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Diversity, characterization and utilization of ginger: a review

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Abstract

Ginger (*Zingiber officinale* Rosc.), originated in the Indo-Malayan region, is now widely distributed across the tropics of Asia, Africa, America and Australia. It was domesticated in India and China, which represent the centre of origin of the species. Cultivated ginger though sterile, exhibits variations in rhizome and vegetative characters. The crop is gaining importance as a curative agent for a variety of ailments. Yield and quality traits (such as essential oil, fibre and oleoresin contents) along with volatile and non-volatile constituents are important determinants of the commodity's end product. Cultivar diversity for yield and morphological features is well known in ginger with few primitive types having excellent quality. However, the common name(s) of ginger cultivars are confusing and have resulted in geographical bias in its *ex situ* conservation. Most of the molecular/biochemical marker studies reported in ginger show low levels of polymorphism in contrast to plentiful phenotypic variability recorded in the species. The large influence of environmental factors on the content of key compounds, lack of seed set and confusion of the common names are the leading constraints to further varietal improvement of ginger. As tailor-made ginger varieties assume future significance these aspects will have relevance.

Keywords: antiquity; biochemical; medicinal use; molecular; morphological; taxonomy

Introduction

Ginger (*Zingiber officinale* Rosc.), originated in the Indo-Malayan region, is now widely distributed across many countries as a spice and medicinal plant (Purseglove *et al.*, 1981; Burkill, 1996; Park and Pizzuto, 2002). Traders took ginger from India to Mediterranean region during the 1st century CE (Current Era). The Arabs introduced ginger to East Africa in the 13th century CE and the Portugese spread it to West Africa and the Pacific islands for commercial cultivation (Ravindran *et al.,* 2006).

The major ginger growing countries include Australia, Brazil, Bangladesh, Cameroon, China, Costa Rica, Fiji, Ghana, Guatemala, Hawaii, India, Indonesia, Jamaica, Mauritius, Malaysia, Nepal, New Zealand, Nigeria, Philippines, Sierra Leone, Sri Lanka, Taiwan, Thailand, Trinidad and Uganda covering a total area of 387,300 ha with a production of 1,476,900 MT. India is the world's largest producer of ginger at present (Table 1). Export of ginger from India was 7500 MT during 2006–2007. 'Cochin ginger', 'Wayanadan ginger' (India), 'Chinese ginger' (China), 'Buderim Gold' (Australia) 'Jamaican' (Jamaica) are globally traded products. Ginger in various forms is used as food flavorant, antioxidant and antimicrobial besides as deodorizing agent in food. Chinese, Indian, Tibetan and Arabic systems of medicine recognized the medicinal value of ginger since ancient times (Atman and Marcussen, 2001).

This review is intended to provide an overview of the diversity of cultivated ginger, its characterization and utilization.

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Table 1. Area, production and productivity of ginger in the world (2006)

Country	Area (ha)	Production (tons)	Productivity (tons/ha)
India	105.50	517.8	4.9
China	24.50	279.0	11.3
Indonesia	18.20	159.0	8.7
Nepal	12.90	154.1	12.0
Nigeria	191.00	134.0	2.4
Bangladesh	7.70	49.4	6.4
Thailand	14.00	34.0	2.4
Philippines	3.90	27.2	6.9
Cameroon	1.30	7.5	5.7
USA	0.04	1.9	47.5
Rest of the World	8.20	71.5	8.7
World	387.30	1476.9	3.8

Source: http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567.

Antiquity

Ayurveda, the Indian 'science of life' of approximately 5000 years of antiquity, documented the medicinal value of ginger in treatises such as *Charaka Samhita*, *Shushrutha Samhita* and *Ashtangahridaya*. In *Ayurveda*, ginger is known as *Mahaoushadhi* meaning great medicine. It is *Sringavera* in Sanskrit, the ancient Indian language, which has given way to the Greek Zingiberi and to the Latin *Zingiber* (Rosengarten, 1969; Purseglove *et al.*, 1981). Ginger is also mentioned in Koran (76: 15–17) though it does not figure in Bible. Ginger was first documented by van Rheede (1692) as *inschi* (*inchi*) in 'Hortus Indicus Malabaricus' – the first printed account of the plants of Western Coast (Malabar Coast) of India.

Taxonomy

The genus *Zingiber* belongs to the family *Zingiberaceae* under the order *Zingiberales* and the tribe *Zingibereae* (Holtum, 1950). *Zingiberaceae* includes three other tribes: *Hedychieae*, *Alpinieae* and *Globbeae* (Petersen, 1889; Burtt and Smith, 1972). The tribe *Zingibereae* has seven other genera: *Boesenbergia*, *Camptandra*, *Roscoea*, *Kaempferia*, *Amomum*, *Hedychium* and *Curcuma* (Kress *et al.*, 2002). Jatoi *et al.* (2006) using rice microsatellite markers assessed the genetic variability among three genera of the family *Zingiberaceae*: *Zingiber*, *Alpinia* and *Curcuma* and found the origin of the genera diverse covering eight Asian countries. *Zingiber* contains 150 species and four sections distributed throughout tropical Asia, China, Japan and tropical Australia besides the subspecies (varieties): *Z. officinale* var. *rubra* and *Z. officinale* var. *rubrum* (Muda *et al.*, 2004). *Z. officinale* is included in the section II, *Lampuzium* (Baker, 1882; Sabu, 2003; Larsen and Larsen, 2006).

