Survey, collection and characterization of indigenous and non-indigenous cucurbits in Vietnam

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Abstract

The plant family Cucurbitaceae is highly diverse and comprises about 118 genera and 825 species. Many of these species with its cultivars and landraces are of economic importance because they are used as vegetables and medicinal crops. Some species belonging to the Cucurbitaceae are indigenous, but many of the non-indigenous ones are also well adapted to different geographical regions in Vietnam.

The study was focused on four main aims: 1) To analyse the importance of cucurbits in vegetable growing farms and its utilization in southern Vietnam, 2) To collect cucurbit germplasm; 3) To characterize the collected cucurbit germplasm, 4) To determine the stable characteristics for classifying bitter gourd accessions. Considering the aims, following methodologies were used:

A survey was carried out in rural areas in those regions where vegetable cultivation is the main agricultural sector. Eight districts with 20 communes were selected for the study. In the survey 1,009 growers were interviewed randomly following the criteria: (1) grower had at least five years of experience for cultivating commercial vegetables, (2) the area used for cultivating vegetable crops was minimum 500m^2 per farm, and (3) farmers had cultivated vegetable in previous three crops. Number of cultivated vegetable species, area of cultivation, frequency of growing, and purpose of cultivation were analysed. In the past collection and conservation of cucurbits was done under guidance of AVRDC and VASI mainly in northern Vietnam. Therefore, this study conducted the cucurbit collection in southern Vietnam; 160 accessions of five species including cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*) of the collected cucurbit germplasm were analysed based on morphological characteristics. The examined characteristics were grouped into two types of variables, continuous variables (quantitative characteristics) and categorical variables (involving qualitative, pseudo-qualitative and some quantitative characteristics). Calculating the eigenvectors and creating 3D bi-plots enabled us to differentiate clearly the accessions that were collected in different regions. UPGMA (un-weighted pair group method using arithmetic averages) method was used to clarify the diversity of the accessions belonging the five mentioned cucurbit species. Moreover, there were 16 continuous variables and 12 categorical variables of seven bitter gourd accessions evaluated for its stability in two different growing conditions, greenhouse and field. Two-sample test, correlation test, and UPGMA method were used to determine the stable variables within two growing conditions.

In result of this study, nine cucurbit species were determined, counting for 16.4% of in total 55 vegetable species cultivated for commercial market whereas more than 45% farmers produced cucurbits. Land used for cultivating cucurbits covered 56.5% of total area of vegetable cultivation. Correlations were calculated between ratios of cucurbit species cultivated and farmers' characteristics including age of farmers, education levels (grades), members in households (people), and vegetable cultivated areas (m^2 per farm). Causes affecting the decision for choosing cucurbits as main crops in vegetable cultivation could be determined, in particular factors as the field size, year round cultivation and way of its utilization. During the studies, 244 accessions from 14 cucurbit species belonging to 12 Cucurbitaceae genera were collected in 24 provinces in southern Vietnam. The accessions were classified in 14 species and one subspecies belonging to 12 genera. The species diversity (H) and evenness (E) indices of the collection were 2.2 and 0.51, respectively. The combination of two methods, 3D bi-plots and UPGMA, for evaluating the diversity of the accessions within species was favourable if the accessions had special characteristics, such as TiGi02 and TiGi03 of cucumber (*Cucumis sativus*), BaLi01 of pumpkin (*Cucurbita moschata*), NiTh03 of bottle gourd (*Lagenaria siceraria*), CaTh01 and HcmC03 of loofah (*Luffa cylindrica*), and HcmC01 and QuNa01 of bitter gourd (*Momordica charantia*). The evaluated characteristics provided essential information for understanding the diversity of the accessions that were collected in different regions. Diversity of plant phenotypes is a result of interaction between genetic factors and environmental ones. The presented data suggested that 12 characteristics were useful for evaluating relationships among accessions of bitter gourd (*Momordica charantia*) as follows: (i) number of leaf lobes, (ii) colour of fruit skin at ripe stage, (iii) present of ridge on fruit, (iv) present of fruit spines, (v) size of fruit warts, (vi) indentation of seed edge, (vii) striation of seed coat, (viii) number of nodes up to node with the 1st male flower, (ix) time of first male flower flowering, (x) fruit length, (xi) fruit weight, and (xii) weight of 100 seeds. Genetic relationships among accessions within species were dependent on the stability of characteristics used for hierarchical clustering. Therefore, determining the stable characteristics was necessary for cluster analysis the accessions within the species. Finally, the thesis provides structured information about the importance of cucurbit species for vegetable cultivation in southern Vietnam; the morphological diversity within the most important species; and the morphological characteristics that can be used for determination of the relationships among accessions within bitter gourd. By this, a contribution for establishment a database and seed collection useful for breeding, genetics, and conservation is given. Mapping the diversity of cucurbits according to regions, and based on this planning a strategy for the further collection, conservation, and utilization of cucurbits in Vietnam should be continued.

Keywords: cucurbits, accessions, morphological characterization, stable characteristics.

Zusammenfassung

Die Familie der Cucurbitaceae ist sehr divers es gehören etwa 118 Gattungen mit 825 Arten zu dieser Familie. Viele dieser Arten mit ihren Sorten und Landsorten haben ökonomische Bedeutung als Gemüse oder Arzneipflanzen. Einige Arten sind indigen, aber auch viele der nicht indigenen Arten sind gut adaptiert in verschiedenen geografischen Regionen Vietnams. Die Untersuchungen hatten vier Hauptziele: 1) Analyse der Bedeutung von Cucurbitaceen in Gemüse anbauenden Landwirtschaftsbetrieben und ihre Verwendung im südlichen Vietnam, 2) Sammlung von Keimplasma der Cucurbitaceen, 3) Morphologische Charakterizierung das gesammelte Keimplasmas, 4) Ermittlung der stabilen morphologischen Charakteristiken um Bitterkürbis Akzessionen zu klassifizieren.

Dazu wurde eine Befragung von Farmern in Gemeinden im Mekong Delta, in welchen die Gemüseproduktion der wichtigste landwirtschaftliche Sektor ist, durchgeführt. Acht Distrikte mit 20 Kommunen wurden für die Studie ausgewählt. 1009 Farmer wurden befragt, wobei die Auswahl stichprobenartig auf der Grundlage folgender Kriterien erfolgte: (1) der Farmer hatte mindesten 5 Jahre Erfahrung in der kommerziellen Gemüseproduktion, (2) die Fläche für die Gemüseproduktion war mindestens 500 m^2 groß, (3) der Farmer hat Gemüse in den 3 vorangegangenen Kulturen angebaut. Erfasst wurden die Anzahl der angebauten Gemüsearten, die Fläche pro Gemüseart, die Häufigkeit des Anbaus und der Zweck der Kultivierung. In der Vergangenheit erfolgte die Sammlung und Konservierung von Cucurbitaceen unter der Anleitung des AVRDC und VASI hauptsächlich im nördlichen Teil Vietnams. Deshalb erfolgten im Rahmen dieser Arbeit die Untersuchungen zur Sammlung von Cucurbitaceen im südlichen Vietnam. 160 Akzessionen von fünf Arten des gesammelten Keimplasmas wurden auf der Grundlage morphologischer Charakteristiken analysiert, dazu gehörten die Gurke (*Cucumis sativus*), Moschus-Kürbis (*Cucurbita moschata*), Flaschenkürbis (*Lagenaria siceraria*), Schwammkürbis (*Luffa cylindrica*) und Bitterkürbis (*Momordica charantia*) wurden anhand morphologischer Merkmale charakterisiert. Die untersuchten Merkmale wurden in zwei Variablen-Gruppen unterteilt, kontinuierliche (quantitative Merkmale) und in kategorische (qualitative, pseudo-qualitative und bestimmte quantitative Merkmale). Die Berechnung des Eigenvektors und die Erstellung von 3D bi plots ergaben klare Aussagen zu morphologischen Beziehungen der Akzessionen der verschiedenen Herkunftsgebiete. Die UPGMA Methode (nicht wichtende Paar-Gruppen Methode mit arithmetischem Mittelwert) wurde zur Klärung der Diversität zwischen den Cucucurbitacee Akzessionen genutzt. Da die Variabilität des Phänotyps aus der Interaktion

von genetischen Faktoren und Umwelteinflüssen resultiert, wurden 16 quantitative (kontinuierliche) und 12 pseudo-qualitative und qualitative (kategorische) Merkmale unter 2 Wachstumsbedingungen (Freiland und Gewächshaus) untersucht. Im Ergebnis der Untersuchungen wurde ermittelt, dass 9 Cucurbitaceae Arten, das sind 16,4% der insgesamt kultivierten 55 Arten, für den Markt angebaut wurden und mehr als 45% der Farmer Nutzpflanzen der Cucurbitaceae kultivierten. Für den Anbau von Cucurbitaceen wurden 56,5% der Gemüseanbaufläche verwendet. Korrelationen zwischen der Anzahl von Cucurbitaceen im Anbau und sozial-ökonomische Bedingungen der Farmer wie Alter, Ausbildungsgrad, Anzahl Familienmitglieder und Größe der Farm (m^2) wurden errechnet. Gründe für den überwiegenden Anbau von Cucurbitaceen in den spezialisierten Gemüseanbaugebieten konnten ermittelt werden, insbesondere waren es die zur Verfügung stehende Landfläche, die Möglichkeit ganzjährig zu produzieren und die vielfältige Nutzungsmöglichkeit der Kürbispflanzen. Es wurden 244 Akzessionen von 14 Arten, die zu 12 Gattungen gehörten, in 24 Provinzen gesammelt. Die Art-Diversität- (H) und Evenness-Indices der Sammlung wurden mit 2,2 und 0,51 bestimmt. Die Kombination der beiden Methoden (3D bi plot und UPGMA) war vorteilhaft, wenn die Akzessionen spezielle Merkmale aufwiesen wieTiGi02 und TiGi03 von *Cucumis sativus*, BaLi01 von *Cucurbita moschata*, NiTh03 von *Lagenaria siceraria,* CaTh01 und HcmC03 von *Luffa cylindrica* und HcmC01 und QuNa01 von *Momordica charantia*. Es wurden sieben *Momordica charantia* Akzessionen hinsichtlich ihrer Stabilität in zwei verschiedenen Wachstumsbedingungen, im Gewächshaus und auf dem Feld, untersucht. Die untersuchten Merkmale wurden ausgewertet und brachten essentielle Informationen zum Verständnis der morphologischen Verwandtschaft der in den verschiedenen Regionen gesammelten Akzessionen. Umweltstabile Merkmale, die erforderlich sind für die Bestimmung der morphologischen Beziehungen zwischen Akzessionen von *Momordica charantia*, wurden herausgearbeitet. 12 dieser Merkmale (Anzahl der Blatteinbuchtungen, Farbe der Fruchtschale im reifen Zustand, Rippung der Früchte, Vorhandensein von Fruchtdornen, Größe der Warzen, Einkerbungen der Samenränder, Streifenbildung der Samenschale, Anzahl von Nodien bis zur 1. männlichen Blüte, Zeit bis zum Aufblühen der 1. männlichen Blüte, Fruchtlänge, Fruchtmasse, Masse von 100 Samen) waren stabil und können für die Untersuchung der Beziehungen zwischen den *Momordica* Akzessionen verwendet werden. Offensichtlich ist die Bestimmung der morphologischen Beziehungen zwischen den Akzessionen abhängig von der Anzahl der Merkmale, die für die hierarchische Clusteranalyse verwendet wurden. Deshalb war die Ermittlung von stabilen Merkmalen erforderlich, um mit der Clusteranalyse die Beziehungen

der Akzessionen zu ermitteln. Im Ergebnis dieser Dissertation stehen strukturierte Informationen zur Verfügung bezüglich der Bedeutung der Cucurbitaceen in der Gemüseproduktion in Südvietnam, der morphologischen Diversität innerhalb der am häufigsten angebauten Arten und zu morphologischen Merkmalen, die zur Bestimmung der Beziehungen zwischen den Akzessionen der Cucurbitaceen herangezogen werden können. Damit wurde ein Beitrag zu Erstellung von Datenbanken und zur Erweiterung der Samensammlungen, die für Züchtung, Genetik und Erhaltung der genetischen Diversität erforderlich sind, geleistet. Die Kartierung die Diversität der Cucurbitaceae in bestimmten Regionen und die Entwicklung einer Strategie für Sammlung, Konservierung und Nutzung von Cucurbitaceae Akzessionen sollte fortgeführt werden.

Keywords: Cucurbitaceen, Akzessionen, morphologische Charakterisierung, umweltstabile Merkmale.

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Terminology explanations

Accession	: A collection of plant material from a particular location and basic working unit of conservation in the genebanks.
Cucurbits	: The general term used to describe all species of the Cucurbitaceae.
Cultivar	: A cultivated variety selected from a landrace anda product of plant breeding that is released for use by growers.
Indigenous cucurbits	: The cucurbit species are genuinely traditional to a region in Vietnam.
Landrace	: A population of plants which is genetically heterogenous and developed in traditional agriculture for numerous years of farmer-directed selection, and which is particularly adapted to local conditions. Landrace has a high capacity to tolerate biotic and abiotic stress resulting in high yield stability and an intermediate yield level under a low input agricultural system (Zeven, 1998).
Local variety	: A variety has been grown in a region for a long period.
Non-indigenous cucurbits	: The cucurbit species introduced into Vietnam.
Variety	: A plant population has the same morphological characteristics.

Abbreviations

Abb.	:	Abbreviation
APF	:	Area of plant family
ASEAN	:	Association of Southeast Asian Nations
ASL	:	Above sea level
AVRDC	:	Asian Vegetable Research and Development Centre
AVGRIS	:	Vegetable Genetic Resources Information System of AVRDC
CAF	:	Cultivated area of plant family
CAS	:	Cultivated area of species
DUS	:	Distinctness, Uniformity and Stability
FAO	:	Food and Agriculture Organization of the United Nations
FAVRI	:	Fruit and Vegetable Research Institute
GSO	:	General Statistic Office of Vietnam
h(s)	:	Hour(s)
ha	:	Hectare (1ha= 10.000 square meters)
I$	:	International Dollar
ICEM	:	International Centre for Environmental Management
m	:	Meter
MARD	:	Vietnamese Ministry of Agriculture and Rural Development
meq	:	Milliequivalents
MRD	:	Mekong River Delta
µg	:	Microgram
nes	:	not elsewhere specified (FAO statistic)
OR	:	Occurrence rate
PGRV	:	Plant genetic resources of Vietnam
ppm	:	Parts per million
PQ	:	Pseudo-qualitative characteristics
QL	:	Qualitative characteristics
QN	:	Quantitative characteristics
RH	:	Relative humidity
RCBD	:	Randomized Complete Block Design
RRD	:	Red River Delta
SD	:	Standard deviation
UF	:	Using frequency
UPGMA	:	Un-weighted pair group method using arithmetic averages
UPOV	:	International Union for the Protection of New Varieties of Plants
URC	:	Using ratio of cucurbits
VASI	:	Vietnam Agricultural Science Institute
VNPPA	:	Vietnam National Park and Protected Area Association

1. Introduction

The plant family Cucurbitaceae is highly diverse and comprises about 118 genera and 825 species. Many of these species with its cultivars and landraces are of economic importance because they are used as vegetables and medicinal crops. As Siemonsma and Piluek (1994) and Pham (1999) reported, this family contributed 13 species that are cultivated for commercial purpose and home consumption in Vietnam. Furthermore edible wild plants and weeds belong to this family (Lira et al., 2001; Green et al., 2007) and were also used as food and medicine in daily life of Vietnamese (Ogle et al., 2003; Tanaka and Nguyen, 2007; Pham, 1999).

Some Cucurbitaceae species have a wide range of adaptation to different geographical regions; i.e. species of *Cucumis* are cultivated from North Africa across Asia to Australia (Sebastian et al., 2010). Also in Vietnam, species belonging to *Cucumis* (*Cucumis sativus* and *Cucumis melo*), *Luffa* (*Luffa cylindrica* and *Luffa acutangula*), *Momordica* (*Momordica charantia*), and *Cucurbita* (*Cucurbita moschata*) are frequently cultivated from the North to the South (Pham, 1999; Lira et al., 2001; Trinh et al., 2003; Green et al., 2007; FAVRI, 2010; Huong et al., 2013b). The economic importance and frequent cultivation of cucurbits in agriculture were demonstrated in previous studies in Vietnam (Siemonsma and Piluek, 1994; Khiem et al., 2000; Everaarts et al., 2006). Various cucurbit species (i.e. *Benincasa hispida, Citrullus lanatus, Cucumis melo, Cucumis sativus, Cucurbita* spp., *Lagenaria siceraria, Luffa* spp., *Momordica* spp., *Sechium edule, and Trichosanthes* spp.) are regularly cultivated for local consumption and market demands (Siemonsma and Piluek, 1994; Pham, 1999; Trinh et al., 2003; Huong et al., 2013b; Pham and Vo, 2013).

Although cucurbit species are regular cultivated as vegetable, its diversity is threatened by climate change and human activities due to various causes: deforestation, arable land expansion, urbanization, and the substitution of traditional cultivars by high yield cultivars due to the market-oriented economy (VNPPA, 1998; Pham and Luu, 2007; Hoang, 2009). According to the decree 80/2005/QĐ-BNN of Ministry of Agriculture and Rural Development (MARD, 2005), Cucurbitaceae ranks on the 16th place of 37 families with valuable and rare species that need to be conserved. In 2005, there were 33 species or sub-species belonging to five important genera of Cucurbitaceae named on the list of genetic losses including *Trichosanthes, Momordica, Cucurbita, Luffa,* and *Cucumis* (MARD, 2005).

The collection and conservation of cucurbits were executed by AVRDC (AVGRIS, 2011) and VASI (PGRV, 2011) with 1,255 accessions recorded. The collections were predominantly concentrated in the North of Vietnam, including Northern Midlands and Mountain Areas, Red River Delta and North central coast. In contrast, in southern Vietnam, including Central coast, Central highland, Southeast, and Mekong River Delta, genetic resources of cucurbits were so far poorly concerned. In addition, previous projects had prioritized for economically important species but did not concern underutilized species (Tran and Ha, 2000; Green et al., 2007; Vu et al., 2010). For illustration Gac (spiny bitter gourd, *Momordica cochinchinensis*) should be mentioned. This indigenous species provides fruits with high carotenoid and lycopene content, moreover seeds, roots, and leaves of this species are used as food and medicine (Do, 2004; Vuong et al., 2006; An-ming and Jeffrey, 2011), however, the genetic diversity of this species in different geographical regions was decreasing (Behera et al., 2011). Another example for non-priority collected species is ivy gourd (*Coccinia grandis*). This non-indigenous species had been introduced and adapted to environmental condition of Vietnam. Its leaves, shoots, green and ripe fruits are edible parts with the various nutritional elements (Lin et al., 2009) and are also used as medicinal plant (Pham, 1999; Umamaheswari et al., 2007; Munasinghe et al., 2011). This species is mainly wild growing in groves and plain forests, but its natural occurrence is decreasing because of deforestation and land use changes (VNPPA, 1998). Despite clear evidence for diversity loss in these species, no collection and conservation projects involved them in Vietnam (Green et al., 2007; Vu et al., 2010; AVGRIS, 2011; PGRV, 2013).

For determining the diversity of cucurbit accessions, their morphological and genetic characterization is important. The evaluated characteristics provide essential information for understanding the genetic relationships among accessions that are collected in different regions. This characterization provides important criterions for use of the accessions for breeding purposes. Within the so far collected cucurbit accessions, only less than 50% of accessions conserved by VASI were evaluated for some basic characteristics, such as growing habit and yield-related characteristics (Vu and Tran, 2010).

Evaluating the existing databases, it seems a further study is necessary in particular in southern Vietnam. The role of Cucurbitaceae has to be explored in vegetable cultivation and the numbers of species cultivated are to determine. Furthermore, accessions of cucurbits in selected regions of southern Vietnam should be collected and evaluated to enrich the current cucurbit germplasm collection and to prevent the further loss of genetic resources. The genetic diversity of this collection has to be characterized basing on morphological characteristics. The characterizations have to be conducted for cucumber (*Cucumis sativus*); pumpkin (*Cucurbita moschata*); bottle gourd (*Lagenaria siceraria*); loofah (*Luffa cylindrica*); and bitter gourd (*Momordica charantia*) using the determination of Yuan et al. (2008), Parvathanen et al. (2011), and UPOV (2013); Ferriol et al. (2004) and UPOV(2013); Mladenovic et al. (2011); Prakash et al. (2013); and Dey et al. (2006), Dalamu et al. (2012), and UPOV (2013), respectively. Because of the economic importance and expected high availability of bitter gourd (*Momordica charantia*) accessions, deeper characterization of morphological characteristics and evaluation regarding characteristics in different growing conditions should carried out.

Furthermore, studies are necessary about the diversity of accessions of that cucurbit species with high importance in different southern Vietnamese regions. These accessions could contribute in further breeding programmes.

2. Literature review

2.1 Cucurbitaceae

2.1.1 Botanical classification of Cucurbitaceae

Cucurbitaceae (cucurbit family) is a family with a large number of genera and species as already mentioned and widely distributed in the Old and New World (Figure 2.1). Cucurbitaceae belongs to the order Cucurbitales together with seven other families (Figure 2.2) (Schaefer and Renner, 2011a). Cucurbitaceae is a family with a high diversity in tropical, sub-tropical and temperate regions (Renner et al., 2007; Sebastian at al., 2010; Schaefer and Renner, 2011a; Schaefer and Renner, 2011b).

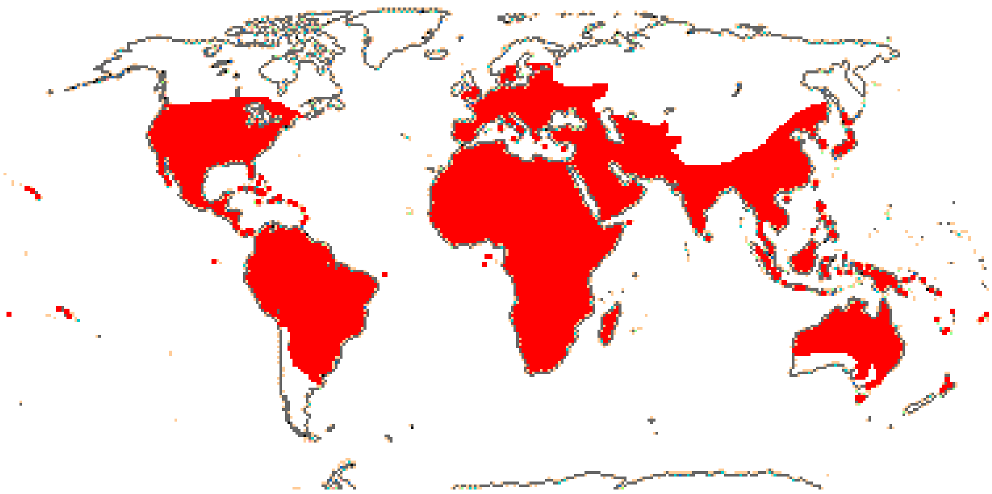


Figure 2.1. Distribution of Cucurbitaceae worldwide (Cucurbitaceae, 2015).

Schaefer and Renner (2011a) analysed recently with molecular methods the phylogenetic relationships in the Cucurbitales order and indicated that Cucurbitaceae are closely related to Coriariaceae, Corynocarpaceae, Tetramelaceae, Datiscaceae, and Begoniaceae, respectively. Anisophylleaceae was ranged next to the group of these six families. Apodanthaceae have the highest distance within the likelihood tree (Figure 2.2).

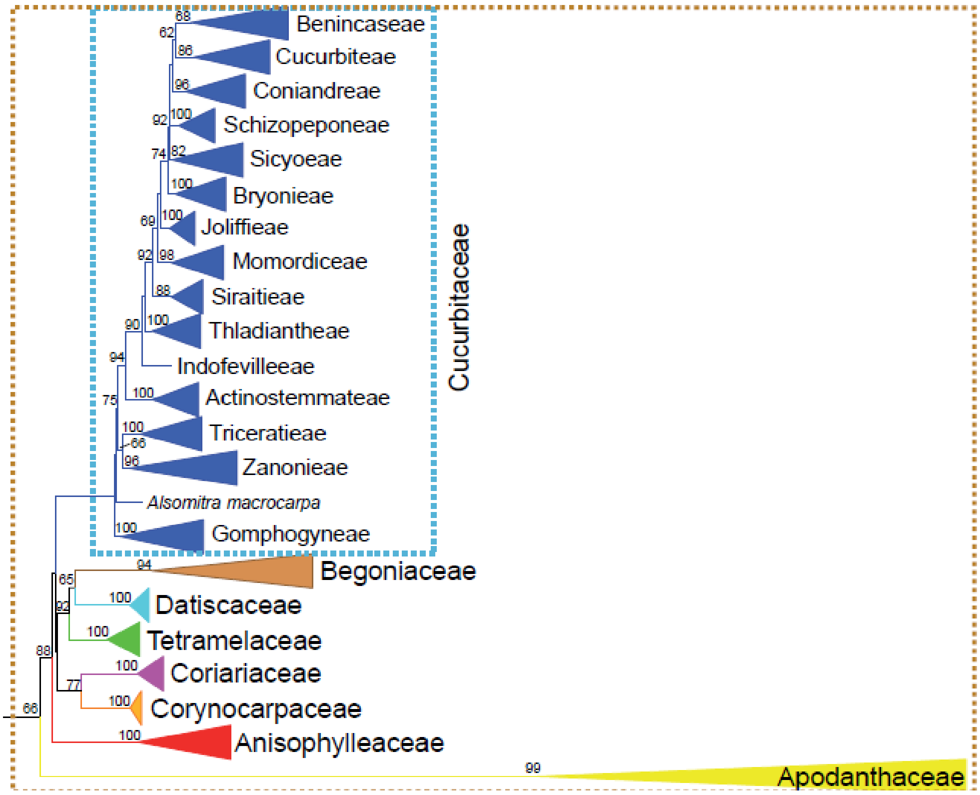


Figure 2.2. Relationships of eight families in Cucurbitales and 15 tribes belonging to Cucurbitaceae based on molecular studies (Schaefer and Renner, 2011a).

The family of Cucurbitaceae is distinct morphologically and bio-chemically from the other families and is therefore considered monophyletic (Schaefer and Renner, 2011a). According to Robinson and Decker-Waltjers (1994), this family consists of two well-define subfamilies (Cucurbitoideae, Zanonioideae) with eight tribes based on morphological evaluation (Figure 2.3 and Appendix 1), whereas 15 tribes were defined by molecular analyses in Cucurbitaceae by Schaefer and Renner (2011a).

Previous studies on Cucurbitaceae (Herklots, 1972; Purseglove, 1976) mentioned that the number of genera is not clearly defined; however, about 750 species belonging to 90 genera were mentioned. In contrast, other studies determined 118 genera and about 825 species belonging to Cucurbitaceae (An-ming and Zhi-yun, 1986; Green et al., 2007; Rai et al., 2008). Major genera are *Trichosanthes* (100 species), *Cayaponia* (60 species), *Momordica* (47 species), *Gurania* (40 species), *Sicyos* (40 species), *Cucumis* (34 species), and 36 minor genera are which are monotypic (Siemonsma and Piluek, 1994).

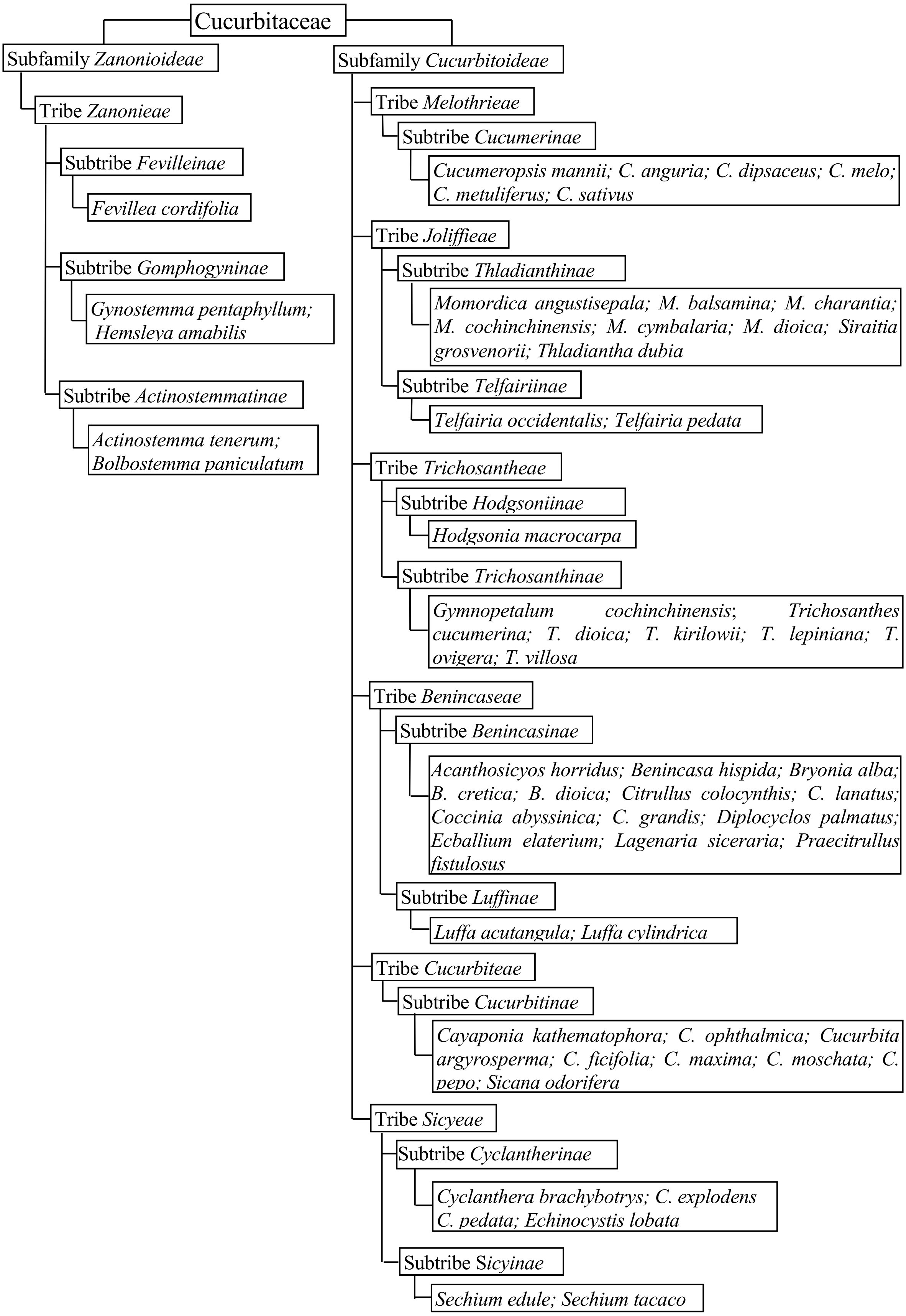


Figure 2.3. Taxonomic relationship of cultivated cucurbits from two subfamilies based on Robinson and Decker-Waltjers (1994).

All cucurbits used for cultivation belong to the Cucurbitoideae subfamily. The most important tribes are the tribe *Benincaseae* with *Benincasa hispida*, *Citrullus lanatus*, *Lagenaria siceraria,* and *Luffa cylindrica;* the tribe *Cucurbiteae* with *Cucurbita ficifolia, Cucurbita maxima, Cucurbita moschata, and Cucurbita pepo*; the tribe *Joliffiaea* with *Momordica charantia,* and the tribe *Melothriaea* with *Cucumis melo* and *Cucumis sativus.*

There are also wild species available belong to already cultivated cucurbits with high economic importance, as they belong to the genera *Benincasa, Cucumis, Luffa* and *Momordica* (Schaefer et al., 2008; Lira et al., 2010; Sebastian, 2011).

2.1.2 Use of Cucurbitaceae

Different organs of cucurbit species are used for various purposes whereas fruits are the main organ used as food and processed beverage for human beings. Nevertheless, other parts of cucurbits such as young leaves and shoots, flowers, and seeds are also used as food, medicine for human beings or decoration or for feeding livestock.

- Food:
  - Fruits: *Benincasa hispida* (ash gourd), *Citrullus lanatus* (watermelon), *Cucumis sativus* (cucumber), *Cucumis melo* (melon), *Cucurbita pepo* (winter squash, zucchini), *Cucurbita maxima* (pumpkin, turban squash), *Cucurbita moschata* (pumpkin, butternut squash), *Momordica charantia* (bitter gourd), *Sechium edule* (chayote), *Luffa cylindrica* (smooth loofah), *Luffa acutangula* (angled loofah), *Lagenaria siceraria* (bottle gourd), *Trichosanthes cucumerina* (snake gourd), and *Cyclanthera pedata* (korila).
  - Young leaves and shoots: *Benincasa hispida* (ash gourd), *Gymnopetalum cochinchinensis*, *Gymnopetalum integrifolium, Coccinia grandis*, *Trichosanthes cucumerina,* and *Zehneria maysorensis.*
  - Flowers: *Cucurbita maxima* (pumpkin, turban squash), *Cucurbita moschata* (pumpkin, butternut squash).
  - Seeds as food: *Cucurbita maxima* (pumpkin, turban squash), *Cucurbita moschata* (pumpkin, butternut squash), *Citrulus lanatus* (watermelon).
- Beverages:

  Citrullus lanatus (watermelon), *Benincasa hispida* (ash gourd), *Momordica charantia* (bitter gourd), *Cucumis melo* (melon).

- Ornamentals:
  Cucurbita pepo (ornamental gourds), *Cucumis dipsaceus* (teasel gourd), *Cucumis metuliferus* (African horned cucumber), *Echinocystis lobata* (wild cucumber), *Lagenaria siceraria* (bottle gourd), *Trichosanthes cucumerina* (snake gourd).

- Medicinal:
  Actinostemma tenerum, two species of *Bryonia* (bryony), *Citrullus colocynthis* (bitter apple), *Coccinia grandis* (ivy gourd), *Cucumis trigonus, Cucurbita foetidissima* (buffalo gourd), *Ecballium elaterium* (squirting cucumber), *Fevillea cordifolia* (antidote vine), *Gymnopetalum cochinchinensis, Gynostemma pentaphyllum* (jiaogulan), *Hemsleya amabilis* (luo guo di), *Momordica charantia* (bitter gourd), *Momordica cochinchinensis* (gac), *Mukia maderaspatana, Sicana odorifera* (cassabanana), *Siraitia grosvenorii* (luo han guo), *Trichosanthes kirilowii* (gua lou), *Zehneria maysorensis.*

- Other uses:
  Lagenaria siceraria (bottle gourd): used as containers, floats, and resonator for musical instruments; *Luffa cylindrica* (loofah): used as a sponge and filter; *Sicana odorifera* (cassabanana): used as an air freshener; *Siraitia grosvenorii* (luo han guo): used as a sweetener. *Gymnopetalum cochinchinensis*: leaves are used as bait for fish; *Hodgsonia macrocarpa*: seeds used as cooking oil.

2.2 Agriculture and horticulture in Vietnam

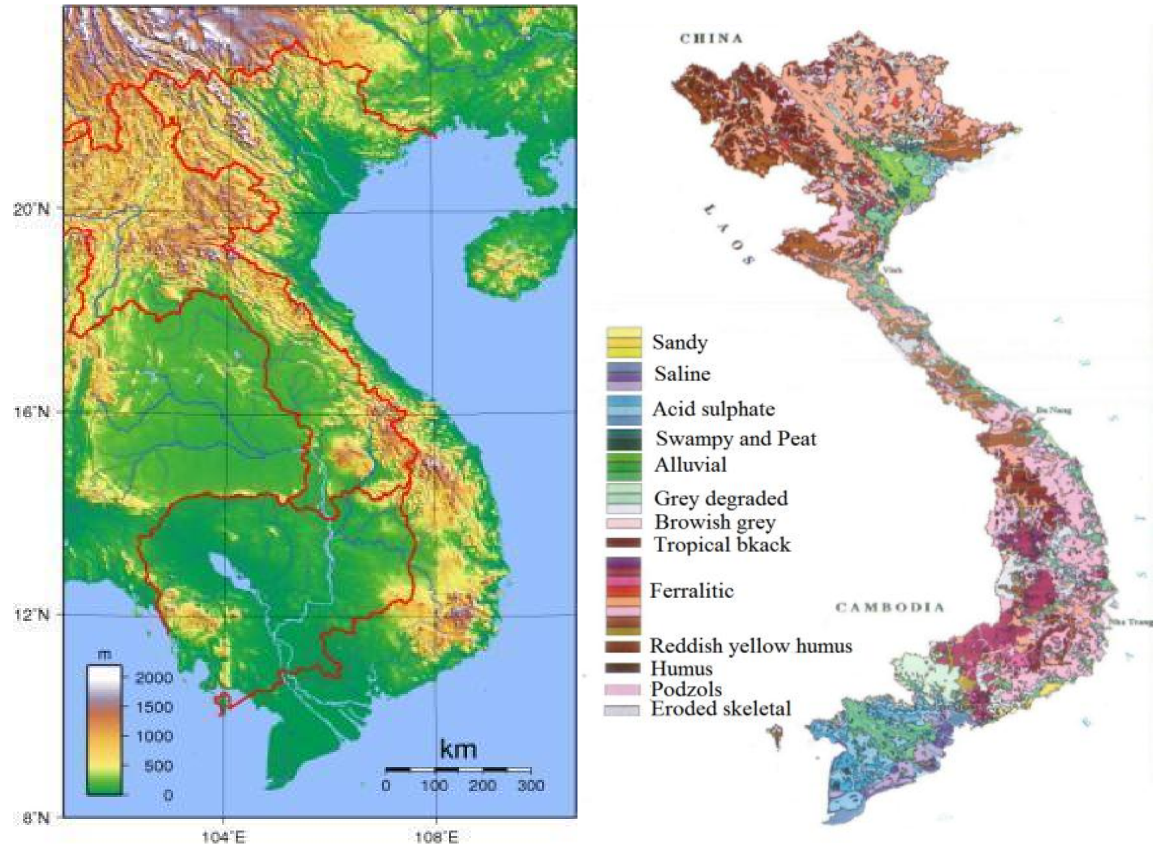
2.2.1 Natural conditions related to agriculture in Vietnam

2.2.1.1 Geography and soils

Vietnam is bordered by China in the North; Laos and Cambodia in the West; and South China Sea in the East. Extending from 8° 30’ N to 23° 22’ N, and 102° 10’ E to 109° 30’ E, the territory is in tropical and sub-tropical climate. The topography differs among mountainous and flat regions (Figure 2.4a). North-eastern and north-western regions from northern areas on the Sino-Vietnamese border to the western regions in Thanh Hoa, Nghe An, and Ha Tinh provinces. North Truong Son Range (from western part of Thanh Hoa province to Hai Van mountain in Thua Thien – Hue province) and South Truong Son Range (from north-western of Quang Nam province to Binh Phuoc province) are hilly or mountainous. Along the 3,260km long coastline (from Gulf of Tonkin to Gulf of Thailand) and in the two major river deltas, Red River Delta in the northern part and Mekong River Delta in the southern part, there is lowland.

Basing on topographic, climatic, and social-economic conditions, the country was partitioned into six different regions (based on GSO, Vietnamese General Statistics Office, from 2008 toward) (see also Figure 2.5). Encompassing provinces and altitude are as follows (Bo et al., 2002; GSO, 2014):

- Northern Midlands and Mountain Areas: the area covers 14 provinces (Ha Giang, Cao Bang, Bac Kan, Tuyen Quang, Lao Cai, Yen Bai, Thai Nguyen, Lang Son, Bac Giang, Phu Tho, Dien Bien, Lai Chau, Son La, and Hoa Binh). Altitude is about 400 – 800m above sea level (ASL) with many mountains and hills.
- Red River Delta: the delta includes 10 provinces (Vinh Phuc, Bac Ninh, Quang Ninh, Hai Duong, Hai Phong, Hung Yen, Thai Binh, Ha Nam, Nam Dinh, and Ninh Binh) and Hanoi (a capital city). Plains are along the Red and Thai Binh rivers with the altitude of about 2 - 4m ASL.
- North Central and Central Coastal Areas: the area covers 14 provinces (Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri, Thua Thien – Hue, Da Nang, Quang Nam, Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa, Ninh Thuan, and Binh Thuan). Many plains are along the Ma, Ca, Ngan Sau, Gianh, Thach Han, Thu Bon, Tra Bong, Tra Khuc, Ha Giao, and Ba rives with the altitude of about 4 – 10m ASL.
- Central Highlands: the area covers five provinces (Kon Tum, Gia Lai, Dak Lak, Dak Nong, and Lam Dong) with the altitude of about 400 – 600m ASL.
- Southeast: the area covers six provinces (Binh Phuoc, Tay Ninh, Binh Duong, Dong Nai, Ba Ria – Vung Tau, and Ho Chi Minh City – formerly Saigon, the largest city in Vietnam). The large plain has an altitude of about 100m ASL.
- Mekong River Delta: the largest flat land includes 13 provinces (Long An, Tien Giang, Ben Tre, Tra Vinh, Vinh Long, Dong Thap, An Giang, Kien Giang, Can Tho, Hau Giang, Soc Trang, Bac Lieu, and Ca Mau). The delta locates in Low Mekong Basin formed by Mekong River. Altitude of this area is about 0 to 4m ASL.



a) b)

Figure 2.4. a) Topography (Sadalmelik, 2007) and b) soils (Bo et al., 2002) of Vietnam.

According to Bo et al. (2002), the soils of Vietnam included 31 soil units (soil units' orders are sorted by color chart given in Figure 2.4b) and which were grouped into 13 main groups. Geographical distributions of soils are as follows:

1. Sandy soils (3 units – white and yellow sand dune soils, red sand dune soils, and sandy marine soils): mainly found in North Central and Central Coastal Areas (Nghe An, Ha Tinh, Quang Binh, Quang Tri, Thua Thien- Hue, Ninh Thuan, Binh Thuan).
2. Saline soils (3 soil units – mangrove saline soils, strongly saline soils, and medium and weak saline soils): found in Mekong River Delta (Bac Lieu, Ca Mau, Kien Giang, Tra Vinh, Ben Tre, Tien Giang); in North Central and at Central Coastal Areas (Thanh Hoa, Ninh Thuan, Binh Thuan); and in the plain of Red River Delta (Quang Ninh, Hai Phong, Thai Binh, Nam Dinh, Ninh Binh).
3. Acid sulphate soils (3 soil units – strong acid sulphate soils, medium and weak acid sulphate soils, and salt affected potential acid sulphate soils): manly situated in Mekong River Delta (Long An, An Giang, Kien Giang, Can Tho, Soc Trang, Bac Lieu, Ca Mau); a small area in Red River Delta (Hai Phong, Thai Binh).

4. Swampy soils and peat soils (2 soil units – swampy soils and peat soils): Swampy soils distribute in Red River Delta, Central part of country, and at High plateaus. Peat soils distribute in Mekong River Delta and scattere in Northern Midland and Mountain Areas.
5. Alluvial soils (3 soil units– alluvial soils of Red River Delta, alluvial soils of Mekong River Delta, and alluvial soils of other rivers): mainly concentrated in Red River and Mekong River Delta. Small areas are observed in other river deltas along the seashore.
6. Grey degraded soils (3 soil units - grey degraded soils on old alluviums, grey degraded gleyic soils on old alluviums, and grey degraded soils derived from acid magmalic rocks and sandstones): found mainly in the Souteast, at high Plateau in Central Highlands; in some provinces Red River Delta (Vinh Phuc, Bac Ninh, Quang Ninh) and Northern Midlands and Mountain Areas (Bac Giang, Thai Nguyen).
7. Brownish grey soil in semi-arid region (1 unit): mainly situated in Ninh Thuan and Binh Thuan, two provinces belonging to North Central and Central Coastal Areas.
8. Tropical black soils (1 unit): mainly found in mountainous areas of Northern and Central regions.
9. Ferralitic soils (8 soil units - violet brown soils derived from basic and intermediate magmatic rocks, reddish brown soils derived from basic and intermediate magmatic rocks, yellowish brown soils derived from basic and intermediate magmatic rocks, brownish red soils derived from limestone, yellowish red soils derived from clay shales and metamorphic igneous rocks, reddish yellow soils on add magmatic rocks, light yellow soils on sandstones, and yellowish brown soils on old alluvium): covering the largest area with about 60.4% of total area of country and distributinh in almost Midland and Mountainous areas throughout the country.
10. Reddish yellow humus soil in mountains (1 unit): distributed in mountainous areas throughout the country where the altitudes are from 700 to 2,000m ASL.
11. Humus soil on high mountains (1 unit): normally found at the tops of Hoang Lien Son, Ngoc Linh, Ngoc Ang, Chu Yang Sinmountains with altitudes of more than 2,000m ASL.
12. The Podzol soil (1 unit): found in Lai Chau province and Central Highlands.
13. The Eroded skeletal soil (1 unit): formed on bare hills in Central Highlands, North Central and Central Coastal Areas, and Northern Midlands and Mountain Areas.

2.2.1.2 Climate and weather conditions

Vietnam has a monsoon climate with three typically climatic features: hot, humid and rainy. A subtropical climate is in the North with four separate seasons, spring, summer, autumn, and winter. A tropical climate is in the South with two different seasons, dry and wet (FAO, 2011). The annual average temperature, the sunshine time, rainfall, and humidity are 24.5^{0}C, 2,300hs/year, and 1,800 mm/year, and 85%, respectively (GSO, 2014). Nevertheless, the regions differ considerably in these respects as indicated for yearly average temperature from 17°C (in mountainous areas) to 32°C (in midlands and plains); average rainfall from 1,600 to 2,200 mm (in midlands and plains) and 2,000 to 2,500 mm (in mountainous areas) (FAO, 2011; IMHEN, 2014). The rainfall and temperature in the six regions (Figure 2.5) are significantly different as follows:

- Northern Midlands and Mountain Areas: Annual rainfall in the region is about 1,730 mm. It increases at the beginning of the year and reaches a peak in August (372 mm), then decreasing until December (3 mm). Yearly average temperature is about 22.0°C with the lowest in January (14°C) and the highest value in June (26.3°C).
- Red River Delta: Annual rainfall is about 1,770 mm. It increases from January (17 mm) and reaches a peak in July (382 mm), then decreasing until December (147 mm). Yearly average temperature is about 24.1°C with the lowest value in February (16.8°C) and the highest value in June (29.8°C).
- North Central and Central Coastal Areas: Annual rainfall is about 1,720 mm. It varies between months, lower in the months at the beginning of year and higher in the months at the end of year. The lowest rainfall is recorded in March (13.8 mm) and the highest rainfall in October (525 mm). Yearly average temperature is about 26.1°C with the lowest value in January (20.3°C) and the highest value in June (30.5°C).
- Central Highlands: High rainfall can be found in seven months from April to October. The annual rainfall is about 2,268 mm, with the highest rainfall is in August (430 mm). It is no rain in February. Yearly average temperature is about 20.3°C with the lowest value in January (16.3°C) and the highest value in May (22.5°C).
- Southeast: High rainfall can be found in five months from June to October. The annual rainfall is about 1,380 mm, with the highest rainfall is in July (352 mm). No rain is recorded in the first three months. Changes in temperature following months

are not so remarkable. Yearly average temperature is about 27.9°C with a range of 25°C (in January) to 30.3°C (in May).

