Jamaica to produce new disease-free seedlings, has the advantage of addressing both the seed multiplication and the species diversity conservation [58].

In the current context of ginger cultivation in Burkina Faso, the challenge of conservation remains a crucial agricultural research theme to investigate. To achieve a thriving ginger production in the country, losses during seed rhizomes storage must be reduced significantly. This requires the development of innovative conservation methods adapted to the environment and the socio-economic conditions of farmers.

7. Varietal Improvement of Ginger

7.1. Main Selection Objectives

As a crop with secondary importance, research in the selection and genetic improvement of ginger is almost non-existent in Burkina Faso. The only known work in this field is that of Nandkangré and co-workers [59] on the genetic characterization of ginger accessions collected in the *Hauts-Bassins* and *Cascades* regions, using microsatellite markers. Additionally, pilot research has been under way at Farakoba Agricultural Research Station, where some varieties have been selected. However, not only are there few or no scientific publications addressing

ginger research in Burkina Faso, but also there is a lack of hindsight to appreciate the work already done. As a result, nationally defined selection targets are not known.

Nevertheless, the various constraints linked to the production and conservation of quality ginger seed-rhizomes suggest that breeding programmes focus efforts on the selection of genotypes that address these constraints. In this way, breeding activities must contribute to the development of cultivars possessing important traits such as productivity, resistance to diseases and pests, essential oil content, oleoresin content, and fibre content [60].

Also, such research efforts should encompass the genetic improvement of cultivars for adaptation to a wider production area and for their commercial traits [61]. Ultimately, cultivar development should lead to new varieties that meet market demand and consumers' preferences.

7.2. Genetic Diversity of Ginger

Genetic diversity increases the chances of having alleles favourable to the various traits of interest for selection. Tools for assessing genetic variability include molecular analyses and varietal testing. These tools of common use, allow a better knowledge of the varieties and help in the decision-making during the selection process of the most efficient varieties for the trait(s) of interest [62,63,64].

The availability of genetically different clones is essential to implement varietal improvement of vegetatively propagated plants. Thus, biodiversity is crucial to ensure a diversified and sustainable production of the spice plant ginger [65] but also to conduct genetic improvement programme.

7.2.1. Agronomic Trials

In plant breeding, agronomic evaluation is essential to know the level of variability present in the genetic material at hand [66]. Thus, many agronomic trials has been conducted, mainly in big ginger-producing countries where ginger is highly appreciated, such as India, China, Japan, Thailand, Brazil and Malaysia [66,67,68]. Such studies revealed variable levels of diversity in ginger. In addition to presenting genetic variability, trials enable to estimate correlations between traits [66,68,69]. Thus, relevant information have been provided on the levels of agronomic and commercial traits of the plant, including yields and essential oils content and rhizome's aesthetics [67]. However, this crop appeared to show, overall, a low genetic variability mainly due to its characteristics of vegetative propagation pathways, which minimise sources of variability.

In Burkina Faso, research on ginger is recent and mainly concerns the study of genetic diversity conducted by [59]. Cultivars currently under cultivation were issued from selection by the farmers themselves based on the phytosanitary status of rhizomes and their preferences in terms of size, colour and taste (spiciness). Particular attention should therefore be paid to the formal management of ginger seed rhizomes in terms of quality control.

7.2.2. Molecular Markers

Molecular markers are the most appropriate tool for the assessment of genetic diversity, since they are not prone to

the effect of the environment. Genetic diversity studies conducted to date on ginger and other related species used AFLP-like molecular markers [31,70,71,72], ISSR, SSR, RAPD [59,73,74] and isoenzyme markers. These markers are renowned for their simplicity, speed and reliability of results. In particular, PCR-based marking systems are known for their effectiveness in genetic diversity studies [55,71,75]. However, the result that has consistently emerged from the different systems of diversity studies was the low genotypic variability, despite the high morphological diversity known in ginger [60].

In Africa, and particularly in Burkina Faso, there is little or no variability [59]. Virtually the same clones may be found in the different producing regions. Generally, vegetatively propagated plants such as ginger have low genetic diversity [57,76]. This is also due to the relatively recent introduction of this spice species in Africa from Asia [13,45]. In addition, in a pivotal study, the analysis of sequence labels expressed had made it possible to detect in the NCBI database, 64026 SNP sites and 7034 sites of indel polymorphism with a frequency of 0.84 SNP / 100 bp [77]. There is then a significant variability hidden in the genome, the study of which should detect more molecular polymorphisms at the proportion of the high phenotypic variability. As a result, diversity analyses based on genome sequencing offer interesting prospects for exploiting genetic diversity for breeding the species [78,79]. Advanced analysis of genetic diversity expressed by variants in a linear sequence of DNA, is relevant for detecting genes responsible for traits of agronomic and commercial interests in ginger [80].

Since the available knowledge on the ginger genome is scarce, RAPDs have been the most widely used markers in the crop diversity studies [75], due to their reproducibility and their high level of polymorphism [81]. However, SSRs remain until then one of the most powerful markers that make it possible to accurately and quickly assess the level of genetic diversity within germs of any crop. To this end, eight (8) SSR markers have been specifically developed on ginger [75,81]. Nowadays, SNPs have become prime markers in the characterization of genetic material, especially in high-throughput detection and easy integration of genotyping data. They have the advantage of accurately characterizing and describing the complete genome of a species [77,82]. The development of this type of markers on ginger would be very useful to deepen the study of the crop genetic diversity. In addition, the application of molecular markers has proved to be effective in the management of collections of genetic material and varietal identification. Furthermore, they contribute to our understanding of the genetic control of quantitative traits and thus support the breeding process.

7.3. Selection and Improvement Methods

Molecular marker-assisted selection (MAS) offers the advantage of reliably identifying appropriate parental lines and tracking target genes in breeding populations [79,83]. The botanical nature of ginger has made varietal improvement projects delicate. It is a species with an exclusively vegetative propagation mode [60]. Thus, clone's selection activities predominate in research programs dedicated to this crop and hybridisations are

rather rare. In addition, the low genotypic variability of this species makes it difficult and slow to progress in genetic gain by sexual routes. Therefore, mutation breeding and tissue culture appear as sources of allelic variability, to provide new genotypic variants in ginger. Mutations in the genome can be induced by gamma irradiation or by the use of mutagens such as ethyl methane sulphonate, diethylsulfate or sodium azide [84,85,86,87].

These methods have been reported as effective in inducing genetic variation in several plant species including groundnuts [85,86,87], cowpea [84], chickpea [88], and also another asexually reproducing plant such as banana [61]. In addition, tissue culture on ginger can generate somaclonal variants which can thus broaden the genetic basis of the species. Such induced variations are opportunities for the selection and cultivar development of ginger [89], especially in regions where its genetic diversity is trivial.

8. Conclusion and Outlook

Ginger is a very widespread plant and consumed all over the world. Therefore, its knowledge and varietal improvement are crucial to enhance the economic value of the crop, develop its industry, and harness its nutritional and therapeutic benefits. The low genotypic diversity of ginger can be compensated on the one hand by the introduction of materials from countries with a high genetic diversity, and on the other hand, by the induction of allelic variability by means of various processes such as mutagenesis and genetic transformation.

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Statement of Competing Interests

The authors declare that they have no competing interests.

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