Diversity

Species level

The genus *Zingiber* includes many economically important species besides *Z. officinale* as given in Table 2. The Indian species reported include *Z. chrysanthum* Rosc., *Z. rubens* Roxb., *Z. roseum* Rosc., *Z. nimmonii* Dalz., *Z. wightianum* Thw., *Z. barbatum* Wall., *Z. squarrosum* Roxb., *Z. ligulatum* Roxb., *Z. cernuum* Dalz., *Z. panduratum* Roxb., *Z. pardocheilum* Wall., *Z. intermedium* Baker, *Z. officinale* Rosc., *Z. griffithii* Baker, *Z. gracile* Jack., *Z. zerumbet* Smith, *Z. cylindricum* Moon,

Table 2. Some of the economically important *Zingiber* species

Species/subspecies	Occurrence	Use
Z. officinale Roscoe	Tropical countries, China, USA	Spice, condiment, medicinal
Z. officinale var. *rubrum*	Malaysia	Medicinal, spice
Z. officinale var. *rubra*	Malaysia	Medicinal, spice
Z. mioga Roscoe	Japan	Vegetable. Shoot and flower are edible
Z. zerumbet (L.) Smith	Tropical Asia	Medicinal, ornamental
Z. montanum (Koenig) Link ex Dietr	India, Malaysia, SriLanka, Java	Used in traditional medicine
Z. *clarkii* King	Sikkim Himalayas	Ornamental
Z. *aromaticum* Val	Tropical Asia	Ornamental, medicinal, flavouring
Z. rubens Roxb	Indo-Malaya	Medicinal, ornamental
Z. griffithii Baker	Malaysia	Ornamental
Z. ottensii Valet	South East Asia	Medicinal, ornamental
Z. corallinum Hance	South East Asia	Chinese medicine, ornamental
Z. americanus Bl.	South East Asia	Medicinal, vegetable
Z. argenteum (J. Mood and I. Theilade)	Sarawak, Malaysia	Ornamental

Table 3. Cultivar diversity of ginger in India (revised from Sasikumar *et al.*, 1999)

S. No.	Cultivar/variety
1	Ambalavayalan (Kerala)
2	Anamika
3	Arippa
4	Assam (Assam)
5	Athira[a] (Kerala)
6	Bahrica (Orissa)
7	Bajpai
8	Bazar local (Arunachal Pradesh)
9	Bhaise (Sikkim)
10	Bola (Assam)
11	Burdwan (West Bengal)
12	China[b] (Kerala)
13	Edappalayam (Kerala)
14	Ellakallan (Kerala)
15	Ernad-Chernad (Kerala)
16	Ernad-Manjeri (Kerala)
17	Gorubathani (Sikkim)
18	Himachal (Kerala, Himachal Pradesh)
19	Himgiri[a] (Himachal Pradesh)
20	Jamaica[b] (Kerala)
21	Jatia (Assam)
22	Jorathangey (Sikkim)
23	Jorhat (Assam)
24	Jugijan (North East India)
25	Kakkakalan (Kerala)
26	Karakkal (Kerala)
27	Karthika[a] (Kerala)
28	Keki (Arunachal Pradesh)
29	Khasi local (Meghalaya)
30	Kozhikkalan (Kerala)
31	Kunduli local (Orissa)
32	Kunnamangalam (Kerala)
33	Kuruppampady (Kerala)
34	Mahim (Maharashtra)
35	Mahima[a] (all over India)
36	Majhauley (Sikkim)
37	Mananthody (Kerala)
38	Maran/Moran (Assam, Kerala)
39	Mowshom (NorthEast India)
40	Nadia (West Bengal, Kerala, Meghalaya)
41	Naga Shing (Manipur)
42	Nangrey (Sikkim)
43	Narasapattam (Andhra Pradesh)
44	Poona
45	Rajagarh local
46	Rejatha[a] (Kerala)
47	Rio-de-Janeiro[b] (Kerala, Karnataka)
48	Sargi guda (Orissa)
49	Saw thing laidum (North East India)
50	Sawthing Pui (North East India)
51	Saying Makhim/pink ginger (Meghalaya)
52	Shing Bhoi (Meghalaya)
53	Shing Bhukir (Meghalaya)
54	Sierra Leone[b]
55	Singhihara
56	Suprabha[a] (all over India)
57	Suravi[a] (Orissa)
58	Suruchi[a] (Orissa)
59	Taffingiva
60	Taiwan[b]
61	Thang-Chang (Mizoram)
62	Thing laidum (Mizoram)
63	Thingaria (Mizoram)
64	Thingpui (Manipur, Mizoram)
65	Thodupuzha (Kerala)
66	Tura (Meghalaya)
67	Uttarpradesh (Uttarpradesh)
68	Valluvanad (Kerala)
69	Varada[a] (all over India)
70	Vellinchi (Kerala)
71	Vengara (Kerala)
72	Wynad Kunnmangalam (Kerala)
73	Wynad local (Kerala)
74	Zahirabad

Words in parenthesis denote important states of cultivation.
[a] Improved variety, [b] Exotic.