- Mekong River Delta: Rainfall in this region starts from April (61 mm) then reaching a peak in July (389 mm) and ending in January (8 mm) of the next year. Annual rainfall (2,065 mm) is highest when comparing with other regions. Similarly in Southeast, changes in temperature following months in this region are not remarkable. Yearly temperature is about 27.7°C with a range of 25.3°C (in January) to 29.4°C (in May).

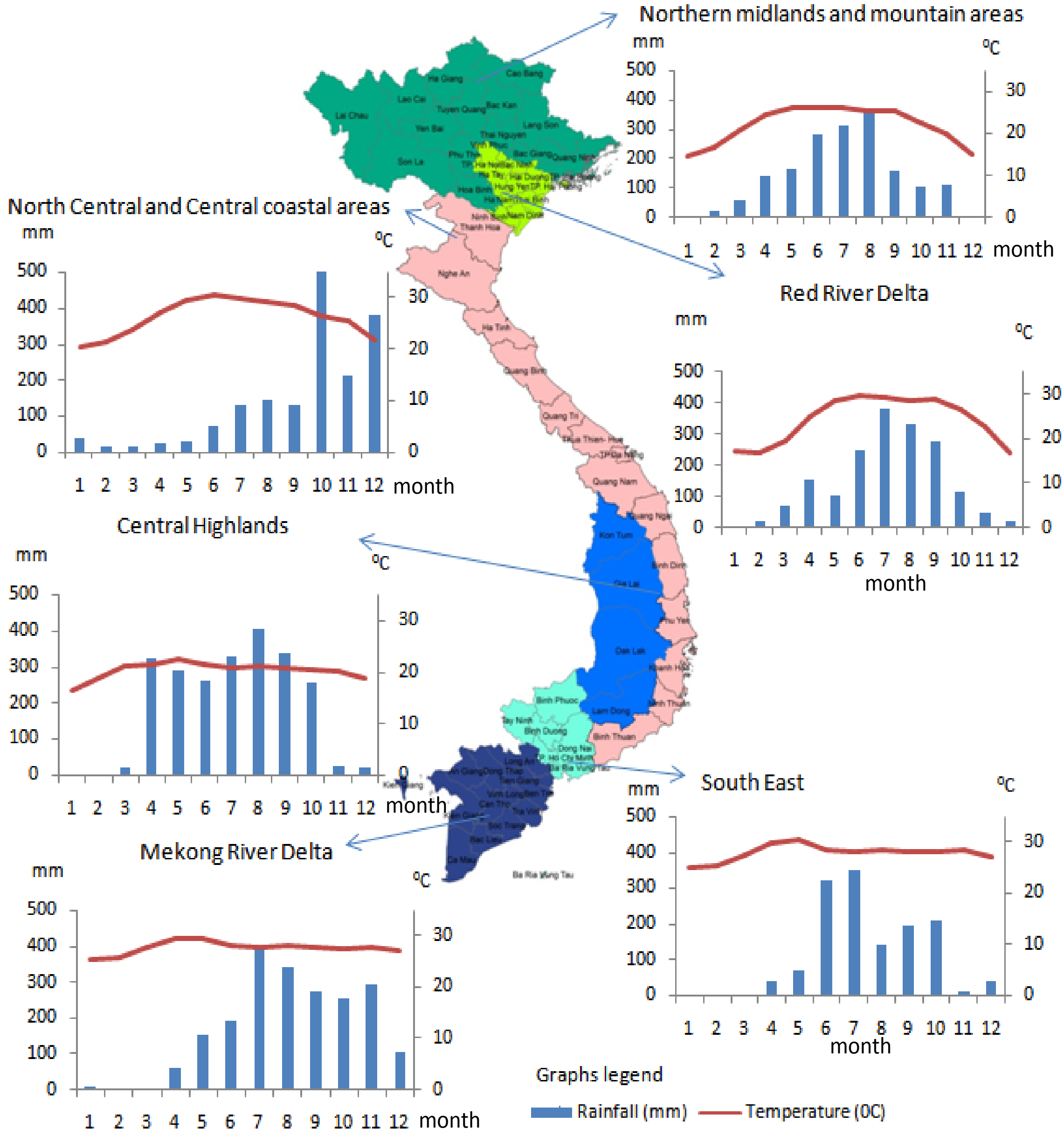


Figure 2.5. Monthly rainfall and temperature of six regions in Vietnam (compiled from IMHEN, 2014 and GSO, 2014).

2.2.1.3 Land use

Land area of whole country is about 33.1 million hectares and is separated into five categories following purpose of use (Figure 2.6). The largest area is forest land; with about 15.8 million hectares it occupies 47.9% total land area. Agriculture land covers more than 10.2 million hectares occupying about 30.9% of total land area. Non-agriculture land (including homestead land, special land used for transportation, military, etc.) covers about 3.8 million hectares occupying 11.5% of total land. Land used for aquaculture is 746 thousand hectares, occupies only 2.3% total land. Unused land or wild land is 2.5 million hectares, occupies 7.5% total land (GSO, 2014).

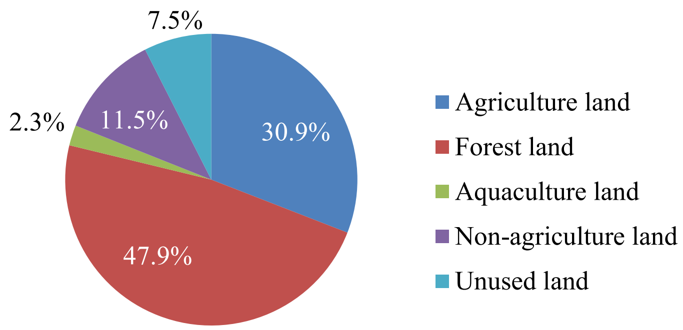


Figure 2.6. Land use in Vietnam (GSO, 2014).

For agriculture according to land area (Table 2.1), the Mekong River Delta (2,607,100ha) has the highest importance followed by Central highlands (2,001,600ha), North Central and Central Coastal Areas (1,902,100ha), Northern Midlands and Mountain Areas (1,597,700ha), Southeast (1,353,900ha) and Red River Delta (769,300ha). Proportion of agriculture land is different depending on the topography of the regions. Mekong River Delta (64.3%) has the highest value, followed by Southeast (57.4%), Central Highlands (36.6%), Red River Delta (36.5%), North Central and Central Coastal areas (19.8%), and Northern Midlands and Mountain Areas (16.8%).

Table 2.1. Agricultural land use in six regions of Vietnam (GSO, 2014, unit in 1,000ha)

Region	Total Area	Agriculture land	% (compared with total area)
Whole country	33,096.7	10,231.7	30.9
Northern Midlands and Mountain Areas	9,526.7	1,597.7	16.8
Red River Delta	2,106.0	769.3	36.5
North Central and Central Coastal Areas	9,583.2	1,902.1	19.8
Central Highlands	5,464.1	2,001.6	36.6
Southeast	2,359.1	1,353.9	57.4
Mekong River Delta	4,057.6	2,607.1	64.3

2.2.2 Social – economic situation in Vietnam and the agricultural sector

Population of Vietnam is the second largest in Southeast Asia countries after Indonesia. More than 90 million people live in 63 provinces/cities. About 68.4% people live in rural area and 48.4% of employees work in agricultural sector (GSO, 2013). The agricultural sector has contributed significantly to the nation's success in the poverty reduction and food security improvement.

According to Pham and Luu, 2007, agricultural sector accounts for one third of the total export value of the country. Agriculture, industry and construction, service, and products taxes subsidies on productions are four sectors that contribute to gross domestic product (GDP) of Vietnam. In 2013, agriculture obtained 746,480 billion VND (~37.3 billion USD) and shared about 20.2% of GDP (Figure 2.7).

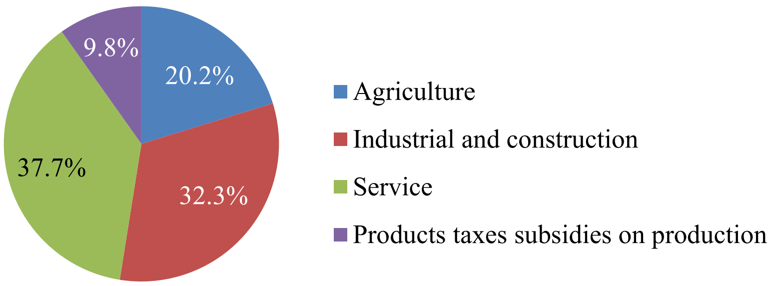


Figure 2.7. Sharing GDP of economic sectors (GSO, 2013).

The gross output of agriculture increased rapidly in 10 years from 2002 to 2012 driven mainly by increases in the crop production sector including all land use systems counting for about 73.4% of total output of agriculture in 2011 (Figure 2.8).

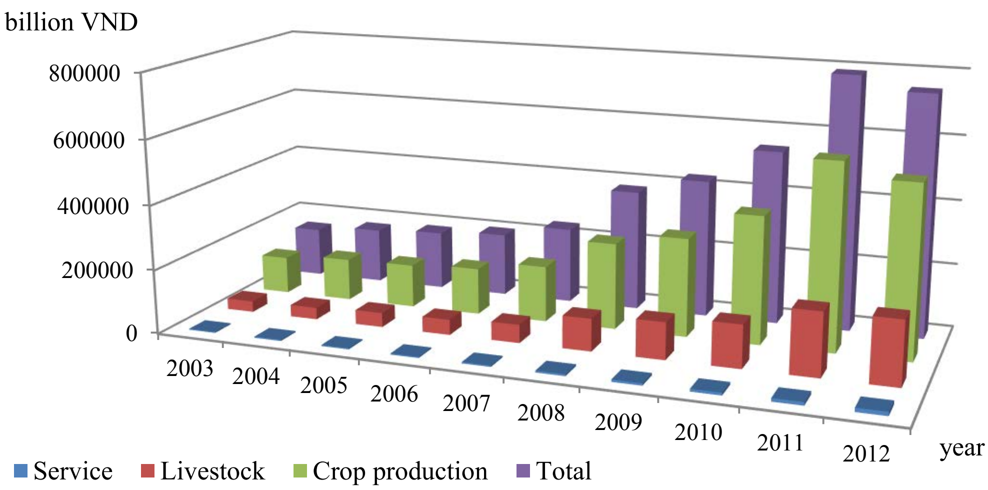


Figure 2.8. Gross output (in billion VND, 1US$ = 20,000VND) in agriculture for service, livestock, crop production and in total (GSO, 2012).

Regarding the crop production sector, vegetable production occupies an important position in improving income for farmers in Vietnam (see also Section 2.2.3.3). Net production value of vegetable production achieved 1.5 billion US$ in 2012, the amount counted for about 24.5% total export value of crop production (FAOSTAT, 2012).

2.2.3 Horticulture and contribution of cucurbit crops

One aim of this thesis is to observe the cultivation and importance of crops belong to the cucurbits in the connection with the situation of horticulture production in general. Therefore, this section will be given a short overview about fruit, flower and vegetable cultivation as well.

2.2.3.1 Fruit cultivation

The fruit cultivation is an important sector in horticulture in Vietnam. The fruits are used as fresh foods and they are used as raw material in food technology. Nguyen et al. (1997) determined 110 fruit species including wild and cultivated species in Vietnam. Citrus (*Citrus* spp.), mango (*Mangifera indica*), durian (*Durio zibethinus*), longan (*Dimocarpus longan*), pineapple (*Ananas comosus*), banana (*Musa* spp.), mangosteen (*Garcinia mangostana*), dragon fruit (*Hylocereus undatus*), lychee (*Litchi chinensis*), rambutan (*Nephelium lappaceum*), and longan (*Dimocarpus longan*) are mainly cultivated (Yen et al., 2007; Nguyen, 2010).

The local distribution of fruit production depends on natural conditions and the market needs. However, the major regions of fruit production are established in alluvial soil along rivers. According to Nguyen (2010), six major regions of fruit production are as follows:

- Northern Midlands and Mountain Areas: longan (*Dimocarpus longan*), lychee (*Litchi chinensis*), orange (*Citrus sinensis*), tangerine (*Citrus tangerina*), persimmon (*Diospyros kaki*), banana (*Musa* spp.), apricot (*Prunus armeniaca*), pear (*Pyrus pyrifolia*), pineapple (*Ananas comosus*), and peach (*Prunus persica*).
- Red River Delta: longan (*Dimocarpus longan*), lychee (*Litchi chinensis*), orange (*Citrus sinensis*), banana (*Musa* spp.), tangerine (*Citrus tangerina*), and plum (*Prunus salicina*).
- North Central and Central Coastal Areas: orange (*Citrus sinensis*), tangerine (*Citrus tangerina*), banana (*Musa* spp.), plum mango (*Bouea oppositifolia*), citron (*Citrus medica* subsp. *Bajoura*), dragon fruit (*Hylocereus undatus*), grape (*Vitis vinifera*), and mango (*Mangifera indica*).

- Central Highlands: strawberry (*Fragaria ananassa*), plum (*Prunus salicina*), persimmon (*Diospyros* spp.), banana (*Musa* spp.), apricot (*Prunus armeniaca*), avocado (*Persea americana*), and durian (*Durio zibethinus*).
- Southeast: rambutan (*Nephelium lappaceum*), mango (*Mangifera indica*), durian (*Durio zibethinus*), jackfruit (*Artocarpus heterophyllus*), mangosteen (*Garcinia mangostana*), banana (*Musa* spp.), guava (*Psidium guajava*) and Java apple (*Syzygium semarangense*).
- Mekong River Delta: mandarin (*Citrus reticulata*), Thai tangerine (*Citrus nobilis* var. *microcarpa*), king orange (*Citrus nobilis* var. *nobilis*), orange (*Citrus sinensis*), pomelo (*Citrus grandis*), longan (*Dimocarpus longan*), rambutan (*Nephelium lappaceum*), durian (*Durio zibethinus*), banana (*Musa* spp.), and mango (*Mangifera indica*).

According to FAOSTAT (Figure 2.9) from 2006 to 2013, harvested area increased by 15,000ha (average increase of 1,875ha per year) and production increased by 260,000 tons (average increase of 32,500 tons per year).

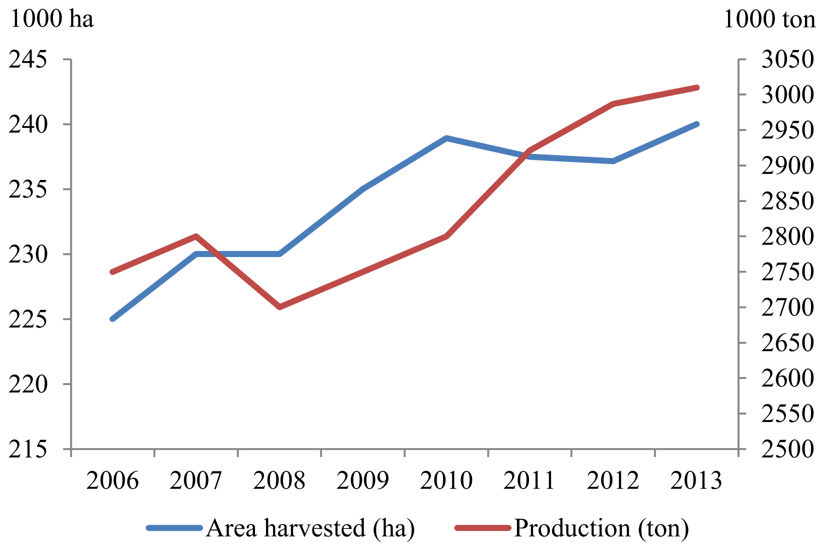


Figure 2.9. Area and production of fruit trees in Vietnam (FAO, 2006 – 2013).

2.2.3.2 Flower and ornamental plant cultivation

Flower cultivation in Vietnam is developing rapidly and is leading to increasing income for farmers in high altitude regions (Danse et al., 2007). The cultivated area of flower and ornamental plant are 12,054ha (Hang 2010) and it covers about 0.1% of the total cultivated area. Recently, authorities in many provinces and cities have encouraged farmers to grow

flowers. The flower production in Vietnam can ensure the domestic demand and a part of the production can be exported to other countries (Phuong, 2014). Flower cultivation is growing rapidly in urban areas near large cities such as Hanoi and Hai Phong in northern Vietnam, Hue and Da Nang in the central coast, Ho Chi Minh, and Can Tho in southern Vietnam.
Various flower species have been cultivated depending on the region. However, rose (*Rosa* spp.) is a major cut flower frequently cultivated in whole country. For example, in Me Linh (Red River Delta) and Sapa (the Northwest), rose production provides more than 50% total household income (Achterbosch, 2007). Moreover, Chrysanthemum (*Dendranthema* spp.), gladioli (*Gladiolus* L.), Limonium (*Limonium* Mill.), Lisianthus (*Eustoma grandiflorum*), carnations (*Dianthus caryophyllus*), lilies (*Lilium longiflorum*), *Anthurium*, *Cymbidium*, and *Gypsophila* are main crops of flower cultivation (Danse et al., 2007, Nguyen, 2013).

Chrysanthemum, gladioli, and roses are three major crops of flower cultivation in Da Lat (central highlands). Nevertheless, other flowers such as Limonium (*Limonium* Mill.), Lisianthus (*Eustoma grandiflorum*), carnations (*Dianthus caryophyllus*), lilies (*Lilium longiflorum*), *Anthurium*, *Cymbidium*, *Gypsophila*, and *Gerbera* are also contributing significantly to the income of farmers in this region.

Chrysanthemum, roses, gladioli, carnations, orchids, dahlia, marigold (*Tagetes erecta*), and tuberose (*Agave polianthes*) are frequently cultivated in sub-urban of Ho Chi Minh City (Cu Chi, Go Vap, Binh Chanh, Thu Duc, Hoc Mon), and other provinces in Mekong River Delta, such as Tien Giang, Ben Tre, and Dong Thap.

Many species such as *Limonia*, *Triphasia*, *Ficus*, *Streblus*, *Wrightia*, *Cermona*, *Podocarpus*, *Ochna*, *Aglaia*, and *Bougainvillea* are cultivated as bonsai plants.

Bottle gourd (*Lagenaria siceraria*), a cucurbit species, is commonly cultivated for decoration (Figure 2.10a) and its fruits are sold as ornamental (Figure 2.10b).

a) b)

Figure 2.10. Decorative bottle gourd at the front of the house (a) and decorated fruits (b) (photo from Huong, 2014).

2.2.3.3 Vegetable cultivation

Vegetables, along with staple crops, contribute an important part in economic development of farmers. Traditionally, vegetables were cultivated in home gardens, in upland areas or in rotation with rice. However, with bedding methods and advanced cultivation techniques farmers can cultivate vegetables also in lowland areas and with intensive systems nowadays (Figure 2.11). As a result, the cultivated land of vegetables is increasing significantly.

a) b)

Figure 2.11. Intercropped cucumbers in rice field (a) and cultivating bottle gourd in lowland bedding in Ben Tre (Mekong River Delta).

The various climates and geographical regions in Vietnam are appropriate for growing of more than 120 tropical, sub-tropical and temperate vegetable species. These species belong to 23 various families (Figure 2.12) and Cucurbitaceae is one of the most dominant among them (FAVRI, 2010; Huong et al., 2013a; Huong et al., 2013b).

Vegetable cultivation is an agricultural sector that enables better income in rural and urban areas. Having the advantages of short growing cycles and appropriate cultivation systems in different growing environments, vegetables are becoming important cash crops (Jansen et al., 1996; Hedlund et al., 2003, Dang et al., 2007). Moreover, vegetables rich in minerals, vitamins and other bioactive metabolites, may improve nutrition and health of consumers, especially for the low-income households those have had daily meals lacking of animal protein (Siemonsma and Piluek, 1994; Böhme and Pinker, 2007). Therefore, already a decade before, there were 66% of households in Mekong villages, and 96% households in Central Highland growing vegetables (Ogle et al., 2003). Mekong River Delta (MRD) with agricultural land of more than 1.6 million ha is the major vegetable area in southern Vietnam (GSO, 2013). In Ben Tre province, e.g. areas of annual crops occupied 62.5% in cultivated land of farmers. The annual crops maintained vegetable crops and grains and they were cultivated as intensive or rotational crops (Pham and Vo, 2013). Vegetables are produced to supply 17.4 million local people especially citizens in some large cities nearby, such as Ho Chi Minh City, Thu Dau Mot, and Bien Hoa. The vegetable production increased in relation to the growth of population and the daily vegetable demand of Vietnamese (Figuié, 2003, Mergenthaler et al., 2009).

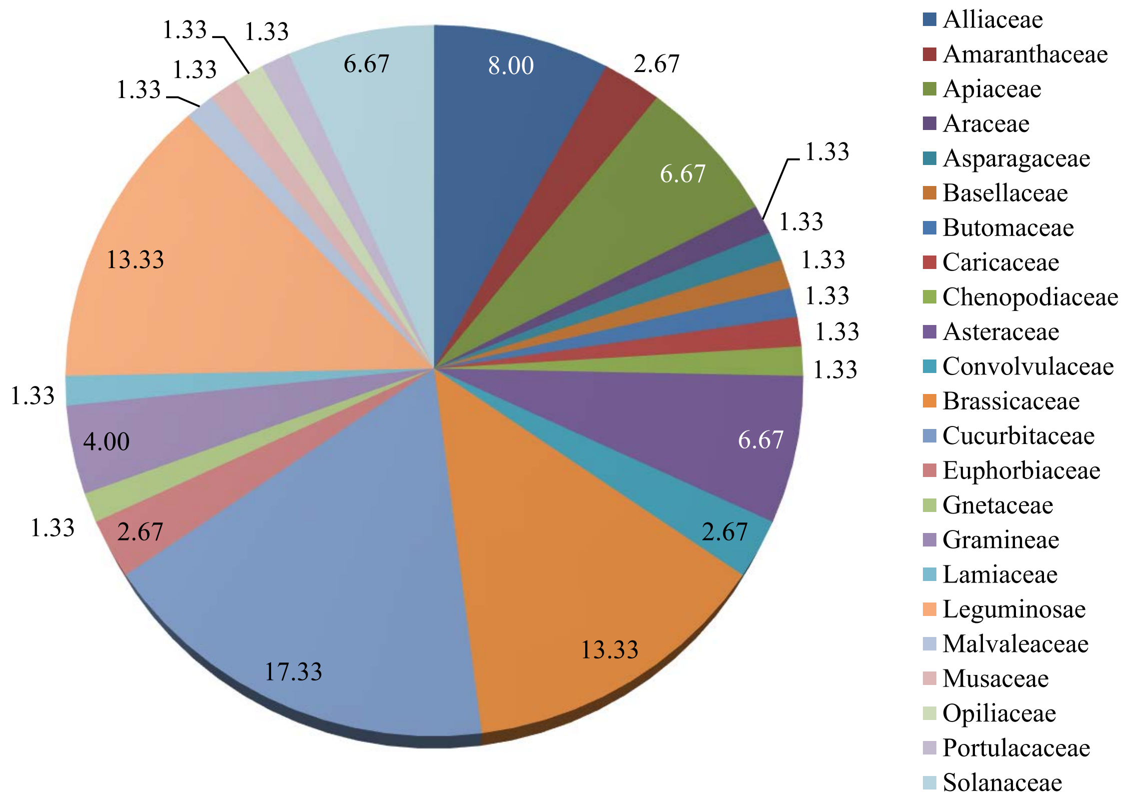


Figure 2.12. Plant families used in vegetable cultivation in Vietnam (in %) (calculated based on Siemonsma and Piluek, 1994; Pham, 1999).

In Vietnam, vegetables are the second important foodstuff after rice (Figuié, 2003). After becoming a member of WTO in 2006, the foreign market for vegetables expanded, that was one of the reasons to increase the cultivated area and vegetable production further (Figure 2.13). From 2006 to 2013, harvested area increased by 155,000ha (average of 19,375ha per year) and production increased by 1,200,000 tons (average of 150,000 tons per year).

The diversity of vegetable species cultivated depends on growing condition of the regions and the local or export market demands (Siemonsma and Piluek, 1994; Trinh et al., 2003). Although a large number of vegetable species can be grown in Vietnam, only some species are cultivated frequently. Among them, some species belonging to Cucurbitaceae can be cultivated in different growing conditions. Therefore, they are often cultivated in intensive and extensive cropping systems (Trinh et al., 2003; FAVRI, 2010; Huong et al., 2013b). The economic importance and frequent cultivation of cucurbits were already explored in previous studies (Siemonsma and Piluek, 1994; Khiem et al., 2000; Everaarts et al., 2006).

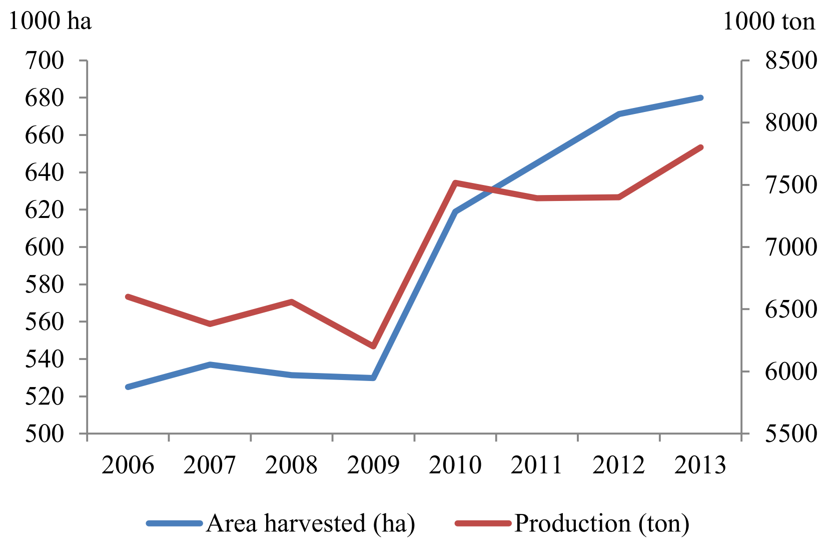


Figure 2.13. Area and production of vegetable in Vietnam (FAOSTAT, 2006-2013).

Vegetable crops can be classified into four groups depending on product types as leafy vegetables, fruit-bearing vegetables, root vegetables, and spice vegetables (FAO, 2005; Vaughan and Geissler, 2009). Cucurbits species were classified into group of fruit-bearing vegetables and this group occupies 67.9 % of cultivated area used for annual crops (Figure 2.14).

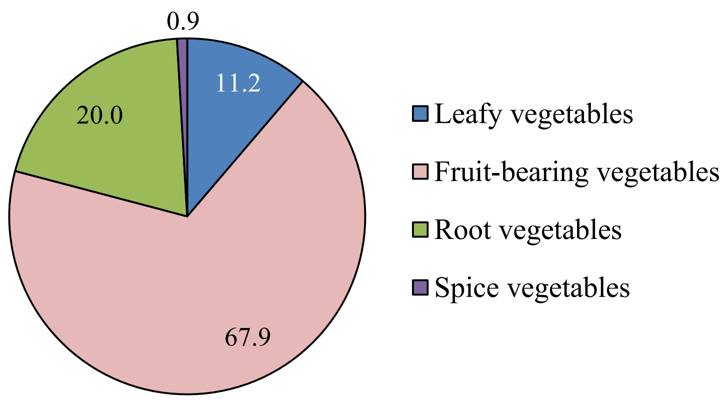


Figure 2.14. Land used for vegetable cultivation (%) according to vegetable groups (calculated from Pham and Vo, 2013).

2.2.3.4 Contribution of cucurbits in vegetable cultivation

Various studies investigating diversity of species have been carried out in vegetable production and urban markets (Siemonsma and Piluek, 1994; Khiem et al., 2000) in Vietnam, indicated 13 cucurbit species within about 75 different vegetable species that are cultivated with high using frequency and large quantities. These species included ash gourd (*Benincasa hispida*), watermelon (*Citrullus lanatus*), melon (*Cucumis melo, C. melo* var. *conomon*), cucumber (*Cucumis sativus*), pumpkin and squash (*Cucurbita pepo, C. moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*, *L. acutangula*), bitter gourd (*Momordica charantia*), chayote (*Sechium edule*), and snake gourd (*Trichosanthes cucumerina*).

The studies on home garden ecosystems identified loofah (*Luffa cylindrica*) as one of the four key species that were cultivated in four different ecosystems, including northern, north-central, south-eastern and south-western Vietnam (Trinhetal., 2003, Mohri et al., 2013). The study about the multiple functions of edible wild plants in four different villages in the Mekong River Delta and the Central Highlands (Ogle et al., 2003) indicated *Gymnopetalum cochinchinensis* and *Trichosanthes tricuspidata,* two wild cucurbit species used as food, feed and medicine.

The survey of FAVRI (2010) about area and production of vegetable in Hung Yen, a province in the Red River Delta (RRD), specialized in vegetable cultivation, showed that the area for cultivating cucurbits covered 16.09% of total cultivated area and represented 18.13% of the total vegetable production.

Regarding watermelon (*Citrullus lanatus*), this species is widely cultivated in whole country. In 2012, there were 31,000 ha harvested area of watermelon, and fruit production reached 470,000 tons. Net production value (constant 2004-2006 1000I$) achieved 127 million USD (FAOSTAT, 2012).

In Central coast, Central highland, Southeast and Mekong River Delta, some cucurbit species were frequently cultivated in home gardens, including pumpkin (*Cucurbita moschata*), loofah (*Luffa cylindrica*), cucumber (*Cucumis sativus*), bottle gourd (*Lagenaria siceraria*), bitter gourd (*Momordica charantia*), ash gourd (*Benincasa hispida*), gac (*M. cochinchinensis*), and snake gourd (*Trichosanthes anguina*). With the advantage of strong growth, larger canopy, and special fruit shape, cucurbits were grown not only for food, but also for shade and decoration (Figure 2.15).


a) b)


c) d)


e) f)

Figure 2.15. Cucurbit species cultivated in home gardens. a) *Luffa cylindrica;* b) *Lagenaria siceraria;* c) *Cucurbita moschata;* d) *Momordica cochinchinensis;* e) *Trichosanthes anguina;* and f) *Momordica charantia*.

2.3 Plant genetic resources in Vietnam and the diversity of cucurbits

2.3.1 Plant genetic resources in Vietnam

Vietnam is in the Indo-Malaya ecozone and the whole country belongs to a biodiversity hotspot named Indo-Burma hotspot. The hotspot, which is one of the most biologically important regions of the planet in terms of species diversity and endemism, is being threatened by pressure of increasing human population and rapid economic development (CEPF, 2012; CEPF, 2014). Over two million square kilometres in area, the hotspot includes mainland of Myanmar (Burma), Thailand, Cambodia, Laos, Vietnam, and small areas of eastern Bangladesh and north-eastern India (CEPF, 2014). The numbers of vascular plants in the hotspot were estimated more than 15,000 species and about 7,000 species were endemic (CI, 2014; CEPF, 2014).

In the National Environmental Present Condition Report 2005 – Biodiversity Subject of Vietnam Environment Protection Agency, in species diversity (MNRE, 2005): "Vietnam is one of 25 countries having high level in biodiversity all over the world, is ranked 16th of biologically diverse level (having 16% world's species)". Regarding the flora, there were more than 12,000 species of 305 vascular plant families existing on 33.1 million hectares of area. 11,611 species in 2,256 genera belonging to 305 plant families were identified, and about 10% of all species are endemic to Vietnam. More than 2,300 species were used in daily life of inhabitant (Pham, 1999; Tran and Ha, 2000).

Plant diversity in Vietnam is remarkable for a relatively small area. The high plant diversity in Vietnam is related to the differences in climate regime, soil, landscape and topography (Averyanow et al., 2003). The endemic species differ highly in various regions. Regarding the two parts of Vietnam separated by Danh River in Quang Tri province at latitude of 17^0, more endemic species are found in northern part (61%) than in the southern part (31%).

Regarding plants used as vegetables, Pham and Luu (2007) reported that 293 indigenous species (72.7%) within 403 species were used. Among the number of species used as vegetables, about 75 species (18.6%) are cultivated vegetables and the other 328 species (81.4%) are wild gathered vegetables.

2.3.2 Cucurbit species in Vietnam

2.3.2.1 Indigenous and non-indigenous cucurbits in Vietnam

According to Engle (2002), "the term indigenous is used to refer to species native to or originating in a particular region or environment. It may include natural species or varieties that evolved from materials introduced to the region from another geographical area and which over a long period have developed into genotypes adapted to the new habitat probably through the process of natural selection or selection by farmers. However, the term indigenous should exclude products of scientific improvement".

Regarding the indigenous vegetables, Wang et al. (2014) defined the species are important for the sustainability of economies, human nutrition and health, and social systems. Yet these species are often underutilized or under valuated (Weinberger, 2007). A small number of indigenous vegetables are cultivated and used by inhabitants in few geographical regions (Engle, 2002). Meanwhile, collecting germplasm and increasing production of indigenous vegetables could increase farmers' income and reduce the risk of genetic erosion (Engle, 2002; Böhme and Pinker, 2007). In the study, therefore, the term "indigenous and non-indigenous cucurbits" refers to cultivated or wild species that belong to Cucurbitaceae, which had its origin in Vietnam or the cucurbit species introduced into the country.
Among cucurbits cultivated in Vietnam indigenous and non-indigenous can be distinguished whereas most mainly cultivated cucurbits are grown at least for more than 500 years.

- For illustration of the indigenous cucurbits in Vietnam:
    - *Cucumis sativus* and *Cucumis melo* are certainly considered indigenous. The study about phylogenetics of cucurbits by Renner et al., (2007) suggested Asia as the ancestral area of *Cucumis sativus* and *Cucumis melo* with high diversity in India and China.
    - The genus *Momordica,* with two important market vegetable in Vietnam, *M. charantia* and *M. cochinchinensis*, originated in Asia, particularly in the Indo-Burma region (Robinson and Decker-Walters, 1997; Marr et al., 2004; Krawinkel and Keding, 2006) including Vietnam can be also considered indigenous.
    - Two widely cultivated *Luffa* species (*L. acutangula* and *L. cylindrica*), on the other hand, probably arose in Southeast Asia (Heiser and Schiling, 1988) or they had dispersed naturally from Africa and are present in Southeast Asia since about 11,000 to 7,000 years before present (Marr et al., 2005).

- *Lagenaria siceraria* originating in Africa (Erickson et al., 2005; Ckarke et al., 2006) was domesticated in East Asia by 9,000 to 8,000 years before present (Erickson et al., 2005). Archaeology in Hoabinhian (a "mesolithic" assemblages from all parts of mainland Southeast Asia) provided evidence that melon (*Cucumis melo*) and bottle gourd (*Lagenaria siceraria*) were domesticated in Southeast Asia about 7000 B.C. (Gorman, 1969; Gorman 1971).

- For illustration of the non-indigenous cucurbits in Vietnam:
  - In Vietnam, three species, *C. moschata, C. pepo, and C. maxima*, might be introduced in the 15th century, when traders from Europe came to Hoi An port (formally Faifo, a Southeast Asia trading port dating from 15th to 19th century, located in Hoi An town, Quang Nam district, Vietnam). Alternatively, they may be present in Vietnam earlier than that period via long-distance dispersal by floating or by birds from America.

2.3.2.2 Species diversity of cucurbits in Vietnam

As already mentioned in Figure 2.3, in the family Cucurbitaceae are two important subfamilies, the *Zanonioideae* with 1 tribe and 3 subtribes and the *Cucurbitoideae* with 6 tribes and 10 subtribes.

Pham (1999) determined 51 cultivated and wild cucurbit species in Vietnam (Table 2.2). He discovered the same subfamilies and number of tribes as mentioned in Figure 2.3. The number of subtribes belong to the subfamily *Cucurbitoideae* are 8. The subtribe *Telfairiinae* (originated in West-Africa) and *Cyclantherinae* (originated in Middle- and North America) are not introduced in Vietnam.

Three species belong to subfamily *Zanonioideae* grow wild, they are adapted in some geographical regions, i.e. *Neoalsomitra sarcophylla* is found in Chau Doc; *Hemsleya chinensis* and *Actinostemma tenerum* are observed in Ha Son Binh.

The cucurbit species given in Table 2.2 are distributed over the whole country. Some of the non-indigenous cucurbits are well adapted in flat land in northern Vietnam, but in southern Vietnam mostly cultivated in hilly areas, e.g. *Sechium edule*, *Cucurbita pepo*. There are also some species, in particular indigenous ones, cultivated in different geographical zones from 1 to 2000m ASL.

Table 2.2. Cultivated and wild cucurbit species in Vietnam (summarized from Pham, 1999)

Scientific name[*]	Vietnamese name	Distribution[**]
Subfamily *Zanonioideae*		
Tribe *Zanonieae*		
Subtribe *Zanoniinae*		
Neoalsomitra integrifolia (Cogn.) Hutch	Lâm mạo lá nguyên	Lao Cai, Ha Son Binh, Thanh Hoa, Kontum
Neoalsomitra sarcophylla (Warb.) Hutch.	Lâm mạo lá mập	Chau Doc
Zanonia indica L.	Thiết bát; Lục lạc dây	Vinh Long, Can Tho (plain forests up to 500m)
Subtribe *Gomphogyninae*		
Gomphogyne cissiformis Griff.	Đầu thư lá nhỏ	Hanoi, Ha Dong
Gynostemma laxum (Wall.) Cogn.	Thư tràng thưa	Lao Cai, Hoa Binh, Ha Nam Ninh, Quang Tri (thin forests)
Gynostemma pentaphyllum (Thunb.) Mak.	Thư tràng 5 lá; Cổ yếm; Giảo cổ lam	Forests, thin forests, the groves (1 -2,000m)
Hemsleya chinensis Cogn.	-	Ha Son Binh
Subtribe *Actinostemmatinae*		
Actinostemma tenerum Griff.	Xạ hùng mềm	Ha Son Binh
Subfamily *Cucurbitoideae*		
Tribe *Melothrieae*		
Subtribe *Cucumerinae*		
Cucumis sativus L.	Dưa leo; Dưa chuột	cultivated up to 1500m
Cucumis melo var. conomon (Thunb.) Mak.	Dưa gang	Cultivated all the country
Cucumis trigonus Roxb.	-	-
Mukia javanica (Miq.) Jeffrey.	Cầu qua Java; Rơ bát	Ca Na, Tuyen Duc, Dong Nai (Mountains around 1000m)
Mukia maderaspatana (L.) M.J. Roem.	Cầu qua nhám	Forests up to 1100m
Zehneria indica (Lour.) Keyr.	Chùm thẳng; Cầu qua trái trắng	From Hoang Lien Son to Ca Mau
Zehneria marginata (Bl.) Ker.	Cầu qua bìa	Hanoi, Lam Dong, Chua Chan mountain (groves up to 800m)
Zehneria maysorensis (W.&A.) Arnott.	Cầu qua Mayso	From Lao Cai to Dong Nai (plain forests up to 1000m)
Tribe *Joliffieae*		
Subtribe *Thladianthinae*		
Momordica charantia L.	Khổ qua; Mướp đắng	Cultivated all the country
Momordica cochinchinensis (Lour.) Spreng.	Gấc	Fallows, forests 1-1500m
Momordica laotica Gagn.	-	Luangbian
Momordica subangulata Bl.	Gấc cạnh	Cao Bằng, Lạng Sơn
Thladiantha cordifolia (Bl.) Cogn.	-	Lao Cai, Lai Chau, Hanoi, Ha Nam Ninh
Thladiantha hookeri C.B.Cl.	-	Ha Son Binh
Thladiantha indochinensis Merr.	-	Lao Cai (thin forests 1500-1800m)
Thladiantha siamensis Craib.	Khổ áo	Lao Cai, Hoa Binh (1200m)
Tribe *Trichosantheae*		
Subtribe *Hodgsoniinae*		
Hodgsonia macrocarpa (Bl.) Cogn.	Beo; Đài hái; Sén; Huất sơn	Vinh Phu to Dong Nai (thin, plain forests)
Subtribe *Trichosanthinae*		
Gymnopetalum cochinchinensis (Lour.) Kurz.	Cứt quạ	Cao Bang to Phu Quoc. Fallows, forests 1-1000m, established forests

Table 2.2. (Continued)

Scientific name[*]	Vietnamese name	Distribution[**]
Gymnopetalum cochinchinensis var. *incisa* Gagn.	Cứt quạ	Fields, established forests, 1 – 1,500m
Gymnopetalum integrifolium (Roxb.) Kurz.	Cứt quạ lá nguyên	Along roads, fallows, 0 – 2000m, from Lai Chau to Chau Doc
Trichosanthes anguina L.	Mướp tây; Mướp hổ	Cultivated all the country
Trichosanthes baviensis Gagn.	-	Ha Tay
Trichosanthes rubriflos Cayla.	Hồng bì	Cao Bang to Chau Doc (mountains up to 1300m)
Trichosanthes cucumerina L.	Dưa núi	Dong Nai (Chua Chang mountain), fallows
Trichosanthes kirilowii Maxim.	Bạc bát; Qua lâu; Dưa trời	Phan Rang, Binh Thuan
Trichosanthes ovigera Bl.	Qua lâu trứng	From Lao Cai to Di Linh (forests, hedges, mountains up to 2000m)
Trichosanthes pedata Merr. & Chun.	-	Quang Ninh (growing on limestones)
Trichosanthes pierrei Gagn.	-	Lu mountain
Trichosanthes tricuspidata Lour.	Lâu xác; Re to	Hoang Lien Son to Dong Nai (plains 100m)
Trichosanthes villosa Bl.	Do mõ	Kontum, Song Be, Dong Nai (edge forests, the groves, plains)
Tribe *Benincaseae*		
Subtribe *Benincasinae*		
Benincasa hispida (Thunb.) Cogn.	Bí đao	Cultivated all the country
Citrulus colocynthus (L.) Schrad.	-	-
Citrulus lanatus (Thunb.) Mats. & Nak.	Dưa hấu	Cultivated all the country
Coccinia grandis (L.) Voigh.	Bát	Hedges, the groves (1 – 1500m)
Diplocyclos palmatus (L.) Jeffrey	Lưỡng luân; Chân vịt; Ba da	Thua Thien, Ba Ria (wet forests, wet grass-plots)
Lagenaria siceraria (Mol.) Standley.	Bầu	Cultivated all the country
Solena heterophylla Lour.	Cầu qua dị diệp	Fallows, hedges, the grove forests 0- 1000m
Subtribe *Luffinae*		
Luffa acutangula (L.) Roxb.	Mướp khía	Cultivated all the country
Luffa cylindrica (L.) M.J. Roem.	Mướp hương	Cultivated all the country
Tribe *Cucurbiteae*		
Subtribe *Cucurbitinae*		
Cucurbita maxima Duch. ex Lam.	Bí rợ; Bí đỏ	Cultivated all the country
Cucurbita moschata Duch. ex Poir.	Bí rợ	Cultivated all the country
Cucurbita pepo L.	Bí đỏ	Cultivated in the North and highland areas
Tribe *Sicyeae*		
Subtribe *Cicyinae*		
Sechium edule (Jacq.) Swartz.	Su su; Chu chu	Middle and Western Highlands

[*]: classified according to Robinson and Decker-Walters (1997).[**] : Some regions were separated: Ha Son Binh was separated into Ha Tay and Hoa Binh; Ha Nam Ninh was separated into Ha Nam, Nam Dinh, and Ninh Binh; Cao Lang was separated into Cao Bang and Lang Son; Song Be was separated into Binh Duong and Binh Phuoc.

Among the 51 cucurbit species in Vietnam, 13 species/varieties are commonly cultivated in Vietnam (Table 2.3) for commercial purpose and daily meals of Vietnamese. The species belong to 9 genera, including *Benincasa* (1 species), *Citrullus* (1 species), *Cucumis* (2 species, 1 variety), *Cucurbita* (2 species), *Lagenaria* (1 species), *Luffa* (2 species), *Momordica* (1 species), *Sechium* (1 species), and *Trichosanthes* (1 species).

Table 2.3. Commonly cultivated cucurbits in Vietnam (Siemonsma and Piluek, 1994; Pham, 1999)

Genus	Species	Variety	Common name
Benincasa	*hispida*		Ash gourd
Citrullus	*lanatus*		Water melon
Cucumis	*sativus*		Cucumber
	melo		Melon
	melo	var. *conomon*	Melon
Cucurbita	*moschata*		Pumpkin
	pepo		Winter pumpkin
Lagenaria	*siceraria*		Bottle gourd
Luffa	*cylindrica*		Loofah
	acutangula		Angled loofah
Momordica	*charantia*		Bitter gourd
Sechium	*edule*		Chayote
Trichosanthes	*anguina*		Snake gourd

Within the species given in Table 2.3, bitter gourd (*Momordica charantia*) fruits contain high phytonutrient (carotenoid, ascorbic acid, and tocopherol), which are beneficial to human health and prevent diabetes, especially for people in developing countries (Yang et al., 2014; Dhillon et al., 2015).

Some other wild cucurbit species used as food and medicinal plants of the Vietnamese are found in home-gardens, fallows, and forests, for instance *Coccinia grandis* (L.) Voigh (Figure 2.16a), *Gynostemma pentaphyllum* (Thunb.) Mak. (Figure 2.16b), *Gymnopelatum integrifolium* (Roxb.) Kurz (Figure 2.16c); *Gymnopetalum cochinchinensis* (Lour.) Kurz., *Mukia maderaspatana* (L.) M.J. Roem. (Figure 2.16d) (Vo, 1997; Pham, 1999; Do, 2004; Tanaka and Nguyen, 2007).

Figure 2.16. Cucurbit species used as food and medicine. a) *Coccinia grandis;* b) *Gynostemma pentaphyllum;* c) *Gymnopelatum integrifolium*; and d) *Mukia maderaspatana*.