Z. macrostachyum Dalz., *Z. spectabile* Griff., *Z. casumunar* Roxb., *Z. parishii* Hook., *Z. clarkii* King, *Z. capitatum* Roxb., *Z. marginatum* Roxb. (Baker, 1882).

Most of the *Zingiber* species are diploid ($2n = 22$) except *Z. mioga* ($2n = 55$) and set seed. In cultivated ginger (*Z. officinale*) $2n = 24$ and $22 + 2B$ are also reported besides the normal diploid number of $2n = 22$ (Ravindran *et al.*, 2005). The species is sterile.

Cultivar level

Ginger is a rhizome propagated crop. Cultivar diversity abounds in India and China, which represents the centre of origin of this species, unlike Simmonds (1979) observed in many other crops. Geographical spread of ginger clones coupled with mutation and selection are considered to be responsible for the cultivar diversity (Ravindran *et al.*, 1994). About 74 cultivars, most of them with vernacular names, possessing varying levels of quality attributes and yield occur in India (Table 3; Sasikumar *et al.*, 1999). Major Chinese cultivars include 'Gandzhou', 'Shandong', 'Zaoyang', 'Zungi big ginger', 'Chenggu yellow', 'Kintoki', 'Sanshu' and 'Oshoga' are three major ginger cultivars from Japan (Ravindran *et al.*, 2005). Ridley (1912) has reported three types of ginger from Malaysia viz. 'halyia betle', 'halyia udang', 'halyia bara', 'Native' and 'Hawaiin' are cultivars from the Philippines. Nepal has about 50 cultivars (Sasikumar *et al.*, 1999). Ginger varieties of Guyana, mainly from the hinterlands of that country, are bold or very bold and lack any varietal names. An obsolete cultivar characterized by very dwarf stature and extremely slender, fibrous rhizome is also grown in Guyana (Sasikumar, 2008). 'Sidda' and 'China' are the cultivars of Sri Lanka (Macloed and Pieris, 1984) and Jamaica has only one popular cultivar (Lawrence, 1984).

Varietal improvement in ginger has been limited to germplasm selection for high yield and better quality attributes besides some mutation breeding and ploidy breeding. So far nine improved ginger varieties ('Varada,' 'Mahima', 'Rejatha', 'Suruchi', 'Suravi', 'Suprabha', 'Himgiri', 'Athira' and 'Karthika') were released in India (Sasikumar *et al.*, 2003, 2007) and one ('Buderim Gold') from Australia (Smith *et al.*, 2004).

Characterization of ginger

Morphological and anatomical characterization

Variability for yield, quality traits and rhizome features has been reported in ginger (Khan, 1959; Thomas, 1966; Krishnamurthy *et al.*, 1972; Muralidharan and Kamalam, 1973; Mohanty and Sharma, 1979; Nybe and Nair, 1979; Nybe *et al.*, 1980; Sreekumar *et al.*, 1980; Kumar *et al.*, 1980; Mohanty *et al.*, 1981; Rattan *et al.*, 1988; Arya and Rana, 1990; Sasikumar *et al.*, 1992; Zachariah *et al.*, 1993; Ravindran *et al.*, 1994; Sasikumar *et al.*, 1994, 1999, 2003; Aiyadurai, 1996; John and Ferreira, 1997; Chandra and Govind, 1999; Yadav, 1999; Zachariah *et al.*, 1999; Singh *et al.*, 1999; Singh *et al.*, 2000; Gowda and Melanta, 2000; Mohandas *et al.*, 2000; Naidu *et al.*, 2000; Singh, 2001; Tiwari, 2003; Abraham and Latha, 2003; Rana and Korla, 2007; Lincy *et al.*, 2008) (Fig. 1). Primitive types (obsolete cultivars) in general are characterized by small rhizomes; poor yield and better quality although the cultivars/improved varieties possess attractive bold rhizomes with good yield and mixed quality traits. Ginger cultivars/varieties suited for various end uses are given as Table S1, available online only at http://journals.cambridge.org. However, yield and quality levels in ginger also vary with genotypes, soil types, locations, seasons, cultural practices and climatic conditions.

Ginger (*Z. officinale*) has distinct anatomical features such as absence of periderm, short lived functional cambium, occurrence of xylem vessels with scalariform thickening in the rhizome compared with *Z. zerumbet*, *Z. roseum* and *Z. macrostachyum* (Ravindran *et al.*, 1998).

Fig. 1. Variability for rhizome features in Indian ginger germplasm (a) 'Varada', (b) 'Mahima', (c) 'Rejatha', (d) 'Suprabha', (e) 'Sabarimala', (f) 'Kozhikkalan', (g) 'Kakakalan', (h) 'Ellakallan', (i) 'Nadia', (j) 'Rio-de-Janeiro', (k) 'Silent valley' and (l) 'Himachal' (A colour version of this figure can be found online at journals.cambridge.org/pgr).

Molecular characterization

RAPD (random amplified polymorphic DNA), AFLP (amplified fragment length polymorphism), ISSR (inter simple sequence repeats), simple sequence repeats markers and isozymes have been used to characterize ginger germplasm. Sasikumar *et al.* (2000) evaluated 14 accessions of ginger from different regions of India for variations in acid phosphatase, polyphenol oxidase, super oxide dismutase (SOD) and peroxidase (PRX). Among them, acid phosphatase showed maximum number of bands followed by SOD, while PRX had the least bands. Though variability in the population was very low, the accessions from Kerala region (southern India) were distinct from those collected from the north-east Indian states suggesting a geographical bias of the germplasm studied. A total of 28 ginger cultivars from China were compared for PRX isoenzyme patterns by fuzzy cluster analysis (Chengkun *et al.*, 1995). The cultivars differed in zonal number, activity intensity and isoenzyme pattern, which were related to rhizome size, growth intensity and blast (blight?) (*Ralstonia solanacearum*) resistance. The cultivars from the Fujian Province were more diverse.

Muda *et al.* (2004) studied the genetic variation among three *Z. officinale* cultivars/subspecies i.e. *Z. officinale* var. *officinale*, *Z. officinale* var. *rubra* ('halia bara') and *Z. officinale* var. *rubrum* ('halia padi') using RAPD analysis and cultivar-specific markers were obtained. Similarly, Nayak *et al.* (2005) based on their study of 16 ginger cultivars from India showed that RAPD primers OPC02, OPD20 and OPN06 had strong resolving powers and were able to distinguish all cultivars. However, Palai and Rout (2007) found that of the eight Indian landraces/varieties of ginger ('Surabhi', 'Tura Local', 'Jugijan', 'Nadia', 'S-558', 'Gorubathani', 'ZO-17' and 'Nangrey') all but one formed a single cluster in the dendrogram. Molecular characterization of seven ginger accessions including primitive, exotic and elite ones using 14 ISSR and 16 RAPD markers by Prem *et al.* (2007) also showed that the four primitive gingers ('Kozhikkalan', 'Kakkakalan', 'Ellakkallan' and 'Sabarimala') formed one cluster while all others were separately clustered in the dendogram. In another molecular characterization study using 25 RAPD primers Zhen-wei *et al.* (2006) reported a narrow genetic base among 20 Chinese cultivars.

AFLP markers were used to study the genetic relationship among three Indonesian type gingers (big ginger, small ginger and red ginger) (Wahyuni *et al.*, 2003). In this analysis, 28 accessions including those from Africa and Japan were used. Red ginger was genetically distinct from the big ginger, but close to some accessions of small ginger. There was no clear genetic differentiation between the small and big types ginger. Lee *et al.* (2007) isolated and characterized eight polymorphic microsatellite markers. A total of 34 alleles were detected across 20 ginger accessions, with an average of 4.3 alleles per locus. This study revealed the existence of moderate level of genetic diversity among the ginger accessions genotyped.

Recently, Kizhakkayil and Sasikumar (2010) characterized 46 accessions using 30 RAPD and 17 ISSR markers. Unweighted pair group method with arithmetic mean dendrograms based on three similarity coefficients (Jaccard's, Sorensen–Dice and Simple Matching) placed the accessions in four similar clusters and revealed less genetic distance among the accessions. Improved varieties/cultivars were grouped together with primitive types. In the clustering pattern of the accessions, a geographical bias was also evident implying that germplasm collected from nearby locations with local identity may not be genetically distinct. The clustering of the accessions was largely independent of its agronomic features.

The different molecular markers in general revealed low level of polymorphism (Figs. 2 and 3) and only moderate variability with some exceptions, among the ginger accessions studied probably due to the confounded effect of the duplicate accessions in the genebank.

Biochemical characterization

Characterization of ginger for the major biochemical constituents viz. oleoresin, essential oil and crude fibre levels has lead to identification of cultivars rich in one or other of these constituents (Table S1, available online only at http://journals.cambridge.org). Oleoresin content of ginger varied from 3 to 11% depending on the genotype, solvent extraction condition, state of rhizome, place of origin and harvest season (Ratnambal *et al.*, 1987; Vernin and Parkanyl, 2005).