2.4 Conservation of cucurbits within plant genetic resource conservation system in Vietnam

2.4.1 Plant genetic diversity loss and threatened cucurbit species

2.4.1.1 Causes of the loss of plant genetic diversity

In recent years, plant genetic resources in Vietnam are in serious erosion and threatened by climate change and human activities with various causes: deforestation, arable land expansion, urbanization, and the substitution of traditional cultivars by high yield cultivars due to the market-oriented economy (VNPPA, 1998; Pham and Luu, 2007; Hoang, 2009). In opening statement of the workshop “Collection, conservation and utilization of indigenous vegetables” (Engle and Altoveros, 2000), Nangju asserted that flora is seriously threatened with losses due to various human activities such as land clearing, urbanization, deforestation, forest logging, and substitution of traditional varieties with improved varieties.

In Vietnam, more than 70% of the population is closely linked to agricultural sector. Pham (1999) stated that flowering flora are the inestimable benefactors of mankind: flowering flora give us basically daily food, flowering flora provide us, particularly Vietnamese people, and a prosperous living place.

Up to now, Vietnam natural forests are rich biodiversity areas. However, increasing population and pressure of economic development are major causes for losses of natural forest and biodiversity in such areas (Figure 2.17).

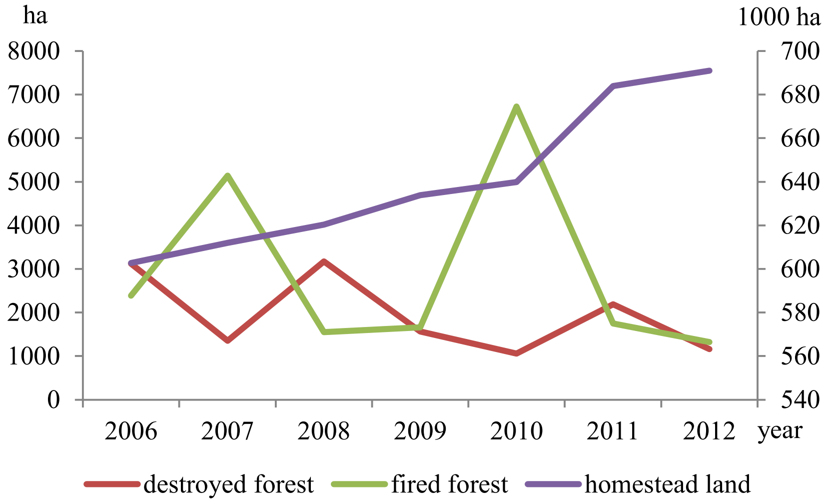


Figure 2.17. Destroyed forest and fired forest (left y-axis) and homestead land (right y-axis) in Vietnam in seven years (GSO, 2006 – 2012).

Rooij and Hilderink (2014) analyzed by modelling impacts of changing land use pattern on Vietnam's economy. They pointed out that Vietnamese socio-economic changes have negative effects on landscape, including natural forest losses with negative consequences for biodiversity and greenhouse gas emissions, and losses of other agriculture lands in the Red River Delta and Mekong River Delta.

2.4.1.2 Threatened cucurbit species

According to the decree 80/2005/QĐ-BNN of Ministry of Agriculture and Rural Development (MARD, 2005), there were 2,342 species belonging to 37 families arranged in valuable and rare species that are needed to conserve (Appendix 2). Cucurbitaceae ranked in the 16th of these 37 families in this decree. There were 33 species belonging to five genera of Cucurbitaceae enumerated (Appendix 3). These species or subspecies belonged to *Trichosanthes, Momordica, Cucurbita, Luffa,* and *Cucumis*, including *Trichosanthes kirilowii, Trichosanthes ovigera, Trichosanthes rubriflos, Trichosanthes tricuspidata, Trichosanthes villosa, Momordica subangulata, Momordica charantia, Cucurbita* sp., *Luffa acutangula, Luffa* sp., *Cucumis sativus, Cucumis* sp..

2.4.2 Plant genetic resources conservation system in Vietnam

Vietnam, a country in Southeast Asia with an enormous richness in genetic resources, counts about 16% world species, (Tran and Ha, 2000; MNRE, 2005). This biodiversity is going extinct or at least is threatened by climate change and human activities. Therefore, it is very important to find appropriate methods for conservation of the indigenous plants and landraces. *In situ* and *ex situ* are two main methods used for conserving national plant genetic resources in Vietnam.

With the support of Asian (ASEAN) and global (FAO) organisations, Vietnam had established more than 2.4 million hectares for *in situ* conservation of biological resources. On 43.4% of this area there are national parks, more than 49.3% are natural conservation areas, and the small rest covers cultural historical environment sites. On-farm conservation, as a special type of *in situ* conservation, is practised in the plant genetic resources centres of Vietnam with fruit trees, root crops, vegetable crops, ornamental crops, medicinal herbs, and forage plants (Ha et al., 2003; Nguyen et al., 2005; Nguyen and Luu, 2007). *Ex situ* conservation methods are mainly concentrated to the seven main groups of crops as grains, fruit crops, annual and perennial industrial crops, vegetables, ornamental crops and forage plants (Vu et al., 2010).

2.4.2.1 *In situ* conservation

In situ conservation is conducted for saving important indigenous plants, landraces, and wild related varieties. There are two main activities in this field: establishment of biological resources in protected areas and on-farm conservation sites. Protected areas have been established with three different levels including National parks, Nature conservation areas, and Cultural historical environment sites. Within seven years, the total areas for *in situ* conservation has increased by 9,957 ha (Table 2.4), from 2,390,135 ha (2002) to 2,400,092 ha (2009).

Table 2.4. Protected areas of genetic resources in Vietnam (ICEM, 2003; Hoang, 2009)

Year	2002		2009	
Types	No.	Area (ha)	No.	Area (ha)
I. National parks	25	851,361	30	1,041,956
II. Nature conservation areas	60	1,351,106	60	1,184,372
IIa. Nature reserves	48	1,259,353	48	1,100,892
IIb. Habitats/species conservation areas	12	91,753	12	83,480
III. Cultural historical environment sites	37	187,668	38	173,764
Total	122	2,390,135	128	2,400,092

Conservation of biodiversity on-farm has been implementing in many provinces to conserve variously traditional crops. With the participation of inhabitants, on-farm conservation activities will share the traditional knowledge about maintenance and sustainable use of plant genetic resources.

2.4.2.2 *Ex situ* conservation

- Field genebanks

There are 21 institutions in The National Plant Genetic Resource Networks of Vietnam conserving 5,371 accessions in field genebanks with different group of crops (Figure 2.18). Field genebanks are established not only for maintenance of vegetatively reproduction plants, but also for propagation and hybridization of sexual reproduction plants.

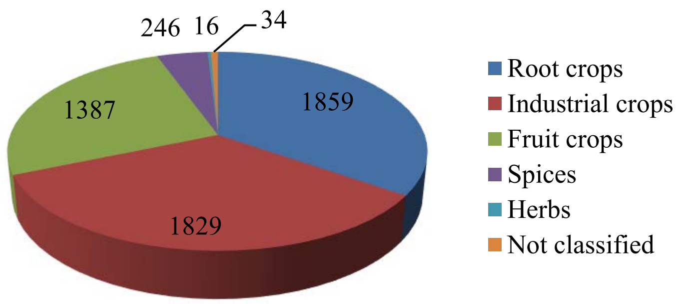


Figure 2.18. Number of accesions related to cultivated crops in field genebanks (calculation based on Hoai et al., 2010; Bay et al., 2010).

- Seed genebanks

Seed genebanks are the main *ex situ* conservation activities for plant genetic resources in Vietnam. Most of the seed collections - more than 18 plant families - are conserved at the National Genebanks at Vietnam Agricultural Science Institute (VASI). Up to now, 15,760 accessions are stored in seedbanks (Table 2.5) with long-term storage condition (- 10°C to - 20°C, 35% RH) and medium-term storage condition (0°C to 5°C, 45%RH).

Table 2.5. Seedbank conservation in medium-term storage condition (Vu and Tran, 2010)

Plant groups	Species number	Accessions number	%
Cereal	5	8123	51.5
Vegetables	64	4008	25.4
Legume	23	2756	17.5
Fiber crops	3	544	3.5
Oil crops	3	315	2.0
Not classified	5	14	0.1

Plant genetic resources of Vietnam were also conserved overseas via international cooperation programs. For example, 1,125 vegetable accessions from 16 different families were collected and stored at seed genebanks of AVRDC – The World Vegetable Center – and in the project ADB RETA 5839 accessions in four years (1999 – 2002).

- *In vitro* genebanks

In vitro conservation method is applied for recalcitrant seed crops and some vegetative-propagated crops that are difficult to maintain in the field condition. In Vietnam, *in vitro* culture technique has been developed and maintained about 515 accessions including root crops (taro, eddoe, and potato); fruit crops (banana, strawberry, and grape); flowers (chrysanthemum, orchid, carnation, rose, gerbera, gladiolus, anthodium, and lily) in 2010 (Vu and Tran, 2010).

2.4.3 Evaluation and utilization of plant genetic resources

Up to now, national programs including *in situ* and *ex situ* conservation maintain less than 1% of total plant species in Vietnam. In addition, evaluation and utilization of plant genetic resources is low, only 6% of conserved accessions are used in national breeding programs (Vu et al, 2010). It is necessary to structure the management networks as well as to modernize the equipment's in order to maintain and utilize the available national plant genetic resources efficiently.

Research and utilization of plant genetic resources are applied with three main targets: allocation, introduction and providing genetic information for users; enhancing the conservation activities via exploitation; and cooperation with institutes and breeding centers in using the valuable underutilized-crops. In the period from 2006 – 2009, 7057 accessions belonging 18 different plant genera were evaluated for quantitative and qualitative characteristics (Vu et al., 2010). Most of the accessions belonged to rice (*Oryza sativa*), corn (*Zea mays*), kaoliang (*Sorghum bicolor, S. vulgare*), sesame (*Sesamum indicum*), soybean (*Glycine max*), peanut (*Arachis hypogaea*), green bean (*Vigna radiata*), broad bean (*Lablab purpureus*), French bean (*Phaseolus vulgaris*), field pea (*Pisum sativum*), potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), taro (*Colocasia antiquorum*), yam (*Dioscorea esculenta*), tomato (*Lycopersicon esculentum*), chilli (*Capsicum annuum*) (Vu and Tran, 2010).

According to Hung (2010) and Vu and Tran (2010), shortcomings of collection, evaluation, and conservation of plant genetic resources in Vietnam were given as follows:

- Collection of plant genetic resources was neglected by Vietnamese government and agricultural research institutions.
- Lack of specific knowledge of researchers working in the fields of collection, in evaluation, conservation
- Lack of facilities and poor conditions of storage systems used for conservation.
- In Passport data of the conserved accessions, only the scientific names were given. The other basic information such as subspecies, time and regions of collection, and time of conservation were missing or incorrect.
- There were no standard evaluation criteria for each plant species. Hence, description and evaluation data of germplasm were incomplete and redundant. There was no information about reproduction and promising accessions.

2.4.4 Collection, conservation and utilization of cucurbit genetic resources

For collection and conservation of cucurbit germplasm some vegetable conservation projects were organised in frame of the Vietnamese national program (AVRDC, 2007; Vu et al., 2010).

2.4.4.1 Collection and conservation

The projects were less focusing to specific plant families, but more to the northern regions of Vietnam, nevertheless many species of the Cucurbitaceae were collected. In result of these projects in 2011, the number of cucurbit genera were eight and the number of stored accessions were 910 (Table 2.6).

Table 2.6. Cucurbits species conserved at VASI's genebank (PGRV, 2011)

Genus	Species	Vietnamese name	No. of accession
Benincasa	*Hispida*	Bí xanh	121
Citrullus	*Lanatus*	Dưa hấu	15
Cucumis	sp.	Dưa các loại	136
Cucurbita	spp.	Bí đỏ	270
Lagenaria	*siceraria*	Bầu	87
Luffa	*acutangula*	Mướp khía	29
Luffa	*cylindrica*	Mướp hương, mướp trâu	185
Momordica	*charantia*	Mướp đắng	25
Trichosanthes	*anguina*	Dưa trời, mướp hổ	42
Total			910

The ADB RETA 5839 project of AVRDC (1999 – 2002) "Collection, Conservation and Utilization of Indigenous Vegetable Germplasm" included also collection and conservation cucurbit in Vietnam. Within the AVRDC project, also the eight most important cucurbit genera (Table 2.7) as in the Vietnamese project (Table 2.6) were collected but fewer accessions. These accessions were stored in Taiwan at seed genebanks for medium-term condition (0 - 5°C and 20 - 30% RH).

Table 2.7. Cucurbits species collected in Vietnam in AVRDC's database (AVGRIS, 2011)

Genus	Species	Variety	No. of accessions
Benincasa	*hispida*		30
Citrullus	*lanatus*		8
Cucumis	*melo*		5
	melo	var. *cantalupensis*	4
	melo	var. *conomon*	4
	sativus + sp.		21 + 9
Cucurbita	*maxima*		8
	moschata		33
	pepo+ sp.		17 + 79
Lagenaria	*siceraria*+ sp.		18 + 16
Luffa	*acutangula*		5
	aegyptiaca+ sp.		26 + 46
	aegyptiaca	var. *insularum*	1
Momordica	*charantia*		10
	cochinchinensis		2
Trichosanthes	*cucumerina* +sp.		1+1
	cucumerina	*cvg snake gourd*	1
Total			345

The regions where cucurbit germplasm was collected in the two projects were concentrated predominantly in the North of the country as follows:

- 12 provinces in Northern Midlands and Mountain Areas (Bac Giang, Bac Kan, Cao Bang, Ha Giang, Hoa Binh, Lai Chau, Lang Son, Lao Cai, Quang Ninh, Son La, Tuyen Quang, and Thai Nguyen).
- 10 provinces in Red River Delta (Bac Ninh, Hanoi, Ha Tay, Hai Duong, Hai Phong, Hung Yen, Nam Dinh, Ninh Binh, Thai Binh, and Vinh Phuc).
- Six provinces in North Central Coast (Thanh Hoa, Nghe An, Ha Tinh, Quang Binh, Quang Tri and Thua Thien – Hue), 1 in Central Coast (Quang Ngai).
- One province in Central Highlands (Kon Tum).

In southern Vietnam, in contrast, including Central Coast, Central Highlands, Southeast, and Mekong River Delta, was poorly concerned.

According to the report of a working group on cucurbits (Lohwasser et al., 2008), the cucurbit collection in Gatersleben (in Germany) consists of 2,702 accessions belonging 27 different cucurbit genera. The accessions of cucurbits were collected from more than 77 countries in the world including *Cucumis melo* accessions that were collected in Vietnam. In addition, Vietnamese bitter gourd (*Momordica charantia*) accessions were collected and conserved at Plant System Department, Humboldt University of Berlin. The accessions were investigated the potential of typical cultivation systems in green house growing condition (Böhme et al. 2014).

2.4.4.2 Seed storage methods of cucurbit species

The seed storage methods are the most important ones for collection and conservation of cucurbit species. Orthodox seeds can be easily stored because their moisture contents can be reduced up to 2 – 6% depending on plant species (Hong et al., 1996a; Hong and Ellis, 1996) and these very dry seeds can be stored in seedbank conditions at -18^{o}C and 10 - 12% RH for a long period without any treatment. For so-called recalcitrant seeds the water content cannot be reduced below 12%. Therefore, the storage of recalcitrant seeds is hampered and alternative as cryo-preservation are to be developed (Hong et al., 1996a; Hong and Ellis, 1996).

With two exceptions (*Telfairia* and *Sechium* spp.), seed storage behaviour of cucurbits is considered to be orthodox (Hong et al., 1996a, Hong et al., 1996b; Hong and Ellis, 1996). In detail, seed storage behavior of some cucurbit species is classified as follows:

- The species with orthodox seed storage behaviour: *Acanthosicyos naudinianus; Apodanthera undulate; Benincasa cerifera; Bryonia dioica; Citrullus colocynthis; Citrullus lanatus* (synonym: *C. vulgaris* Schrad.; *Colocynthis citrullus* (L.) Kuntze); *Coccinia sessilifolia; Corallocarpus triangularis; Cucumis aculeate; Cucumis africanus; Cucumis anguria; Cucumis halabada; Cucumis melo; Cucumis metuliferous; Cucumis myriocarpus; Cucumis pustulosus; Cucumis sagittatus; Cucumis sativus; Cucurbita foetidissima; Cucurbita* sp.; *Cyclanthera brachystachya* (synonym: *C. explodens*); *Ecballium elaterium; Kedrostis crassirostrata; Lagenaria sphaerica; Luffa acutangulata; Momordica balsamina; Momordica charantia; Posadaea sphaerocarpa*; *Zehneria marlothii.*
- The species with probable orthodox seed storage behaviour: *Cucumis prophetarum; Cucurbita maxima*; *Cucurbita moschata*; *Cucurbita pepo; Echinocystis lobata; Lagenaria siceraria* (synonym: *L. vulgaris* Ser.); *Momordica* sp.

- The species with recalcitrant seed storage behaviour: *Sechium edule; Telfairia occidentalis*.
- The species with more than 0.5 probability of orthodox seed storage behaviour: *Sicyos deppei; Siolmatra brasiliensis; Zehneria marlothii.*

2.4.4.3 Evaluation and utilization of cucurbit accessions

In 2010, there were in total 1,255 cucurbit accessions that belonged to eight genera collected in the North of Vietnam (Table 2.6; Table 2.7). Less than 50% of cucurbits accessions collected and conserved by VASI were evaluated for some basic characteristics (statistical data only, no details about the characteristics which were evaluated), such as growing habits and yield-related characteristics (Vu and Tran, 2010). No data were shown on utilization of the collected cucurbit accessions, except the general information of sharing accessions of bitter gourd (*Momordica charantia*), watermelon (*Citrullus lanatus*), ash gourd (*Benincasa hispida*), and pumpkin (*Cucurbita moschata*).

No data about morphological characterization of cucurbit accessions has been published by VASI up to now. Moreover, there are no studies on genetic relationships among cucurbit accessions, except the study on *Cucumis melo* done by Nhi et al. (2010).

Also in AVRDC genebank, passport data (family, genus, species, species local name, collection place, collection source) were given, but no information about evaluation and characterization of Vietnamese cucurbits (AVGRIS, 2011) were provided, excepted for three species. The loofah (*Luffa cylindrica*), angled loofah (*Luffa acutangula*), and snake gourd (*Trichosanthes anguina*) were chosen as promising species to be used in production. Moreover, a part of the accessions was lost due to lack of facilities and poor conditions for seed regeneration (AVRDC, 2007).

2.4.5 Characterization and evaluation cucurbit germplasm in conservation

Morphological characterization and molecular analysis are two methods applied for genetic resources evaluation and each method shows its own advantages. The morphological analysis evaluates genotypes on characteristics resulting from interaction between genes and environments – called phenotype (Franco et al., 2003). In morphological analysis, categorical and continuous variables are two types of descriptors used. The continuous variables are more frequently used in evaluating genetic diversity of cucurbits than the categorical ones (Dey et al., 2006; Pandey et al., 2008; Koffi et al., 2008). However, in case of accessions similar in quantitative characteristics but dissimilar in qualitative characteristics, using only continuous variables was inefficient in distinguishing the morphological differences of them (Knezovic et al., 2005).

With respect to morphological evaluation for cucurbit species, various qualitative, quantitative and pseudo-qualitative characteristics are given enclosing the criteria of assessment for examination. UPOV (2013) introduced the test guidelines for evaluating the distinctness, uniformity and stability for new crops. There are six species belonging to Cucurbitaceae, including *Cucumis melo, Cucumis sativus, Cucurbita maxima, Cucurbita moschata, Cucurbita pepo,* and *Momordica charantia* that are instructed by UPOV (UPOV, 2013). Meanwhile, genetic diversity of other cucurbit species is analyzed by its morphological characteristics considering continuous and categorical variables (Heiserand Schilling, 1988; Cruz et al., 1997; Brown and Myers, 2002; Ferriol et al., 2004; Dey et al., 2006; Zalapa et al., 2007; Verma et al., 2007; Koffi et al., 2008; Pandey et al., 2008; Macusi and Rosario, 2009; Nhi et al., 2010; Dalamu et al., 2012; Prakash et al., 2013).

Therefore, in analysis method in this study was included three types of characteristics, qualitative, pseudo-qualitative, and quantitative ones, for evaluating the five most cultivated cucurbit species to elaborate clear relationships between the accessions within species. There are two methods applied for cluster analysis based on the variables, UPGMA and Ward. UPGMA method is based on hierarchical agglomerative technique, while Ward method is based on partition and optimization of an object function technique (Crossa and Franco, 2004). The UPGMA was used in my study, because this method provides higher morphological correlations between accessions (Hale and Dougherty, 1988).

Molecular analysis concentrates to the differences in the DNA sequences of germplasm. Various methods are already applied for evaluating cucurbit germplasm, such as RAPD (Randomly Amplified Polymorphic DNAs) and ISSR (Inter-Simple Sequence Repeat) (Decker-Walters, 2001; Verma et al., 2007; Behera et al., 2008), MicroRNAs sequence (Jagadeeswaran et al., 2012), EST (Expressed Sequence Tag) and GSS (Genomic Survey Sequence) (Hu et at., 2014). However, the genetic relationships analysed using two different molecular methods are sometimes mismatched, as in *Cucumeropsis mannii* (Koffi et al., 2008), *Benincasa hispida* (Pandey et al., 2008), *Momordica charantia* (Dey et al., 2006; Dalamu et al., 2012), and *Momordica cochinchinensis* (Wimalasiri et al., 2015).

3. Aims and objectives of the study

3.1 Aims

Cucurbits are important vegetable crops in Vietnam; however, there is a gap of knowledge about its status in cultivation, and insufficient collection and characterization of cucurbits in Vietnam as shown in the literature review. Therefore, this study aims to contribute to fill this gap and to prepare establishing a databases that could be combined with the already existing data in the genebank. The role of cucurbits in current vegetable production should be examined focusing on the diversity of species used and the genetic diversity within species should be determined to support genebanks work and to prevent gene erosion.

Therefore, the following specific aims were focusing on different regions in southern Vietnam.

- Determination of the vegetable species diversity and the importance of cucurbit species in vegetable cultivation in southern Vietnam.
- Examination of the current situation of collection and conservation of cucurbit species in Vietnam and collect cucurbit in regions so far not involved.
- Collecting of cucurbit accessions and analysing the relationships among accessions within cucurbit species in order to create the germplasm database, to share information (data sharing) with other collections and conservation projects, and to use breeding programs.
- Describing of reliable characteristics for evaluating the relationships among bitter gourd accessions (evaluation of methods for characterization of accessions developing reliable characteristics).

3.2 Objectives

1) Preparing a program for the field survey in southern Vietnam, searching for appropriate regions and communities there according specific selection criteria.
2) Elaborating of a questionnaire for the interviews with farmers and stakeholders in these communities.
3) Analysing of the situation of the cucurbit germplasm conservation and determining regions for current collection.
4) Describing the cucurbit accessions collected in the study areas and maintaining their seeds.

5) Cultivation of selected accessions in the field in Vietnam and in greenhouse in Germany in order to investigate their growth habit and environment depended differences in morphological characteristics.

6) Classification of the accessions for different cucurbit species and investigation of the relationships among accessions within species based on the defined morphological characteristics. Computation of cluster analyses for selected economically important species as cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*).

7) Determination of stable characteristics for evaluating the relationships among accessions within cucurbit species, in particular for bitter gourd (*Momordica charantia*).

8) *Ex situ* conservation of all collected seeds in a seedbank and storage in medium-term storage condition.

In order to achieve the aims and objectives, the framework of study it is planned to executed in three phases as shown in Figure 3.1.

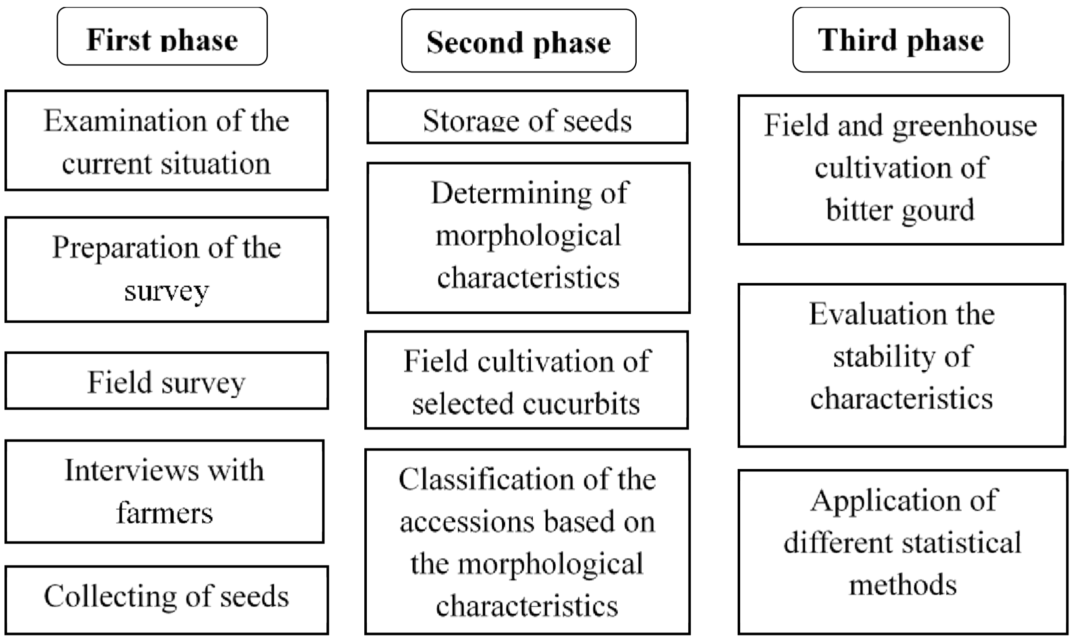


Figure 3.1. Basic scheme of the study framework.

4. Study design and methods

4.1 Survey the use of cucurbit species in vegetable cultivation

4.1.1 The study area for field survey

The study area (Ben Tre province) is located downstream of Mekong River (10°14′25″N, 106°22′44″E). The Ben Tre province is characterized by four main river branches (Tien Giang, Ba Lai, Ham Luong, and Co Chien Rivers) separated from Tien River, one of two main tributaries of Mekong River. Within the dense river and canal systems, many islands are found. This province represents all geographical and climatic features of MRD (Figure 4.1a). The province is influenced by the tropical monsoon climate, with the average temperature 27.1°C and humidity 83.6%, respectively (see also Figure 2.5). There are two distinct seasons, rainy and dry seasons: the rainy season starts at the beginning of May and ends in late November, with an average rainfall of 1,591.4 ±152.1 mm annually; the dry season comes afterwards in December to April when the average rainfall in this period drops down significantly, about 2% to 6% of annual average.

With the 60.6% of in total 236,100 ha of area is cultivated land in this province. The soil types of cultivated land can be divided into four groups including sandy, alkaline, aluminium, and alluvial soils. The sandy soil and alkaline soil appear in coastline; the aluminium soil are scattered over the province; and the alluvial soil are formed along the river systems (Ta et al., 2002; BTSO, 2010; see also Figure 2.4b). Different farming techniques are applied for lowland and upland. In the lowland, vegetable crops are rotated with rice, whereas in the upland vegetable crops are cultivated as intensive farming or are rotated with legume and corn. Therefore, vegetable species that farmers choose for cultivation in this province are abundant.

The survey was carried out in such rural areas where vegetable cultivation is the main agricultural sector. At those places, the estimated number of vegetable growers was over 70% of the total households (BTSB, 2009). Moreover, the chosen areas exhibited the features of natural conditions and farming techniques in MRD (Nguyen et al, 2000; Ta et al., 2002; BTSO, 2010). Eight districts, including Ba Tri, Binh Dai, Chau Thanh, Giong Trom, Mo Cay Bac, Mo Cay Nam, Thanh Phu, and Ben Tre were selected for the study. There were 20 communes in these eight mentioned districts (Figure 4.1b, Appendix 5) examined in detail.

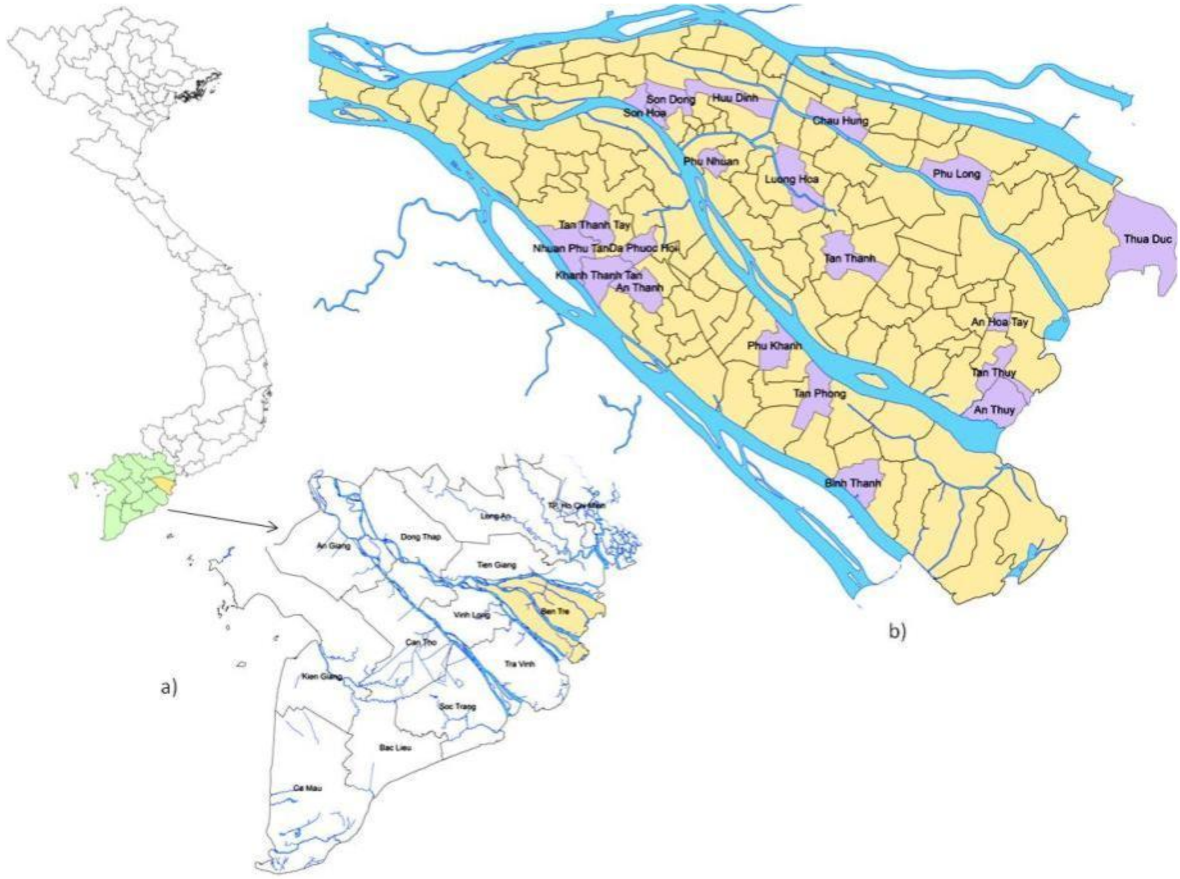


Figure 4.1. a) The study sites in Ben Tre province (yellow) within the Mekong River Delta (green) and b) involved 20 communes (purple).

4.1.2 Data collection

A questionnaire (Appendix 4) was developed in order to collect same information of all interviewed farmers. The growers in the districts were selected randomly following the criteria: (1) grower had at least five years of experience for commercial cultivation of vegetables, (2) the area used for cultivating vegetable crops was minimum 500m^2, and (3) grower had cultivated vegetable in previous three crops. Concerning the confidence level of 95% accompanied by 3% margin of error, 120 farmers were required for each of the eight districts. To compensate for 5% of unresponsiveness, it was planned to interview 126 farmers for each district with the given questionnaire. The questionnaire was focused to classify the diversity of vegetable species and its cultivated areas in dry season (current crop) and whole year (year-round crop).

4.1.3 Variables calculation

The data collections and calculations were as follows:

Current crop: only one vegetable species that had the largest cultivated area in each household was recorded.

Year-round crop: combines the species cultivated in current crop and the species cultivated in three previous crops for calculation.

Using frequency (UF) of plant family (species): equals number of same family/species recorded in study site.

$$\text{Occurrence rate (OR)(\%)} = \frac{\text{UF of plant family (species)} \times 100}{\text{total plant families (species)}} \qquad (4.1)$$

$$\text{Ares of plant family(APF)(\%)} = \frac{\text{area cultivated per plant family} \times 100}{\text{total cultivated area of all families}} \qquad (4.2)$$

$$\text{Cultivated area of plant family(CAF)(m}^2\text{/farm)} = \frac{\text{area cultivated per plant family(m}^2\text{)}}{\text{UF per plant familiy}} \qquad (4.3)$$

$$\text{Cultivated area of species (CAS)(m}^2\text{/farm)} = \frac{\text{area cultivated per species(m}^2\text{)}}{\text{UF per species}} \qquad (4.4)$$

To analyse the effects of farmer's characteristics on the possibility of choosing cucurbits for cultivation, the using ratio of cucurbits (URC) were calculated following the age of farmers, education levels (grades), members in households (people) as follows:

$$\text{Using ratio of cucubits (URC}_{\text{ij}}\text{)} = \frac{\text{UF of cucurbitsx}_{\text{ij}}}{\text{Total species}} \qquad (4.5)$$

Where URC_{ij} is at level *i* of *j,* with *j* replaced by age of farmers, education levels (grades), members in households (people), and cultivated areas (m^2 per farm).

4.1.4 Statistical data analysis

For the survey of vegetable production, two questions were interesting in this study: What are the frequencies of Cucurbitaceae compared to other plant families? Are there any relationships between farmers' characteristics (age of farmers, education levels, members in households and cultivated areas) and using ratio of Cucurbitaceae? Therefore, in the first step of analysis, using frequencies and relative variables were calculated for all vegetable families. Then in the next step, calculating was concentrated to vegetable species in particular for cucurbit species.

Chi-square (χ^2) test, t-test, permutation test (non-parametric statistics) and analysis of variance (ANOVA) were applied depending on the distribution of variables and number of groups in variables. All statistical significant levels tested at $P < 0.05$.

Multivariate analyses were conducted with matrix plot of correlations to understand the relationships between household characteristics and using frequency of species. Moreover, correlations between household characteristics and using frequency of cucurbits were calculated separately. Data were transformed in case of the variables were not normally distributed (Gomez and Gomez, 1984; McDonald, 2008).

These analyses and plots were performed with the R software version 3.1.3 (R Core Team, 2013). Moreover, to map the study site or distribution of cucurbit species, mapping method was applied with query builder in ArcMap 10 (ESRI, 2011).

4.2 Collection cucurbits' accessions

4.2.1 Regions for cucurbit collection

The regions, where cucurbit germplasm was already collected in the projects AVRDC and VASI, were indicated. From these provinces passport data were available (AVGRIS, 2011; PGRV, 2011). They were summarized and mapped by using ArcMap 10 (Figure 4.2, dark blue). These data were the basic reference to select the collection regions for this study.

In this study, the cucurbit accessions were collected in 24 provinces in southern Vietnam (Figure 4.2, green dots) as follows:

- Five provinces in South Central Coast (Binh Thuan, Khanh Hoa, Ninh Thuan, Quang Nam, and Quang Ngai).
- Four provinces in Central Highlands (Daklak, Daknong, Lam Dong, and Gia Lai).
- Six provinces in Southeast (Binh Duong, Binh Phuoc, Ba Ria – Vung Tau, Dong Nai, Tay Ninh, and Ho Chi Minh City)
- Nine provinces in Mekong River Delta (An Giang, Bac Lieu, Ben Tre, Can Tho, Hau Giang, Kien Giang, Long An, Soc Trang, and Tien Giang).

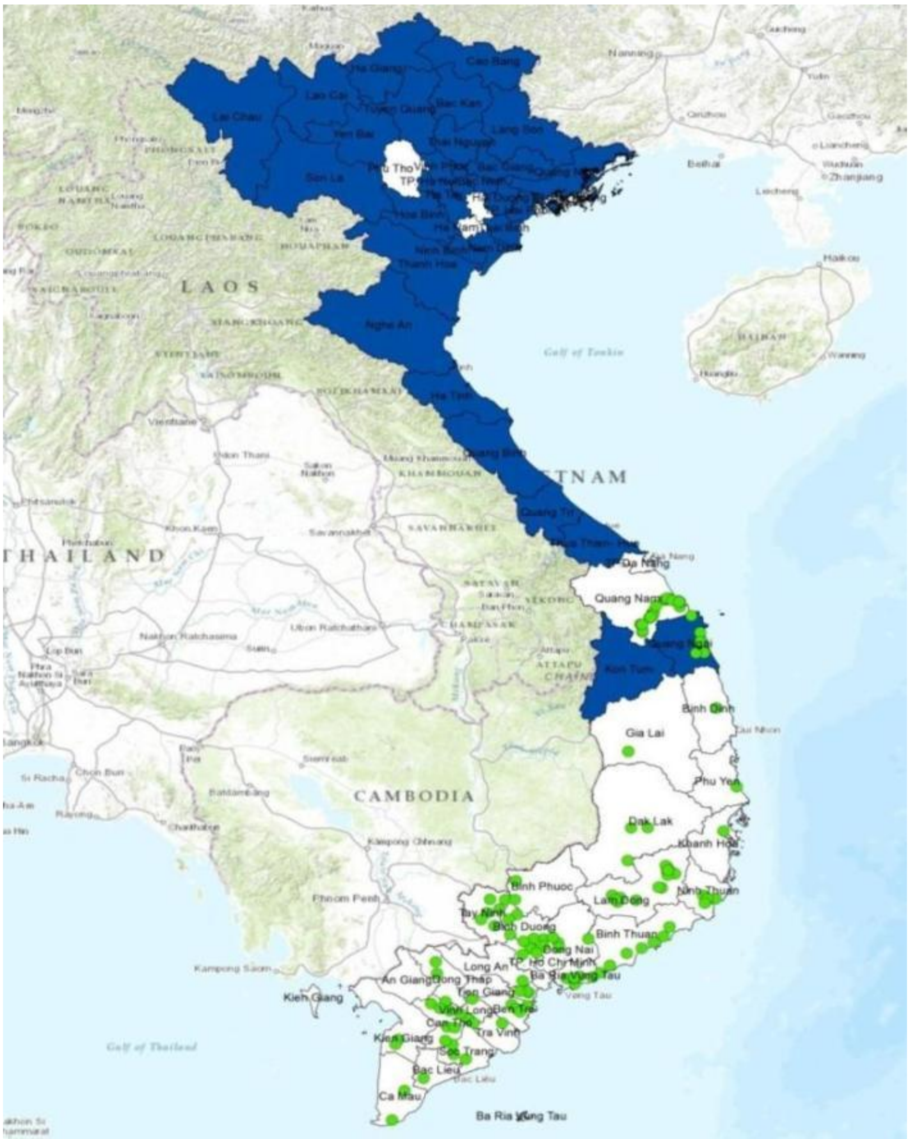


Figure 4.2. The regions where cucurbits were collected in previous projects (dark blue) and in this study (green dots).

4.2.2 Plant material collected

Mature fruits and seeds of landraces that were propagated and maintained by farmers themselves were collected. Moreover, wild types (cucurbits that grow naturally and had been gathered) and underutilized types were collected following the suggestions of Pham (1999) in farmers' backyards, as well as fallows and thin forests or purchased in local markets. Cultivars from international and Vietnamese seed companies were not collected. Cultivars from international and Vietnamese seed companies were not collected.

Passport data: based on the collecting record sheet (Appendix 8), e.g. scientific name of the species/cultivar, local name, place of collection (GPS data), source of collection, name of collector.

4.2.3 Species diversity index and evenness index

The diversity of species in this collection was calculated based diversity indices and then compared with previous collections including AVRDC collection (AVGRIS, 2011) and VASI collection (PGRV, 2011) by using Shannon-Wiener index of species diversity (Peet, 1974; Beisel and Moreteau, 1997; Spellerberg and Fedor, 2003; Grunewald and Schubert, 2007).

$$\mathrm{H}' = -\sum_{i=1}^{S}\left(\frac{p_i}{n}\right)\ln\left(\frac{p_i}{n}\right) \tag{4.6}$$

Where H' is the index of species diversity, p_i is the number of individuals in the i^{th} species, n is total number of individuals, and S is the number of species (or species richness).

The evenness index (E) was calculated basing on Hurlbert's equation (Beisel and Moreteau, 1997):

$$E = \frac{H' - H'_{min}}{H'_{max} - H'_{min}} \tag{4.7}$$

$$H'_{max} = \ln(S) \tag{4.8}$$

$$H'_{min} = \ln(n) - \frac{(n - S + 1)\ln(n - S + 1)}{n} \tag{4.9}$$

Where S is species richness and n is total number of accessions as defined in equation 4.6.

4.2.4 Specifying collected regions and statistical data analysis

The regions of the two previous collections (AVRDC and VASI collections) were specified based on the passport information of accessions. To rely on the results, regions for this current study were concentrated to geographical areas not involved in previous studies. They were tracked with GPS Garmin and displayed on ArcMap10 (ESRI, 2011).

Chi square (χ^2) test was used to evaluate the difference between cucurbit species and number of accessions collected in two previous collections (AVRDC and VASI) and this collection. Analysis of covariance (ANOVA) was applied to compare the cucurbit accessions within the three collections. Standard derivation (SD) was calculated based on the numbers of accessions in AVRDC, VASI, and this collection. These analyses and plots were performed with the R software version 3.1.3 (R Core Team, 2013).

4.3 Morphological characterization of cucurbit species

4.3.1 Selected species and accessions

The data comprised 160 accessions from the most cultivated species that were collected in this study (details are shown in section 5.2), including *Cucumis sativus* (25 accessions), *Cucurbita moschata* (22 accessions), *Lagenaria siceraria* (32 accessions), *Luffa cylindrica* (39 accessions), and *Momordica charantia* (42 accessions) collected from difference geographic regions.

4.3.2 Field evaluation

The field evaluation was carried out in research farm of TH Company located in Dong Nai Province, Southeast Vietnam (150 km northeast Ho Chi Minh City). Soil type at experiment site is basaltic, good drainage with pH = 6.0, organic matter = 2.6%, solution salts = 130ppm, 100% base saturation, and cation exchange capacity (CEC) = 8.5 meq/100 cm^3. The concentrations of basic mineral elements in the soil and fertilizer suggestions are given in Table 4.1. In addition, 10 tons manure and one ton lime were added before bedding.

Table 4.1. Nutrition elements in soil and fertilizer suggestions (Agro Services International, INC. 2011)

ELEMENTS	SOIL ANALYSIS Lab No. W1 29 - 2				INTERPRETATION GUIDE (Below – Optimum – Above)	FERTILIZER SUGGESTIONS		
		meq/100cm3	lbs/acre		Critical Level		lbs/1000 sq. ft. or kg/230 m^2	lbs/acre or X 1.12=kg/ha
Act. Acidity	A.A.	0.0						
Calcium	Ca	5.5	1980		Ca	Calcium	0.0	0
Magnesium	Mg	2.24	487		Mg	Magnesium	0.0	0
Potassium	K	0.74	623	K_2O	K	Potash (K_2O)	1.0	45
Sodium	Na							
Ca/Mg Ratio	Ca/Mg	2.5			Ca/Mg	Dolomitic Lime	0	0
Mg/K Ratio	Mg/K	3.0			Mg/K	Calcitic Lime	0	0
		ug/cm3						
Nitrogen	N	3	5		N	Nitrogen	3.5	155
Phosphorus	P	33	135	P_2O_5	P	Phosphate(P_2O_5)	3.1	135
Sulfur	S	21	38		S	Sulfur (as Sulfate)	1.0	45
Boron	B	0.48	0.9		B	Boron	.03	1.5
Copper	Cu	8.4	15.1		Cu	Copper	0.0	0
Iron	Fe	98	176		Fe	Iron	0.0	0
Manganese	Mn	85.6	154.1		Mn	Manganese	0.0	0
Zinc	Zn	5.5	9.9		Zn	Zinc	0.0	0

Plastic mulch was applied to control weeds and maintain soil moisture (Figure 4.3). Chemical weed control was used once before bedding and crop protection chemicals were applied when plants were affected by insects or diseases.

a) b)

Figure 4.3. Land preparation with plastic mulch (a) and an overview of field experiment (b).

The experiments were organized in Randomized Complete Block Design (RCBD) with two replications and with different densities depends on the species (Table 4.2). Trellis was made to support plants climbing (Figure 4.3b). Female flowers were hand pollinated by male flowers of other plants in the same accession.

Table 4.2. Distances between plants and rows for different cucurbit species

Species	Plant to plant (m)	Row to row (m)
Cucumis sativus	0.4	1.5
Cucurbita moschata	0.8	1.8
Lagenaria siceraria	0.8	1.8
Luffa cylindrica	0.6	1.6
Momordica charantia	0.5	1.5

Assuming the mortality rate in field condition is 50% (risks from biotic and abiotic factors); there were 20 individuals for each accession planted with the spacing as follows. Five plants at each replication were chosen randomly for observation.

The weather conditions during experimental period were given in Figure 4.4. The monthly sunshine duration was increasing from February (231hs) and reaching the peak at March (297hs), then decreasing and getting the bottom at June (180hs). Precipitation in the last three month of experimental period with increasing the amounts of rainfall was 15, 98, and 106 mm for April, May, and June, respectively. The monthly temperature changed in a range being 26.6 to 29.4^{0}C, increasing at the beginning of experimental period and reaching a peak at May, then decreasing.

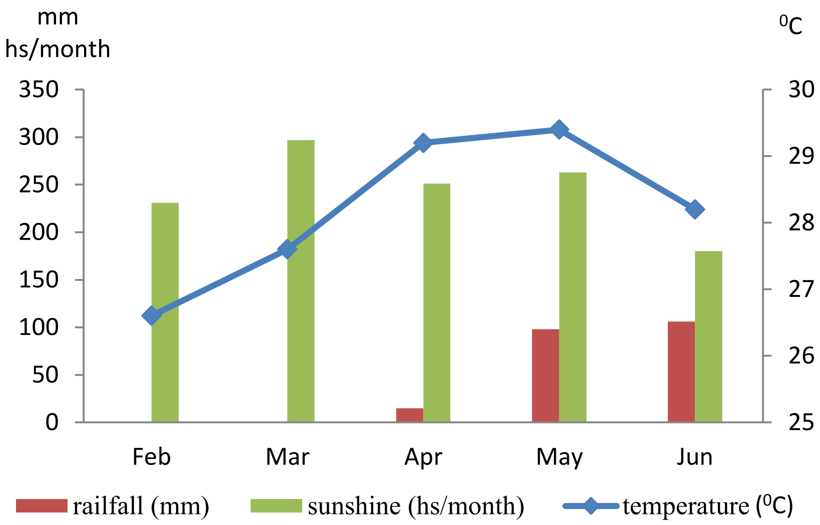


Figure 4.4. Rainfall, sunshine (left y-axis), and temperature (right y-axis) during experimental period at research farm of TH Company located in Dong Nai Province, Southeast.