Crude fibre content of dried ginger ranged from 4.8 to 9% (Natarajan *et al.*, 1972) although essential oil content of ginger varied from 0.2 to 3%, depending on the origin and state of rhizome (van Beek *et al.*, 1987; Ekundayo *et al.*, 1988). Characterization of 46 ginger accessions revealed that the primitive type gingers such as 'Sabarimala', 'Kozhikkalan' and 'Kakakalan' as well as few landraces have higher levels of oleoresin and essential oil compared with the improved varieties. (Kizhakkayil and Sasikumar, 2009). Menon (2007) too has observed that primitive ginger types such as 'Kozhikkalan' and 'Vellinchi' are rich in essential oil content. *Shing Bhukir*, a primitive type ginger from Meghalaya, India, is sold at a premium price for its medicinal value (Rahman *et al.*, 2009). 'Kintoki', a landrace from Japan, has very low fibre content (Kizhakkayil, 2008). Indian ginger cultivars are known to vary for the pungent and non-pungent constituents: gingerol and shogaol (Zachariah *et al.*,

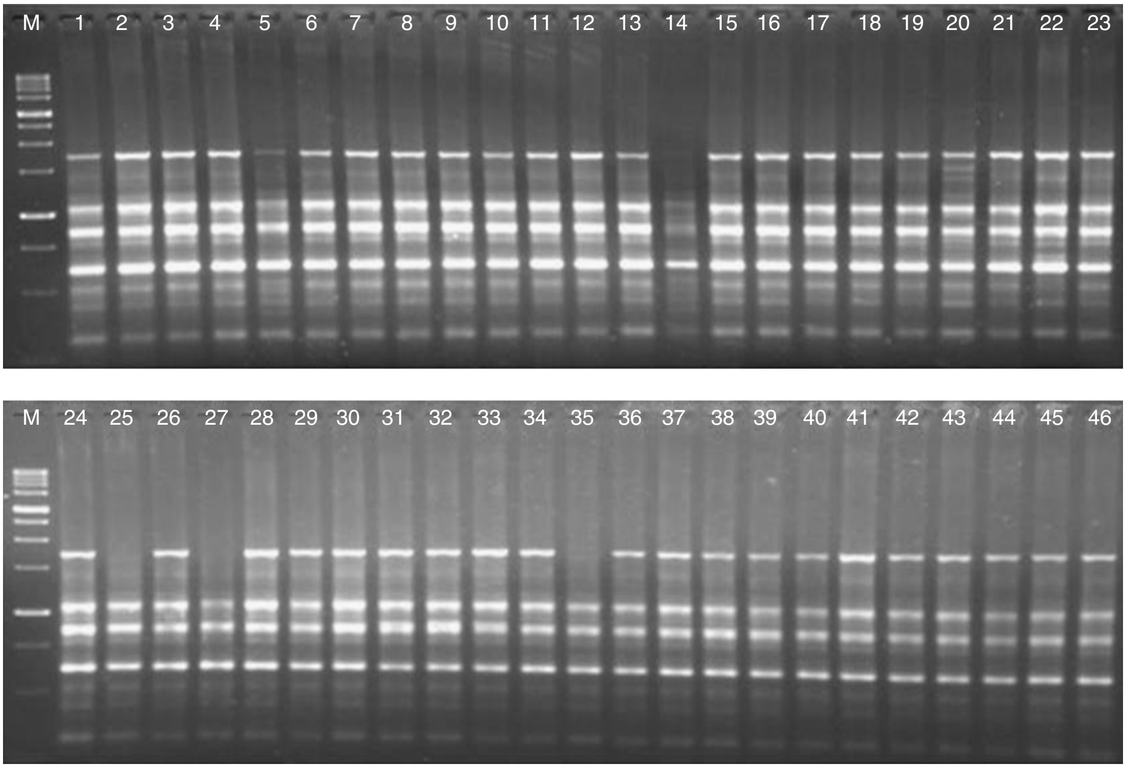

Fig. 2. RAPD profile of the DNA isolated from different ginger accessions amplified with primer OPA 07. M-marker; lane 1–46 'Varada', 'Mahima', 'Rejatha', 'Suruchi', 'Suprabha', 'Himachal', 'Maran', 'Nadia', 'Karakkal', 'Mananthodi', 'Sabarimala', 'Kozhikkalan', 'Ellakkallan', 'Kakakalan', 'Pakistan', 'Oman', 'Brazil', 'Jamaica', 'Rio-de-Janeiro', 'Pink ginger', 'Bakthapur', 'Kintoki', 'Nepal', 'China', 'Jugijan', 'Acc. no. 50', 'Pulpally', 'Acc. no. 95', 'Ambalawayalan', 'Kozhikode', 'Thodupuzha-1', 'Konni local', 'Angamali', 'Thodupuzha-2', 'Kottayam', 'Palai', 'Silent valley', 'Wayanad local', 'Vizagapatnam-1', 'Vizagapatnam-2', 'Fiji', 'Gorubathani', 'Bhaise', 'Naval parasi', 'Neyyar', 'Jolpaiguri', respectively.

1993) though lack of variability for gingerol and shogaol has been observed in Australian ginger (Wohlmuth *et al.*, 2005). High levels of *ar*-curcumene and β-bisabolene with reasonable levels of citral isomers and very low levels of zingiberene were observed in dried Sri Lankan ginger (Macloed and Pieris, 1984).