4.3.3 Variable types used for morphological characterization of cucurbit species

There were 91 different morphological characteristics, including quantitative (QN), qualitative (QL), and pseudo-qualitative (PQ), used for evaluation of these five cucurbit species. The characteristics were abbreviated to "Cr." and numbered from 01 to 91. The details of description, criteria of evaluation and method of measurement are given in Appendix 10.

The characteristics were classified into two types of variables, continuous and categorical:

- Categorical variables referred to qualitative, pseudo-qualitative and immeasurably quantitative characteristics.
- Continuous variables referred to measurably quantitative characteristics.

4.3.4 Morphological characteristics used for evaluating five cucurbit species

4.3.4.1 Cucumber (*Cucumis sativus*)

There were 39 characteristics, including 26 qualitative, pseudo-qualitative, and quantitative characteristics (regarded as categorical variables) and 13 quantitative characteristics (regarded as continuous variables) used to evaluate 25 cucumber accessions (Yuan et al., 2008; Parvathanen et al., 2011; UPOV, 2013).

- Categorical variables: cotyledons color (Cr.01), growth type (Cr.03), blistering of leaf blade (Cr.10), dentation of leaf blade margin (Cr.11), shape of apex of terminal lobe (Cr.18), undulation of leaf margin (Cr.20), attitude of leaf blade (Cr.22), leaf color

(Cr.23), vestiture color (Cr.25), sex description (Cr.34), fruit color at market stage (Cr.41), fruit color at ripe stage (Cr.42), fruit creasing (Cr. 45), density of vestiture (Cr.49), distribution of the dots on fruit (Cr. 53), glaucosity of fruit skin (Cr. 56), content dots on fruit (Cr.60), stripes on fruit (Cr.63), fruit parthenocarpy (Cr. 68), fruit ribs (Cr.73), shape in transverse section of fruit (Cr.75), shape of fruit apex (Cr.76), shape of fruit base (Cr. 77), fruit sutures (Cr. 81), type of vestiture on fruit (Cr. 84), and fruit warts (Cr. 86).

- Continuous variables: cotyledons length (Cr.02), stem length (Cr.04), length of leaf blade (Cr.13), width of leaf blade (Cr.21), time taken of first female flower (Cr.35), time taken of first male flower (Cr.36), fruit circumference (Cr.40), diameter of fruit core (Cr.44), fruit weight (Cr.55), fruit length (Cr.59), length of fruit peduncle (Cr.61), thickness of fruit flesh (Cr.82), and weigh of 100 seeds (Cr.91).

4.3.4.2 Pumpkin (*Cucurbita moschata*)

There were 36 characteristics, including 19 qualitative, pseudo-qualitative and quantitative characteristics (regarded as categorical variables) and 17 quantitative characteristics (regarded as continuous variables) used to evaluate 22 pumpkin accessions (Ferriol et al., 2004 and UPOV, 2013).

- Categorical variables: margin of leaf blade (Cr.14), density of silver patches on leaf blade (Cr.19), leaf color (Cr.23), fruit color at market stage (Cr.41), fruit color at ripe stage (Cr.42), fruit curving (Cr.46), present of fruit grooves (Cr.47), distance between fruit grooves (Cr.52), depth of fruit grooves (Cr.57), color of fruit flesh (Cr.65), fruit marbling (Cr.66), broadest part position of fruit (Cr.70), present of fruit neck (Cr. 71), fruit shape in longitudinal section (Cr.74), shape of fruit apex (Cr.76), shape of fruit base (Cr. 77), present fruit warts (Cr.67), waxiness of fruit skin (Cr.87), and color of testa (Cr. 88).
- Continuous variables: cotyledons length (Cr.02), stem length (Cr.04), length of leaf blade (Cr.13), width of leaf blade (Cr.21), length of leaf petiole (Cr.24), length of female flower peduncle (Cr.28), length of male flower peduncle(Cr.29), length of sepal of female flower (Cr.30), length of sepal of male flower (Cr.31), peduncle diameter of female flower (Cr.33), fruit circumference (Cr.40), fruit diameter (Cr.50), diameter of flower scar (Cr.51), fruit weight (Cr.55), fruit length (Cr.59), thickness of fruit flesh (Cr.82), and weight of 100 seeds (Cr.91).

4.3.4.3 Bottle gourd (*Lagenaria siceraria*)

There were 28 characteristics, including 14 qualitative, pseudo-qualitative, and quantitative characteristics (regarded as categorical variables) and 14 quantitative characteristics (regarded as continuous variables) used to evaluate 32 bottle gourd accessions (Mladenovic et al., 2011 and UPOV, 2013).

- Categorical variables: cotyledons color (Cr.01), stem shape (Cr.07), margin of leaf blade (Cr.14), shape of leaf blade (Cr.17), undulation of leaf margin (Cr.20), leaf color (Cr.23), fruit color at market stage (Cr.41), luster of fruit skin (Cr.64), fruit marbling (Cr.66), shape of fruit peduncle (Cr.69), fruit shape in longitudinal section (Cr.74), shape of fruit apex (Cr.76), shape of fruit base (Cr.77), and stripes on fruit skin (Cr.80).
- Continuous variables: cotyledons length (Cr.02), stem length (Cr.04), length of leaf blade (Cr.13), width of leaf blade (Cr.21), length of leaf petiole (Cr.24), time taken of first female flower (Cr.35), time taken of first male flower (Cr.36), fruit circumference (Cr.40), fruit diameter (Cr.50), fruit weight (Cr.55), fruit length (Cr.59), length of fruit peduncle (Cr.61), time of physiological maturity of fruit (Cr.83), and weigh of 100 seeds (Cr.91).

4.3.4.4 Loofah (*Luffa cylindrica*)

There were 27 characteristics, including 15 qualitative, pseudo-qualitative, and quantitative characteristics (regarded as categorical variables) and 12 quantitative characteristics (regarded as continuous variables) used to evaluate 39 loofah accessions (Prakash et al., 2013 and UPOV, 2013).

- Categorical variables: cotyledons color (Cr.01), stem shape (Cr. 07), depth of leaf lobe (Cr.12) leaf margin (Cr. 14), leaf blade shape (Cr.17), leaf color (Cr.23), density of fruit ridge (Cr.37), fruit aroma (Cr.38), color of fruit skin at market stage (Cr.41), color of fruit stripes (Cr.43), shape of fruit peduncle (Cr.69), shape of fruit in longitudinal section (Cr.74), shape of fruits in transversal section (Cr. 75), shape of fruit apex (Cr.76), and shape of fruit base (Cr.77).
- Continuous variables: cotyledons length (Cr.02), stem length (Cr.04), length of leaf blade (Cr.13), width of leaf blade (Cr.21), length of leaf petiole (Cr.24), time taken of first female flower (Cr.35), time taken of first male flower (Cr.36), fruit circumference (Cr.40), fruit weight (Cr.55), fruit length (Cr.59), length of fruit peduncle (Cr.61), and weigh of 100 seeds (Cr.91).

4.3.4.5 Bitter gourd (*Momordica charantia*)

There were 37 characteristics, including 19 qualitative, pseudo-qualitative, and quantitative characteristics (regarded as categorical variables) and 18 quantitative characteristics (regarded as continuous variables) used to evaluate 42 bitter gourd accessions (Dey et al., 2006; Dalamu et al., 2012; UPOV, 2013).

- Categorical variables: cotyledons color (Cr.01), leaf color (Cr.23), intensity of green color of flower stigma (Cr.26), bitterness of fruit flesh (Cr.39) (3 fruits were randomly chosen from each accession for organoleptic testing, this process was done by post-harvest department of TH Co.), fruit color at market stage (Cr.41), fruit color at ripe stage (Cr.42), length of fruit ridge (Cr.62), luster of fruit skin (Cr.64), present of warts on fruit (Cr.67), present of fruit spines (Cr. 72), fruit shape in longitudinal section (Cr.74), shape of fruit apex (Cr.76), shape of fruit base (Cr. 77), shape of the top of warts on fruit (Cr.78), size of warts on fruit (Cr.85), number of warts on fruit (Cr.86), color of testa (Cr. 88), edger of seeds (Cr. 89), and seed size (Cr.90).
- Continuous variables: stem length (Cr.04), number of leaf lobes (Cr. 15), number of nodes up to node with 1st female flower (Cr.05), number of nodes up to node with 1st male flower (Cr.06), number of side shoots (Cr.08), thickness of main stem (Cr.09), length of leaf blade (Cr.13), width of leaf blade (Cr.21), length of leaf petiole (Cr.24), length of ovary (Cr.27), time taken of first female flower flowering (Cr.35), time taken of first male flower flowering (Cr.36), fruit circumference (Cr.40), fruit weight (Cr.55), fruit length (Cr.59), length of fruit peduncle (Cr.61), time of physiological maturity of fruit (Cr.83), and weigh of 100 seeds (Cr.91).

4.3.5 Data coding and analysis

4.3.5.1 Data coding

The passport numbers (PNo.) of cucurbit accessions were encoded basing on four characters of local names and two ordinal numbers. QuNa01, for example, means that this is the first accession collected at Quang Nam province. The local names were given following passport numbers (PNo.) in result tables with "Origin" column excepted for two abbreviation of BR-VT (Ba Ria – Vung Tau), and Tp.HCM (Ho Chi Minh City) with the accessions codes were BrVt and HcmC, respectively.

Binomial coding was used for categorical variables with number 1 was present and number 0 was absent of the observed characteristics. For he categorical variables that included more than two assessment levels, the cardinal numbers were used for coding, i.e. a variable with three levels: small, medium, and large then converted to numbers were 1= small, 2 = medium, 3 = large.

4.3.5.2 Data analysis

The continuous variables were compared basing on mean values of each accession. χ^2-test was applied to specify the differences within the continuous variables among species accessions with the aim to analyse the effect of the examined characteristics on the relationships between accessions within species.

The data were set as rectangular data matrix and then standardized following characteristic to get average values = 0 and variance values = 1 before performing cluster analysis. The matrix with standardisation values transformed to symmetric dissimilarity matrix with distance coefficient was used.

To understand independent effects of categorical and continuous variables on the distributions of accessions, the symmetric dissimilarity matrix was converted to double-centered matrix and then performed for eigenvectors to plot in three dimensions (3D bi-plots) views. Correlations among examined variables in the first three canonical axes (C1, C2, and C3) were calculated with the purpose of determining the similarity of the variables in different accessions. Un-weighted pair group method using arithmetic averages (UPGMA) was applied to analyse the relationships of accessions. Accessions placed with smaller values of coefficient were less variable in morphological characteristics. Analyses and dendrogram were done with R version 3.1.2 (R Core Team) and NTSYSpc version 2.1 (Rohlf, 2000).

4.4 Determination of stable characteristics for evaluating the relationships among bitter gourd (*Momordica charantia*) accessions

4.4.1 Selected bitter gourd accessions

Seven accessions of bitter gourd collected in different provinces in southern Vietnam were included in this experiment (Figure 4.5). These accessions were chosen based on the specific characteristics of fruit and seed (Table 4.3) with the purpose of determine the stable characteristics for morphological analysis.

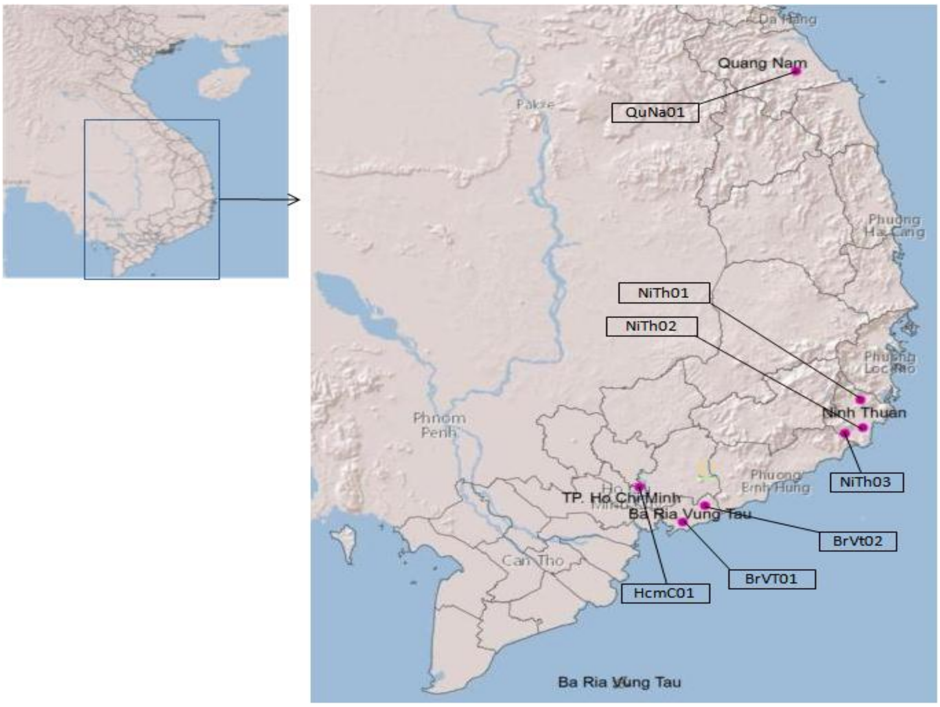


Figure 4.5. The collection places of seven bitter gourd accessions.

Table 4.3. Passport number (PNo.), Collection place and specific characteristics of fruit and seeds of seven accessions

PNo.	Collection place	Fruits	Seeds
HcmC01	Linh Trung, Thu Duc, Ho Chi Minh City	wild type, very small fruit with spines	small seeds with smooth coat, without indentation of edge
QuNa01	Tien Phuoc, Quang Nam	Big white fruit with spines	medium seed with prominent striation, sparse indentation of edge
BrVt02	Dat Do, Ba Ria – Vung Tau	short fruit with spines	medium seed with prominent striation, sparse indentation of edge
BrVt03	Chau Duc, Ba Ria – Vung Tau	medium fruit with spines	medium seed with prominent striation, sparse indentation of edge
NiTh01	Ninh Phuoc, Ninh Thuan	Long smooth fruit,	medium seed with unnoticeable striation, sparse indentation of edge
NiTh02	Ninh Son, Ninh Thuan	Short smooth fruit	medium seed with unnoticeable striation, sparse indentation of edge
NiTh03	Phan Rang – Thap Cham, Ninh Thuan	Acute white fruit with spines	medium seed with clearly white prominent striation, sparse indentation of edge,

4.4.2 Evaluation methods

The two cultivation experiments were carried out in Randomized Complete Block Design (RCBD) with two replications. Each replication compromised 10 plants. Seeds were treated with hot water before sowing. Two weeks after sowing, seedlings were transplanted in the beds. The female flowers were hand pollinated by male flowers of other plants in the same accession. Drip systems were applied for irrigation in both, greenhouse and field experiments.

4.4.2.1 Greenhouse condition

The experiment was conducted in Dahlem Campus, Humboldt University of Berlin from March to September 2012. Coconut fibre slabs were used as substrates, two plants per one slab (2.5 plants per m^2). Wire fences were made for plants climbing. The slabs were watered by trickle irrigation in average every 45 minutes for 3 minutes between 6 AM and 10 PM. 'Netafim' drippers with a capacity of 2 L h^{-1} were used. The frequency of irrigation was corrected based on the tensiometer values in order to keep values between 25 to 30 hPa in coconut fibre slabs. The basic composition of the nutrient solution was N (130 ppm), P (50), K (225), Ca (120), Mg (60), Fe (3), HCO_3 (90). The EC-value was adjusted to 2.3 mS cm^{-1} and the target pH-value was 5.7. Mean values of temperature, relative humidity, and photoperiod were set at 20°C, 60%, and 13.5 hs, respectively (see also Böhme et al. 2014).

4.4.2.2 Field condition

The accessions were planted in the research farm of TH Company in Dong Nai province, Southeast Vietnam, from February to June. The monthly sunshine duration was increasing from February (231 hs) and reaching the peak at March (297 hs), then decreasing and getting the bottom at June (180hs). Precipitation in the last three month of experimental period with increasing the amounts of rainfall was 15, 98, and 106 mm for April, May, and June, respectively. The monthly temperature changed in a range being 26.6 to 29.4^{0}C, increasing at the beginning of experimental period and reaching a peak at May, then decreasing.

The farm was located on basalt soil type with pH = 6.0, organic matter = 2.6%, solution salts = 130ppm, 100% base saturation, and cation exchange capacity (CEC) = 8.5 meq/100 cm^3. Nitrogen (N) was below critical level, boron (B) and sulphur (S) were poor, whereas other elements were optimal (Table 4.4).

Table 4.4. The concentration of mineral elements in soil

Units	meq/100cm^3			ug/cm^3							
Elements	Ca	Mg	K	N	P	S	B	Cu	Fe	Mn	Zn
	5.5	2.24	0.74	3	33	21	0.48	8.4	98	85.6	5.5

Based on the concentration of soil elements and the nutrients requirement for bitter gourd (Amarasekara et al., 2007; Nasreen et al., 2013), we applied (per hectare) 50kg K_2O, 200kg N, 135kg P_2O_5, 50kg S, and 0.5kg B (foliar sprays). The plant distance was set at 1.2m for rows and 0.6m within the row. Trellis with 1.8m height was made to support plant climbing. Plastic mulch was applied to control weeds and to maintain soil moisture. Chemical weed control was used once before bedding and crop protection chemicals were applied when plants had effected by insects and diseases.

4.4.3 Morphological characterization

Five plants of each replication were chosen randomly (excluding the two edge plants in the rows) for measurement and visual assessment. The evaluated leaves were taken from the same position on main stems. The second or third flower was marked for measurement and evaluation. Similarly, the second or the third fruit at commercial harvesting stage was used for morphological assessment. The examined characteristics were grouped into two types of variables, continuous ones (related to measurably quantitative characteristics) and categorical ones (related to qualitative, pseudo-qualitative, and immeasurably quantitative characteristics). Sixteen continuous variables and 12 categorical variables were included in stable assessment (Table 4.5).

Table 4.5. Parameters and method of measurement to characterise cucurbit accession

Code	Method of measurement	Variable type
thickst	Stem: thickness of main stem (the 15th node) (mm)	Continuous
shootn	Branch: number of side shoots	
lobeno	Leaf: number of lobe	
Ratiol	Leaf: ratio length/ width	
timemf	Flower: time of first male flower flowering (days)	
timeff	Flower: time of first female flower flowering (days)	
lengto	Ovary: length (mm)	
circuf	Fruit: circumference (cm)	
diamef	Fruit: diameter (mm)	
lengtf	Fruit: length (cm)	
ratiof	Fruit: ratio length/diameter	
weighf	Fruit: weight (g)	
timepm	Fruit: time of physiological maturity (days)	
nodema	Flower: number of nodes up to node with 1st male flower	
nodefe	Flower: number of nodes up to node with 1st female flower	
P100se	Seed: weight of 100 seeds (g)	
bittef	Fruit: intensive of bitterness (weak, medium, strong). Three fruits were randomly chosen from each accession for organoleptic testing. This process was done by post-harvest department of TH Co.	Categorical
comark	Fruit: color of skin at market stage (white, light green, medium green, dark green)	
coripe	Fruit: color of skin at ripe stage (yellow, orange, reddish orange)	
ridgef	Fruit: present of ridge (absent, present)	
shapel	Fruit: shape in longitudinal section (triangular, ovate, spindle-shape, oblong)	
basesh	Fruit: shape of base (acute, obtuse, rounded, flattened)	
apexsh	Fruit: shape of apex (acute, obtuse, rounded, flattened)	
spinef	Fruit: present of spines (absent, present)	
wartst	Fruit: shape of the top of wart (acute, obtuse, rounded)	
wartsi	Fruit: wart size (small, medium, large)	
striat	Seed: striation of seed coat (smooth, unnoticeable, prominent, clear prominent)	
edges	Seed: indentation of edge (smooth, sparse)	

4.4.4 Data analysis

- Continuous variables

Means of continuous variables were calculated following accessions. Then, two statistical analyses, including two-sample test (permutation test) and correlation test, were used to evaluate the differences of variables from two growing conditions. The permutation and correlation tests were applied to eliminate the variables that were significant different and non-significant correlation, respectively. The remaining variables, furthermore, were compared based on symmetric dissimilar values to determine the stable variables.

- Categorical variables

Binomial coding method was used for categorical variables, with 1 = present and 0= absent of the observed characteristics. Meanwhile, the categorical variables that included more than two assessment levels, the cardinal numbers were used for coding, i.e. 1= small, 2 = medium, 3 = large. Unlike continuous variables, the categorical variables were evaluated via two methods of comparisons: direct and indirect comparisons. The former was directly relied on assessment results, whereas the later was based on symmetric dissimilar matrix.

The data from two different growing conditions (greenhouse and field) were separately set as rectangular data matrix and then standardizing following variables to get average values = 0 and variance values = 1. The matrix with standardization values then transformed to symmetric dissimilarity matrix with distance coefficient was used. Moreover, UPGMA (un-weighted pair group method using arithmetic averages) method was applied to clarify relationships of the involved accessions following growing conditions. All calculations were done with R version 3.1.2 (R Core Team) and NTSYSpc version 2.1 (Rohlf, 2000).

5. Results and discussions

5.1 The contribution of cucurbit species in vegetable cultivation

5.1.1 Basic information related to farmers in study site

The survey included 1,009 farmers from 20 communes of eight different districts within the Mekong River Delta (Figure 4.1). Based on the questionnaires (Appendix 4) the interviewed farmers and their families can be characterized. The average age of farmers was 45.5 years, with range being 39 to 52. The number of people in each household was 4.4 members in average. The average education level of farmers in the entire communes was 6.0 grades meaning they had the first level of secondary education. Between the 20 communes there were no significant difference regarding average values of age, education levels, and members in a household (χ^2 – test). In contrast, the average areas of cultivated land in these 20 communes were significantly different and ranged from 1,656m^2 per farm in Tan Thuy to 7,437m^2 per farm in Phu Nhuan. Similarly, the average areas of vegetable land in these communes were also significantly different. The lowest value was 982m^2 per farm in Phu Long and the highest value was 4,225m^2 per farm in An Thuy. More detail information of data collection is shown in Appendix 5.

Although the ratios of vegetable land and cultivation land were different between the communes, the average area of vegetable land (2,017m^2 per farm) occupied 49.7% of average area of cultivation land (4,054m^2 per farm, Figure 5.1).

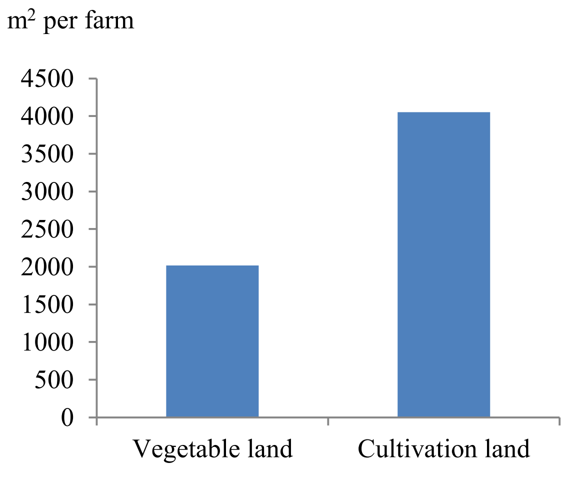


Figure 5.1. Areas of vegetable land and cultivation land in study site.

5.1.2 Number of vegetable species and using frequencies according to plant families

In Vietnam, vegetable cultivation is an important agricultural field in rural and semi-urban regions. The diversity of vegetable species used in vegetable cultivation depends on natural condition of regions. 74 vegetable species were determined as the commercial crops in vegetable cultivation (Siemonsma and Piluek, 1994). More recently, over 90 wild edible species were gathered that are widely used as vegetables in Mekong and Central Highland villages (Ogle et al., 2003).

The present study in MRD calculated 55 vegetable species belonging to 19 different plant families that are used in vegetable cultivation (Table 5.1, Appendix 6). More than 45% species belonged to Brassicaceae (Cruciferae), Cucurbitaceae, or Leguminosae (Fabaceae); 32.7% species belonged to Lamiaceae (Labiatae), Apiaceae (Umbelliferae), Solanaceae, Asteraceae (Compositae), Araceae, and Convolvulaceae; and 16.4% species belonged to Amaranthaceae, Basellaceae, Dioscoreaceae, Malvaceae, Nyctaginaceae, Polygonaceae, Saururaceae, Scrophulariaceae, and Zingiberaceae. As Table 5.1 shows, the numbers of species used in vegetable cultivation were significantly different among the families (χ^2 test). Brassicaceae (Cruciferae) had the largest number with 10 species (18.18%), Cucurbitaceae was the second largest family with nine species (16.36%), and Leguminosae (Fabaceae) with six species (10.9%), was the third. Lamiaceae (Labiatae) and Apiaceae (Umbelliferae) were represented by four species (7.27%). Three plant families, Solanaceae, Alliaceae and Asteraceae (Compositae) had the same number of species cultivated - three species (5.45%), while the number of species belonging to Araceae and Convolvulaceae were two (3.64%). For the remaining families, including Amaranthaceae, Basellaceae, Dioscoreaceae, Malvaceae, Nyctaginaceae, Polygonaceae, Saururaceae, Scrophulariaceae, and Zingiberaceae only one species (1.82%) was used in vegetable cultivation.

Using frequencies of species according to the families (calculated based on equation 4.1) were significantly different in current crop and year-round crop (χ^2 - test) (Table 5.1). The highest using frequencies were recorded in Cucurbitaceae followed by Alliaceae. Cucurbitaceae had a using frequency in current crop and in a year-round crop with 431 and 988, respectively. Alliaceae had a using frequency of 192 in current crop and 444 in year-round crop. On the third place the Brassicaceae (Cruciferae) with 145 using frequency in the current crop and 460 using frequency in year-round crop were positioned. Solanaceae (52 using frequencies in current crop and 173 using frequencies in year-round crop) and Leguminosae (66 using frequencies in current crop and 167 using frequencies in year-round crop) had the approximately using frequency in current crop and year-round crop.

There was significant correlations between the number of species in families and using frequency in current crop (r = 0.76) and in year-round crop (r = 0.81). However, concerning the occurrence rate of 19 families in current crop and year-round crop, they were not significantly different (permutation test).

Table 5.1. The number of species by families and using frequency (UF) and occurrence rate (OR) of families in vegetable in current crop and year-round crop cultivation

Family	Species		Current crop		Year-round crop	
	number	%	UF	OR	UF	OR
Alliaceae	3	5.45	192	19.0	444	17.18
Amaranthaceae	1	1.82	-	-	4	0.15
Araceae	2	3.64	1	0.1	5	0.19
Basellaceae	1	1.82	1	0.1	4	0.15
Asteraceae	3	5.45	38	3.8	93	3.60
Convolvulaceae	2	3.64	24	2.4	60	2.32
Brassicaceae	10	18.18	145	14.4	460	17.79
Cucurbitaceae	9	16.36	431	42.7	988	38.22
Dioscoreaceae	1	1.82	-	-	2	0.08
Lamiaceae	4	7.27	6	0.6	18	0.70
Leguminosae	6	10.91	66	6.5	167	6.46
Malvaceae	1	1.82	17	1.7	42	1.62
Nyctaginaceae	1	1.82	1	0.1	1	0.04
Polygonaceae	1	1.82	2	0.2	5	0.19
Saururaceae	1	1.82	3	0.3	11	0.43
Scrophulariaceae	1	1.82	1	0.1	2	0.08
Solanaceae	3	5.45	52	5.2	173	6.69
Apiaceae	4	7.27	28	2.8	104	4.02
Zingiberaceae	1	1.82	1	0.1	2	0.08

Year-round crop values were calculated based on 779 valid samples. Amaranthaceae and Dioscoreaceae were not cultivated in current crop.

The analysis of correlation indicated that, the families with large number of species used in cultivation had a high using frequency (r = 0.76 in current crop and r = 0.81 in year-round crop). However, a correlation could not be found for some families and Cucurbitaceae is in this circumstance (Table 5.1). An illustration for Cucurbitaceae and Brassicaceae (Cruciferae): Cucurbitaceae has nine species used in vegetable cultivation, whereas Brassicaceae has 10 species, one species more than Cucurbitaceae. However, using frequency of Cucurbitaceae is 2.25 and 2.23 times more than Brassicaceae (Cruciferae) in current crop and year-round crop, respectively.

The previous studies (Siemonsma and Piluek, 1994; Khiem et al., 2000; Huong et al., 2013b) indicated the using frequencies of vegetable species of Brassicaceae (Cruciferae), Cucurbitaceae, Alliaceae, Solanaceae, and Leguminosae (Fabaceae). However, the related data, such as using frequency and cultivated areas, were not given, especially in Mekong River Delta.

Concerning the Cucurbitaceae, previous studies (Siemonsma and Piluek, 1994; Pham, 1999) indicated 12 species and one variety (Table 2.3) frequently used in vegetable cultivation. This study showed (Table 5.1) that actually Cucurbitaceae contributed nine species with the highest using frequency (145 and 460 using frequencies in current crop and in year-round crop, respectively) compared to the others. The occurrence rate of cucurbits in current crop (0.427) was little higher than in year-round crop (0.382).

5.1.3 Cultivated areas according to plant family in current crop

From that land used for vegetable cultivation, the largest area with 95% was used for cultivating the species belonging to fruits, leafy, and root vegetables, such as Cucurbitaceae, Alliaceae, Brassicaceae (Cruciferae), Leguminosae (Fabaceae), Solanaceae, and Asteraceae (Compositae) (Figure 5.2) while for species used as spices belonging to Araceae, Lamiaceae (Labiatae), Polygonaceae, Saururaceae, and Zingiberaceae, only up to 5% of the land is used. Figure 5.2 illustrates the area of land (in % total) used for cultivation of the certain plant families in the study sites. Cucurbitaceae occupies the largest area with 56.5%; this can be due to the plant size of the cucurbits or maybe due to other reasons, such as their adaptation and economic importance. The next plant family is Alliaceae covering 15.0% of the cultivated area used for vegetables.

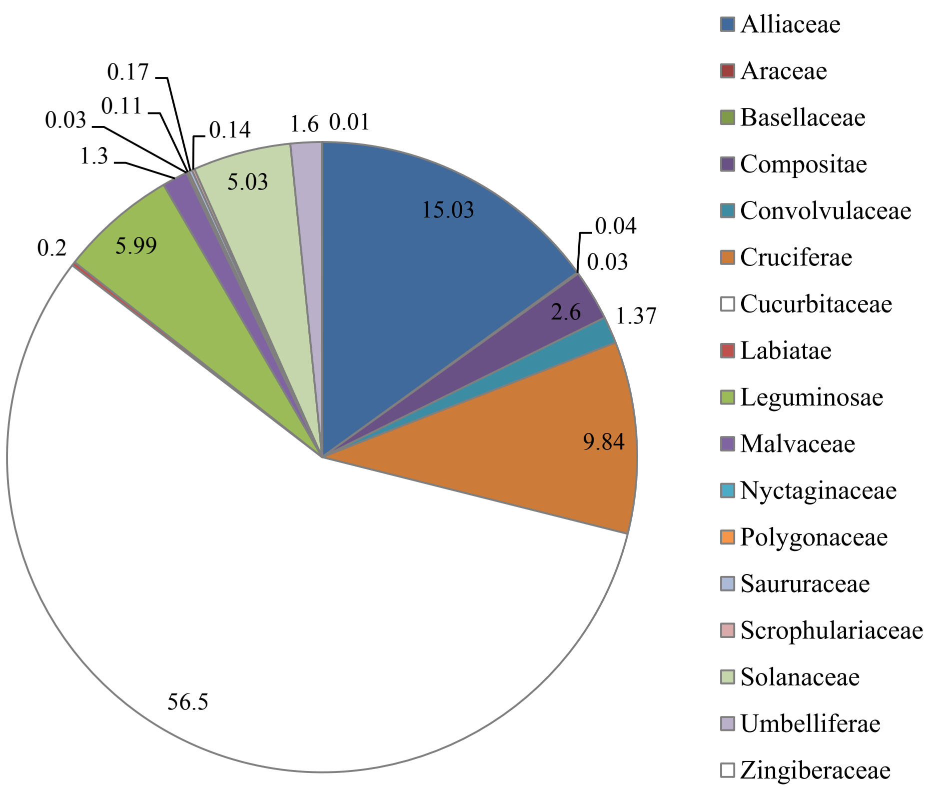


Figure 5.2. Cultivated areas (in % total) according to plant families in current crop (calculated based on equation 4.2).

Concerning the average areas calculated according to vegetable families, there were significant differences among them (Kruskal-Wallis χ^2 = 136.4) with the range of 250 to 2,500m^2 per plant family per farm (Figure 5.3, Appendix 6). Figure 5.3 indicates nine families having the same median of cultivated area (1,500m^2), including Apiaceae (Umbelliferae), Saururaceae, Polygonaceae, Malvaceae, Leguminosae (Fabaceae), Brassicaceae (Cruciferae), Convolvulaceae, Asteraceae (Compositae), and Alliaceae. Exceptions were found for five families as Araceae, Basellaceae, Nyctaginaceae, Scrophulariaceae, and Zingiberaceae, in which only 1 using frequency in current crop was recorded. Solanaceae and Leguminosae (Fabaceae) had the same inter quartile range (IQR) of cultivated area (1,000 – 2,000m^2). However, median of cultivated area for Solanaceae (1,500m^2) were 500m^2 larger than median of cultivated area for Leguminosae (1,000m^2). Cucurbitaceae had the largest IQR of cultivated area (1,000 – 3,000m^2) with the median was equal 2,000 (50% farms had cultivated area larger than 2,000m^2).

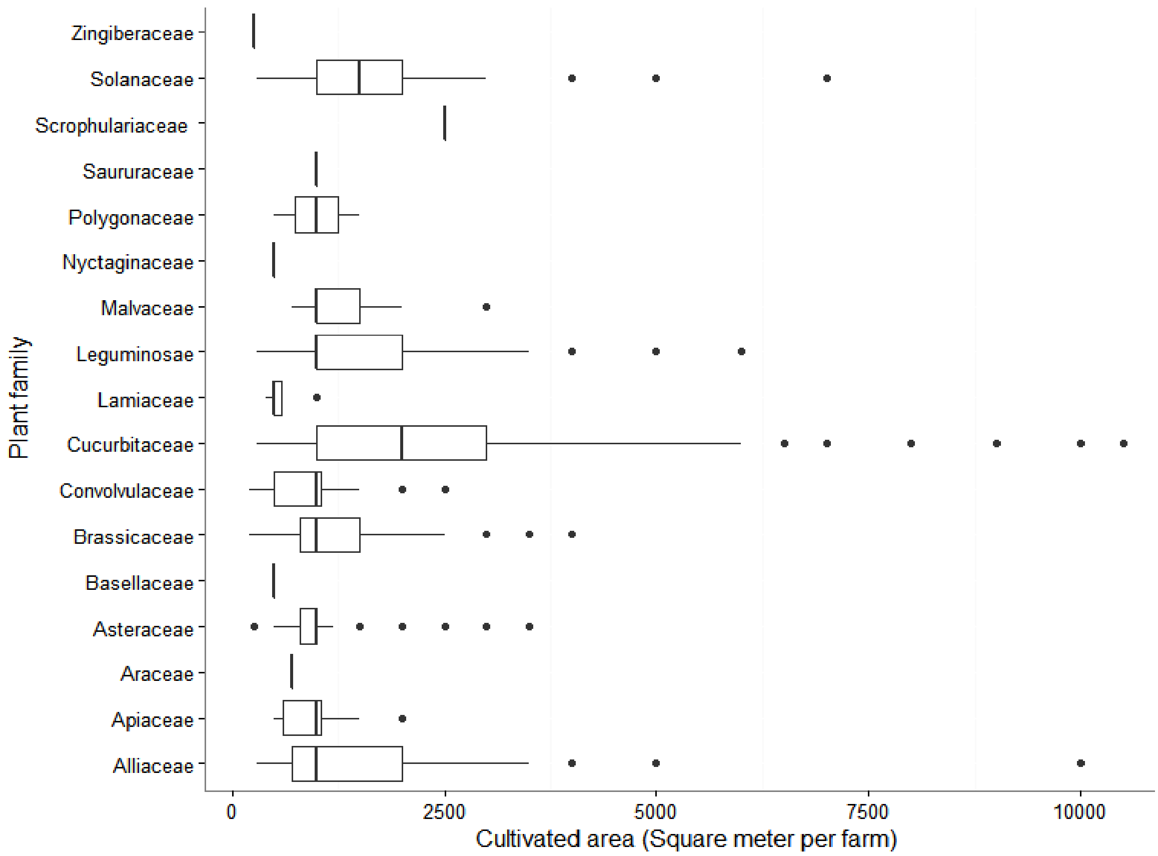


Figure 5.3. Cultivated areas according to 17 plant families used in current crop (calculated based on equation 4.3).

Regarding the average of cultivated areas according to families, 10 plant families had cultivated areas lower than the average values for all families (1,246m^2 per farm) (Appendix 6), including Zingiberaceae (250m^2 per farm), Basellaceae (500m^2 per farm), Nyctaginaceae (500m^2 per farm), Lamiaceae (583m^2 per farm), Araceae (700m^2 per farm), Polygonaceae (1,000m^2 per farm), Saururaceae (1,000m^2 per farm), Convolvulaceae (1,017m^2 per farm), Apiaceae (1,125m^2 per farm), Brassicaceae (1,208m^2 per farm) , and Asteraceae (1,217m^2 per farm). The rest had cultivated areas higher than average values, including Scrophulariaceae (2,500m^2 per farm), Cucurbitaceae (2,339m^2 per farm), Solanaceae (1,719m^2 per farm), Leguminosae (1,615m^2 per farm), Alliaceae (1,392m^2 per farm), and Malvaceae (1,359m^2 per farm).

5.1.4 The correlations between farmers' characteristics and using vegetable species

To understand the relative contributions of the age of farmers, education levels (grades), members in households (people), average value of vegetable area (m^2 per farm), and using frequency of species, matrix plot of correlations were used (Figure 5.4). As a result, correlations between age of farmers, education levels, members in households, and cultivated areas had negative values, except a positive correlation between education levels and cultivated areas. There was only one significant correlation between age of farmers and members in households (r = -0.31, P = 0.03). The other correlations were not significant, including the relations between age of farmers and education levels (r = -0.23, P = 0.12), age of farmers and cultivated areas (r = -0.14, P = 0.1), education levels and members in households (r = -0.27, P = 0.07), education levels and cultivated areas (r = 0.10, P = 0.51), and members in households and cultivated areas (r = -0.14, P = 0.35).

Regarding correlation between farmers' characteristics and using frequency of vegetables species: there were no significant correlations between using frequency of species and farmers' ages (r= -0.27, P = 0.06), education levels (r = 0.12, P = 0.40), and members in households (r = -0.16, P = 0.27). In contrast, a significant positive correlation (P = 0.00) between using frequency of species and cultivated areas was found with correlation coefficient, r = 0.64.

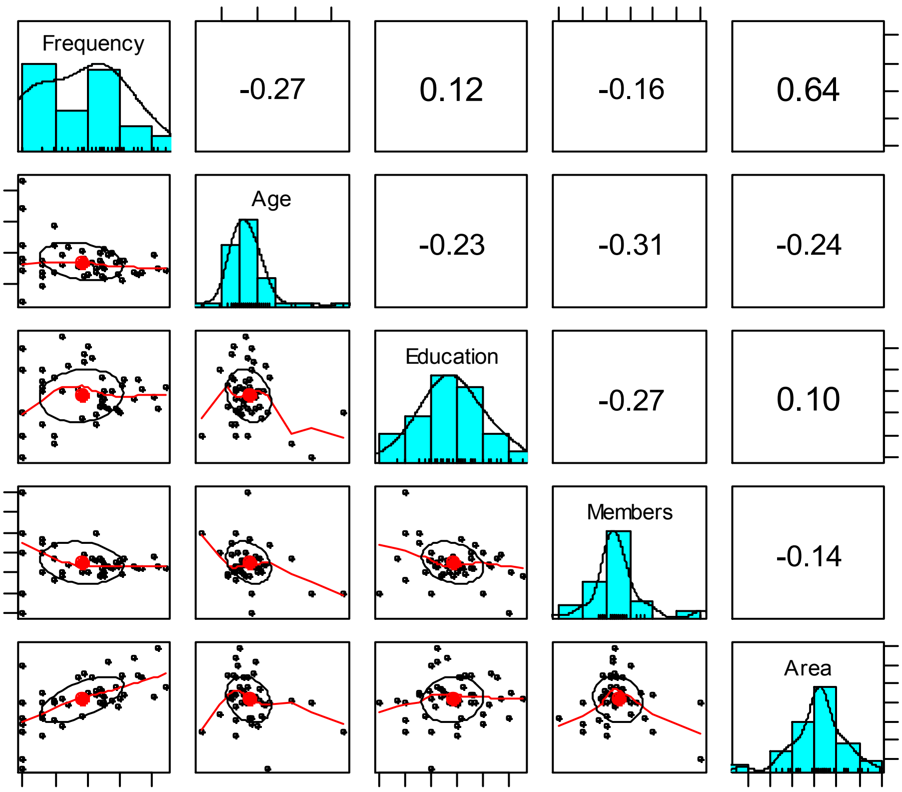


Figure 5.4. Matrix correlations between using frequency of all vegetable species (Frequency), farmers' ages (Age), education levels (Education), members in households (Members), and cultivated areas (Area) of all vegetable species. Values of farmers' ages, cultivated areas, and using frequency were logarithm base 10 transformed (data see Appendix 7).

5.1.5 Cucurbit species used in vegetable cultivation

5.1.5.1 Using frequency and occurrence rate of cucurbit species

There were nine cucurbit species from seven genera cultivated in current crop and in year-round crop (Table 5.2). In current crop, cucurbit species were cultivated 431 times (42.7%) from in total 1,009 vegetable crops. In year-round crop, cucurbit species were cultivated 988 times (38.2%) from in total 2,585 vegetable crops (details for all species were given in Appendix 6).

Table 5.2. Using frequency (UF) and occurrence rate (OR) of cucurbit species in current crop and year-round crop

Scientific name	Common name	Current crop		Year-round crop	
		UF	OR	UF	OR
Benincasa hispida	Ash gourd	7	0.7	41	1.6
Citrullus lanatus	Watermelon	116	11.5	274	10.6
Cucumis melo var. *conomon*	Melon	52	5.2	92	3.6
Cucumis sativus	Cucumber	68	6.7	143	5.5
Cucurbita moschata	Pumpkin	5	0.5	7	0.3
Lagenaria siceraria	Bottle gourd	18	1.8	58	2.2
Luffa acutangula	Angled loofah	2	0.2	3	0.1
Luffa cylindrica	Loofah	9	0.9	32	1.2
Momordica charantia	Bitter gourd	154	15.3	338	13.1

The occurrence rate of cucurbit species (calculated based on equation 4.1) was not significantly different in current crop and year-round crop (permutation test). Table 5.2 shows that five species among the nine had a high using frequency. Especially bitter gourd (*Momordica charantia*) (154 and 338 using frequency in current crop and year-round crop) and watermelon (*Citrullus lanatus*) (116 and 274 using frequency in current crop and year-round crop) were very often recorded even more than cucumber (*Cucumis sativus*) (68 and 143 using frequency in current crop and year-round crop), melon (*Cucumis melo* var. *conomon*) (52 and 92 using frequency in current crop and year-round crop) and bottle gourd (*Lagenaria siceraria*) (18 and 58 using frequency in current crop and year-round crop.

The other species had a considerably lower using frequency. Ash gourd (*Benincasa hispida*) and loofah (*Luffa cylindrica*) had a using frequency with an average value for all species in year-round crop (47 using frequencies). Pumpkin (*Cucurbita moschata*) and angled loofah (*Luffa acutangula*) are ranked in the low using frequency species. In contrast, loofah ((*Luffa* *cylindrica*) (9 and 32 using frequency in current crop and year-round crop), pumpkin (*Cucurbita moschata*) (5 and 7 using frequency in current crop and year-round crop), and angled loofah (*Luffa acutangula*) (2 and 3 using frequency in current crop and year-round crop) were cultivated with a low frequency in vegetable cultivation.

Bitter gourd (*Momordica charantia*), watermelon (*Citrullus lanatus*), cucumber (*Cucumis sativus*), melon (*Cucumis melo* var. *conomon*), and bottle gourd (*Lagenaria siceraria*) were cultivated with high using frequency (Table 5.2) because the market demands of vegetable had been remarkably increased relating to the increase in vegetable consumption per capita and the population growth (Khiem et al., 2000; Figuié, 2003; Jean-Josehh et al., 2003; Johnson et al., 2008; Mergenthaler et al., 2009; Rasco Jr, 2009). In contrast, the low using frequencies of pumpkin (*Cucurbita moschata)* and angled loofah (*Luffa acutangula*) found in this survey could be explained by their traditional cultivation in home gardens (Trinh et al., 2003; Pham and Vo, 2013). The two species can be cultivated easily in home gardens, and this production can satisfy the market needs. Therefore, farmers may cultivate other crops in fields for increasing effectiveness of land use.

Three other species (*Cucurbita pepo, Sechium edule,* and *Trichosanthes anguina*), those were determined as frequently cultivated crops in Vietnamese vegetable cultivation (Siemonsma and Piluek, 1994; Pham, 1999), were not found in this study. These three species are mainly produced in North central coast, Central highland, and North Vietnam (Pham, 1999) and therefore they were not found in the study area. Regarding to chayote (*Sechium edule*) and snake gourd (*Trichosanthes anguina*), moreover, the two crops were not cultivated in South Vietnam because the two vegetable had been rarely used in cuisine style of southerners.

5.1.5.2 Seeds sources

Cucurbit seeds used in cultivation by the farmers came from two sources: the farmers had bought the commercial seeds from seed agencies (60.6%) or they had maintained the own seeds of previous crops (39.4%). The contribution of both seed sources was depending on cucurbit species as given in Figure 5.5 and differed remarkably among the species.