In short, the volatile and/or non-volatile compounds of ginger are affected by the environment and the state of rhizome (Connel and Jordan, 1971; Macloed and Pieris, 1984; Ekundayo *et al.*, 1988; Menut *et al.*, 1994; Vernin and Parkanyl, 1994; Fakim *et al.*, 2002; Wohlmuth *et al.* 2006). However, a wide variability in the essential oil profile of ginger is unseen though there are few odd cultivars/primitive types excelling in one or the other compounds including the pungent constituents.

Characterization against pests

Bacterial wilt (*R. solanacearum*), soft rot (*Pythium* spp.) and shoot borer (*Conogethes punctiferalis*) are three major pests of ginger. No stable bacterial wilt resistant ginger cultivar is known to exist. Consistent with this, 600 accessions screened for bacterial wilt tolerance using soil inoculation method were found susceptible (Kumar and Hayward, 2005). However, Shylaja *et al.* (2010) reported that the ginger clone 'Athira' is relatively more tolerant to bacterial wilt and soft rot than its mother clone 'Maran'. Clones 'Maran' 'Suprabha' and 'Himachal' have been reported to show field tolerance to ginger rot (*Pythium aphanidermatum*) (Indrasenan and Paily, 1974; Setty *et al.*, 1995).

Nybe and Nair (1979a) while recording shoot borer incidence in 25 ginger cultivars reported cultivar 'Rio de Janeiro' with minimum incidence. Devasahayam *et al.* (2010) could not find any shoot borer resistant lines in 592 ginger accessions screened though 49 accessions were rated as moderately resistant.

Uses

Products and end uses

Ginger imparts flavour and pungency to food and beverages (Arctangder, 1960; Pruthy, 1993; Bakhru, 1999).

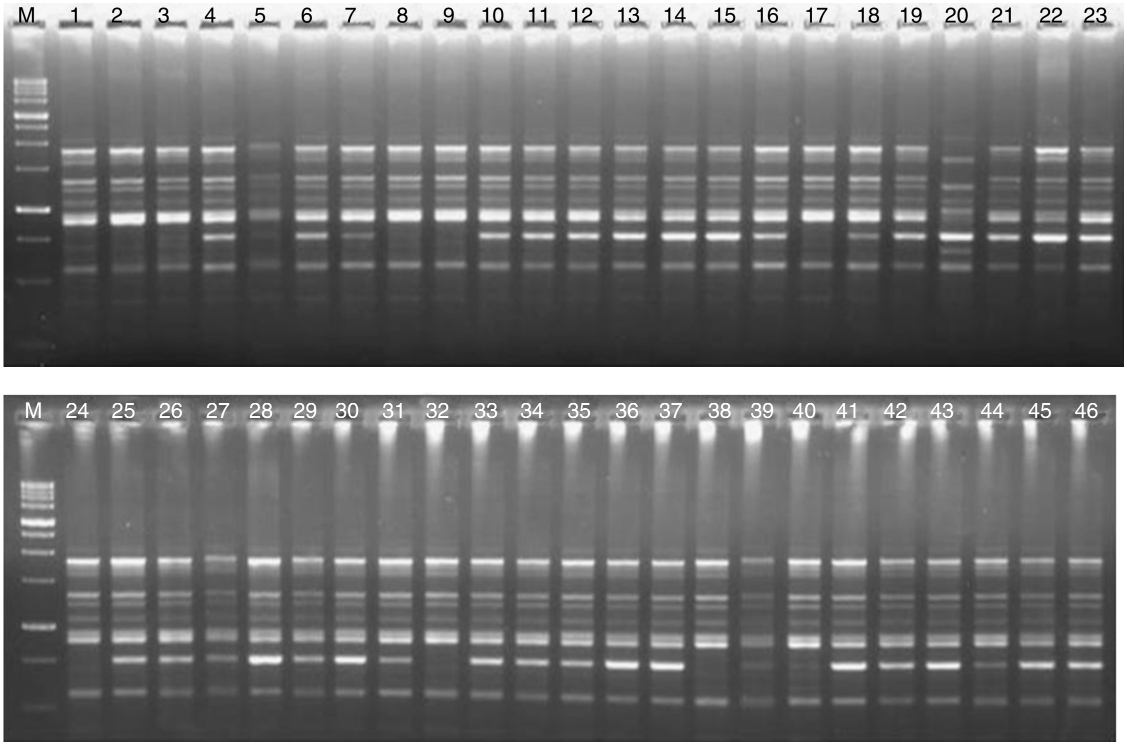

Fig. 3. ISSR profile of the DNA isolated from different ginger accessions amplified with primer ISSR3. M-marker; lane 1–46 ‘Varada’, ‘Mahima’, ‘Rejatha’, ‘Suruchi’, ‘Suprabha’, ‘Himachal’, ‘Maran’, ‘Nadia’, ‘Karakkal’, ‘Mananthodi’, ‘Sabarimala’, ‘Kozhikkalan’, ‘Ellakkallan’, ‘Kakakalan’, ‘Pakistan’, ‘Oman’, ‘Brazil’, ‘Jamaica’, ‘Rio-de-Janeiro’, ‘Pink ginger’, ‘Bakthapur’, ‘Kintoki’, ‘Nepal’, ‘China’, Jugijan’, ‘Acc. No. 50’, ‘Pulpally’, ‘Acc. No. 95’, ‘Ambalawayalan’, ‘Kozhikode’, ‘Thodupuzha-1’, ‘Konni local’, ‘Angamali’, ‘Thodupuzha-2’, ‘Kottayam’, ‘Palai’, ‘Silent valley’, Wayanad local’, ‘Vizagapatnam-1’, ‘Vizagapatnam-2’, ‘Fiji’, ‘Gorubathani’, ‘Bhaise’, ‘Naval parasi’, ‘Neyyar’, ‘Jolpaiguri’, respectively.