More than 98% seeds of cucumber (*Cucumis sativus*) and watermelon (*Citrulus lanatus*) of the current crop was bought. Also for pumpkin (*Cucurbita moschata*) of the current crop about 80% seeds were bought. In contrast, more than 88% seeds of loofah (*Luffa cylindrica*) and melon (*Cucumis melo* var. *conomon*) of current crop were kept from previous crops. Also more than 60% seeds of bitter gourd (*Momordica charantia*) were maintained from previous crops. The ratios of both seed sources were equal for angled loofah (*Luffa acutangula*) and bottle gourd (*Lagenaria siceraria*).

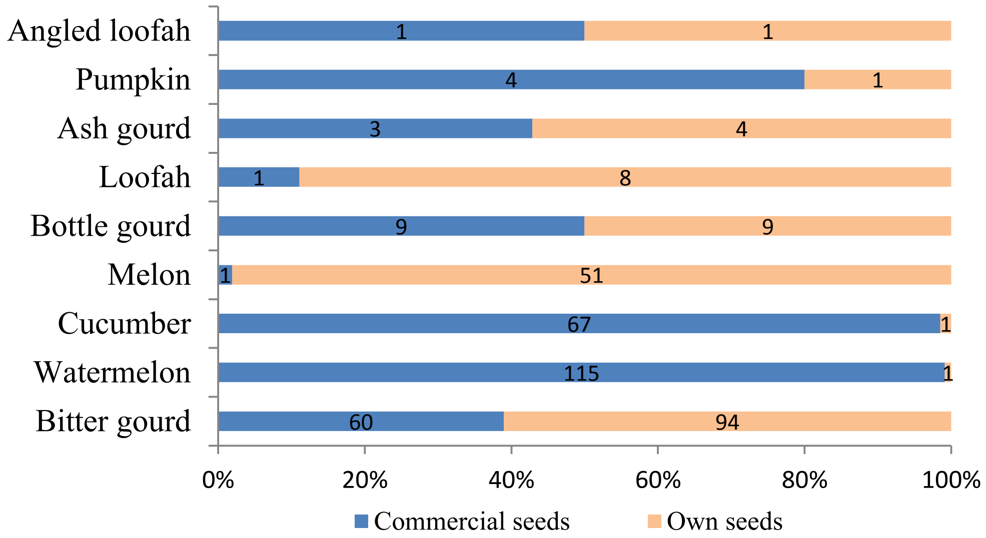


Figure 5.5. Seed sources (%) of cucurbit species used in vegetable cultivation: commercial seeds (blue), own seeds (orange) (numbers indicated using frequency).

In Vietnam, local and international seed companies provide their commercial seeds via seed agencies. According to Rasco Jr (2009) and Groot (2013), since 1980, local and international seed companies had been breeding F1 hybrid seeds of cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus*), bitter gourd (*Momordica charantia*), pumpkin (*Cucurbita moschata*), and loofah (*Luffa cylindrica* and *L. acutangula*) and selling them in Vietnam. Accordingly, high yielding commercial seeds of the mentioned species are commonly used and local seeds are more and more neglected. This progress is one of the causes making loss of cucurbit genetic diversity.

This study found that nearly all seeds for cucumber (*Cucumis sativus*) and watermelon (*Citrullus lanatus*) were bought from seed companies (Figure 5.5). The consequence of this is that genetic diversity in these crops is determined by the seed companies especially in the commercial field production. Genetic variability in these crops can be expected only if sources from home gardens are collected.

5.1.5.3 Cultivated areas of cucurbit species

As aforementioned in section 5.1.3, the area used for cultivating Cucurbitaceae occupied 56.5% total area of all species in vegetable cultivation. This plant family had a large average value of cultivated area (2,339m^2 per farm, Figure 5.3) with enormous differences from farm to farm were recorded on cultivated areas of the species in this plant family (Figure 5.3, Figure 5.6). Some farms did not cultivate cucurbits at all; others had up to 10,500m^2.

Regarding the cultivated areas of nine cucurbit species (Table 5.3, calculated based on equation 4.4), they varied from 750 to 3,816m^2, per farm, and the differences were significant (Kruskal-Wallis χ^2 = 163.8, Figure 5.6). Among them, the average of cultivated areas of watermelon (3,816m^2 per farm), melon (2,971m^2 per farm), loofah (2,022m^2 per farm), cucumber (1,868m^2 per farm), ash gourd (1,857m^2 per farm), and bitter gourd (1,492m^2 per farm) were larger than the average value of all vegetable species (1,246m^2 per farm, details for each species are given in Appendix 6). Conversely, averages of cultivated areas of pumpkin (1,156m^2 per farm), bottle gourd (933m^2 per farm), and angled loofah (750m^2 per farm) were lower than the average value of all vegetable species.

Table 5.3. Cultivated areas (m^2 per farm) of cucurbit species in current crop

Scientific name	Common name	Cultivated areas (Average ± SD)
Benincasa hispida	Ash gourd	1857±1600
Citrullus lanatus	Watermelon	3816±2074
Cucumis melo var. *conomon*	Melon	2971±1728
Cucumis sativus	Cucumber	1868±1376
Cucurbita moschata	Pumpkin	1156±365
Lagenaria siceraria	Bottle gourd	933±550
Luffa acutangula	Angled loofah	750±354
Luffa cylindrica	Loofah	2022±1247
Momordica charantia	Bitter gourd	1492±945

The standard deviations (SD) of cultivated area of each species were high (Table 5.3) because of the wide range in cultivated areas following farms (Figure 5.6): ash gourd (500 – 5,000m^2), watermelon (400 – 10,500m^2), melon (800 – 10,000m^2), cucumber (500 – 9,000m^2), pumpkin (500 – 1,500m^2), bottle gourd (400 – 2,000m^2), angled loofah (500 – 1,000m^2), loofah (500 – 4,000m^2), and bitter gourd (300 – 6,000m^2). The Figure 5.6 shows that watermelon had the highest median of cultivated areas (3,500m^2). In contrast, angled loofah had the lowest median of cultivated areas (750m^2). Bitter gourd, ash gourd, bottle gourd, and pumpkin had the same median of cultivated areas (1,000m^2). Whereas, the medians of cultivated areas of cumber, loofah, and melon were 1,500m^2, 2,000m^2, and 3,000m^2, respectively.

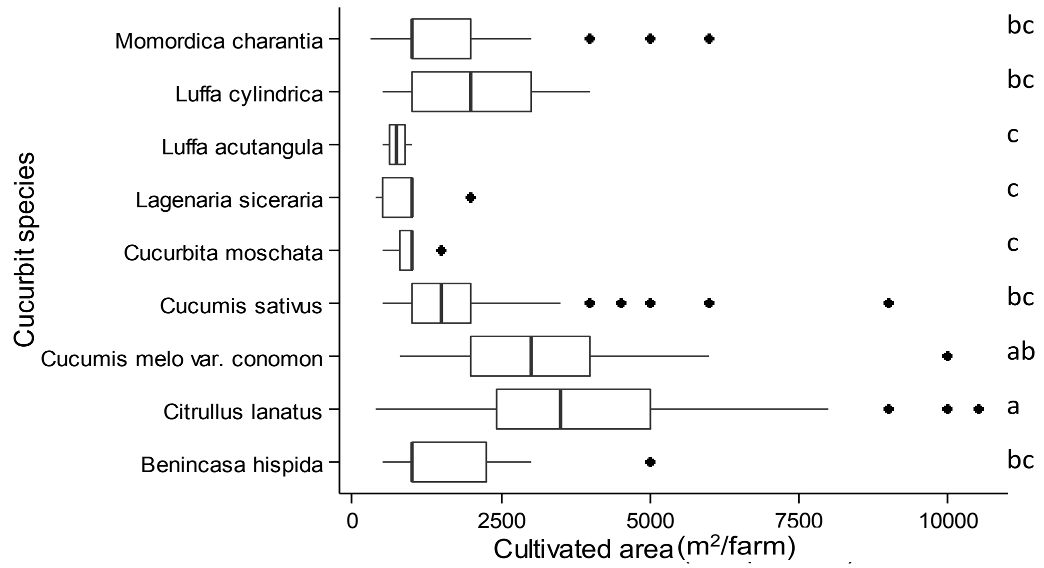


Figure 5.6. Cultivated areas of nine cucurbit species in vegetable cultivation (different letters indicate significant differences (multiple comparison tests after Kruskal-Wallis (kruskalmc)).

Statistical analysis showed that the average of cultivated area of watermelon is largest and significantly different from bitter gourd, cucumber, and bottle gourd (Figure 5.6). The average area of melon is the second rank and not significantly different comparing with watermelon, cucumber, and bitter gourd. Bottle gourd has the lowest average of cultivated area within the five species. However, the difference is not significant comparing with bitter gourd and cucumber.

5.1.5.4 The occurrence rate of cucurbit species in study site

Cucurbit species were chosen as main vegetable crops in crop systems of all communes, where the survey was executed. However, occurrence rate of cucurbit species was different among the locals. To classify the adaptation of cucurbit species in different growing conditions, mapping method was applied to figure out the occurrence rate of cucurbit species following the communes (Figure 5.7). As a result, five levels of occurrence rate (%) of cucurbits were determined in study site as follows:

- Less than 20% households cultivated cucurbits: in Tan Thuy, Phu Long, An Hoa Tay, Binh Thanh, and Nhuan Phu Tan.
- 20% – 40% households cultivated cucurbits: in Son Hoa, Son Dong, Khanh Thanh Tan, and Tan Thanh Tay.
- 41% – 60 households cultivated cucurbits: in An Thanh, Thua Duc, Da Phuoc Hoi, and Chau Hung.

- 61% – 80% households cultivated cucurbits: in Tan Thanh, Huu Dinh, Phu Khanh, and Luong Hoa.
- > 80% households cultivated cucurbits: in An Thuy, Tam Phong, and Phu Nhuan.

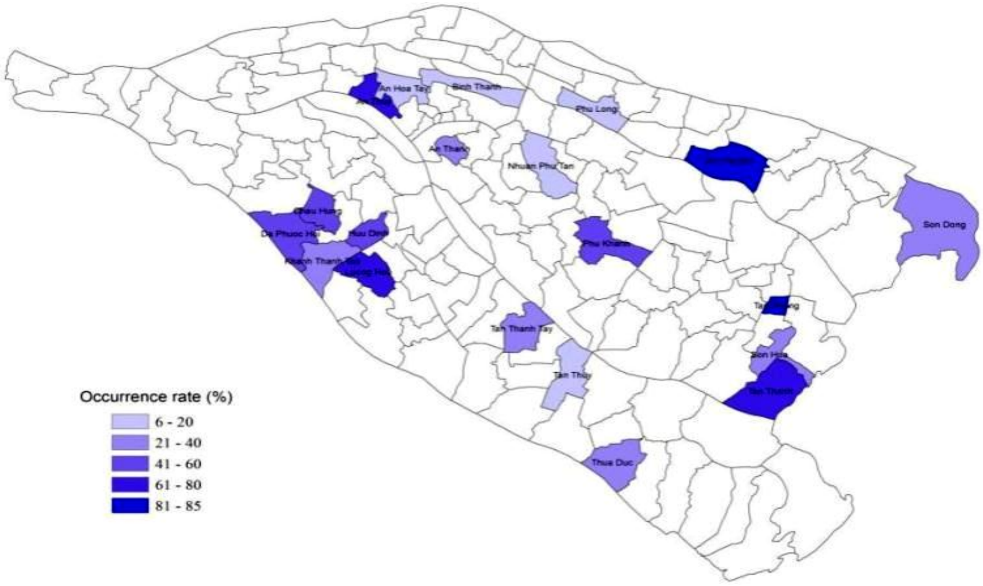


Figure 5.7. Occurrence rate of cucurbits in study sites (calculated based on equation 4.1).

The Figure 5.7 shows that cucurbits are cultivated in all regions, and the differences of occurrence rate of cucurbits may depend on farming systems or natural conditions of regions. Moreover, land use planning by local government for specializing in the growing of some vegetable crops (Pham and Vo, 2013) may be another cause of unequal distribution of cucurbit species in study regions.

5.1.5.5 Correlations between farmers' characteristics and cultivated cucurbit species

Section 5.1.4 was presented the correlation coefficients between farmer characteristics and using frequency for all vegetable species (Figure 5.4). In difference, this section presents the correlations between using ratios of selected cucurbit species and age of farmers, education levels, members in households, and cultivated areas. The correlations were calculated separately following equation 4.5. As a result, there were no significant correlations between using ratios of cucurbit and age of farmer (Figure 5.8a) and education levels of farmer (Figure 5.8b). In contrast, the significant correlation between using ratios of cucurbits and members in households with r = –0.81 (Figure 5.8c), and cultivated areas (values converted to logarithm base 10) with r = 0.85 (Figure 5.8d), and the adjustted coefficient of determination (R^2_{adj}) were 0.63 and 0.71, respetively.

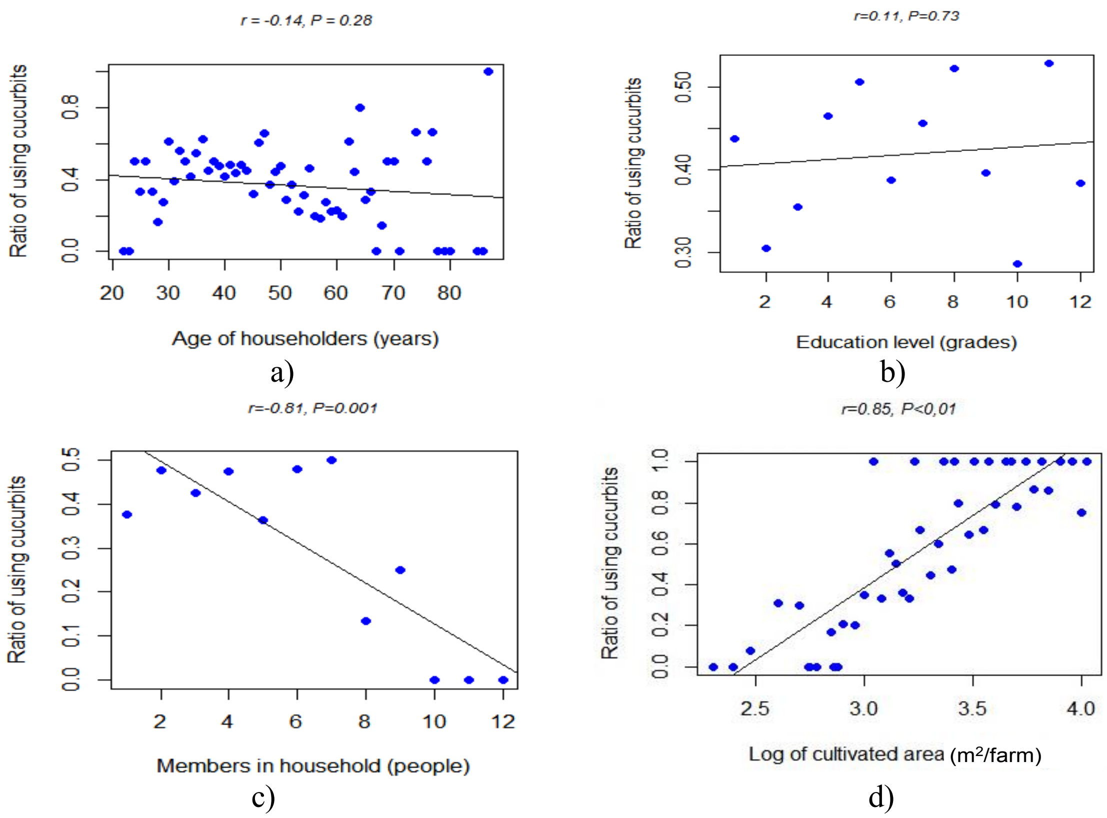


Figure 5.8. Linear regressions of using ratio of cucurbits (URC) and age of farmers (a), members in households (b), education levels of farmers (c), and cultivated areas (d).

The regression model between the using ratios of cucurbits and cultivated areas shows the possibility of choosing cucurbits for cultivation increased when farmers have large cultivated land. In contrast, the regression model between using ratios of cucurbits and members in households represents that possibility of choosing cucurbits for cultivation was low when the households had many members.

The positive correlation between ratio of using cucurbits and cultivated areas could be explained by the large size of cucurbit species (as aforementioned). Whereas, the negative correlation between ratio of using cucurbits and members in households could be understood based on the assumptions as follows:

- Cucurbit seeds can be sown directly on cultivating beds; therefore labors for nursery stage are not required.
- Numbers of plants per unit area are low, thus no need for more labors for cultivating.
- The harvest of cucurbits is subsequently, and at each time, therefore there is no need more labors for harvesting.
- Cucurbit fruits can be sold directly after harvesting; therefore there is no need more labors for preliminary treatment before selling.

5.2 Collections cucurbit germplasm in southern Vietnam

5.2.1 Collections of cucurbits' germplasm

- AVRDC and VASI collections

There were 1,255 cucurbits' accessions, including 345 accessions in AVRDC and 910 accessions in VASI genebanks collected in 31 provinces (Table 5.4, Figure 4.2). The collection of AVRDC was rich in species (22 species belonging to eight genera). In contrast, the collection of VASI concentrated mostly to cultivated cucurbit species (nine species belonging to eight genera). Nine species of VASI collection are also found in AVRDC collection (*Benincasa hispida, Citrullus lanatus, Cucumis* sp., *Cucurbita* sp., *Lagenaria siceraria, Luffa acutangula, Luffa* sp., *Momordica charantia,* and *Trichosanthes cucumerina*).

- This study collections

There were 224 cucurbits' accessions collected in 24 provinces in the central and southern of Vietnam (Table 5.4, Figure 4.2). The accessions were classified in 12 genera, 14 species, and 1 subspecies including *Benincasa hispida* (19 accessions), *Citrulus lanatus* (6 accessions), *Coccinia grandis* (2 accessions), *Cucumis melo* var. *conomon* (15 accessions), *Cucumis sativus* (25 accessions), *Cucurbita moschata* (30 accessions), *Gymnopetalum cochinchinensis* (2 accessions), *Lagenaria siceraria* (33 accessions), *Luffa acutangula* (2 accessions), *Luffa cylindrica* (39 accessions), *Momordica charantia* (42 accessions), *Momordica cochinchinensis* (2 accessions), *Mukia maderaspatana* (1 accession), *Trichosanthes anguina* (1 accession), and *Zehneria indica* (5 accessions).

- Sum of these three collections

Total numbers of cucurbits accessions from three collections were 1,479 accessions, the accessions were classified in 12 different cucurbit genera, 23 species, and 3 subspecies. There were five species appearing in all three collections including *Benincasa hispida, Citrulus lanatus, Lagenaria siceraria, Luffa acutangula,* and *Momordica charantia* (Table 5.4). Regarding the number of accessions in the three collections according to species, there were no significant differences according to Kruskal-Wallis test. There were also no significant differences among the accessions of species in these three collections.

The numbers of accessions collected were significantly different dependent on cucurbit species (χ^2-test) and ranged from 1 (*Trichosanthes* sp., *Mukia maderaspatana,* and *Luffa cylindrica* var. *insularum*) to 231 (*Luffa* sp.) with average and median of 56.9 and 18, respectively. It was collected a higher number of accessions than the median of all species

(18) for the eight frequently cultivated genera (*Benincasa, Citrullus, Cucumis, Cucurbita, Lagenaria, Luffa, Momordica,* and *Trichosanthes*). In contrast, the species belonging to underutilized and wild genera (*Coccinia, Gymnopetalum, Mukia, Trichosanthes,* and *Zehneria*) were collected with a lower number of accessions than median. Because of the significant differences in number of accessions in dependence on the species, the standard deviation (SD) of three collections was large (85.16).

Table 5.4. Cucurbits germplasm collected by AVRDC (2011), VASI (2011) and in this study

Scientific name	Number of accessions			
	AVRDC	VASI	This study	Sum
Benincasa hispida	30	121	19	170
Citrullus lanatus	8	15	6	29
Coccinia grandis	0	0	2	2
Cucumis melo	5	0	0	5
Cucumis melo var. *cantalupensis*	4	0	0	4
Cucumis melo var. *conomon*	4	0	15	19
Cucumis sativus	21	0	25	46
Cucumis sp.	9	136	0	145
Cucurbita maxima	8	0	0	8
Cucurbita moschata	33	0	30	63
Cucurbita pepo	17	0	0	17
Cucurbita sp.	79	270	0	349
Gymnopetalum cochinchinensis	0	0	2	2
Lagenaria siceraria	18	87	33	138
Lagenaria sp.	16	0	0	16
Luffa acutangula	5	29	2	36
Luffa cylindrica var. *insularum*	1	0	0	1
Luffa cylindrica	26	0	39	65
Luffa sp.	46	185	0	231
Momordica charantia	10	25	42	77
Momordica cochinchinensis	2	0	2	4
Mukia maderaspatana	0	0	1	1
Trichosanthes cucumerina	1	42	0	43
Trichosanthes anguina	1	0	1	2
Trichosanthes sp.	1	0	0	1
Zehneria indica	0	0	5	5
Average ±SD	13.3±18.	35.0±69.12	8.6±13.61	56.9±85.16

AVRDC, Vietnamese cucurbit species conserved in AVRDC (AVGRIS, 2011). VASI, cucurbit genebank in VASI (PGRV, 2011). Sum, total of the accessions in three collections.

5.2.2 Collected cucurbit species per province

AVRDC and VASI collections concentrated to the North of Vietnam and collected seeds from the 5 mainly cultivated cucurbit species only, whereas by this study seeds were collected in southern Vietnam and apart of the 5 mostly cultivated species also so far neglected cucurbit species were collected. The regions of three collections were mapped by using query builder in ArcMap 10 and results were given in Figure 5.9. The sum of regions, where cucurbits were collected by all three collections, compromised 57 provinces of total 63 provinces of Vietnam. There are still six provinces where no cucurbit accessions were collected so far including three in Red River Delta (Hung Yen, Ha Nam, and Phu Tho) and three in Central Coast (Binh Dinh, Phu Yen, and Da Nang). The number of collected cucurbit species was different in dependence on the provinces with a range from 1 to 14 species as follows:

- 21 provinces where 1 – 3 cucurbit species were collected, including 4 in Northern Midlands and Mountain Areas (Hai Phong, Lao Cai, Ninh Binh, and Tuyen Quang), 4 in Red River Delta (Ha Tay, Nam Dinh, Thai Binh, and Vinh Phuc), 1 in North Central Coast (Thua Thien – Hue), 1 in Central Coast (Khanh Hoa), 3 in Central Highlands (Daklak, Dak Nong, and Gia Lai), 1 in Southeast (Tay Ninh), and 7 in Mekong River Delta (Bac Lieu, Dong Thap, Kien Giang, Long An, Soc Trang, Tra Vinh, Vinh Long).
- 18 provinces where 4 – 7 cucurbit species were collected, including 6 in Northern Midlands and Mountain Areas (Bac Giang, Cao Bang, Dien Bien, Ha Giang, Thai Nguyen, and Yen Bai), 1 in Red River Delta (Bac Ninh), 2 in North Central Coast (Ha Tinh and Quang Tri), 1 in Central Coast (Quang Ngai), 1 in Central Highlands (Lam Dong), 4 in Southeast (Binh Duong, Binh Phuoc, Ba Ria – Vung Tau, and Dong Nai), and 3 in Mekong River Delta (An Giang, Can Tho, and Hau Giang).
- 13 provinces where 8 – 11 cucurbit species collected, including 3 in Northern Midlands and Mountain Areas (Lang Son, Quang Ninh, and Son La), 3 in Red River Delta (Hanoi, Hai Duong, and Hoa Binh), 3 in North Central Coast (Nghe An, Quang Binh, and Thanh Hoa), 1 in Central Coast (Quang Nam), 1 in Southeast (Ho Chi Minh), and 2 in Mekong River Delta (Ben Tre and Tien Giang).
- 5 provinces where 12 – 14 cucurbit species were collected, including 2 in Northern Midlands and Mountain Areas (Bac Kan and Lai Chau), 2 in Central Coast (Binh Thuan and Ninh Thuan), 1 in Central Highlands (Kon Tum).

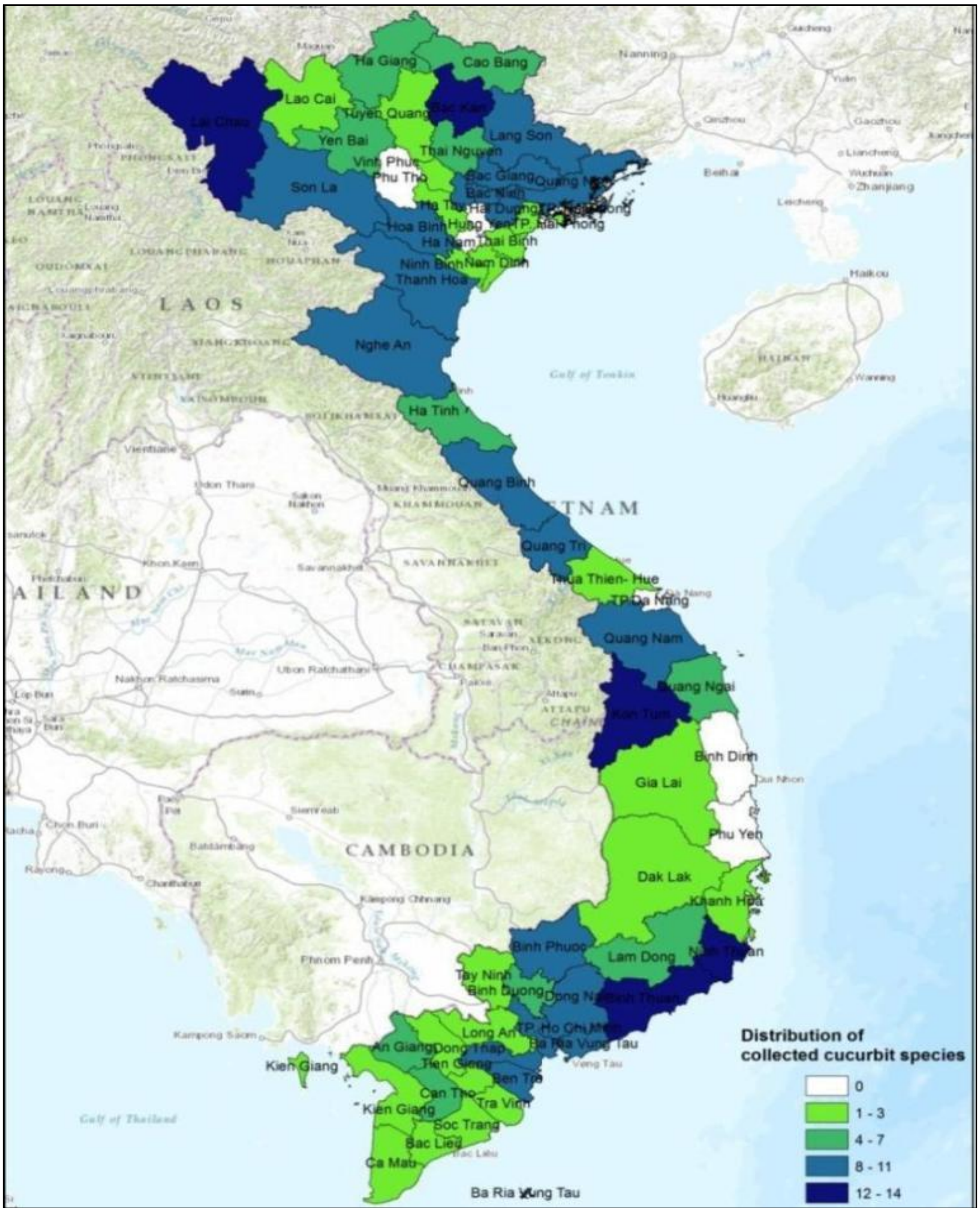


Figure 5.9. Total number of collected cucurbit species per province summarizing collection of AVRDC (AVGRIS, 2011); VASI (PGRV, 2011); and this study. Details see Appendix 9.

The previous collections of cucurbit germplasm (PGRV, 2011; AVGRIS, 2011) performed in the north of Vietnam have archived 1,255 accessions of 22 different cucurbit species or subspecies, and there is still insufficient data for characterization of the collected accessions. The objective of this study was, therefore, to collect cucurbit germplasm in regions located in southern Vietnam in order to include the so far ignored areas for cucurbits' collection. This study contributed 224 cucurbit accessions increased hereby the total number of cucurbit accessions to 1,479. Equally important, the available germplasm need to be examined for the diversity and genetic relationships basing on morphological characteristics. Furthermore, the useful genotypes, which involve special characteristics such as bearing rich fruits, good fruit shape, and long harvesting period, are to select and to introduce in breeding programs.

The number of collected species/subspecies (23 species and 3 subspecies) up to now reach 51% of total cucurbit species (51 species/subspecies were determined by Pham (1999); details were given in Table 2.2). All commonly cultivated species except *Sechium edule*, a species produces recalcitrant seeds, that are occurring in whole Vietnamese territory (e.g. *Benincasa hispida, Citrullus lanatus, Coccinia grandis, Cucumis sativus, Cucumis melo, Cucurbita moschata, Gymnopetalum cochinchinensis, Gymnopetalum integrifolium, Lagenaria siceraria, Luffa acutangula, Luffa cylindrica, Momordica charantia, Momordica cochinchinensis,* and *Trichosanthes anguina*) were collected and conserved. Other species (*Coccinia grandis, Gymnopetalum cochinchinensis, Mukia maderaspatana, and Zehneria indica*) used as food, medicine and feed (commonly used by Ethnic minority people) were also concerned.

The other species were not considered in the current collections, because:

- The species are economically least important in vegetable cultivation of Vietnam, or rarely used by Vietnamese i.e. *Actinostemma tenerum*, *Cucumis anguria*, *Cucumis trigonus, Gynostemma laxum, Hemsleya chinensis, Hodgsonia macrocarpa, Mukia javanica, Mukia maderaspatana, Neoalsomitra integrifolia, Neoalsomitra sarcophylla, Solena heterophylla, Thladiantha cordifolia, Thladiantha hookeri, Thladiantha indochinensis, Thladiantha siamensis, Zanonia indica,* and *Zehneria marginata.*
- Some species are rare (MARD, 2005) and can be found only in the forests or mountains of particular regions (Pham, 1999), i.e. *Citrullus colocynthus, Gynostemma pentaphyllum, Momordica subangulata, Momordica laotica, Trichosanthes ovigera, Trichosanthes rubriflos, Trichosanthes tricuspidata, Trichosanthes villosa, Trichosanthes baviensis, Trichosanthes pedata, Trichosanthes pierrei,* and *Zehneria maysorensis.*

5.2.3 Species diversity and evenness indices

Diversity and evenness indices have been used to express the actual status of the species in the investigated regions. The diversity index refers to the abundance of species in the collections and is calculated following Shannon–Wiener formulation (equation 4.6) (Hill, 1973; Peet, 1974; Beisel and Moreteau, 1997; Spellerberg and Fedor, 2003; Grunewald and

Schubert, 2007; Spellerberg, 2008). The evenness index (a relative diversity index with a range from 0 and 1 calculated following equation 4.7) relates to how individuals of the plant community are distributed among present species (Peet, 1974, Beisel and Moreteau, 1997).

According to Pham (1999), 51 cucurbit species/subspecies are highly adapted to the natural conditions and farming habits of Vietnam. Consequently, the maximum value of diversity index (H'_{max}) was 3.93 (equation 4.8). The calculated minimal value diversity index (H'_{min}, calculated following equation 4.9), species diversity index (H') and evenness index (E) of three cucurbit collections (AVRDC, VASI, and this study) are given in Table 5.5.

With 345 accessions belonging to 22 species/subspecies, the AVRDC collection had the highest values of H'_{min} (0.41), H' (2.55), and E (0.61). This study collection, with 224 accessions in 15 species/subspecies, had the mean value of H'_{min} (0.4), H' (2.2), and E (0.51). Contrary, with 910 accessions in nine species, the VASI collection had the lowest values of H'_{min} (0.07), H' (1.88), and E (0.47). In total, the three collections (sum) obtained 1,479 accessions of 26 different cucurbit species/subspecies with the values of H'_{min}, H', and E of 0.14, 2.43, and 0.60, respectively.

Table 5.5. The lower limit of diversity index (H'_{min}), species diversity index (H') and evenness index (E) of cucurbit collections

Collection	Number of species/subspecies[†]	Number of accessions	H'_{min}	H'	E
AVRDC	22	345	0.41	2.55	0.61
VASI	9	910	0.07	1.88	0.47
This study	15	224	0.40	2.20	0.51
Sum	26	1479	0.14	2.43	0.60

Sum = total of the accessions in three collections; [†]: the numbers of collected species were overlapped in the collections.

AVRDC database recorded 1,085 available accessions of Vietnamese vegetable species including 345 accessions of 22 cucurbit species. The accessions were collected in Project AVRDC ADB RETA 5839 from 1999 to 2002 (Green et al., 2007). The numbers of cucurbit species in AVRDC collection are the highest of all three collections. As a result, the diversity index and the evenness index are high. However, a part of the accessions was lost due to lack of facilities and poor conditions for seeds regeneration (AVRDC, 2007). Therefore, a certain number of cucurbit accessions may only be available on the search engine but do not exist anymore in seed genebanks of AVRDC.

The accessions of different crops had been collected by VASI with the purpose of strengthening conservation of plant genetic resources of Vietnam to attend the agricultural development and food security strategies. *In situ* conservation systems were established on 2.4 million ha land. In addition, in e*x situ* conservation systems about 21,646 accessions of grain crops, fruit crops, and vegetable crops were conserved (Vu and Tran, 2010).

Regarding cucurbit species, *ex situ* conservation was applied in seed genebank storing seeds in medium-term storage condition. In 2000, there were seven cucurbit genera with about 107 accessions stored in VASI genebank (Tran and Ha, 2000). The number of genera increased to nine in 2010 and the number of accession increased from 107 to 910 after 10 years (Vu and Tran, 2010; PGRV, 2011). The VASI collection focused only on cultivated genera including *Cucumis*, *Cucurbita*, *Lagenaria*, *Luffa*, *Trichosanthes* and *Momordica*. In contrast, the underutilization and wild species are not collected (Table 5.4). Therefore, the diversity index and the evenness index of this collection are lowest in three collections.

The cucurbit accessions collected in this study considered also wild species that are used as food and feed by highland people (*Gymnopetalum cochinchinensis*), or that are used in traditional medicine (*Mukia maderaspatana*) or bearing many fruits (*Zehneria indica*). As a result, the number of cucurbit genera in this study was highest in three collections. The diversity and evenness indices in this study collection were lower than AVRDC collection (0.35 and 0.1 points, respectively); but the indices were higher than VASI collection (0.32 and 0.04 points, respectively). *Gynostemma pentaphyllum,* a species with high economical and medicine values, was found in this collection (Figure 2.16b). Nevertheless, only the position (latitude and longitude) of the species was recorded because it was not in the fruiting period.

Nhi et al. (2010) collected 59 accessions of *Cucumis melo* that belonged to three different groups (*Agrestis, Conomon,* and *Momordica*). These accessions were collected in 18 different provinces in Northern Midland and Mountain Areas (31 accessions collected in 8 provinces, including Cao Bang, Hoa Binh, Son La, Lang Son, Dien Bien, Bac Kan, Tuyen Quang, and Lao Cai), Red River Delta (5 accessions collected in 3 provinces, include Hung Yen, Ninh Binh, and Hai Duong), North Central Coast (19 accessions collected in 5 provinces, including Thua Thien – Hue, Quang Tri, Thanh Hoa, Ha Tinh, and Nghe An), and Central Coast (4 accessions collected in 3 provinces, including Quang Nam, Quang Ngai, and Phu Yen) of Vietnam. These accessions were phenotypic and molecular evaluated and conserved at Okayama University, Japan. Five accessions of *Cucumis melo* var. *conomon* from Nhi et al. (2010) were available in this study collection.

5.2.4 Cucurbits' accessions with undefined species

AVRDC and VASI collections were concentrated to eight cultivated cucurbits with five undefined species written as "sp.". These undefined species belonged to genera *Cucumis*, *Cucurbita*, *Lagenaria*, *Luffa* and *Trichosanthes*. Based on the cucurbits existent in Vietnam (Pham, 1999), the undefined species could be classified as follows:

- With *Cucumis* sp. accessions, these may belong to *C. sativus, C. melo* or *C. trigonus*.
- With *Cucurbita* sp. accessions, these may belong to *C. maxima, C. moschata* or *C. pepo*.
- With *Lagenaria* sp. accessions, these possibly belong to *L. siceraria,* because it is only one species in genus *Lagenaria* existent in Vietnam.
- With *Luffa* sp. accessions, these may belong to *L. acutangula* or *L. cylindrica.*
- With *Trichosanthes* sp. accessions, these may belong to *T. anguina, T. baviensis, T. rubriflos, T. cucumerina, T. kirilowii, T. ovigera, T. pedata, T. pierrei, T. tricuspidata* or *T. villosa*.

Another possibility is that there are some new species found belonging to such cucurbit genera. Therefore, it is necessary to evaluate the undefined species accessions and to classify them into right species.

In conclusion, within three different collections in total 1,479 accessions of 26 species/subspecies in 12 cucurbit genera are provided. The accessions were collected in 57 provinces in total 63 provinces of Vietnam. The evenness index of the total cucurbit accessions reached 60% and the diversity index reach 61.8% of maximum diversity value of cucurbits in Vietnam. Collection and conservation of cucurbit species are necessary for cucurbit breeding program and reducing the loss of cucurbit genetic diversity. Therefore, it is necessary to intensify collection and conservation all cucurbit species existence in Vietnam.

5.3 Morphological characterization of five frequently cultivated cucurbit species

Accessions of cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*) were characterized and evaluated for the diversity basing on variability of morphological characteristics. This study determined 91 different quantitative (QN), qualitative (QL) and pseudo-qualitative (PQ) characteristics for the species. These characteristics were divided into two types of variables: continuous variables and categorical (Appendix 10). There were 39, 36, 28, 27, and 37 characteristics evaluated for cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*), respectively. The characteristics are not only useful for genetic diversity evaluation, but also necessary for initial materials identification in breeding programs.

5.3.1 Evaluation of continuous variables within accessions of five species

The continuous variables of accessions from five species were analysed for their expression in two different growing environments (χ^2-test). The analyses included 13, 17, 14, 12, and 17 continuous variables of the accessions belonged to cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*), respectively (Table 5.6). Regarding the statistical significance at P-value < 0.05 level:

- For cucumber (*Cucumis sativus*) accessions, the significant differences were recorded on stem length (cm) and fruit weight (g).
- For pumpkin (*Cucurbita moschata*) accessions, the significant differences were found on seven characteristics, including length of female and male flower peduncles (cm), length of sepals of female and male flowers (cm), fruit circumference (cm), fruit length (cm) and fruit weight (g).
- For bottle gourd (*Lagenaria siceraria*) accessions, the significant differences were found on fruit weight and fruit length characteristics.
- For loofah (*Luffa cylindrica*) and bitter gourd (*Momordica charantia*) accessions, the significant difference occurred only on fruit weight (g) of the accessions.

It can be assumed that the significant differences of the variables for some cucurbit accessions can be a result of different growing conditions.

Table 5.6. The differences of continuous variables of the accessions in five cucurbit species

Characteristics	P-values of χ^2 test				
	Cs	Cm	Ls	Lc	Mc
Cotyledon length (Cr.02)	0.86	1.00	1.00	1.00	
Stem length (Cr.04)	0.00	0.64	0.84	1.00	0.09
Number of nodes up to node bearing 1st female flower (Cr.05)					0.79
Number of nodes up to node bearing 1st male flower (Cr.05)					0.00
Number of side shoots (Cr.08)					0.17
Thickness of main stem (Cr.09)					1.00
Length of leaf blade (Cr.13)	1.00	1.00	1.00	1.00	1.00
Width of leaf blade (Cr.21)	1.00	1.00	1.00	1.00	1.00
Length of leaf petiole (Cr.24)		0.96	1.00	0.49	1.00
Length of ovary (Cr.27)					0.95
Length of female flower peduncle (Cr.28)		0.00			
Length of male flower peduncle (Cr.29)		0.00			
Length of sepal of female flower (Cr.30)		0.00			
Length of sepal of male flower (Cr.31)		0.83			
Peduncle diameter of female flower (Cr.33)		1.00			
Time taken of first female flower flowering (Cr.35)	0.08		1.00	1.00	0.68
Time taken of first male flower flowering (Cr.36)	0.99*		1.00	1.00	0.04
Fruit circumference (Cr.40)	1.00	0.00	0.37	1.00	1.00
Diameter of the core (Cr.44)	1.00				
Fruit diameter (Cr.50)		0.13	1.00		
Diameter of flower scar (Cr.51)		0.06			
Fruit weight (Cr.55)	0.00	0.00	0.00	0.00	0.00
Fruit length (Cr.59)	1.00	0.01	0.00	0.20	0.86
Length of fruit peduncle (Cr.61)	1.00		1.00	0.92	0.97
Thickness of fruit flesh (Cr.82)	0.99	0.99			
Time for physiological maturity of fruit (Cr.83)			1.00		1.00
Weight of 100 seeds (Cr.91)	1.00	0.87	0.92	1.00	0.93

Cs, *Cucumis sativus*; Cm, *Cucurbita moschata*; Ls, *Lagenaria siceraria*; Lc, *Luffa cylindrica*; Mc, *Momordica charantia*; *, not included gynoecious accessions.

5.3.2 Morphological diversity among cucurbit accessions collected in different regions

The study determined 91 different qualitative, quantitative and pseudo-qualitative characteristics divided into two types of variables, categorical and continuous variables (Appendix 10) for evaluating genera *Cucumis, Cucurbita, Lagenaria, Luffa*, and *Momordica*.

5.3.2.1 Cucumber (*Cucumis sativus*)

- Morphological expressions of examined characteristics from 25 cucumber accessions

There were 39 different variables used to evaluate 25 cucumber accessions. All accessions were determinate in growth type (Cr.03). The flowers were determined as monoecious (Cr.34), except accession TiGi02 and TiGi03. In the young stage, the fruits grew with prickles (Cr.84), and then these prickles dropped down when fruits in maturity stage. In the market stage, fruits were green in skin color with small white dots, and the fruits of all accessions had obtuse shape of fruit base (Cr.77). Moreover, fruits skins at harvest stage of all accessions were no sutures (Cr.81), creasing (Cr.45), glaucosity (Cr.56), and warts (Cr.86). No parthenocarpy fruit (Cr.68) was found, and the other 30 variable characteristics are given in Appendix 11 and Appendix 12 for categorical and continuous variables, respectively.

Coefficients of variables calculated from 25 cucumber accessions (Table 5.7) showed high similarity of three variables, including sex description (0.63 and 0.54), time of taken first female flower (0.62 and 0.63) and time of taken first male flower (0.62 and 69) in first two canonical axes. Similarly, high similar coefficients of weight of 100 seeds (0.65), fruit ribs (0.55), and intensive with green color of leaf (0.53) were found in the first canonical axis, and blistering of leaf blade (0.55) was found in the second canonical axis.

- Genetic relationships among cucumber accessions based on morphological characteristics

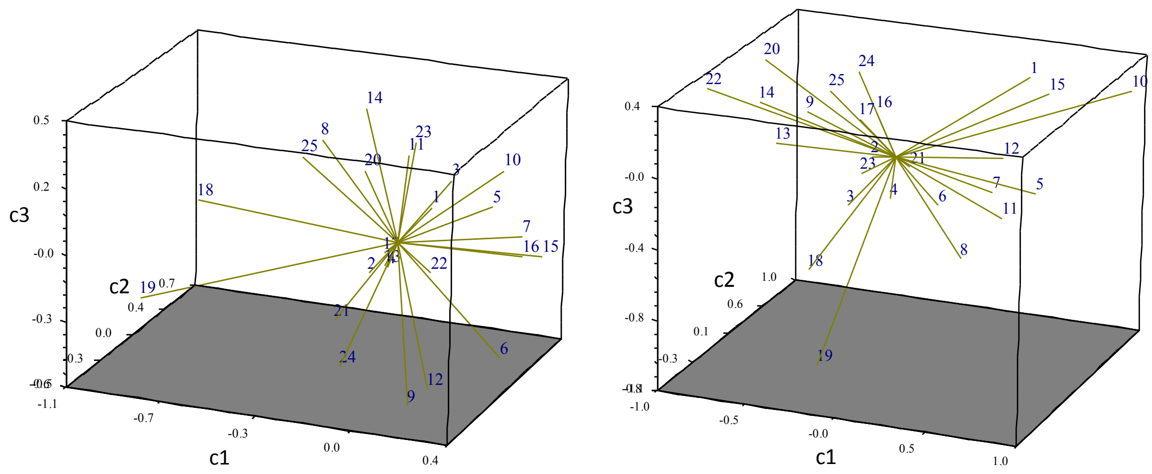
Distributions of 25 cucumber accessions were plotted in 3D separately for categorical variables (Figure 5.10a) and continuous variables (Figure 5.10b). Additionally, cluster analysis was performed using UPGMA method to clarify genetic relationships among cucumber accessions (Figure 5.11).