Flavour properties of ginger depend on both volatile and non-volatile fractions. Fresh succulent baby pink ginger, salted ginger, crushed fresh ginger, dry ginger, ginger powder, ginger oil, ginger oleoresin, dry soluble ginger, ginger paste and ginger emulsion are used in different preparations. Fresh young ginger, succulent in nature with low fibre content is preferred for products such as ginger candy, preserves, and salted ginger while mature fresh ginger is used for preparing ginger shreds, the ethnic ginger chutney, ginger tea and ginger curry (*Inchi puli*). Ginger is an indispensable component of curry powder, sauces, ginger bread and ginger flavoured carbonated drinks (Hirara and Takesma, 1998) in addition to its use in biscuits, pickles, confectionaries and other dietary preparations.

Ginger in medicine

Ayurveda recommends ginger as a carminative, diaphoretic, antispasmodic, expectorant, peripheral circulatory stimulant, astringent, appetite stimulant, anti-inflammatory agent, diuretic and digestive aid (Warrier, 1989). Recent pharmacological studies attest this age-old medicinal value of ginger (Aimbire *et al.*, 2007; Ansari and Bhandari, 2008; Morakinyo *et al.*, 2008; Heimes *et al.*, 2009; Nammi *et al.*, 2009, 2010; Lakshmi and Sudhakar, 2010). Ginger is recommended to expecting women as an antenatal medicine as well as to alleviate the ‘morning sickness’ during pregnancy (Ozgoli *et al.*, 2009; Broussard *et al.*, 2010) and motion sickness. *Trikatu* is a favourite carminative remedy prepared with equal portions of *Z. officinale*, *Piper nigrum* and *Piper longum* (Anonymous, 1982). Ginger is the major constituent in formulations including *Chatarbhada Kvatha* used against fever and respiratory disorders; in antitussive drug *Lavangadhichurn* and in *Hingvastaka churna* recommended for indigestion (Singh, 1983; Thakur *et al.*, 1989).

Ginger is also a major ingredient in *Unani* preparations such as ‘Hub-gul-pista’, an expectorant, ‘Sufuf-shirin’ an anti-dysenteric drug and ‘Majun Izuroqui’ a geriatric tonic as well as in the ginger based carminatives ‘Qurs Pudina’ and ‘Murraba Adrak’ (Singh, 1983; Thakur *et al.*, 1989).

Chinese medicine too value ginger since 4th century BC (Wagner and Hikino, 1965). The Chinese administer ginger for a wide variety of medical problems such as stomachache, headache, diarrhoea, nausea, cholera, asthma, heart conditions, respiratory disorders, toothache and rheumatic complaints (Wagner and Hikino, 1965; Grant and Lutz, 2000). Africans and West Indians also use ginger for many ailments (Tyler *et al.*, 1981). Ginger has been used in the Mediterranea for treatment of arthritis, rheumatological problems and muscular discomfort (Langner *et al.,* 1998; Sharma and Clark, 1998). It has also been recommended for the treatment of various other conditions including atherosclerosis, migraine, rheumatoid arthritis, high cholesterol, ulcers, depression and impotence (Liang, 1992).

In folk/ethnic medicine too ginger is indispensable. Fresh ginger juice is administered to pregnant women just before childbirth for easy delivery (Rao and Jamir, 1982). Ginger is an ethnic remedy for pain, rheumatism, mad convulsion, collapse, scabies, constipation, indigestion, prolepsis, fistula, cholera, throat pain, tuberculosis, cold, fever and cough (Jain and Tarafder, 1970; Anonymous, 1978). Ginger along with *P. longum* is used as an abortifacient in some tribes (Tarafder, 1983).

In veterinary medicine too ginger is important against many livestock maladies. Iqbal *et al.* (2006) reported the anthelmintic activity of crude powder and crude aqueous extract of dried ginger in sheep naturally infected with gastrointestinal nematodes.