- Accessions which were similar in expression regarding categorical variables:
    - QuNa01, QuNa03, BiTh01, TiGi04, and HcmC01
    - DoNa02 and HaGi01
    - QuNa02, LaDo01, ViLo01, QuNa04, and BiTh02
    - BeTr01, TaNi01, and NiTh02
    - QuNa05, DoNa03, BiPh01, and QuNg01
    - TiGi02 and TiGi03
- Accessions which were similar in expression regarding continuous variables:
    - QuNa01, BiPh01, DoNa03, and LaDo01

* QuNa02, ViLo01, HcmC01, BiTh02, TiGi01, QuNg01, and HaGi01
* NiTh02, TaNi01, DoTh01, and TiGi04
* QuNa05, DoNa02, BeTr01, DoNa01, and BrVt01
* TiGi02 and TiGi03

Table 5.7. Correlations among variables in the first three canonical axes (C1, C2, and C3) based on 25 cucumber accessions

Variables	C1	C2	C3
Cotyledon color	0.03	0.42	0.07
Cotyledon length	0.17	-0.61	0.08
Stem length	-0.03	-0.34	0.5
Blistering of leaf blade	-0.38	0.55	-0.4
Dentation of leaf blade margin	0.14	-0.14	-0.42
Leaf length	0.34	-0.51	0.43
shape of apex of terminal leaf lobe	-0.03	0.48	-0.14
Undulation of leaf blade margin	-0.3	0.06	-0.3
Leaf width	0.25	-0.58	0.36
Attitude of leaf blade	-0.25	0.08	-0.11
Intensive with green color of leaf	0.53	-0.21	0.28
Color of ovary vestiture	-0.13	-0.48	-0.44
Sex description	0.63	0.54	0.26
Time of taken first female flower	0.62	0.63	-0.21
Time of taken first male flower	0.62	0.69	0.07
Fruit circumference	-0.65	0.19	0.37
Color of fruit skin at market stage	0.34	0.12	-0.37
Color of fruit at ripe stage	-0.61	-0.51	-0.06
Core diameter of fruit	-0.19	0.35	0.46
Density dots on fruit	-0.27	-0.26	0.15
Density of fruit vestiture	0.16	0.05	0.27
Distribution of dot on fruit	0.38	0.21	0.15
Fruit weight	-0.65	0.38	0.08
Fruit length	-0.6	0.38	0.28
Length of fruit content dots	-0.04	-0.39	-0.47
Fruit peduncle length	0.2	-0.2	0.22
Length of stripes on fruit	-0.19	-0.16	-0.4
Fruit ribs	0.55	-0.04	-0.28
Fruit shape in transverse	-0.53	-0.14	0.11
Shape of fruit apex	-0.02	-0.12	-0.41
Thickness of fruit flesh	-0.72	0.04	0
Weight of 100seed	0.65	-0.49	-0.12



a) b)

Legend

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
QuNa01	QuNa02	QuNa03	QuNa04	QuNa05	DoNa01	DoNa02	BeTr01	TiGi01	BiPh01	BrVt01	LaDo01	NiTh02	BiTh01	DoNa03	QuNg01	HcmC01	TiGi02	TiGi03	DoTh01	ViLo01	TiGi04	HaGi01	BiTh02	TaNi01

Figure 5.10. 3D distributions of 25 cucumber accessions based on 19 categorical (a) and 13 continuous (b) variables (green lines indicate eigenvectors).

- Hierarchical clustering of 25 cucumber accessions

The dendrogram representing the relationships of 25 cucumber accessions was analyzed from 31 varying variables and showed two main groups meet at 1.67 of coefficient value (Figure 5.11). The first group consists only of two accessions collected in the same provinces (TiGi02 and TiGi03), the second group consists of all the other accessions. The large group can be divided into two minor groups at the coefficient range from 0.99 to 1.44. The first minor group consists of six accessions (QuNg01, DoNa01, DoNa02, DoNa03, BiPh01 and QuNa05). The second minor group consists of the rest 17 accessions (see Figure 5.12 for the variability in fruits of the accessions).

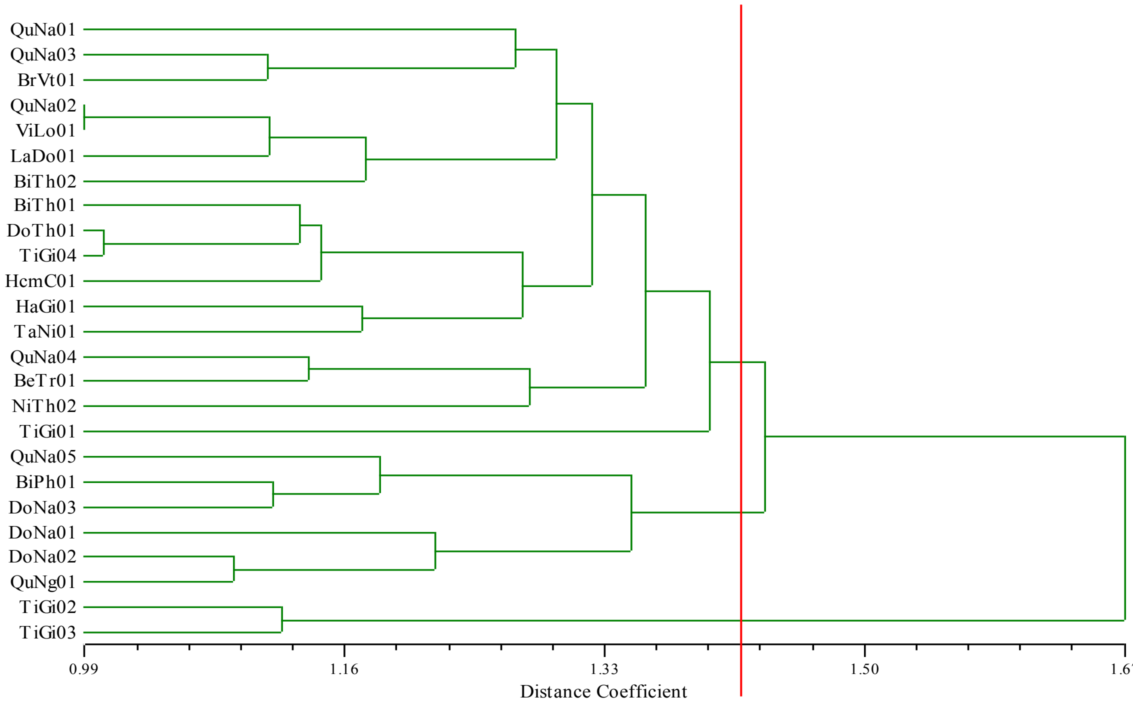


Figure 5.11. Relationships of 25 cucumber accessions based on 19 categorical and 13 continuous variables (the red line is level of cut for three groups).

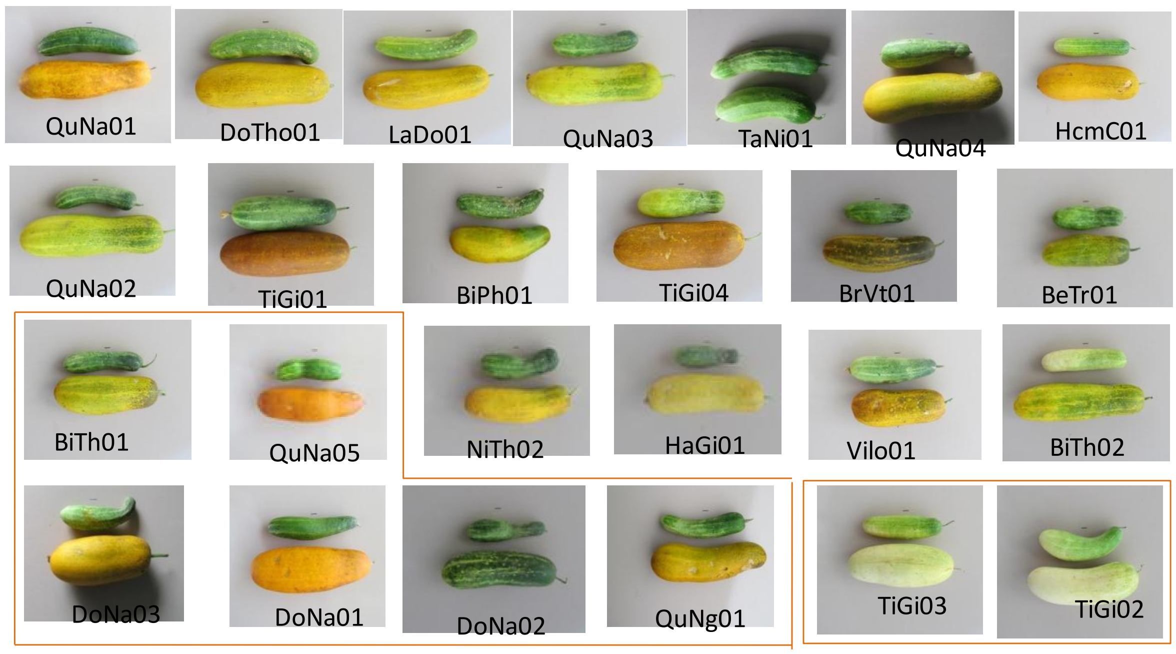


Figure 5.12. Variation in size, shape, and color of fruit of 25 cucumber accessions. The accessions were boxed following level of cut in dendrogram.

5.3.2.2 Pumpkin (*Cucurbita moschata*)

- Morphological expressions of examined characteristics from 22 pumpkin accessions

There were 36 variables applied for evaluation of 22 pumpkin accessions. All accessions had silver patch on the leaves. The fruits of all accessions present grooves (Cr.47) exception for accession BaLi01. There were no necks (Cr.71) and warts (Cr.67) on fruits. Seeds of all accessions had a yellowish-white color of testa (Cr.88). Other varying characteristics are given in Appendix 13 and Appendix 14 for categorical and continuous variables, respectively.

Coefficients of variables calculated from 22 pumpkin accessions are shown in Table 5.8 indicating the high similarity of fruit circumference (0.91), fruit diameter (0.91), fruit weight (0.79), and position of broadest part on fruit (0.69) in the first canonical axis. Very similar values for intensity of green color of leaf (0.51), depth of fruit grooves (0.77), and thickness of fruit flesh (0.52) were found in the second axis; density of silver patches on leaf (0.71) and shape of fruit apex (0.53) in the third axis.

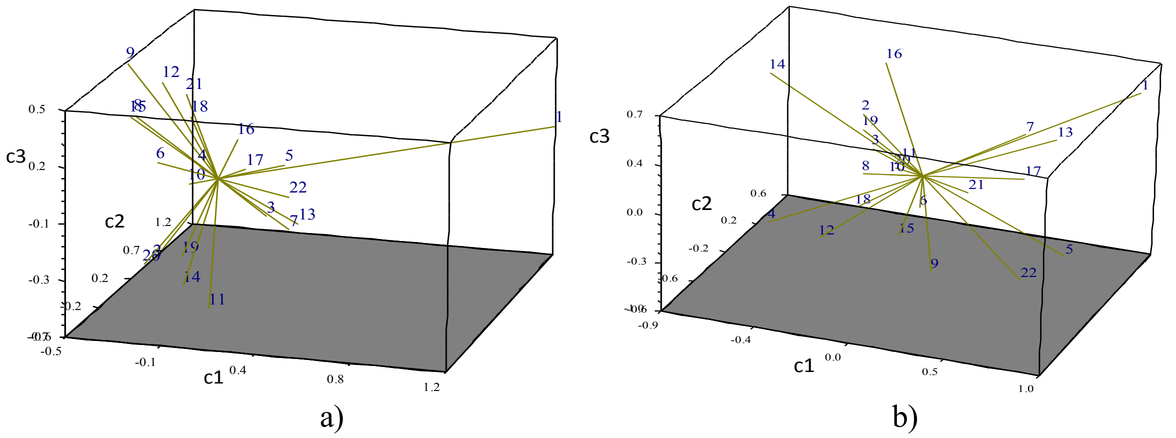
- Genetic relationships among pumpkin accessions based on morphological characteristics

Distributions of 22 pumpkin accessions were plotted in 3D separately for categorical variables (Figure 5.13a) and continuous variables (Figure 5.13b). Furthermore, genetic relationships among pumpkin accessions were analyzed by using UPGMA method of cluster analysis (Figure 5.14).

- The accessions which were similar in expression regarding categorical variables:
    - BeTr01, QuNa03, BiDu01, BeTr02, NiTh01, and DoTh01
    - DoNa02, BiPh02, TaNi01, BrVt01, and QuNg02
    - TiGi01 and CaTh01
    - TiGi02 and HcmC02
    - QuNa02, BiTh02, HaGi01, and DoNa01
- The accessions which were similar in expression regarding continuous variables:
    - BeTr01, TiGi01, and BiDu01
    - QuNa03, DoTh01, TaNi01, BrVt01, and QuNg02
    - NiTh01, HcmC02CaTh02, and BeTr02
    - TiGi02, BiTh01, and BiPh02

Table 5.8. Correlations among variables in the first three canonical axes (C1, C2, and C3) based on 22 pumpkin accessions

Variables	C1	C2	C3
Cotyledon length	0.01	0.33	0.25
Stem length	0.09	0.18	-0.13
Leaf length	-0.07	0	-0.68
Leaf margin	0.24	0.21	-0.31
Density of silver patches on leaf	-0.1	-0.19	0.71
Leaf width	-0.26	-0.04	-0.73
Intensive with green color of leaf	0.01	0.51	-0.2
Length of leaf petiole	-0.49	-0.21	-0.35
Length of female flower peduncle	0.03	-0.36	-0.11
Length of male flower peduncle	-0.24	0.17	-0.33
Length of sepal of female flowers	0.21	-0.15	0.36
Length of sepal of male flower	0.2	-0.23	0.2
Peduncle diameter of female flower	-0.05	0.29	0.42
Fruit circumference	0.91	0.16	0.07
Color of fruit skin at market stage	-0.25	0.38	0.27
Color of fruit skin at ripe stage	-0.05	-0.53	-0.18
Fruit curving	-0.93	-0.01	0.18
Fruit grooves	-0.02	-0.67	-0.23
Fruit diameter	0.91	0.16	0.07
Diameter of flower scar	0.49	-0.17	-0.28
Distance between grooves of fruit	0.21	-0.24	0.27
Fruit weight	0.79	0.37	0.05
Depth of fruit grooves	-0.46	0.77	-0.13
Fruit length	-0.41	0.7	-0.1
Color of fruit flesh	-0.33	0.19	0.4
Fruit marbling	-0.09	-0.51	-0.14
Position of broadest part of fruit	0.69	0.03	-0.3
Shape of fruit apex	0.27	-0.03	0.53
Shape of fruit base	-0.47	-0.3	0.32
Thickness of fruit flesh	0.38	0.52	0.11
Waxiness of fruit skin	-0.1	0.06	-0.35
Weight of 100 seeds	0.22	-0.48	-0.43
Shape of fruit in longitudinal section	-0.46	-0.65	0.07



Legend

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
BaLi01	BeTr01	TiGi01	TiGi02	QuNa02	QuNa03	DoNa01	DoNa02	BrVt01	LaDo02	NiTh01	BiTh01	BiTh02	BiDu01	QaNg02	CaTh01	HcmC02	BiPh02	BeTr02	DoTh01	TaNi01	HaGi01

Figure 5.13. 3D distributions of 22 pumpkin accessions based on 15 categorical (a) and 17 continuous (b) variables (green lines indicate eigenvectors).

- Hierarchical clustering of 22 pumpkin accessions

Figure 5.14 shows genetic relationships of 22 pumpkin accessions calculated basing on 32 morphological characteristics. The accessions were divided into two main groups with the separation of the BaLi01 accession from the others. Moreover, the large group can be divided into two minor groups at 1.46 coefficient value. The first minor group included the accessions Dona01, HcmC02, HaGi01, BiTh02, and QuNa01. The second minor group included the other 16 accessions (see Figure 5.15 for the differences on fruits of the accessions).

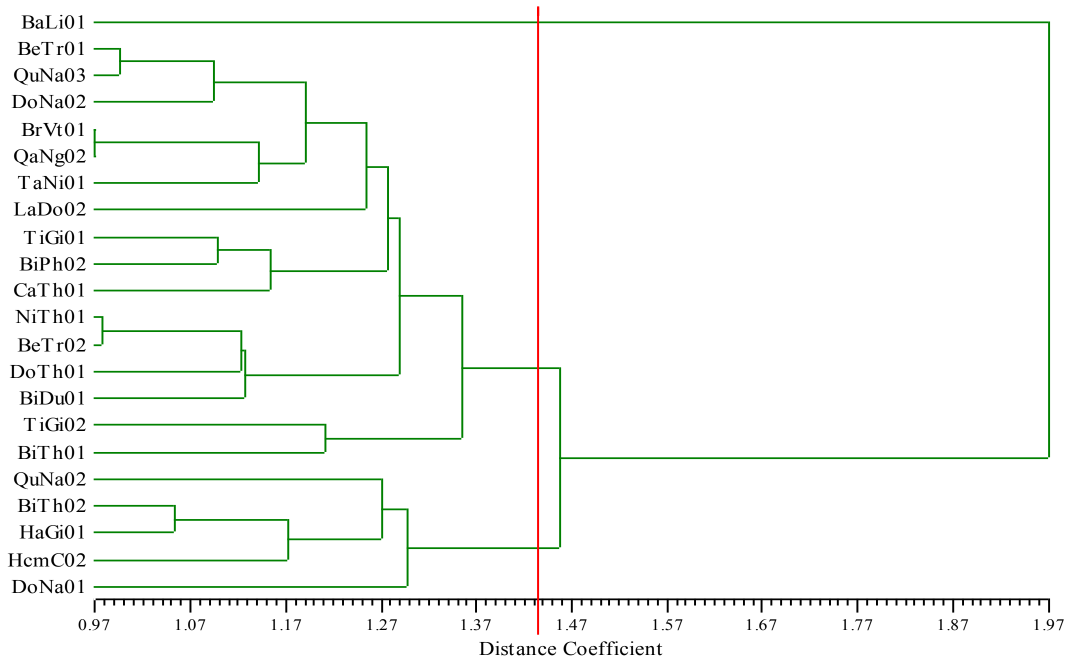


Figure 5.14. Relationships among 22 pumpkin accessions accessions based on 15 categorical and 17 continuous variables (the red line is level of cut for three groups).

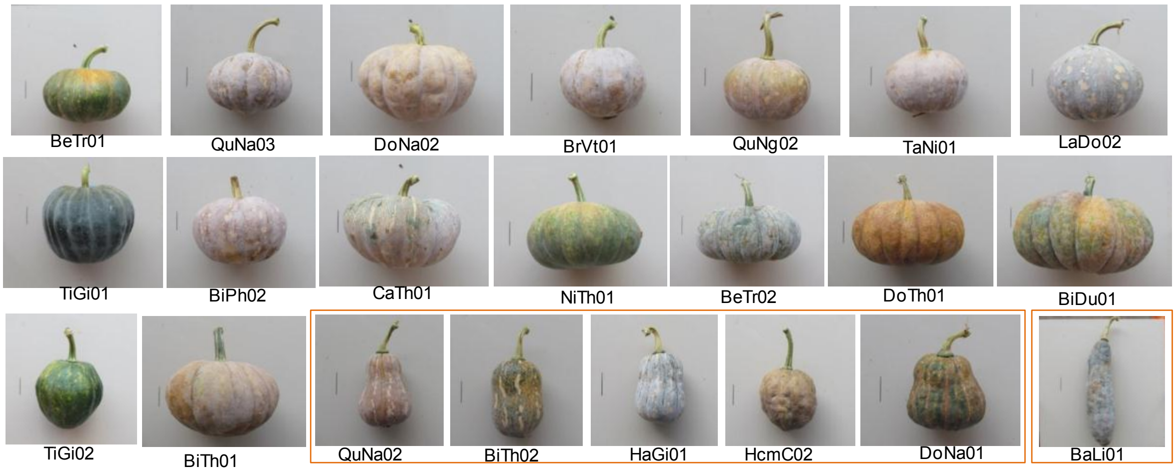


Figure 5.15. Variation in size, shape, and color of fruits of 22 pumpkin accessions. The accessions were boxed following level of cut in dendrogram (bars = 5cm).

5.3.2.3 Bottle gourd (*Lagenaria siceraria*)

- Morphological expressions of examined characteristics from 32 bottle gourd accessions

There were 28 variables used to evaluate 32 bottle gourd accessions. As a result, all accessions had the same stem shape with angular (Cr.07). Other varying characteristics are given in Appendix 15 and Appendix 16 for categorical and continuous variables, respectively.

Similar coefficients among variables are given in Table 5.9 showing high values of leaf length (0.77), leaf width (0.77), and length of leaf petiole (0.78) in the first canonical axis; fruit length (0.48) in second canonical axis; undulation of leaf margin (0.51), intensive with green color of leaf blade (0.54), and shape of fruit peduncle (0.53) in the third canonical axis.

- Genetic relationships among bottle gourd accessions based on morphological characteristics

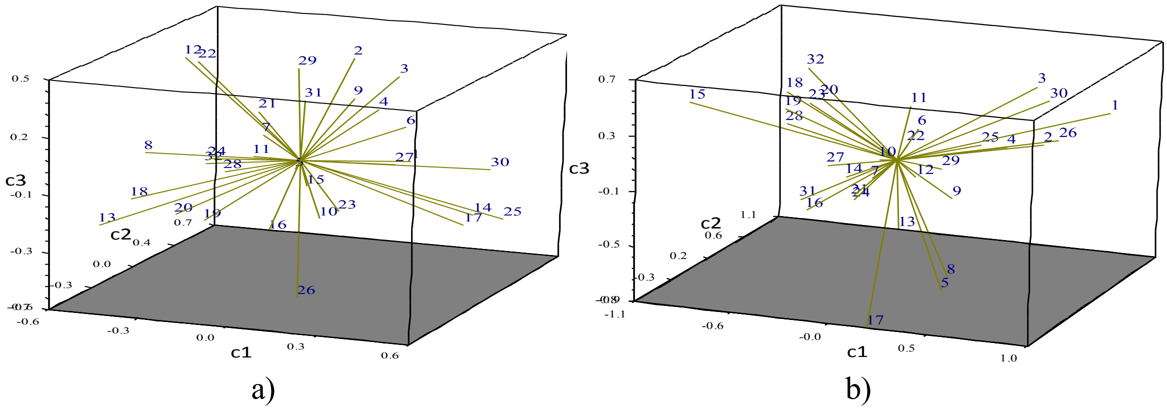
Distributions of 32 bottle gourd accessions were plotted in 3D separately for categorical variables (Figure 5.16a) and continuous variables (Figure 5.16b). Furthermore, genetic relationships among accessions were analyzed by using UPGMA method (Figure 5.17).

- The accessions which were similar in expression regarding categorical variables:
    - DoNa01, TaNi02, QuNa02, QuNa05, HaGi03, and QuNa04
    - TiGi01, BrVt02, and DoNa01
    - QuNa03, NiTh02, and BiTh01
    - LaDo01, LaDo02, and GiLa01
    - HaGi01 and CaTh01
    - KiGi01, TaNi02, and LaDo03
    - QuNa01 and HaGi02

- The accessions which were similar in expression regarding continuous variables:
    - ThHo01 and HcmC01
    - DaNo01, TaNi01, DoNa01, and TaNi02
    - QuNa01, LaDo01, and LoAn01
    - DoNa02, BiPh01, and PhYe01
    - TiGi01, QuNa02, NiTh01, HaGi03, TiGi02, and LaDo03
    - QuNa01, KiGi01, QuNa04, and QuNa05
    - LaDo02, HaGi01, BiTh01, CaTh01, HaGi02, LoAn02, and BrVt02

Table 5.9. Correlations among variables in the first three canonical axes (C1, C2, and C3) based on 32 bottle gourd accessions

Variables	C1	C2	C3
Intensive with green color of cotyledon	-0.46	0.19	0.13
Cotyledon length	0.31	0.39	0.27
Stem length	0.43	-0.04	-0.35
Leaf length	0.77	0.17	-0.18
Leaf margin	-0.04	-0.22	0.22
Leaf shape	0.36	-0.03	0.32
Undulation of leaf margin	0.12	-0.22	0.51
Leaf width	0.77	0.17	-0.20
Intensive with green color of leaf blade	-0.21	0.19	0.54
Length of leaf petiole	0.78	0.25	-0.10
Time taken of first female flower	-0.43	0.17	-0.56
Time taken of first male flower	-0.45	0.30	-0.48
Fruit circumference	0.01	-0.80	-0.01
Color of fruit skin at market stage	-0.30	-0.08	0.10
Fruit diameter	0.01	-0.79	-0.01
Fruit weight	-0.12	0.01	-0.05
Fruit length	-0.06	0.48	-0.04
Length of fruit peduncle	0.19	0.27	0.21
Luster of fruit skin	-0.15	-0.49	-0.15
Fruit marbling	-0.20	-0.35	0.03
Shape of fruit peduncle	0.09	-0.03	0.53
Shape of fruit in longitudinal section	-0.24	-0.62	0.08
Shape of fruit apex	-0.19	0.43	0.31
Shape of fruit base	-0.49	0.10	-0.05
Stripes on fruit skin	-0.53	0.43	0.38
Time of fist harvesting fruit	-0.56	0.13	-0.43
Weight of 100 seeds	-0.11	0.05	-0.53



Legend

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
ThHo01	DaNo01	HcmC01	TaNi01	TiGi01	DoNa01	QuNa01	QuNa02	DoNa02	QuNa03	QuNa04	QuNa05	NiTh01	LaDo01	LaDo02	NiTh02	NiTh03	HaGi01	CaTh01	HaGi02	HaGi03	KiGi01	BrVt02	TiGi02	BiPh01	GiLa01	LoAn01	LoAn02	TaNi02	PhYe01	LaDo03	BiTh01

Figure 5.16. 3D distributions of 32 bottle gourd accessions based on 13 categorical (a) and 14 continuous (b) variables (green lines indicate eigenvectors).

- Hierarchical clustering of bottle gourd accessions

Genetic relationships of 32 bottle gourd accessions were analysed from 27 varying morphological characteristics indicated two main groups (Figure 5.17) in which accession NiTh03 was separated from the others with 0.07 point of coefficient value. The large main group was divided into two minor groups (see Figure 5.18 for the variability in fruits of the accessions). The first minor group included three accessions (ThHo01, PhYe01, and BiPh01). The second minor group included the rest 28 accessions.

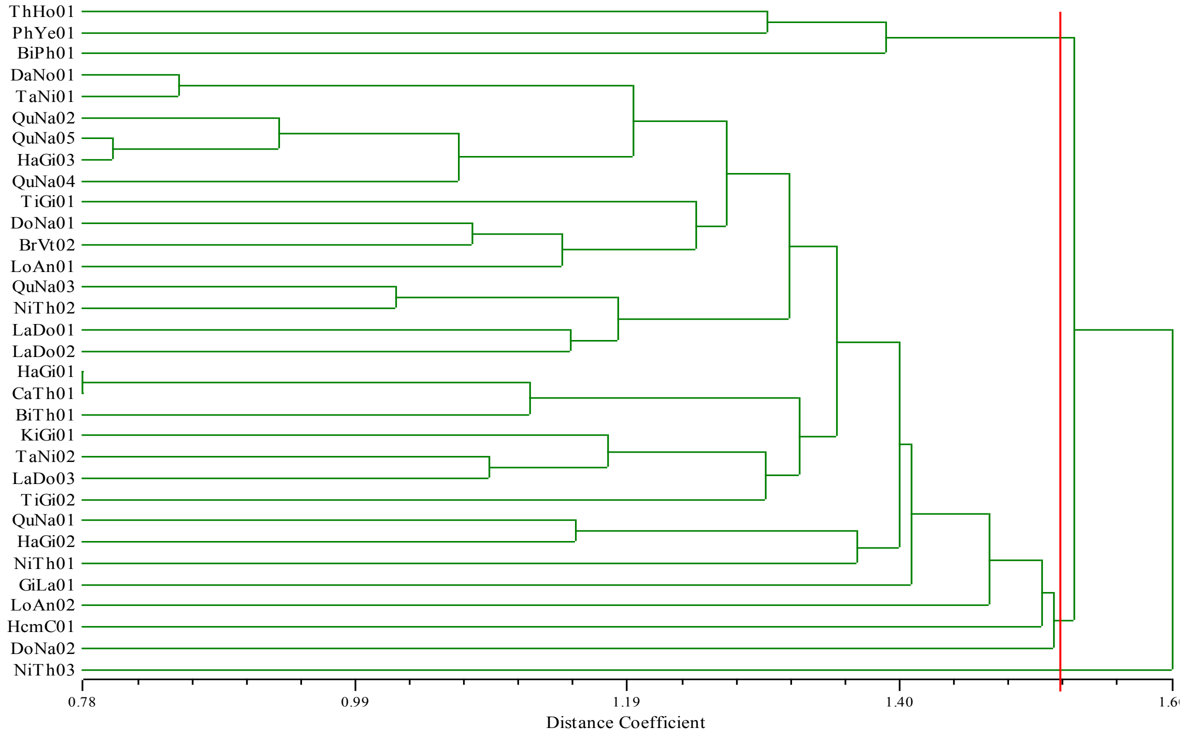


Figure 5.17. Relationships among 32 bottle gourd accessions based on 13 categorical and 14 continuous variables (the red line is level of cut for three groups).

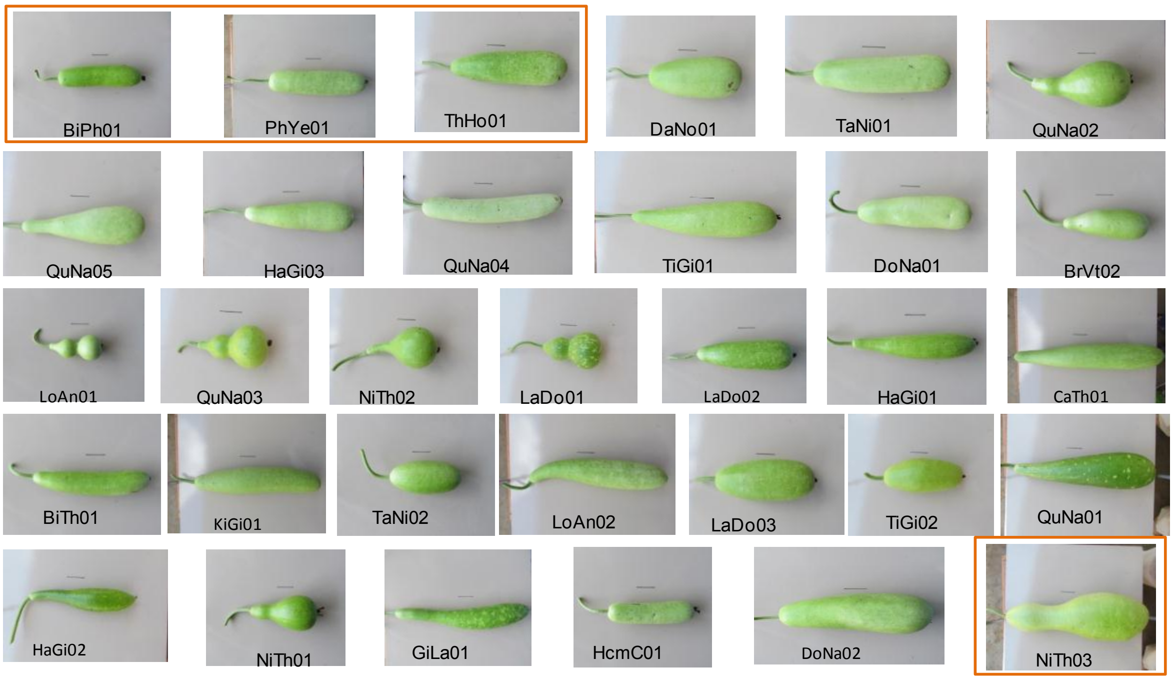


Figure 5.18. Variation in size, shape, and color of fruit of 32 bottle gourd accessions. The accessions were boxed following level of cut in dendrogram (bars = 5cm).

5.3.2.4 Loofah (*Luffa cylindrica*)

- Morphological expressions of examined characteristics from loofah accessions

There were 27 different variables used to evaluate 39 loofah accessions. All accessions had cotyledons color in dark green (Cr.01), shape of stem in angular (Cr.07). Leave margin were dented (Cr.14) and shape of fruits in transversal section were round (Cr.75). Other 23 varying characteristics are given in Appendix 17 and Appendix 18 for categorical and continuous variables, respectively.

Similar coefficients among variables are given in Table 5.10 showing high values of fruit weight in first two canonical axes with 0.52 and 0.5, respectively. Two other variables including length of leaf petiole (0.56) and fruit length (0.62) also had very similar values in the first canonical axis. Two other variables including color of fruit skin at market stage (0.59) and shape of fruit peduncle (0.52) also had highly similar values in the second canonical axis. Leaf width appeared with the similarity value of 0.43 which was the highest value in the third canonical axis.

Table 5.10. Correlations among variables in the first three canonical axes (C1, C2, and C3) based on 39 loofah accessions

Variables	C1	C2	C3
Cotyledon length	0.24	0.02	0.35
Stem length	0.33	0.12	0.27
Depth of lobbing of leaf blade	0.03	-0.59	-0.37
Leaf length	0.43	-0.42	0.39
Leaf shape	-0.25	-0.23	0.13
Leaf width	0.35	-0.49	0.43
Intensive with green color of leaf blade	0.13	-0.18	-0.53
Length of leaf petiole	0.56	-0.03	0.01
Time taken of first female flower	-0.80	-0.01	0.05
Time taken of first male flower	-0.67	-0.02	0.09
Density of ridges on fruit	0.20	0.00	-0.06
Fruit aroma	0.12	0.05	-0.50
Fruit circumference	-0.19	0.18	-0.30
Color of fruit skin at market stage	-0.30	0.59	0.20
Color of fruit stripes	-0.30	0.42	0.21
Fruit weight	0.52	0.50	-0.43
Fruit length	0.62	0.32	-0.20
Length of fruit peduncle	0.22	0.20	0.37
Shape of fruit peduncle	-0.16	0.52	-0.01
Present of ribs on fruit	-0.25	-0.34	0.02
Shape of fruit apex	-0.44	0.10	0.06
Shape of fruit base	-0.32	-0.45	-0.53
Weight of 100 seeds	-0.05	-0.27	0.35

- Genetic relationships among loofah accessions based on morphological characteristics

Distributions of 39 loofah accessions were plotted in 3D separately for categorical variables (Figure 5.19a) and continuous variables (Figure 5.19b). Furthermore, cluster analysis was performed by using UPGMA method to determine genetic relationships among accessions (Figure 5.20).

- The accessions which were similar in expression regarding categorical variables:
    - QuNa01, QuNa03, BiTh01, QuNa02, LoAn01, HaGi05, NiTh01, and KiGi01
    - BiDu02 and TiGi01
    - QuNa04, LoAn02, and ViLo01
    - BeTr02, DoNa02, HaGi02, and QuNg01

  * NiTh02 and CaTh02
  * BeTr01, NiTh03, QuNa05, and HaGi04
  * BiDu01 and HaGi03

- The accessions which were similar in expression regarding continuous variables:
  * QuNa01, DoNa01, BrVt01, HaGi01, QuNa06, PhYe01, HaGi03, and NiTh03
  * QuNa02, BeTr02, BiPh01, QuNa04, BeTr01, NiTh01, and ViLo01
  * HcmC02, BiTh01, and HcmC03
  * QuNa03, NiTh02, and KiGi01
  * QuNa05, LoAn02, DoNa02, HaGi05, HaGi04, BaLi02, HcmC04, and HaGi03
  * BiDu01, NiTh04, BaLi01, LoAn01, TiGi01, CaTh02, and BiDu02

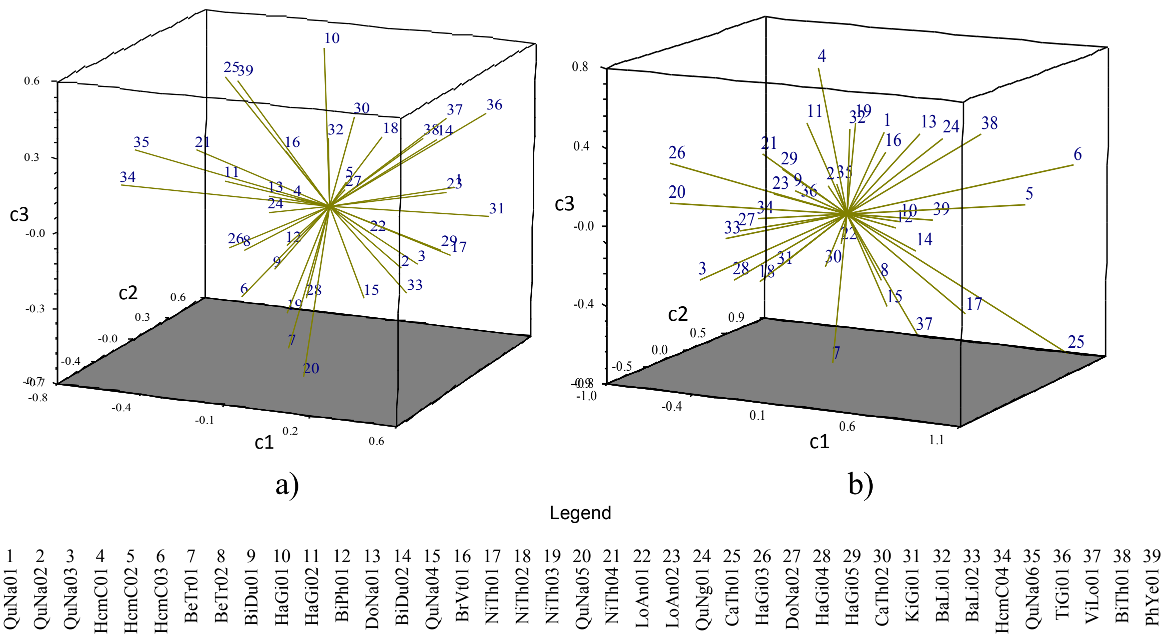


Figure 5.19. 3D distributions of 39 loofah accessions based on 11 categorical (a) and 12 continuous (b) variables (green lines indicate eigenvectors).

- Hierarchical clustering of loofah accessions

Genetic relationships of 39 loofah accessions based on 23 varying morphological characteristics is given in Figure 5.20. The dendrogram shows two main groups of the accessions with the independent position of accession CaTh01 and the large group including 38 accessions. Regarding the level of cut for three groups, the accessions HcmC03 was separated from the rest 37 accessions (see Figure 5.21 for the variability in fruits of the accessions).

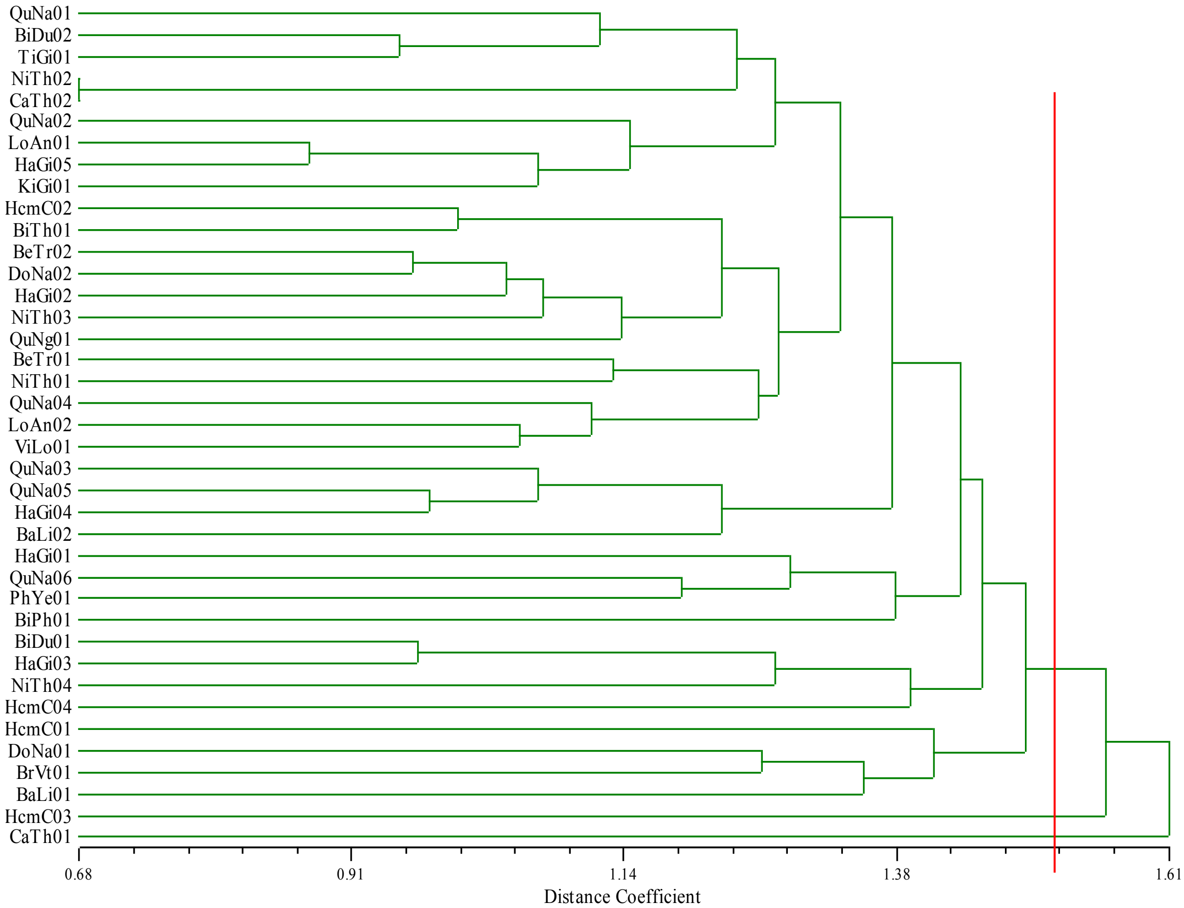


Figure 5.20. Relationships among 39 loofah accessions based on 11 categorical and 12 continuous variables (the red line is level of cut for three groups).

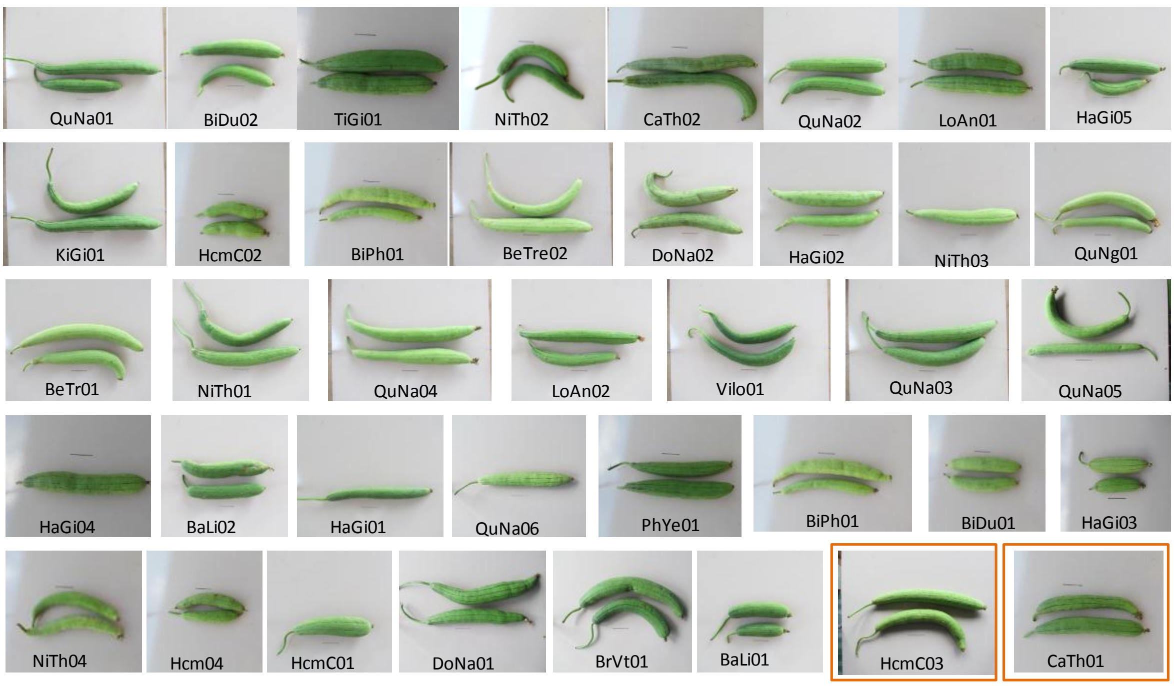


Figure 5.21. Variation in size, shape, and color of fruit of 39 loofah accessions. The accessions were boxed following level of cut in dendrogram (bars = 5cm).

5.3.2.5 Bitter gourd (*Momordica charantia*)

- Morphological expressions of examined characteristics from bitter gourd accessions

There were 37 variables used to evaluate 42 bitter gourd accessions. As a result, all accession had the same number of lobes (Cr.15), the fruit with warts (Cr.67) and spines (Cr.72), and the large indentation of edger of seeds (Cr.89), except accession HcmC01. Other varying characteristics were given in Appendix 19 and Appendix 20 for categorical and continuous variables, respectively.

Correlations of variables calculating from 42 bitter gourd accessions (Table 5.11) indicated high similarities of three variables, including stem length (0.64), fruit circumference (0.57), and indentation of seed edge (0.68) in the first canonical axis. Similarly, high similar coefficients of length of fruit ridge (0.60), luster of fruit skin (0.64), and shape of the top of warts on fruit (0.53) in the second canonical axis.

- Genetic relationships among bitter gourd accessions based on morphological characteristics

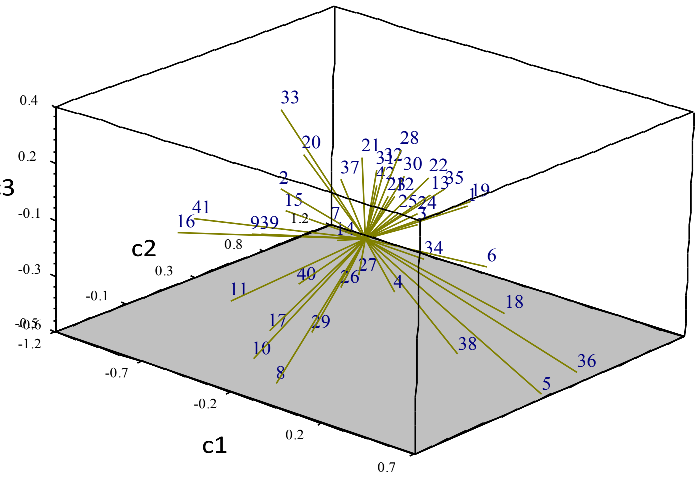
Distributions of 42 bitter gourd accessions were plotted in 3D separately for categorical variables (Figure 5.22a) and continuous variables (Figure 5.22b). Furthermore, cluster analysis was performed by using UPGMA method to determine genetic relationships among accessions (Figure 5.23).

- The accessions which were similar in expressions regarding categorical variables:
  - BrVt01, QuNa04, DoNa04, and TaNi01
  - BiPh01, DoNa02, BiDu04, BiDu05, NiTh01, BrVt06, TiGi02, and BiPh02
  - TiGi03, AnGi02, BrVt05, and BiPh04
  - BiDu02 and HcmC03
  - SoTr01, BiPh03, and NiTh02
  - TiGi01, BiDu03, and BiDu02
  - QuNa01, BrVt02, BrVt04, BrVt03, DoNa05, NiTh03, and QuNa03
  - LaDo01 and BiPh05
  - AnGi01, TiGi05, and HcmC02
  - DoNa01 and DoNa03
  - QuNa02 and TiGi04
- The accessions which were similar in expressions regarding continuous variables:
  - BrVt01, AnGi02, and BiDu02
  - DoNa01, DoNa05, NiTh01, BiDu05, TiGi05, TaNi01, and HcmC03
  - BiPh01, DoNa03, DoNa04, QuNa04, BrVt03, BiDu03, TiGi03, NiTh02, TiGi02, BiPh04, and DoNa02

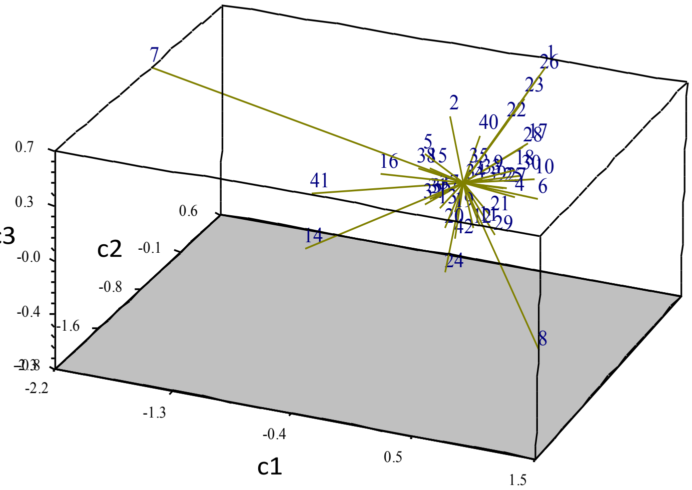
* TiGi01, BiDu01, BrVt06, BiPh05, TiGi04, BrVt05, QuNa02, BrVt04, BiPh02, HcmC02, BrVt02, SoTr01, and BiDu04
* AnGi01 and BiPh03
* QuNa03, DaLa01, and BiTh01

Table 5.11. Correlations among variables in the first three canonical axes (C1, C2, and C3) based on 42 bitter gourd accessions

Variables	C1	C2	C3
Intensive with green color of cotyledon	0.40	0.09	0.45
Stem length	0.64	0.13	-0.22
Number of nodes up to node with the 1st female flower	-0.47	-0.08	0.22
Number of nodes up to node with the 1st male flower	-0.85	0.09	0.08
Number of side shoots	-0.36	-0.14	-0.26
Thickness of main stem	-0.32	-0.01	-0.17
Leaf length	0.34	-0.29	-0.59
Leaf width	0.32	-0.41	-0.47
Intensive with green color of leaf lobes	0.12	0.19	0.27
Length of leaf petiole	0.43	0.11	-0.50
Intensive with green color of stigma	-0.11	0.23	-0.50
Ovary length	0.42	-0.25	-0.08
Time taken of first female flower	-0.73	-0.29	0.21
Time taken of first male flower	-0.83	-0.16	0.16
Bitterness of fruit flesh	0.07	0.48	0.02
Fruit circumference	0.57	-0.35	0.10
Color of fruit skin at market stage	-0.10	0.35	0.19
Color of fruit skin at ripe stage	0.08	0.31	-0.10
Fruit weight	0.32	-0.50	0.15
Fruit length	0.21	-0.53	0.25
Length of fruit peduncle	-0.26	-0.38	0.01
Length of fruit ridge	0.37	0.60	0.27
Luster of fruit skin	0.17	0.64	-0.32
Shape of fruit in longitudinal section	0.16	0.35	0.11
Shape of fruit apex	0.16	0.20	0.03
Shape of fruit base	-0.19	0.47	0.36
Shape of the top of warts on fruit	-0.17	0.53	-0.17
Time for physiological maturity of fruit	-0.71	-0.22	0.09
Wart size	0.38	0.17	0.43
Number of warts	-0.53	-0.17	-0.46
Color of seed coat	-0.62	-0.02	-0.17
Indentation of seed edge	0.68	-0.33	0.15
Seed size	0.04	-0.33	0.22
Weight of 100 seeds	0.34	-0.47	0.23



a)



b)

Legend

1	BrVt01
2	DoNa0
3	BiPh01
4	TiGi01
5	AnGi01
6	SoTr01
7	HcmC0
8	QuNa0
9	QuNa0
10	BrVt02
11	BrVt03
12	NiTh01
13	NiTh02
14	NiTh03
15	QuNa0
16	DaLa01
17	BrVt04
18	HcmC0
19	TiGi02
20	TiGi03
21	TiGi04
22	BiPh02
23	AnGi02
24	BiPh03
25	BiDu01
26	BiDu02
27	BrVt05
28	BrVt06
29	BiDu03
30	BiDu04
31	BiDu05
32	DoNa0
33	DoNa0
34	DoNa0
35	QuNa0
36	TiGi05
37	BiPh04
38	TaNi01
39	BiPh05
40	DoNa0
41	BiTh01
42	HcmC0

Figure 5.22. 3D distributions of 42 bitter gourd accessions based on 17 categorical (a) and 17 continuous (b) variables (green lines indicate eigenvectors).

- Hierarchical clustering of bitter gourd accessions

Genetic relationships among 42 bitter gourd accessions were given in Figure 5.23. The dendrogram shows two main groups met at 2.39 of coefficient value. The first small group had only HcmC01 accession, whereas, the second large group included the rest 41 accessions. Regarding the level of cut for three groups, the accession QuNa01 was distant separation from the second large group (see Figure 5.24 for the variability in fruits of the accessions).

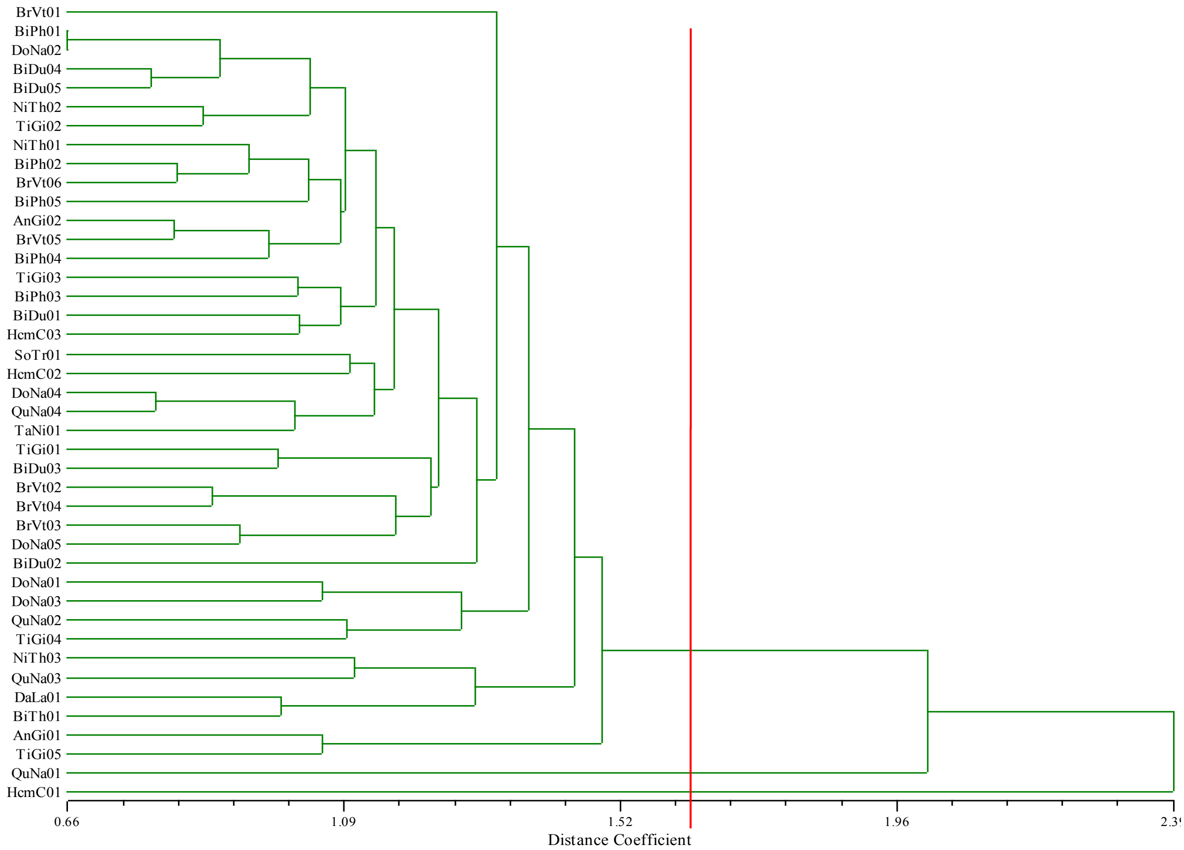


Figure 5.23. Relationships among 42 bitter gourd accessions based on 17 categorical and 17 continuous variables (the red line is level of cut for three groups).

Figure 5.24. Variation on size, shape, and color of fruit of 42 bitter gourd accessions. The accessions were boxed following level of cut in dendrogram.

5.3.3 Discussion on morphological diversity among accessions of five cucurbit species

Continuous and categorical variables were applied for classifying the diversity of vegetable accessions (Franco et al., 1998; Franco and Corssa, 2002; Knezovic et al., 2005; Ortiz et al., 2010). Continuous variables are related to measurable quantitative characteristics, while categorical variables are related to qualitative and pseudo-qualitative characteristics and some other quantitative characteristics that were assessed qualitatively.

With respect to morphological evaluation for cucurbit species, various qualitative, quantitative and pseudo-qualitative characteristics are given enclosing the categorical variables for examination, i.e. UPOV (2013) introduced the test guidelines for evaluating distinctness, uniformity and stability (DUS test) for new cultivars. Meanwhile, other studies of genetic diversity of cucurbit species are using continuous variables for evaluating cucurbit germplasm.

Quantitative characteristics that are related to fruits and seeds were already used for classifying cucurbit diversity, such as in ash gourd (Pandey et al., 2008), egusi (Koffi et al., 2008) and bitter gourd (Dey et al, 2006; Macusi and Rosario, 2009; Dalamu et al., 2012). In contrast, qualitative and pseudo-qualitative characteristics are less interesting, even though some of them were recommended for classifying the relationships of phenotypes within plant species (UPOV, 2013). In addition, if it is not possible to distinguish the morphological differences between the accessions using only quantitative or only qualitative variables, then a combination of both types of variables is suggested (Knezovic et al., 2005). Therefore, the study combined two types of variables describing qualitative and quantitative characteristics for evaluating five most cultivated cucurbit species.

In this study, genetic diversity of the accessions within five cucurbit species, including cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*), were characterized by quantitative, qualitative and pseudo-qualitative characteristics. Almost of these characteristics related to morphology and yield were useful for breeders to rely on for choosing initial materials of breeding programs.

The distributions of the accessions based on 3D bi-plots result indicate the position of the accessions based on the different morphological characteristics. Similarly, combining categorical and continuous variables for hierarchical clustering was useful in separation the accessions that own special characteristics, i.e. the accessions TiGi02 and TiGi03 of cucumber (*Cucumis sativus*) (Figure 5.12), the accession BaLi01 pumpkin (*Cucurbita moschata*) (Figure 5.14, Figure 5.15) and the accession HcmC01 and QuNa01 of bitter gourd (*Momordica charantia*) (Figure 5.24). The morphological diversity of cucurbit germplasm was independent from the origin regions, exception for accession TiGi02 and accession TiGi03 of cucumber (with the distance coefficient value of 1.12 in a range of 0.99 to 1.67; see Figure 5.11), accession BiDu04 and accession BiDu05 of bitter gourd (with the distance coefficient value of 0.79 in a range of 0.66 to 2.30; Figure 5.23).

The characterizations of germplasm can be helpful for choosing appropriate materials for breeding. Combination the categorical and continuous variables were useful for evaluation the variability of cucurbit accessions that were collected in different regions.

5.4 Determination of stable characteristics for classifying bitter gourd (*Momordica charantia*) accessions

5.4.1 Effect of growing conditions on 28 characteristics of bitter gourd accessions

The study examined 28 different characteristics (based on Dey et al., 2006; Dalamu et al., 2012; and UPOV, 2013) of seven bitter gourd (*Momordica charantia*) accessions in two different growing conditions. These characteristics were measured and evaluated on stems, leaves, flowers, and fruits of the accessions.

5.4.1.1 Variations of continuous variables in different growing conditions

The continuous variables including 16 quantitative characteristic are shown in Table 5.12 (rows 1 to 16). All variables were different expressions within two growing conditions, except the number of leaf lobes. With seven separated lobes in each leaf, this variable was counted the same for all accessions in both environments. The number of lobes on leaf blade is one of the key-assessments for bitter gourd (Herklots, 1972; Anming et al., 1986; Pham, 1999). Thus, the exact number of leaf lobes of all accessions in two different growing conditions proved again the stability of this characteristic.

A characteristic is stable in different growing conditions, if it response is similar to the effects of living environment. Stability of continuous variables in the study was measured based on the test for significant difference (two-sample test) and the correlation within two growing conditions (Table 5.13).

Table 5.12: Morphological expressions of 28 examined characteristics of seven bitter gourd accessions in two different growing conditions

Row	Characteristic	Greenhouse condition							Field condition						
		HcmC 01	QuNa 01	BrVt 02	BrVt 03	NiTh 01	NiTh 02	NiTh 03	HcmC 01	QuNa 01	BrVt 02	BrVt 03	NiTh 01	NiTh 02	NiTh 03
1	Number of side shoots	42	31	26	25	20	21	20	29	27	30	22	14	17	26
2	Thickness of main stem (the 15th node) (mm)	4.2	4.6	4.5	4.1	4.1	4.3	4.5	4.2	4.4	4	3.7	3.8	3.7	3.9
3	Number of leaf lobes	7	7	7	7	7	7	7	7	7	7	7	7	7	7
4	Ratio length/ width of leaf	0.99	0.79	0.73	0.92	0.96	0.85	1.10	1.17	0.84	0.9	0.97	0.95	1.02	0.99
5	Number of nodes up to node with 1st male flower	27	17	5	7	5	5	18	21	17	6	6	6	6	14
6	Number of nodes up to node with 1st female flower	24	17	21	14	13	17	27	19	18	10	14	16	14	25
7	Time of first male flower flowering (days)	48	45	32	32	29	30	46	47	52	28	29	28	28	51
8	Time of first female flower flowering (days)	45	42	37	33	30	36	52	45	55	31	32	39	39	55
9	Ovary length (mm)	13.6	33.0	20.4	22.0	18.2	25.8	19.8	12.1	31.5	24.3	25.1	22.2	20.3	19.8
10	Fruit circumference (cm)	6.0	20.4	17.9	18.2	13.5	17.3	9.4	5.3	18	15.2	17.6	18.3	13.5	12.4
11	Fruit diameter (mm)	19	65	57	58	43	55	30	17	57	48	56	58	43	39
12	Fruit length (cm)	5.9	28.7	18	16.8	17.3	18.8	14.1	4.1	29.4	14.7	14.5	16.8	17.6	20.2
13	Ratio length/ diameter of fruit	3.11	4.42	3.16	2.9	4.02	3.42	4.7	2.41	5.16	3.06	2.59	2.90	4.09	5.18
14	Time for physiological maturity of fruit (days)	65	68	54	54	54	57	85	67	77	54	57	59	61	73
15	Fruit weight (g)	5	310	134	136	155	150	52	4	279	123	132	161	142	92
16	Weight of 100 seeds (g)	3.99	22.64	23.2	22.83	16.63	16.7	20.2	4.03	23.32	22.38	20.3	18.04	17.52	21.46

Table 5.12. (Continued)

Row	Characteristic	Greenhouse condition							Field condition						
		HcmC 01	QuNa 01	BrVt 02	BrVt 03	NiTh 01	NiTh 02	NiTh 03	HcmC 01	QuNa 01	BrVt 02	BrVt 03	NiTh 01	NiTh 02	NiTh 03
17	Fruit spines	Pre	Pre	Pre	Pre	Abs	Abs	Pre	Pre	Pre	Pre	Pre	Abs	Abs	Pre
18	Intensive of fruit bitterness	Str	Wea	Med	Med	Med	Med	Wea	Str	Wea	Wea	Wea	Med	Wea	Med
19	Color of fruit skin at market stage	Lgr	Wht	Gre	Gre	Gre	Gre	Wht	Gre	Wht	Gre	Gre	Gre	Gre	Wht
20	Color of fruit skin at ripe stage	Ora	Ora	Ora	Ora	Ora	Ora	Ora	Ora	Ora	Ora	Ora	Ora	Ora	Ora
21	Fruit ridge	Abs	Abs	Abs	Abs	Pre	Pre	Abs	Abs	Abs	Abs	Abs	Pre	Pre	Abs
22	Fruit shape in longitudinal section	Spi	Spi	Obl	Spi	Spi	Spi	Spi	Spi	Obl	Obl	Spi	Spi	Spi	Spi
23	Shape of fruit apex	Acu	Obt	Obt	Obt	Obt	Obt	Acu	Acu	Obt	Obt	Obt	Acu	Obt	Acu
24	Shape of fruit base	Acu	Obt	Obt	Obt	Obt	Obt	Acu	Acu	Acu	Obt	Acu	Obt	Acu	Acu
25	Shape of the top of fruit wart	Acu	Obt	Obt	Obt	Rou	Rou	Obt	Acu	Obt	Obt	Obt	Rou	Rou	Rou
26	Size of fruit wart	Sma	Med	Med	Med	Lar	Lar	Med	Sma	Med	Med	Med	Lar	Lar	Med
27	Indentation of seed edge	Smo	Spa	Spa	Spa	Spa	Spa	Spa	Smo	Spa	Spa	Spa	Spa	Spa	Spa
28	Striation of seed coat	Smo	Pro	Pro	Pro	Unn	Unn	Cpr	Smo	Pro	Pro	Pro	Unn	Unn	Cpr

Abb.: Pre, present; Abs, absent; Str, strong; Wea, weak; Med, medium; Lgr, light green; Gre, green; Wht, white; Drg, dark green; Ora, orange; Spi, spindle; Obl, oblong; Acu, acute; Obt, obtuse; Rou, round; Sma, small; Lar, large; Smo, smooth; Pro, prominent; Unn, unnoticeable; Cpr, clear prominent.

Table 5.13. Differences of continuous variables from seven bitter gourd accessions in two growing conditions, greenhouse (G) and field (F)

Characteristics	Mean values G	Mean values F	Two-sample test	Correlation coefficient
Number of side shoots	26.4	23.6	(0.50)	0.62(0.14)
Thickness of main stem (the 15th node) (mm)	4.33	3.96	(0.02)	-
Ratio length/ width of leaf	0.91	0.98	(0.29)	0.56(0.19)
Number of nodes up to node with the 1st female flower	19.0	16.6	(0.40)	0.57(0.18)
Number of nodes up to node with the 1st male flower	12.0	10.9	(0.83)	0.98(0.00)
Time of first female flower flowering (days)	39.3	42.3	(0.57)	0.77(0.05)
Time of first male flower flowering (days)	37.4	37.6	(1.00)	0.97(0.00)
Ovary length (mm)	21.8	22.2	(0.92)	0.83(0.02)
Fruit circumference (cm)	14.7	14.3	(0.90)	0.80(0.03)
Fruit diameter (mm)	46.7	45.4	(0.89)	0.81(0.03)
Fruit length (cm)	17.1	16.6	(0.92)	0.91(0.00)
Ratio of fruit length/ fruit diameter	3.7	3.6	(0.93)	0.83(0.02)
Time for physiological maturity of fruit (days)	62.4	64.0	(0.73)	0.82(0.02)
Fruit weight (g)	134.6	133.3	(0.97)	0.98(0.00)
Weight of 100 seeds (g)	18.0	18.2	(0.96)	0.98(0.00)

The numbers in brackets indicated P-values.

The two sample test (Table 5.13, the 4th column) indicated that the thickness of main stem of the accessions were significantly different (permutation test, P = 0.02) in the two different growing conditions and was therefore not further considered. The variables which did not respond differently in both growing conditions were evaluated later on with correlation test.

Similarly, correlation analyses (Table 5.13, the 5th column) proved three variables, which had non-significant correlations:

- Number of side shoots (r = 0.62, P = 0.14)
- Ratio length/ width of leaf (r = 0.56, P = 0.19)
- Number of nodes up to node with the 1st female flower (r = 0.57, P = 0.18).

Eleven variables were significant correlations, including:

- Number of nodes up to node with 1st male flower (r = 0.98, P = 0)

- Time of first female flower flowering ($r = 0.77$, $P = 0.05$)
- Time of first male flower flowering ($r = 0.97$, $P = 0$)
- Ovary length ($r = 0.83$, $P = 0.02$)
- Fruit circumference ($r = 0.80$, $P = 0.03$)
- Fruit diameter ($r = 0.81$, $p = 0.03$)
- Fruit length ($r = 0.91$, $P = 0$)
- Ratio of fruit length/ fruit diameter ($r = 0.83$, $P = 0.02$)
- Time for physiological maturity of fruit ($r = 0.82$, $P = 0.02$)
- Fruit weight ($r = 0.98$, $P = 0$)
- Weight of 100 seeds ($r = 0.98$, $P = 0$).

Consequently, one variable, the thickness of main stem, was significantly different ($P < 0.05$) in permutation test. Three variables, including number of side shoots, ratio length / width of leaf, and number of nodes up to node with the 1st female flower, that were not significantly correlated within two different growing conditions were determined as unstable variables and eliminated from the later calculations.

5.4.1.2 Variations of categorical variables in different growing conditions

Contrary to the continuous variables, the categorical variables were rarely used in hierarchy analyses so far. The reason for this circumstance may be the unclear-expression of the characteristics and the subjectivity of evaluators. In fact, there are some clear determinations, such as UPOV guidelines (UPOV, 2013), that can be relied on for assessing categorical variables. In the study, 12 categorical variables were involved for evaluation, and the results are given in Table 5.12 (rows 17 to 28).

Similar to the number of leaf lobes characteristic, the color of fruit skin at ripe stage were the same for all accessions. The fruit turning orange at ripening stage is also a particular characteristic for identifying bitter gourd (Anming and Jeffrey, 2011). Therefore, this characteristic was stable for all accessions but not suitable for differing among the accessions. Five other categorical variables were also stable for the accessions within two different growing conditions, including presence of ridge on fruits, presence of fruit spines, size of fruit warts, indentation of seed edge, and striation of seed coat. The others characteristics were varying in response to different environments. Furthermore, the stabilities of categorical variables were continued comparing based on dissimilar values to evaluate their stable levels.

5.4.2 Dissimilarity assessment of the variables in different growing conditions

5.4.2.1 Continuous variables

Except one variable that was firmly fixed on all accessions (number of leaf lobes), one variable was significantly different in two-samples tested (thickness of main stem), and three variables were non-significant correlated (including number of side shoots, ratio length / width of leaf, and number of nodes up to node with the 1st female flower), 11 other variables were involved in dissimilar calculations and the results are given in Table 5.14 (rows 1 to 11). The data show that dissimilar values of the variables within two growing conditions were found with a range of 0.17 to 0.58. It is easy to recognize directionality that the variables with higher correlation coefficient enclose lower dissimilar values. Therefore, basing on correlation coefficient (r) or significance levels (P) from correlation test, the variables were divided into two groups as follows:

- $r < 0.90$: the group involved six variables, as time for first female flower flowering, ovary length, fruit circumference, fruit diameter, ratio of fruit length/ fruit diameter, and time for physiological maturity of fruit, with dissimilarity values of 0.63, 0.58, 0.58, 0.57, 0.54, and 0.55, respectively.
- $r > 0.90$: the group involved five variables, as number of nodes up to node with the 1st male flowers, time for first male flower flowering, fruit length, fruit weight, and weight of 100 seeds, with the dissimilarity values of 0.19, 0.24, 0.39, 0.17, and 0.19, respectively.

UPGMA clustering was executed following these two groups for each growing condition. As a result, the hierarchy of the accessions in the first group (including 6 variable with $r < 0.90$ or $0.01 < P \leq 0.05$) were clearly different under the two different growing conditions (Figure 5.25 A, B). In contrast, the hierarchy of the accessions in the second group (including 5 variables with $r > 0.90$ or $P < 0.01$) were exactly the same in the two different growing conditions (Figure 5.25 C, D).

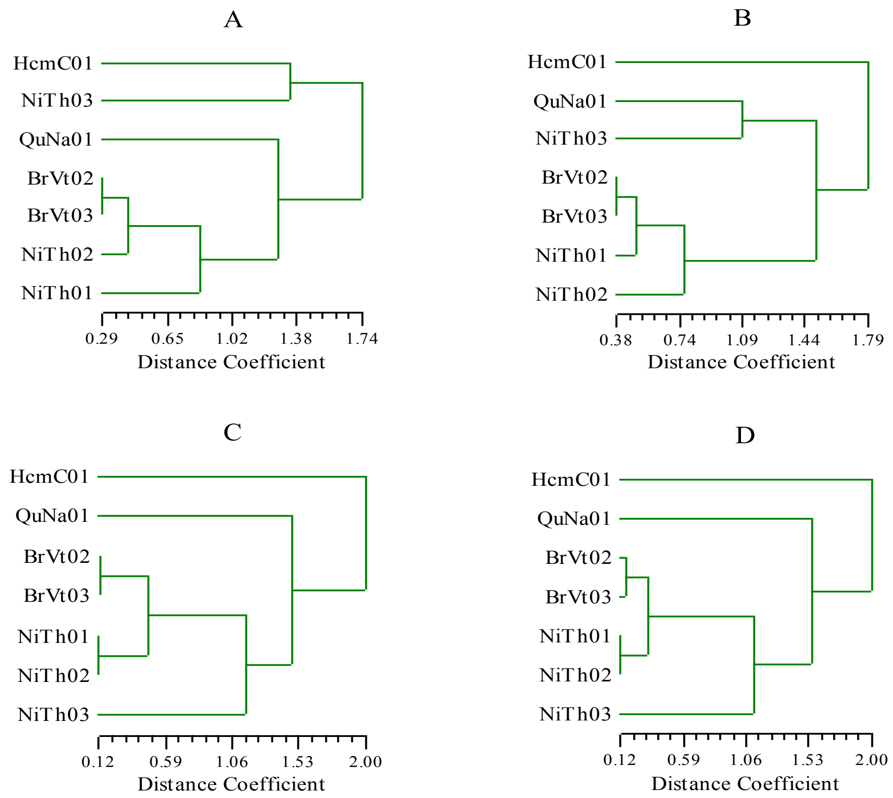


Figure 5.25. Relationships among 7 bitter gourd accessions based on the continuous variables with $r < 0.90$ (or $0.01 < P \leq 0.05$) in greenhouse (A) and field (B) conditions; and with $r > 0.90$ (or $P < 0.01$) in greenhouse (C) and field (D) conditions.

5.4.2.2 Categorical variables

Except for color of fruit skin at ripe stage, the variable that was firmly fixed, five variables (including the presence of ridge on fruit, presence of fruit spines, size of fruit warts, indentation of seed edge, and striation of seed coat) were stable in the two growing conditions, six other variables involved in this calculation (Table 5.14, rows 12 to 17) exhibited dissimilarity values ranging from 1.01 to 0.45. The dissimilarity values of categorical variables were calculated indirectly from coding digits. To find out variables that are stables it should be relied on magnitude of dissimilarity from continuous variables:

- dissimilarity value ≥ 0.54: variable was determined as instability,
- dissimilarity value ≤ 0.39: variable was determined as stability, and
- 0.39 < dissimilarity value < 0.54: stability of variable was undefined.

Relying to three determinations, four categorical variables were determined as unstable because they had had dissimilarity values larger than 0.54; those were intensive of bitterness of fruit flesh, shape of fruit in longitudinal sections, shape of fruit base, and shape of fruit apex with dissimilarity values of 0.94, 0.78, 1.01, and 0.68, respectively.

The other two variables including color of fruit skin at market stage (dissimilarity value = 0.51) and shape of the top of fruit wart (dissimilarity value = 0.45) were ranked in undefined characteristics. Therefore, UPGMA clustering was executed separately for them to clarify their stability. Consequently, the hierarchy of the accessions indicated that neither color of fruit skin at market stage (Figure 5.26 A, B) nor shape of the top of wart (Figure 5.26 C, D) were stable characteristics.

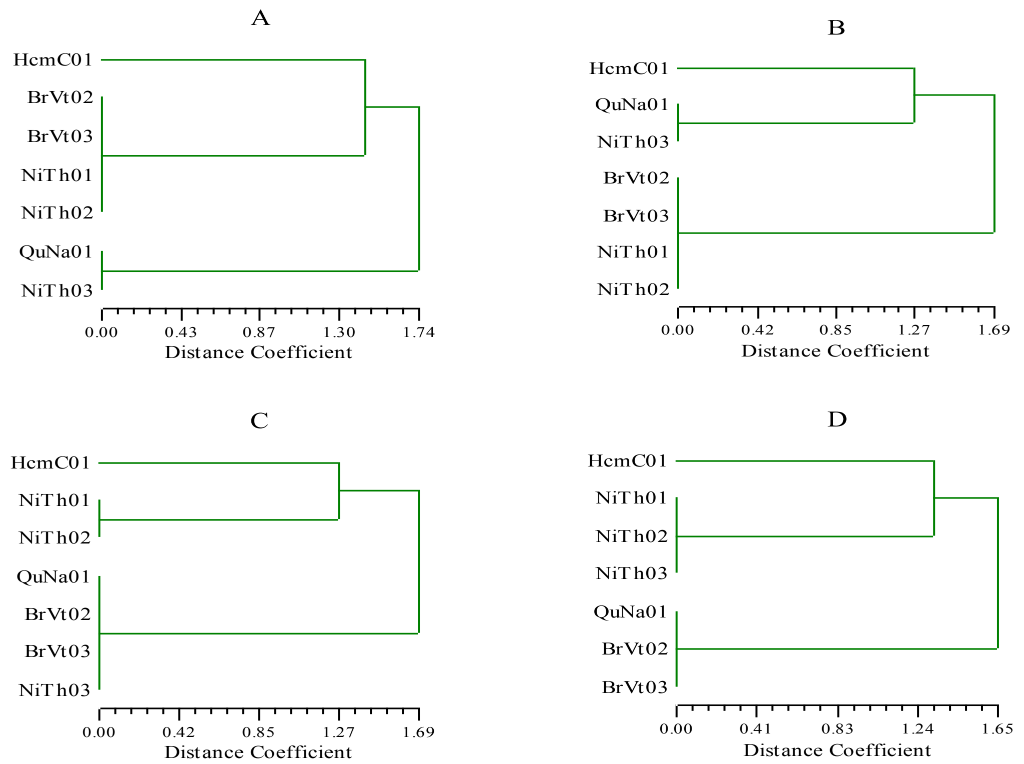


Figure 5.26. Relationships among 7 bitter gourd accessions based on fruit skin at market stage in greenhouse (A) and field (B) conditions; and based on shape of the top of wart in greenhouse (C) and field (D) conditions.

Bitter gourd (*Momordica charantia*) is an important vegetable species belonging to Cucurbitaceae. This is cultivated in whole country and used in daily meal of Vietnamese. Moreover, this crop has been used in various traditional medicine prescriptions of Vietnamese and other inhabitants in Asia, South America, and East Africa (Vo, 1997; Do, 2004; Kumar et al., 2010; Josheph and Jini, 2013). Because of nutritional and medicinal values, numerous accessions have been collected, evaluated and conserved in Vietnam with the purpose of eliminating genetic erosion and diversifying genetic resources for breeding programs (Tran and Ha, 2000; Altoveros and Engle, 2000).

Table 5.14. The symmetric of dissimilar values of 21 examined characteristics of seven bitter gourd accessions in two different growing conditions

Row	Characteristic	timemf	timeff	circuf	diamef	lengtf	ratiof	weighf	timepm	lengto	nodema	P100se	bitter	comark	shapel	basesh	wartst	apexsh
1	Time of first male flower flowering (timemf)	0.24																
2	Time of first female flower flowering (timeff)		0.63															
3	Fruit circumference (circuf)			0.58														
4	Fruit diameter (diamef)				0.57													
5	Fruit length (lengtf)					0.39												
6	Ratio of fruit length/ fruit diameter (ratiof)						0.54											
7	Fruit weight (weighf)							0.17										
8	Time of physiological maturity of fruit (timepm)								0.55									
9	Ovary length (lengto)									0.54								
10	Number of nodes up to node with 1st male flower (nodema)										0.19							
11	Weight of 100 seeds (p100se)											0.19						
12	Intensive of bitterness of fruit flesh (bittef)												0.94					
13	Color of fruit skin at market stage (comark)													0.51				
14	Shape of fruit in longitudinal section (shapel)														0.78			
15	Shape of fruit base (basesh)															1.01		
16	Shape of the top of wart (wartst)																0.45	
17	Shape of fruit apex (apexsh)																	0.68

Morphological characterization and molecular markers are two approaches used for evaluating the genetic variation in bitter gourd. Quantitative characteristics that are related to fruits and seeds were already used (Dey et al, 2006; Dalamu, 2012). In contrast, qualitative and pseudo-qualitative characteristics were less often used although some of them were recommended for grouping (UPOV, 2013). It is clear that using stable characteristics brings accurate results in determination of genetic relationships among accessions within the species, irrespective of being quantitative, qualitative or pseudo-qualitative characteristics. Genetic relationships among accessions within species depends on the number of examined characteristics. The characteristics that are stable in different growing conditions are useful for cluster analysis. This study was designed to specify the stable characteristics that are useful for morphological analysis of genetic relations of collected accessions belonging bitter gourd.

There are two methods applied for cluster analysis, UPGMA and Ward. UPGMA method was based on hierarchical agglomerative technique, while Ward method was based on partition and optimization of an object function technique (Crossa and Franco, 2004). The UPGMA was used in the study because this method has already given higher morphological correlation (Hale and Dougherty, 1988).

UPGMA clustering method relied on the data from the two different growing condition indicated that seven characteristics were firmly fixed, including number of leaf lobes, ridge of fruit, size of fruit warts, present of fruit spines, color of fruit skin at ripe stage, indentation of seed edge, and striation of seed coat. Five characteristics were stable, including number of node up to node with first male flower, time of first male flower flowering, fruit length, fruit weight, and weight of 100 seeds.

6. Conclusions and recommendations

6.1 Conclusions

The plant family Cucurbitaceae has a high importance in vegetable cultivation of Vietnam and it can be stated this vegetable group was so far under-concerned in terms of collection and characterization.

The collection of this study contributed to increase the number of species collected and now germplasm of all provinces except 3 was collected. Nevertheless, more accessions should be collected and underutilized species should be included.

The study was also concentrated to characterize accessions of five frequently cultivated species, including cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*). Moreover, the effective characteristics for evaluating the diversity of the *M. charantia* accessions were determined. Based on the available information in previous studies, and calculated and analysed results of this study, the following conclusions regarding the four specific studies aims could be given:

1. By the survey on vegetable cultivation an overview on vegetable cultivation systems in Mekong River Delta, Vietnam is now available. The collected data provided basic information relating to all important vegetable families in vegetable cultivation. The study results proved an important role of Cucurbit family (Cucurbitaceae) in vegetable cultivation. Regarding the number of species according plant families: with 9 frequently cultivated species (16.4%) in 55 counted vegetable species, Cucurbitaceae was the second largest family after Brassicaceae (Cruciferae). Nevertheless, the species belonging to Cucurbitaceae shared the most significant using frequency proportion in vegetable cultivation (38.2% annual vegetable crops). The cultivated areas of cucurbit species covered 56.6% of total vegetable areas. This study, moreover, sought to validate the data by focusing on individual species. Despite of the cultivated areas of cucurbits corresponding to the large plant size of almost cucurbit species, large number of farmers had chosen cucurbits as main crops for cultivation that proves an important role of cucurbit in improving farmers' income.

   Previous studies relating to the diversity of plant species in vegetable production in different regions of Vietnam found 75 plant species cultivated in vegetable production with 13 cucurbit species that were commonly cultivated, yet, other important statistics such as using frequency and cultivated areas of cucurbit species were not given. The numbers of cucurbit species found in this specific study were lower than that in previous studies, because this study was focused in Mekong River Delta only. Yet, the sharing percentage following species (17.3% in previous studies and 16.4% in this study) was only little different. Therefore, the results in this study are efficient references for later studies related to vegetable cultivation in Vietnam.

In addition, based on this research a clear evidence for the substitution of local seeds by commercial seeds; especially for economically important crops i.e. cucumber and watermelon (more than 98% seeds were F1 hybrid, for pumpkin it was more than 88%) was indicated. This situation may lead to the loss of genetic diversity in this cucurbit species in Vietnam. Thus, collection and conservation of local and landrace cucurbits are necessary to prevent the erosion of plant genetic resources in Vietnam.

2. In terms of collection germplasm, analysing the situation a gap in collection and conservation cucurbit in southern Vietnam was obvious. Thus, the collection of cucurbit germplasm in the southern Vietnam was carried out to conserve the diversity of and in cucurbit species in this region. This collection has contributed in total 224 accessions (15.1 %) and increased the total number of cucurbit accessions in Vietnam up to now to 1,479 accessions with the lower limit of diversity index (H_{min}), diversity index (H), and evenness index (E) of the collections reach 0.4, 2.2, and 5.1, respectively. This collection, therefore, shared the *ex situ* conservation on cucurbit germplasm in southern Vietnam.

   Highly varying in topographic, soils, climate and weather conditions (Figure 2.4; Figure 2.5) southern Vietnam can considerable contribute to the diversity of cucurbits. Therefore, collection of cucurbits in any regions in the southern Vietnam could be significant in conserving diversity in cucurbit germplasm. The cucurbit accessions in this study were collected in different regions (24 provinces) in the central and southern Vietnam, which are regarded as high in endemic species but so far no cucurbit accessions were collected there.

   Rare, valuable, threatened germplasm were the three main initial criteria for collection and conservation germplasm. Except species occurring in certain regions in northern Vietnam, many species or varieties existing only in the South were collected (e.g. local varieties "mướp đắng quả trắng", "mướp đắng quả xanh", "mướp đắng quả xanh có gai", and "mướp đắng Mekong 59", semi-wild variety "mướp đắng quả nhỏ" belonging to

Momordica charantia; "Mướp kía" (*Luffa acutangula*); "dưa leo" (*Cucumis sativus*); and "bí đỏ superma" (*Cucurbita moschata*).

The study contributes accessions and data providing relevant knowledge in field of collection plant germplasm of cucurbits.

3. The morphological characterization clarified the genetic diversity of the collected accessions within species-level entities that were collected in different geographical regions. Five commonly cultivated cucurbits in Vietnam, *Cucumis sativus* (cucumber)*, Cucurbita moschata* (pumpkin)*, Lagenaria siceraria* (bottle gourd)*, Luffa cylindrica* (loofah)*, and Momordica charantia* (bitter gourd) were investigated as main materials. The accessions were landraces or local varieties that maintained by farmers.

   The detail information on morphological characterization and evaluation were necessary to analyse the relationships of the accessions within the five mentioned cucurbit species. The numbers of evaluated characteristics (39, 36, 28, 27, and 37 characteristics of *Cucumis sativus, Cucurbita moschata, Lagenaria siceraria, Luffa cylindrica, and Momordica charantia*, respectively) in this study were relevant for morphological characterization.

   Applying Chi-square (χ^2-test) to determine the differences between continuous variables of cucurbit accessions was a new approaching method in morphological characterization of Vietnamese cucurbits. Regarding analysed results from five cucurbit species, the results indicated 13 characteristics as significant different between the accessions. Those were stem length and fruit weight of *Cucumis sativus* (cucumber) accessions; length of female and male flower peduncles, length of sepals of female and male flowers, fruit circumference, fruit weight, and fruit length of *Cucurbita moschata* accessions; fruit weight and fruit length of *Lagenaria siceraria* accessions; fruit weight of *Luffa cylindrica* accessions; and fruit weight of *Momordica charantia* accessions.

   UPGMA hierarchical clustering was commonly applied for evaluating genetic relationships among accessions in various plant species. This study also used this method to evaluate genetic relationships among accessions within *Cucumis sativus, Cucurbita moschata, Lagenaria siceraria, Luffa cylindrica, and Momordica charantia*. In addition, the 3D plots executed separately for categorical and continuous variables were applied in this study. This method was used less than UPGMA method, but the plots clarified clearly differences of the accessions within species. The combination of the two methods for evaluating genetic relationships among accessions within species obviously figured out the accessions bearing special characteristics, such as TiGi02 and TiGi03 of cucumber (*Cucumis sativus*), BaLi01 of pumpkin (*Cucurbita moschata*), NiTh03 of bottle gourd (*Lagenaria siceraria*), CaTh01 and HcmC03 of loofah (*Luffa cylindrica*), and HcmC01 and QuNa01 of bitter gourd (*Momordica charantia*).

This is the first morphological study on five frequently cultivated cucurbits in Vietnam. The variation in morphological characteristics of the accessions could result from different growing conditions. Basing on morphological variations of the accessions in this study, some accessions bearing useful characteristics (e.g. many fruit-bearing branches, short time for flowering, long harvesting period, and good fruit shape) had been used already in cucurbit breeding programs in TH Company. Two new varieties of bitter gourd (*Momordica charantia*) and one new variety pumpkin (*Cucurbita moschata*) were released. Other accessions had been evaluating and selecting for effectively agronomical and economical characteristics.

Genetic relationships among accessions within species was dependent on the characteristics (qualitative, quantitative, and pseudo-qualitative), measurement method (categorical and continuous), and the numbers of characteristics used for hierarchal clustering. Therefore, determining the stable characteristics was necessary for cluster analysis the relationship of the accessions within species.

As a consequence, the results in this research field provided definite details on morphological characterization and the methodological evaluation that are related to genetic diversity of cucumber (*Cucumis sativus*), pumpkin (*Cucurbita moschata*), bottle gourd (*Lagenaria siceraria*), loofah (*Luffa cylindrica*), and bitter gourd (*Momordica charantia*).

4. Comparing the expressions of the characteristics of bitter gourd (*Momordica charantia*) in two different growing condition (greenhouse and field) indicated that some characteristics were stable, whereas the other were significantly different. Therefore, the significantly different characteristics in different growing conditions were regarded as “noise characteristics” because they gave negative effect for evaluating genetic relationships among accessions within species. Therefore, determination of stable characteristics for evaluating genetic relationships was useful in eliminating of “noise characteristics” or the unstable characteristics.

Two statistical analyses were applied including Two-sample test and UPGMA clustering method. The examined characteristics included 16 quantitative and 12 qualitative and pseudo-qualitative characteristics. Combining the two statistical methods had provided a reliable result for proving stable characteristics and eliminating unstable characteristics of bitter gourd accessions. Therefore, applying the two statistical methods for determination of the stable characteristics could be advisable for evaluating genetic relationships among accessions of cucurbit species or other plant species.

6.2 Recommendation for further research and use of new accessions

It is necessary to continue with periodically collecting cucurbit germplasm in different regions, especially concentrating to the regions where no cucurbit accessions have been collected, in order to illustrate the distribution of cucurbit species in Vietnam.

With the cucurbit accessions collected in previous projects, it is necessary to continue with evaluating and classifying of morphological characteristics. A germplasm database with sufficient information accommodates for researchers easy to assess and helpful to decide which accessions are appropriate for their study or research circumstance needs to be developed. Determination of stable characteristics for cluster analysis is also necessary executed for other cucurbit species to establish clear genetic relationships database.

Mapping the particular diversity of cucurbits according regions, and then planning the strategy for the collection, conservation, and utilization of cucurbits in Vietnam should be continued.

Using the accessions with impressive characteristics that are related to crop yield, such as the strong growth, plenty of fruits and good quality (size, shape, color, and taste), found in morphological characterization experiments in various cucurbit-breeding programs to improve production of cucurbit crops.

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Declaration

I hereby declare that this dissertation entitled “Survey, collection and characterization of indigenous and non-indigenous cucurbits in Vietnam” was carried out, analysed, and written by me for Doctor rerum agriculturarum. This work contains no material previously published or written by another author, except where due reference has been cited in the text.