Pharmacology

Both the volatile and non-volatile compounds of ginger are credited with medicinal properties besides imparting pungency and aroma to ginger as a spice (Fig. S1, available online only at http://journals.cambridge.org). The main volatile compounds are mono- and sesqui-terpenes, camphene, phellandrene, curcumene, cineole, geranyl acetate, terphineol, terpenes, borneol, geraniol, limonene, linalool, zingiberene, sesqui-phellandrene, bisabolene and farnesene. Many of these compounds are credited with curative properties. (Feng and Lipton, 1987; Zebovitz, 1989; Keeler and Tu, 1991; Yamahara *et al.*, 1992; Hansel *et al.*, 1992; Reddey and Lokesh, 1992; Martin *et al.*, 1993; Denyer *et al.*, 1994; Leung and Foster, 1995; Newall *et al.*, 1996; Obeng-Ofori and Reichmuth, 1997; Blascheck *et al.*, 1998; Atsumi *et al.*, 2000; Coppen, 2002; Murakami *et al.*, 2003; Zhou *et al.*, 2004; Juergens *et al.*, 2004; Masuda *et al.*, 2004; Ali *et al.*, 2005; Hsu *et al.*, 2005; Kuo *et al.*, 2005; Shin *et al.*, 2005; Rao and Rao, 2005; Riyazi *et al.*, 2007; Chen *et al.*, 2007; Shukla and Singh, 2007; Lee *et al.*, 2009; El-Baroty *et al.*, 2010; Hsu *et al.*, 2010). β-Phellandrene and zingiberene are the major compounds in Indian commercial gingers. Ginger oil *per se* is also having antiulcer, antidepressant and anti-inflammatory properties (Sharma *et al.*, 1997; Khushtar *et al.*, 2009; Qiang *et al.*, 2009).

The major non-volatile pungent compounds of ginger, the gingerols and shogaols, too possess analgesic, antipyretic, cardio tonic, antioxidant, and anti-inflammatory properties besides suppressing cytokine formation and promoting angiogenesis. (Mascolo *et al.*, 1989; Yamahara *et al.*, 1989; Yamahara and Huang, 1990; Huang *et al.*, 1991; Mustafa *et al.*, 1993; Lee and Surh, 1998; Surh *et al.*, 1998; Surh, 1999; Bhattarai *et al.*, 2001; Chung *et al.*, 2001; Ficker *et al.*, 2003; Jolad *et al.*, 2004; Isa *et al.*, 2008; Pan *et al.*, 2008; Park *et al.*, 2009; Koh *et al.*, 2009; Imm *et al.*, 2010). Gingerol, particularly 6-gingerol, has been found to be the most active compound biologically (Yamahara *et al.*, 1989; Mascolo *et al.*, 1989; Huang *et al.*, 1991; Mustafa *et al.*, 1993; Aeschbach *et al.*, 1994; Agarwal *et al.*, 2001; Ficker *et al.*, 2003; Kim *et al.*, 2005; Tripathi *et al.*, 2006; Lam *et al.*, 2007; Sjmonatj, 2009; Jeong *et al.*, 2009; Wu *et al.*, 2010; Yang *et al.*, 2010).

Biologically active compounds of ginger are given in the Table S2, available online only at http://journals.cambridge.org.

Ginger has strong antibacterial and to some extent antifungal properties too (Kapoor, 1997; Habsah *et al.*, 2000; Srinivasan *et al.*, 2001). *In vitro* studies have shown that active constituents of ginger inhibit multiplication of colon bacteria (Bakhru, 1999). Ginger also inhibits the growth of *Escherichia coli*, *Proteus* spp., *Staphylococci*, *Streptococci* and *Salmonella* (Gugnani and Ezenwanze, 1985; James *et al.*, 1999). O'Mahony *et al.* (2005) reported curative effects against *Helicobacter pylori*. Fresh ginger juice showed inhibitory action against *Aspergillus niger*, *Saccharomyces cerevisiae*, *Mycoderma* spp. and *Lactobacillus acidophilus* at 4, 10, 12 and 14%, respectively, at ambient temperatures (Nanir and Kadu, 1987; Meena, 1992; Kapoor, 1997). Martins *et al.* (2001) demonstrated antimicrobial activity of essential oil against gram-positive and gram-negative bacteria using agar diffusion method.

Conclusion

Ginger is one of the most important and ancient spices. Though ginger is sterile, plentiful cultivar diversity, recognized mostly by local names exists. However, most of the molecular/biochemical characterization studies attempted so far failed to reveal significant polymorphism commensurating with the observed morphological variability or yield. A geographical bias in the ginger germplasm conserved in the *ex situ* genebanks, probably due to local (vernacular) identity problems during germplasm collection and the geographical effect on key constituents are the hallmark of most of the germplasm characterization studies. Variability for the essential oil profile as well as the pungent constituents is also not that remarkable though few primitive cultivars with excellent quality traits have been reported from different countries. The primitive types (obsolete cultivars), invariably poor yielders on the verge of extinction, require special attention in long-term conservation strategy especially because convergent improvement or hybridization is rather difficult in a sterile ginger. Pharmacokinetic studies on the long-term effect of the curative compounds are still in infancy. Taxonomic and pharmacological studies on the subspecies of *Z. officinale* will also be rewarding. In future, there may be premium for tailor-made ginger varieties to meet a specific end use. Thus, research on the effect of environmental factors including the changing climate on quality profile and aroma of ginger, pharmacokinetics of the medicinally important constituents, problem of sterility and above all a comprehensive characterization study on the global germplasm should assume priority.

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