Appendices

Appendix 1. Taxonomy based morphological characters of cultivated cucurbit species (Robinson and Decker-Walters, 1997)

Scientific name	Common name[1]	Frequency and place of cultivation[2]	Usage
Subfamily *Zanonioideae*			
Tribe *Zanonieae*			
Subtribe *Fevilleinae*			
Fevillea cordifolia L.	Antidote vine	Rare (N)	Medicinal
Subtribe *Gomphogyninae*			
Gynostemma pentaphyllum (Thunb.) Mak.	Jiao-gu-lan	Localized (S)	Medicinal
Hemsleya amabilis Diels	Luo-guo-di	Localized (S)	Medicinal
Subtribe *Actinostemmatinae*			
Actinostemma tenerum Griff.	He-zi-cao	Localized (S)	Medicinal
Bolbostemma paniculatum (Maxim.) Franq.	Pseudo-fritillary	Localized (S)	Medicinal
Subfamily *Cucurbitoideae*			
Tribe *Melothrieae*			
Subtribe *Cucumerinae*			
Cucumeropsis mannii Naud.	Whitr-seeded melon	Localized (A)	Food
Cucumis anguria L.	Bur gherkin	Localized (W)	Food
Cucumis dipsaceus Ehrenb. ex Spach	Teasel gourd	Sporadic (W)	Ornamental
Cucumis melo L.	Melon	Common (W)	Food
Cucumis metuliferus E. Mey. ex Naud.	African horned cucumber	Sporadic (W)	Food
Cucumis sativus L.	Cucumber	Common (W)	Food
Tribe *Joliffieae*			
Subtribe *Thladianthinae*			
Momordica angustisepala Harms	Sponge plant	Rare (A)	Utilitarian
Momordica balsamina L.	Balsam apple	Frequent (W)	Medicinal
Momordica charantia L.	Bitter melon	Common (W)	Food, medicinal
Momordica cochinchinensis (Lour.) Spreng.	Cochinchin gourd	Sporadic (W)	Medicine
Momordica cymbalaria Frenzl. ex Hook. f.	-	Rare (O)	Food
Momordica dioica Roxb. ex Willd.	Kaksa	Localized (S)	Food

Appendix 1. (Continued)

Scientific name	Common name[1]	Frequency and place of cultivation[2]	Usage
Siraitia grosvenorii (Swingle) Lu & Zhang	Luo-han-guo	Localized (S)	Medicinal
Thladiantha dubia Bunge	Red hail stone	Sporadic (W)	Medicinal, ornamental
Subtribe *Telfairiinae*			
Telfairia occidentalis Hook. f.	Fluted pumpkin	Localized (A)	Food
Telfairia pedata (Sims) Hook.	Oyster nut	Localized (A)	Food
Tribe *Trichosantheae*			
Subtribe *Hodgsoniinae*			
Hodgsonia macrocarpa (Bl.) Cogn.	Lard plant	Infrequent (S)	Food
Subtribe *Trichosanthinae*			
Gymnopetalum cochinchinense (Lour.) Kurz	-	Rare (S)	Food
Trichosanthes cucumerina L.	Snake gourd	Frequent (W)	Food
Trichosanthes dioica Roxb.	Pointed gourd	Localized (S)	Food
Trichosanthes kirilowii Maxim.	Chinese snake gourd	Localized (S)	Medicinal
Trichosanthes lepiniana (Naud.) Cogn.	Indreni	Localized (S)	Medicinal
Trichosanthes ovigera Blume	Japanese snake gourd	Frequent (S)	Food
Trichosanthes villosa Bl.	Mi-mao-guo-lou	Localized (S)	Food
Tribe *Benincaseae*			
Subtribe *Benincasinae*			
Acanthosicyos horridus Welw. ex Hook. f.	!nara	Localized (A)	Food
Benincasa hispida (Thund.) Cogn.	Ash gourd	Frequent (W)	Food
Bryonia alba L.	Bryony	Sporadic (W)	Medicinal
Bryonia cretica L.	Bryony	Localized (O)	Medicinal
Bryonia dioica Jacq.	Bryony	Sporadic (W)	Medicinal
Citrullus colocynthis (L.) Schrad.	Colocynth	Sporadic (W)	Medicinal
Citrullus lanatus (Thunb.) Matsum. & Nakai.	Watermelon	Common (W)	Food
Coccinia abyssinica (L.) Cogn.	-	Localized (A)	Food
Coccinia grandis (L.) Voigt	Ivy gourd	Sporadic (W)	Food
Diplocyclos palmatus (L.) C. Jeffrey	Lollipop climber	Localized (O)	Ornamental
Ecballium elaterium (L.) A. Rich.	Squirting cucumber	Sporadic (O)	Ornamental

Appendix 1. (Continued)

Scientific name	Common name[1]	Frequency and place of cultivation[2]	Usage
Lagenaria siceraria (Molina) Stand.	Bottle gourd	Common (W)	Utilitarian, ornamental
Praecitrullus fistulosus (Stocks) Pang.	Round melon	Localized (S)	Food
Subtribe *Luffinae*			
Luffa acutangula (L.) Roxb.	Angled loofah	Frequent (W)	Food
Luffa cylindrica (L.) M. J. Roem.	Smooth loofah	Common (W)	Utilitarian, food
Tribe *Cucurbiteae*			
Subtribe *Cucurbitinae*			
Cayaponia kathematophora R. E. Schult.	-	Rare (N)	Ornamental
Cayponia ophthalmica R. E. Schult.	-	Rare (N)	Medicinal
Cucurbita argyrosperma Huber	Squash, pumpkin	Localized (W)	Food
Cucurbita ficifolia Bouché	Malabar gourd	Localized (W)	Food
Cucurbita maxima Duch. ex Lam.	Squash, pumpkin	Common (W)	Food
Cucurbita moschata Duch. ex Poir.	Squash, pumpkin	Common (W)	Food
Cucurbita pepo L.	Squash, pumpkin	Common (W)	Food
Sicana odorifera (Vell.) Naud.	Cassabanana	Sporadic (N)	Food
Tribe *Sicyeae*			
Subtribe *Cyclantherinae*			
Cyclanthera brachybotrys (Poepp. & Endl.) Cogn.	-	Localized (N)	Food
Cyclanthera explodens Naud.	-	Localized (N)	Food
Cyclanthera pedata (L.) Schrad.	Stuffing cucumber	Sporadic (W)	Food
Echinocystis lobata (Michx.) Torr. & Gray	Wild cucumber	Sporadic (W)	Ornamental
Subtribe *Cicyinae*			
Sechium edule (Jacq.) Swartz	Chayote	Common (W)	Food
Sechium tacaco (Pitt.) C. Jeffrey	-	Localized (N)	Food

Most species, the common name given in English or an English translation. Common name in other languages are listed in Kays and Silva Dias (1995).
Locations: A = Africa, N = neotropics, O = Old world, S = Asia, W = widespread.

Appendix 2. Valuable and rare species belong to 37 families need to conserve (MARD, 2005)

Families	No. of species/ subspecies	Families	No. of species/ subspecies
Poceae	645	Ebenaceae	17
Araceae	252	Piperaceae	16
Rubiaceae	193	Malvaceae	14
Dioscoreaceae	163	myetaceae	12
Convolvulaceae	135	Sapotaceae	9
Moraceae	134	Bombacaceae	6
Rutaceae	125	Liliaceae	6
Solanaceae	107	Anonaceae	6
Anacardiaceae	83	Rosaceae	5
Zingiberaceae	65	Brassicaceae	4
Sapindaceae	58	Cactaceae	4
Musaceae	58	Menispermaceae	3
Leguminoceae	44	Clusiaceae	2
Vitaceae	39	Typhaceae	1
Polygonaceae	36	Asteraceae	1
Cucurbitaceae	33	Flacourtiaceae	1
Cannaceae	24	Lauraceae	1
Euphorbiaceae	20	Meliaceae	1
Theaceae	19		

Appendix 3. Valuable and rare cucurbit species needs to conserve (MARD, 2005)

Local name	Scientific name
Bạc bát (qua lâu)	*Trichosanthes kirilowii*
Qua lâu trứng	*Trichosanthes ovigera*
Hồng bì	*Trichosanthes rubriflos*
Lâu xác	*Trichosanthes tricuspidata*
Do mõ	*Trichosanthes villosa*
Gấc cạnh	*Momordica subangulata*
Mướp đắng quả trắng	*Momordica charantia*
Mướp đắng quả xanh có gai	*Momordica charantia*
Mướp đắng quả xanh	*Momordica charantia*
Mướp đắng quả to	*Momordica charantia*
Mướp đắng quả nhỏ	*Momordica charantia*
Mướp đắng quả xanh	*Momordica charantia*
Mướp đắng	*Momordica charantia*
Mướp đắng 277	*Momordica charantia*
Mướp đắng Mê Kông 59	*Momordica charantia*
Mướp khía	*Luffa acutangula*
Cha bi	*Luffa acutangula*
Mạc khnoi	*Luffa acutangula*
Mướp bắn	*Luffa acutangula*
Mắc lòi	*Luffa acutangula*
Kơ nói	*Luffa acutangula*
Quả vách	*Luffa acutangula*
Mướp váy	*Luffa acutangula*
Mướp nương	*Luffa acutangula*
Mắc hói (Điện Biên)	*Luffa* sp.
Dưa chuột ta (Vĩnh Phúc)	*Cucumis sativus*
Dưa leo 783	*Cucumis sativus*
Dưa leo 179	*Cucumis sativus*
Dưa leo 702	*Cucumis sativus*
Phú Thịnh	*Cucumis sativus*
Dưa chuột nếp	*Cucumis sativus*
Mắc ư măn (Điện Biên)	*Cucurbita sativus*
Bí đỏ superma	*Cucurbita moschata*

Appendix 4. Survey questionnaire for classifying the use of cucurbits in vegetable cultivation

Sample No.: ………. date: / / 2011 Interviewer: …………………………………

1. General information
Interviewee: …………………………………… …age: ……… sex: ☐male☐female
Ethnic group: …………………………. ……… ………………………………………….
Address:………………………………………………………………………………

2. Producer specialism

- Producer experiences: ………… (years)
- Education level: ………………
- Member of household: ……… (people); No. of workers: ………… (people);
- No. of workers in agriculture: ..………… …(people)
  Others (specific)
  ………………………………………………………………………………
- Cultivated area: ………… ha
  - home garden: …………… ha
  - perennial plants: …………..ha
  - annual crops: …………. ha
  - specializing in vegetables: …………………. ha
    - leafy vegetables: …………..
    - fruit-bearing vegetables: ………..
    - root vegetables: …………
    - spice vegetable: …………

3. Cultivated species in current crop

Species	Type*	source			Cultivated area (ha)
		Buy	Maintain**	Others	

*: F1; landraces; OP or other specific
**If maintaining:
Reserve method: ……………………………………………………………………
Preservation: ……………………………………………………………………

4. Cultivated species in three previous crops

Crop	Species	Type*	source			Cultivated area (ha)
			Buy	Reserve**	Others	
1						
2						
3						

Appendix 5. Farmers' characteristics and land used for cultivation (average ±SD)

Districts	Communes	N	Age of farmers	Members in households	Education level(grades*)	Average area (m^2 per farm) of Cultivation land	Vegetable land
Ba Tri	An Hoa Tay	59	52.2±9.0	4.6±1.5	5.4±3.3	2782±3025	1460±1143
	An Thuy	55	45.5±9.0	4.1±1.2	5.0±3.0	4244±2278	4225±2284
	Tan Thuy	72	46.8±9.4	4.7±1.5	6.1±3.2	1656±1741	1281±812
Binh Dai	Chau Hung	25	39.0±10.2	3.6±0.9	5.7±2.5	3656±2477	2396±1396
	Phu Long	33	47.2±13.1	4.2±1.5	6.3±3.6	2058±2345	982±527
	Thua Duc	89	44.8±9.9	4.4±1.2	4.8±3.1	4557±3013	3354±1711
Chau Thanh	Huu Dinh	74	40.6±9.4	3.7±1.1	6.3±3.3	4536±2639	2209±1164
	Son Hoa	37	45.4±8.8	4.0±1.1	6.5±2.5	4332±2064	2046±990
Giong Trom	Luong Hoa	39	44.3±9.3	4.1±1.3	5.1±1.8	4045±2575	2036±1691
	Tan Thanh	90	47.0±11.1	4.4±1.6	7.0±2.7	3232±2486	1242±710
Mo Cay Bac	Khanh Thanh Tan	24	42.8±8.7	4.4±1.4	7.1±2.5	4800±3229	1633±844
	Nhuan Phu Tan	23	48.7±10.3	5.4±1.7	5.8±2.5	5708±3060	2683±2185
	Tan Thanh Tay	26	44.9±8.9	4.4±1.2	7.0±2.5	4331±2480	1846±1147
Mo Cay Nam	An Thanh	74	49.2±12.3	4.7±1.5	6.4±5.8	4243±2756	1292±760
	Da Phuoc Hoi	51	48.0±10.9	4.9±1.5	7.6±1.9	5315±3115	1597±947
Thanh Phu	Binh Thanh	44	46.1±9.6	4.4±1.8	5.1±2.7	3973±3189	1200±529
	Phu Khanh	48	48.5±11.8	4.6±1.8	5.5±2.6	4392±4470	1635±1397
	Tan Phong	61	44.2±10.0	4.3±1.2	5.6±2.0	5643±4266	2844±1962
Ben Tre	Phu Nhuan	19	42.2±6.7	4.4±0.8	5.7±2.6	7437±3759	2942±1154
	Son Dong	66	43.1±8.4	3.9±1.2	5.9±3.2	4082±4103	1803±1102

*, 1-5: elementary education; 6-9: secondary education; 10-12: higher education.

Appendix 6. The diversity of species in vegetable cultivation in Mekong River Delta

Scientific name	Common name	Family	Using frequencies *		Cultivated areas** (m² per farm)
			Current crop	Year-round crop	Average ± SD
Allium cepa var. *aggregatum*	Red onion	Alliaceae	102(10.1)	254(9.83)	1176±704
Allium fistulosum	Welsh onion	Alliaceae	59(5.8)	123(4.76)	1923±1570
Allium odorum	Chinese chives	Alliaceae	31(3.1)	67(2.59)	1094±699
Alocasia odora	Night-scented lily	Araceae	1(0.1)	2(0.08)	700±0
Amaranthus viridis	Green amaranth	Amaranthaceae	0	4(0.15)	
Apium graveolens	Celery	Apiaceae	8(0.8)	35(1.35)	713±264
Basella alba	Malabar spinach	Basellaceae	1(0.1)	4(0.15)	500±0
Benincasa hispida	Ash gourd	Cucurbitaceae	7(0.7)	41(1.59)	1857±1600
Boerhavia diffusa	Punarnava	Nyctaginaceae	1(0.1)	1(0.04)	500±0
Brassica integrifolia	Mustasa	Brassicaceae	1(0.1)	2(0.08)	1000±0
Brassica juncea	Leaf mustard	Brassicaceae	18(1.8)	52(2.01)	1017±488
Brassica oleracea var. *botrytis*	Cauliflower	Brassicaceae	17(1.7)	36(1.39)	1221±483
Brassica oleracea var. *italica*	Broccoli	Brassicaceae	2(0.2)	2(0.08)	700±424
Brassica oleracea var. *viridis*	Collard greens	Brassicaceae	13(1.3)	99(3.83)	1185±511
Brassica rapa subsp. pekinensis	Pe-tsai	Brassicaceae	10(1.0)	50(1.93)	1275±750
Brassica rapa var. *chinensis*	Pak choi	Brassicaceae	12(1.2)	21(0.81)	1854±1058
Brassica rapa var. *parachinensis*	Choysum	Brassicaceae	29(2.9)	86(3.33)	929±358
Brassica oleracea var. *capitata*	Cabbage	Brassicaceae	15(1.5)	32(1.24)	1017±544
Capsicum annuum	Chilli pepper	Solanaceae	34(3.4)	84(3.25)	1921±1333
Centella asiatica	Centella	Apiaceae	0	2(0.08)	
Chrysanthemum coronarium	Garland chrysanthemum	Asteraceae	9(0.9)	14(0.54)	1083±957
Citrullus lanatus	Watermelon	Cucurbitaceae	116(11.5)	274(10.6)	3816±2074

Appendix 6. (Continued)

Scientific name	Common name	Family	Using frequencies *		Cultivated areas** (m^2 per farm)
			Current crop	Year-round crop	Average ± SD
Colocasia esculenta	Taro	Araceae	0	3(0.12)	
Coriandrum sativum	Coriander	Apiaceae	2(0.2)	28(1.08)	1250±1061
Cucumis melo var. *conomon*	Melon	Cucurbitaceae	52(5.2)	92(3.56)	2971±1728
Cucumis sativus	Cucumber	Cucurbitaceae	68(6.7)	143(5.53)	1868±1376
Cucurbita moschata	Pumpkin	Cucurbitaceae	5(0.5)	7(0.27)	1156±365
Dioscorea esculenta	Lesser yam	Dioscoreaceae	0	2(0.08)	
Hibiscus esculentus	Okra	Malvaceae	17(1.7)	42(1.62)	1359±603
Houttuynia cordata	Fishwort	Saururaceae	3(0.3)	11(0.43)	1000±0
Ipomoea aquatica	Water spinach/Kang kong	Convolvulaceae	23(2.3)	52(2.01)	1052±578
Ipomoea batatas	Sweet potato	Convolvulaceae	1(0.1)	8(0.31)	200±0
Lactuca sativa subsp. *asparagina*	Iceberg lettuce	Asteraceae	16(1.6)	33(1.28)	1213±774
Lactuca sativa var. *capitata*	Lettuce	Asteraceae	13(1.3)	46(1.78)	1315±738
Lagenaria siceraria	Bottle gourd	Cucurbitaceae	18(1.8)	58(2.24)	933±550
Limnophila aromatica	Rice paddy herb	Scrophulariaceae	1(0.1)	2(0.08)	2500±0
Luffa acutangula	Angled loofah	Cucurbitaceae	2(0.2)	3(0.12)	750±354
Luffa cylindrica	Loofah	Cucurbitaceae	9(0.9)	32(1.24)	2022±1247
Lycopersicon esculentum	Tomato	Solanaceae	15(1.5)	77(2.98)	1400±632
Mentha aquatica	Water mint	Lamiaceae	1(0.1)	6(0.23)	600±0
Mentha arvensis	Field mint	Lamiaceae	3(0.3)	4(0.15)	667±289
Mentha spicata	Spearmint	Lamiaceae	0	3(0.12)	
Momordica charantia	Bitter gourd	Cucurbitaceae	154(15.3)	338(13.08)	1492±945
Neptunia oleracea	Water mimosa	Leguminosae	1(0.1)	1(0.04)	1000±0

Appendix 6. (Continued)

Scientific name	Common name	Family	Using frequencies *		Cultivated areas** (m^2 per farm)
			Current crop	Year-round crop	Average ± SD
Ocimum basilicum	Basil	Lamiaceae	2(0.2)	5(0.19)	450±71
Oenanthe javanica	Japanese parsley	Apiaceae	18(1.8)	39(1.51)	1128±473
Pachyrhizus erosus	Jam bean	Leguminosae	21(2.1)	74(2.86)	2648±1587
Persicaria odorata	Hot mint	Polygonaceae	2(0.2)	5(0.19)	1000±707
Phaseolus vulgaris	Common bean	Leguminosae	36(3.6)	37(1.43)	1206±661
Psophocarpus tetragonolobus	winged pea	Leguminosae	4(0.4)	13(0.5)	575±299
Raphanus sativus var. *longipinnatus*	White radish	Brassicaceae	28(2.8)	80(3.09)	1466±1082
Sesbania grandiflora	Swamp pea	Leguminosae	0	1(0.04)	
Solanum melongena	Eggplant	Solanaceae	3(0.3)	12(0.46)	1033±252
Vigna unguiculata subsp. *sesquipedalis*	Yardlong bean	Leguminosae	4(0.4)	41(1.59)	1075±650
Zingiber officinale	Ginger	Zingiberaceae	1(0.1)	2(0.08)	250±0
	55 species	19 families	1009 crops	2585 crops	Average of total: 1246

ID, identification number; SD, standard deviation; NA, not available; Numbers in brackets indicated the occurrence rate (OR) of species. *Numbers of valid interviews in current crop and year-round crop were 1009 and 779, respectively.**, calculated for species in current crop only;

Appendix 7. The relative contribution between using frequency of species and households' characteristics

Species	Using frequencies	Farmers' ages (year)	Education levels*	Members in households	Cultivated areas (m^2 per farm)
Allium cepa var. *aggregatum*	102	49.6	5.8	4.8	1176
Allium fistulosum	59	42.8	6.5	4.2	1923
Allium odorum	31	47.9	5.0	4.6	1094
Alocasia odora	1	48.0	8.0	2.0	700
Apium graveolens	8	51.3	4.8	4.0	713
Basella alba	1	35.0	4.0	6.0	500
Benincasa hispida	7	45.7	6.1	4.4	1857
Boerhavia diffusa	1	86.0	5.0	3.0	500
Brassica integrifolia	1	47.0	4.0	8.0	1000
Brassica juncea	18	45.2	5.7	4.0	1017
Brassica oleracea var. *botrytis*	17	42.3	6.6	4.2	1221
Brassica oleracea var. *italica*	2	47.7	6.2	5.6	700
Brassica oleracea var. *viridis*	13	43.5	4.5	6.0	1185
Brassica rapa subsp. *pekinensis*	10	43.0	8.1	4.0	1275
Brassica rapa var. *chinensis*	12	47.0	7.6	4.7	1854
Brassica rapa var. *parachinensis*	29	43.2	5.2	4.4	929
Brassica oleracea var. *capitata*	15	47.6	5.8	3.9	1017
Capsicum annuum	34	41.2	6.3	3.9	1921
Chrysanthemum coronarium	9	42.4	7.7	4.7	1083
Citrullus lanatus	116	44.8	5.2	4.4	3816
Coriandrum sativum	2	42.5	4.5	5.5	1250
Cucumis melo var. *conomon*	52	43.3	5.6	4.3	2971
Cucumis sativus	68	43.5	6.1	4.2	1868
Cucurbita moschata	5	52.8	7.2	4.4	960
Hibiscus esculentus	17	45.4	5.4	3.9	1359
Houttuynia cordata	3	53.7	6.7	5.3	1000
Ipomoea aquatica	23	50.3	6.1	4.3	1052
Ipomoea batatas	1	53.0	5.0	NaN	200
Lactuca sativa subsp. *Asparagina*	16	45.9	5.6	4.6	1213
Lactuca sativa var. *capitata*	13	45.0	4.9	4.6	1315
Lagenaria siceraria	18	51.7	6.0	4.4	933
Limnophila aromatica	1	44.0	5.0	5.0	2500
Luffa acutangula	2	39.5	7.0	5.0	750

Appendix 7. (Continued)

Species	Using frequencies	Farmers' ages (year)	Education levels*	Members in households	Cultivated areas (m^2 per farm)
Luffa cylindrica	9	48.6	7.3	4.3	2022
Lycopersicon esculentum	15	50.7	5.3	4.7	1400
Mentha aquatica	1	48.0	7.0	3.0	600
Mentha arvensis	3	43.7	4.0	3.7	667
Momordica charantia	154	44.4	6.2	4.2	1492
Neptunia oleracea	1	70.0	3.0	3.0	1000
Ocimum basilicum	2	43.5	6.0	4.0	450
Oenanthe javanica	18	41.5	5.3	3.8	1128
Pachyrhizus erosus	21	49.4	5.2	4.3	2648
Persicaria odorata	2	46.5	6.5	5.0	1000
Phaseolus vulgaris	36	47.5	6.6	4.7	1206
Psophocarpus tetragonolobus	4	49.8	6.0	4.0	575
Raphanus sativus var. *longipinnatus*	28	46.6	5.2	4.5	1466
Solanum melongena	3	62.0	3.7	4.7	1033
Vigna unguiculata subsp. *sesquipedalis*	4	46.0	8.5	3.8	1075
Zingiber officinale	1	NaN	NaN	8.0	250

*, 1-5: elementary education; 6-9: secondary education; 10-12: higher education, NaN: not available.

Appendix 8. Questionnaire - Collecting Record Sheet

(Based on Asian Vegetable Research and Development Center (AVRDC)-Genetic Resources and Seed Unit (GRSU) Collecting Record Sheet)

GENERAL INFORMATION:

Collectors ....

Collecting No. ....

Day of collection _____y/_____m/____d.

Country: Vietnam

District/Province ....

Town...

Village ....

Site..

Latitude ....

Longitude..

Altitude ....

Crop selected ....

Genus ....

Species ....

Species local name ....

....

Meaning ....

Varieties local name ....

....

Meaning ....

Varieties name language ....

Grower name ....

COLLECTION SOURCE

1. farmland
2. backyard/home garden
3. farm store/threshing place
4. village market
5. commercial seed shop (name ....)
6. agriculture institute (name.....................)
7. bordering field
8. natural vegetation/wild
9. other (specify ....)

GENETIC STATUS:

1. wild
2. weedy
3. primitive cultivar/landrace
4. improved OP cultivar
5. hybrid cultivar
6. other (specify..)

SAPLING METHOD:

1. random
2. non-random (specify............................)

MATERIAL: 1 Seed; 2 Fruit; 3 Pod; 4 Other ....

PART USED AND USAGE:

Whole plant...

Young shoot..

Sprouts ....

Leaf ....

Stem ....

Root/tuber...

Flower ....

Fruit..

Seed..

CULTURAL PRACTICE: DISEASE AND PESTS

Shifting: yes no

Terraced: yes no

Direct seeding: yes no

Intercropping: yes no

Intensive: yes no

Rotation crop: yes no

Irrigated: hand overhead drip none (specify ....)

SOWING MONTH: ....

TRANSPLANT MONTH: ....

HARVEST MONTH:..

TOPOGRAPHY: ....

1. swamp
2. flood plain
3. level plain
4. undulating
5. hilly
6. mountainous
7. other (specify..)

SITE:

1. level
2. slope
3. plateau
4. depression

SOIL TEXTURE:

1. sand
2. sandy loam
3. loam
4. clay loam
5. silt
6. clay
7. highly organic (peat/much)
8. other (specify ....)

DRAINAGE:

1. poor
2. moderate
3. good
4. excessive

SOIL COLOR:

1. black
2. dark brown
3. light brown
4. grey
5. yellow
6. red
7. other (specify ....)

STONINESS:

1. none
2. low
3. medium
4. rocky

HERBARIUM SPECIMEN: yes no

PHOTOGRAPH: yes no (No:..................)

NOTE: (Morphological description, special plant characters and morphological variation, pests and disease, associated crop, wild and weedy species, status of genetic erosion, seed practices, etc.)...............................

....

....

....

Appendix 9. Collection accessions of cucurbit species followed by provinces (not including the accessions without collected region information that storage at VASI)

Province	Benincasa hispida	Citrullus lanatus	Coccinia grandis	Cucumis melo	Cucumis melo var. cantalupensis	Cucumis melo var. conomon	Cucumis sativus	Cucurbita sp	Cucurbita maxima	Cucurbita moschata	Cucurbita pepo	Cucurbita sp	Gymnopetalum cochinchinensis	Lagenaria siceraria	Lagenaria sp	Luffa acutangula	Luffa cylindrica var. insularum	Luffa cylindrica	Luffa sp	Momordica charantia	Momordica cochinchinensis	Mukia maderaspatana	Trichosanthes cucumerina	Trichosanthes anguina	Trichosanthes sp	Zehneria indica	Total species
An Giang	1						6					2								2							4
Bac Giang	9							1			5			9		4		1		1							7
Bac Kan	3	2			1	1	3		7		5	32		14		1		2	12								12
Bac Lieu	1									4								2									3
Bac Ninh	4						1	1				15						1	7	3							7
Ben Tre	3						9	4		1		11		1				2		1							8
Binh Duong							2			1								2		2							4
Binh Phuoc	1						2			1				1	1			5		2							7
Binh Thuan	3	1	1			1	4	12		1			1	1		1		2				1					12
Ba Ria-Vung Tau		1				1	7			2				2				2		1							7
Can Tho		1								2				1				2									4
Cao Bang						2	1		1										3								4
Daklak	1																			6							2
Dak Nong														2													1

Appendix 9. (Continued)

Dien Bien	2					1		2				1		4				7					5				7
Dong Nai	2						2			2			1	1				2		6							7
Dong Thap							1													1			1				3
Gia Lai														1				2									2
Ha Giang	2											2						2	2								4
Hanoi	3			1			1	1				4				2		7		1			1				9
Ha Tay	1																										1
Ha Tinh	1	1				3	3											7									5
Hai Duong	9						1					12		4	1			5	1				6				8
Hai Phong	1													2				1									3
Hau Giang	2									2				3				4									4
Hoa Binh	4			2	1									2		1		3	1					1			8
Khanh Hoa												4											1			1	2
Kien Giang														1				1									2
Kon Tum	5	1		1	1		1			2		3		8	1	2		7	1	1							13
Lai Chau	3	1				1	1	2			1	11		3	3	3				2	2		1				13
Lam Dong							4			1		21		3				1									5
Lang Son	3				1					1	5	5		1	1		1	2	3	1							11
Lao Cai														2													1
Long An																		2									1
Nam Dinh								9																			1
Nghe An	5						3	4				1		1		1				3			7				8
Ninh Binh						1	3											1									3
Ninh Thuan	4	2	1			3	1			2		3		3	1			4	2	1			1		2		14
Quang Binh	7	2					1			2		10		6	2			5	5	2							10
Quang Nam	7					1	5			4				5				6		4				1		4	9
Quang Ngai	1					1	2			1		8						2									6

Appendix 9. (Continued)

Quang Ninh	4	2					1	1		3		9		4				1	2								9
Quang Tri	1	4					4			6		2		4				2									7
Soc Trang	1																			3							2
Son La	11	2					2	4			1	2		15	1	8			1				3				11
Tay Ninh							2							1		2											3
Thai Binh	1																	5									2
Thai Nguyen	3											1		5				5									4
Thanh Hoa	12	1					1					5		1	1	8		4	1	1			6				11
Thua Thien-Hue										3								4									2
Tien Giang	1	7				2	2			3				2				1		3							8
Ho Chi Minh	4	1				1	6			3				1	2			4		4							9
Tra Vinh														1													1
Tuyen Quang	9						6											2									3
Vinh Long	1						2																				2
Vinh Phuc	1			1			1																				3
Yen Bai	2	1					3											2									4
Total accessions	139	30	2	5	4	19	94	41	8	47	17	164	2	115	14	33	1	122	41	51	2	1	32	2	2	5	

Appendix 10. Morphological characteristics use for evaluation

Cr.	Type	Characteristic description and measurement method
01	QL	Cotyledon: intensity of green color (dark green, green, light green)
02	QN	Cotyledon: length of cotyledon at 1 week after germination (mm)
03	PQ	Stem: growth type (determinate, indeterminate)
04	QN	Stem: length of 3 nodes beginning with the node bearing first female flower (cm)
05	QN	Stem: number of nodes up to node with the 1st female flower
06	QN	Stem: number of nodes up to node with the1st male flower
07	QN	Stem: shape
08	QN	Stem: number of side shoots (number of primary branches per plant)
09	QN	Stem: thickness of main stem (mm)
10	QN	Leaf blade: blistering (absent or very weak, weak, medium, strong, very strong)
11	QN	Leaf blade: dentation of margin (very weak, weak, medium, strong, very strong)
12	QN	Leaf blade: depth of lobbing (cm)
13	QN	Leaf blade: length (cm)
14	QN	Leaf blade: margin (entire or very weakly incised, weakly incised, moderate or strongly incised)
15	QN	Leaf blade: number of lobes
16	QN	Leaf blade: ratio length/width of leaf blade
17	QL	Leaf blade: shape
18	PQ	Leaf blade: shape of apex of terminal lobe
19	QL	Leaf blade: density of silver patches (sparse, medium, dense)
20	QN	Leaf blade: undulation of margin (absent or weak, moderate, strong)
21	QN	Leaf blade: width (cm)
22	QN	Leaf: attitude of leaf blade (erect, horizontal, drooping)
23	QN	Leaf: intensive with green color (light, medium, dark)
24	QN	Leaf: length of petiole (cm)
25	QL	Flower: color of vestiture on ovary
26	QL	Flower: intensity with green color of stigma (light, medium, dark)
27	QN	Flower: length of ovary (mm)
28	QN	Flower: length of female flowerpeduncle (mm)
29	QN	Flower: length of male flowerpeduncle (mm)
30	QN	Flower: length of sepal of female flower (mm)
31	QN	Flower: length of sepal of male flower (mm)
32	QN	Flower: number of female flowers /node
33	QN	Flower: peduncle diameter of female flower (mm)

Appendix 10. (Continued)

Cr.	Type	Characteristic description and measurement method
34	QL	Flower: sex description
35	QN	Flower: time taken of first female flower (day)
36	QN	Flower: time taken of first male flower (day)
37	QN	Fruit: density of ridge (cm)
38	QL	Fruit: aroma (low, medium, high)
39	QL	Fruit: bitterness of flesh (low, medium, high)- 3 fruits were randomly chosen from each accessions for organoleptic testing. This process was done by post-inspection department of TH Co.
40	QN	Fruit: circumference (cm), measure at the largest part
41	PQ	Fruit: color of skin at market stage
42	PQ	Fruit: color of skin at ripe stage
43	QL	Fruit: color of stripes
44	QN	Fruit: core diameter (mm), measure at the largest part
45	QL	Fruit: creasing (absent, present)
46	QN	Fruit: curving (absent or very weak, weak, medium, strong, very strong)
47	QL	Fruit: grooves (absent, present)
48	QN	Fruit: density of dots (very sparse, sparse, medium, dense, very dense)
49	QL	Fruit: density of vestiture (very sparse, sparse, medium, dense, very dense)
50	QN	Fruit: diameter (cm), measure at the largest part
51	QN	Fruit: diameter of flower scar (mm)
52	QN	Fruit: distance between grooves (small, medium, large)
53	PQ	Fruit: distribution of dots (in bands only, predominantly in bands, evenly distributed)
54	QL	Fruit: dots on fruit skin (absent, present)
55	QN	Fruit: weight (g)
56	QN	Fruit: glaucosity (absent or weak, weak, medium, strong, very strong)
57	QN	Fruit: depth of grooves (shallow, medium, deep)
58	QN	Fruit: intensity of bitterness (low, medium, high)
59	QN	Fruit: length (cm)
60	PQ	Fruit: length of fruit content dots (distal 1/3, distal 1/2,distal 2/3, excluding area around peduncle, whole length)
61	QN	Fruit: length of peduncle (cm)
62	QN	Fruit: length of ridge (short, medium, long)
63	QN	Fruit: length of stripes (absent or very short, short, medium, long, very long)

Appendix 10. (Continued)

Cr.	Type	Characteristic description and measurement method
64	QL	Fruit: luster of skin (matt, medium, glossy)
65	PQ	Fruit: main color of flesh
66	QN	Fruit: marbling (absent or very weak, weak, medium, strong)
67	QL	Fruit: present of warts (absent, present)
68	QL	Fruit: parthenocarpy (absent, present)
69	QL	Fruit: peduncle shape
70	QN	Fruit: position of broadest part (toward stem end, middle, toward bottom end)
71	QN	Fruit: present of neck (absent or very weak, weak, medium, strong)
72	QL	Fruit: present of spines
73	QN	Fruit: ribs (absent or weak, medium, strong)
74	PQ	Fruit: shape in longitudinal section
75	QN	Fruit: shape in transverse section (round, round to angular, angular)
76	PQ	Fruit: shape of apex (profile of blossom end)
77	PQ	Fruit: shape of base (profile of stem end)
78	PQ	Fruit: shape of the top of warts (acute, obtuse, rounded)
79	QN	Fruit: size of warts (very small, small, medium, large, very large)
80	QN	Fruit: stripes on skin (absent of very weak, weak, medium, dense, very dense)
81	QL	Fruit: sutures (absent, present)
82	QN	Fruit: thickness of flesh (mm)
83	QN	Fruit: time for physiological maturity (days)
84	QL	Fruit: type of vestiture (hairs only, hairs and prickles, prickles)
85	QN	Fruit: wart size (small, medium, large)
86	QN	Fruit: number of warts (few, medium, many)
87	QL	Fruit: waxiness of skin (absent, present)
88	QN	Seed: color of testa (seed coat)
89	QN	Seed: indentation of edge (deep, medium, shallow)
90	QN	Seed: size (small, medium, large)
91	QN	Seed: weight of 100 seeds (g)

Cr., characteristic order; QN, quantitative characteristics (continuous variables); QL, qualitative characteristics (categorical variables); PQ pseudo-qualitative characteristics (categorical variables).

Appendix 11. Differentiation of 17 categorical variables (QL, PQ, and QN characteristics) of 25 cucumber accessions

PNo.	Origin	Cr.01	Cr.10	Cr.11	Cr.18	Cr.20	Cr.22	Cr.23	Cr.25	Cr.41	Cr.42
BeTr01	Ben Tre	light green	weak	medium	right-angled	moderate	horizontal	dark	white	dark green	orange
BiPh01	Tien Giang	Green	very strong	weak	right-angled	moderate	drooping	light	black	green	yellow
BiTh01	Binh Thuan	Green	medium	weak	right-angled	moderate	drooping	medium	white	green	orange
BiTh02	Binh Thuan	Green	strong	medium	right-angled	strong	horizontal	dark	black	light green	orange
BrVt01	BR-VT	Green	medium	very weak	right-angled	moderate	drooping	dark	white	green	yellow
DoNa01	Dong Nai	Green	absent or very weak	weak	right-angled	absent or weak	drooping	very dark	black	light green	yellow
DoNa02	Dong Nai	Green	absent or very weak	weak	acute	moderate	drooping	very dark	black	dark green	yellow
DoNa03	Dong Nai	Green	very strong	weak	obtuse	moderate	drooping	light	black	green	yellow
DoTh01	Dong Thap	Green	medium	very weak	right-angled	moderate	drooping	medium	white	green	orange
HaGi01	Hau Giang	Green	medium	medium	right-angled	moderate	horizontal	very dark	white	dark green	yellow
HcmC01	Tp. HCM	Green	strong	weak	acute	moderate	drooping	medium	white	light green	orange
LaDo01	Lam Dong	green	strong	medium	obtuse	strong	drooping	dark	black	light green	yellow
NiTh02	Ninh Thuan	light green	weak	weak	right-angled	strong	drooping	dark	black	dark green	orange
QuNa01	Quang Nam	green	strong	very weak	right-angled	moderate	horizontal	medium	black	green	yellow
QuNa02	Quang Nam	green	weak	medium	acute	strong	horizontal	dark	white	green	yellow
QuNa03	Quang Nam	green	strong	very weak	right-angled	moderate	drooping	medium	black	green	yellow
QuNa04	Quang Nam	green	weak	medium	right-angled	moderate	horizontal	dark	white	light green	yellow
QuNa05	Quang Nam	light green	very strong	weak	right-angled	moderate	horizontal	light	white	green	yellow
QuNg01	Quang Ngai	green	strong	weak	acute	moderate	drooping	very dark	black	green	yellow
TaNi01	Tay Ninh	light green	weak	medium	right-angled	moderate	drooping	medium	white	dark green	white
TiGi01	Tien Giang	light green	absent or very weak	very weak	acute	absent or weak	horizontal	dark	black	light green	orange
TiGi02	Tien Giang	green	strong	very weak	right-angled	moderate	drooping	light	white	light green	white
TiGi03	Binh Phuoc	light green	medium	medium	right-angled	strong	drooping	medium	white	light green	white
TiGi04	Dong Thap	green	medium	weak	right-angled	moderate	drooping	very dark	black	light green	orange
ViLo01	Vinh Long	green	strong	medium	right-angled	strong	drooping	dark	white	light green	yellow

Appendix 11. (Continued)

PNo.	Cr.48	Cr.49	Cr.53	Cr.60	Cr.63	Cr.73	Cr.75	Cr.76
BeTr01	sparse	sparse	predominantly in bands	distal 2/3	short	medium	round to angular	obtuse
BiPh01	very dense	very sparse	evenly distributed	excluding area around peduncle	short	medium	round	obtuse
BiTh01	medium	sparse	predominantly in bands	distal 2/3	medium	absent or weak	round to angular	obtuse
BiTh02	very dense	sparse	predominantly in bands	whole length	absent or very short	absent or weak	round to angular	rounded
BrVt01	very sparse	sparse	in bands only	distal 1/2	medium	absent or weak	round to angular	rounded
DoNa01	very sparse	very sparse	evenly distributed	whole length	long	medium	round to angular	rounded
DoNa02	sparse	sparse	evenly distributed	distal 2/3	medium	absent or weak	round to angular	rounded
DoNa03	dense	very sparse	evenly distributed	excluding area around peduncle	medium	absent or weak	round to angular	rounded
DoTh01	very dense	medium	in bands only	excluding area around peduncle	short	absent or weak	round	rounded
HaGi01	dense	sparse	evenly distributed	distal 1/3	medium	absent or weak	round to angular	obtuse
HcmC01	medium	sparse	evenly distributed	distal 2/3	long	absent or weak	round	rounded
LaDo01	very dense	medium	evenly distributed	excluding area around peduncle	medium	absent or weak	round to angular	rounded
NiTh02	medium	sparse	in bands only	excluding area around peduncle	long	medium	round to angular	rounded
QuNa01	dense	sparse	predominantly in bands	excluding area around peduncle	long	absent or weak	round to angular	rounded
QuNa02	very sparse	medium	predominantly in bands	excluding area around peduncle	medium	absent or weak	round to angular	obtuse
QuNa03	very dense	sparse	evenly distributed	excluding area around peduncle	medium	absent or weak	round to angular	obtuse
QuNa04	medium	very sparse	in bands only	whole length	medium	medium	round to angular	rounded
QuNa05	dense	very sparse	evenly distributed	whole length	medium	absent or weak	round to angular	rounded
QuNg01	very dense	very sparse	evenly distributed	distal 1/3	short	medium	round to angular	rounded
TaNi01	dense	very sparse	predominantly in bands	distal 1/3	medium	absent or weak	round to angular	rounded
TiGi01	very dense	medium	evenly distributed	excluding area around peduncle	medium	absent or weak	round	rounded
TiGi02	very dense	very sparse	predominantly in bands	distal 1/3	long	absent or weak	round	obtuse
TiGi03	sparse	very sparse	predominantly in bands	distal 2/3	long	absent or weak	round	rounded
TiGi04	very dense	sparse	evenly distributed	excluding area around peduncle	short	absent or weak	round	rounded
ViLo01	dense	sparse	predominantly in bands	excluding area around peduncle	long	absent or weak	round to angular	rounded

Appendix 12. Means of 13 continuous variables (QN characteristics) of 25 cucumber accessions

Passport No.	Cr.02	Cr.04	Cr.13	Cr.21	Cr.35	Cr.36	Cr.40	Cr.44	Cr.55	Cr.59	Cr.61	Cr.82	Cr.91
BeTr01	34.6	20.0	20.6	19.6	37	28	17.4	31.4	190.4	15.6	2.0	10.6	3.81
BiPh01	24.0	14.0	17.1	15.4	48	36	19.0	37.4	238.8	20.2	1.7	12.8	1.98
BiTh01	31.8	19.1	23.1	22.7	34	26	19.5	41.2	227.2	17.8	1.8	12.2	2.38
BiTh02	33.2	22.2	21.0	18.3	34	28	22.2	41.8	284.4	24.5	2.5	12.6	2.65
BrVt01	33.2	22.7	18.5	18.7	37	28	18.1	32.4	236.8	17.5	2.1	12.6	2.79
DoNa01	40.8	16.4	21.5	19.5	37	30	18.5	37.6	228.8	15.4	2.1	10.2	4.24
DoNa02	37.8	19.6	20.7	19.2	46	35	17.3	33.8	189.8	15.6	1.9	12.4	3.39
DoNa03	28.0	15.7	17.5	17.5	38	35	21.4	37.4	281.8	21.2	1.6	16.8	1.8
DoTh01	33.4	24.0	20.8	20.0	33	28	24.2	43.6	277.6	21.4	1.8	15.4	2.78
HaGi01	36.2	21.6	20.5	18.0	35	28	21.7	35.2	269.4	19.2	1.7	16.2	3.39
HcmC01	34.6	23.2	20.4	17.9	34	28	22.4	37.8	245.6	20.5	2.4	12.6	1.69
LaDo01	27.6	14.1	17.2	13.0	36	29	19.3	36.6	275.2	21.6	1.8	13.8	2.31
NiTh02	34.0	22.7	20.5	19.5	36	27	20.8	35.4	268.6	20.0	2.7	15.2	2.45
QuNa01	22.2	17.3	16.5	15.5	45	36	21.9	36.6	263.8	21.7	1.8	16.6	2.2
QuNa02	38.6	20.4	20.0	19.0	37	22	22.4	39.8	224.2	21.2	2.3	16.2	3.13
QuNa03	37.2	26.0	20.3	18.1	36	27	20.5	32.2	223.8	23.1	2.8	14.8	3.5
QuNa04	27.8	19.9	22.0	20.8	38	29	17.2	33.2	199.2	15.5	2.7	10.6	3.5
QuNa05	37.4	14.4	20.5	18.6	45	34	17.8	33.4	228	16.7	1.7	12.6	3.61
QuNg01	36.6	19.4	23.2	20.2	39	34	19.9	37.6	236.4	18.9	1.7	12.8	2.86
TaNi01	27.2	20.2	20.4	19.6	36	31	22.8	35.2	300.2	21.8	2.1	18.2	2.32
TiGi01	35.4	19.6	22.5	22.0	37	28	21.0	39.6	235.4	19.3	1.8	16.4	2.95
TiGi02	35.2	17.5	19.0	18.5	25	-	21.9	36.2	270.8	18.3	1.6	18.2	2.21
TiGi03	39.4	19.8	19.3	18.2	26	-	19.2	29.4	234.2	21.0	2.0	17.2	3.19
TiGi04	37.4	24.7	23.4	21.5	36	27	22.7	38.2	273.8	23.9	2.2	18.0	2.83
ViLo01	34.6	20.1	19.9	19.5	34	28	20.4	37.8	248.8	16.5	2.5	13.2	2.92

Appendix 13. Differentiation of 15 categorical variables (QL, PQ, and QN characteristics) of 22 pumpkin accessions

PNo.	Origin	Cr.14	Cr.19	Cr.23	Cr.41	Cr.42	Cr.46	Cr.47	Cr.52
BaLi01	Bac Lieu	entire or very weakly incised	medium	medium	dark	green	absent or very weak	absent	absent
BeTr01	Ben Tre	entire or very weakly incised	dense	dark	medium	green	Absent	deep	large
TiGi01	Tien Giang	weakly incised	medium	dark	dark	green	Absent	medium	medium
TiGi02	Tien Giang	entire or very weakly incised	medium	dark	dark	cream	absent	shallow	large
QuNa02	Quang Nam	weakly incised	dense	dark	very light	cream	absent or very weak	shallow	medium
QuNa03	Quang Nam	entire or very weakly incised	dense	dark	very light	green	absent	shallow	large
DoNa01	Dong Nai	weakly incised	dense	dark	dark	cream	absent or very weak	medium	medium
DoNa02	Dong Nai	entire or very weakly incised	dense	dark	very light	cream	absent	deep	small
BrVt01	BR-VT	entire or very weakly incised	sparse	dark	very light	cream	absent	shallow	large
LaDo02	Lam Dong	weakly incised	dense	dark	medium	green	absent	medium	large
NiTh01	Ninh Thuan	weakly incised	dense	medium	dark	green	absent	medium	medium
BiTh01	Binh Thuan	entire or very weakly incised	sparse	medium	very light	cream	absent	medium	small
BiTh02	Binh Thuan	weakly incised	medium	dark	medium	green	absent or very weak	shallow	medium
BiDu01	Binh Duong	entire or very weakly incised	medium	dark	medium	green	absent	deep	small
QaNg02	Quang Ngai	entire or very weakly incised	dense	dark	medium	cream	absent	shallow	large
CaTh01	Can Tho	entire or very weakly incised	medium	medium	dark	green	absent	deep	medium
HcmC02	Tp. HCM	entire or very weakly incised	medium	dark	medium	cream	absent or very weak	medium	medium
BiPh02	Binh Phuoc	weakly incised	medium	dark	very light	cream	absent	shallow	large
BeTr02	Ben Tre	entire or very weakly incised	medium	medium	medium	green	absent	shallow	large
DoTh01	Dong Thap	entire or very weakly incised	dense	dark	very light	orange brown	absent	medium	small
TaNi01	Dong Thap	entire or very weakly incised	dense	medium	very light	cream	absent	shallow	medium
HaGi01	Hau Giang	entire or very weakly incised	dense	dark	dark	cream	absent or very weak	medium	medium

Appendix 13. (Continued)

PNo.	Cr.65	Cr.66	Cr.70	Cr.74	Cr.76	Cr.77	Cr.87
BaLi01	yellowish orange	medium	toward blossom end	cylindrica	raised	raised	present
BeTr01	yellowish orange	absent or very weak	at middle	transverse broad elliptic	flat	slightly depressed	absent
TiGi01	yellowish orange	absent or very weak	toward stem end	transverse medium elliptic	flat	moderately depressed	present
TiGi02	yellowish orange	weak	toward stem end	ovate	raised	slightly depressed	absent
QuNa02	yellowish orange	medium	toward blossom end	pear shape	flat	flat	present
QuNa03	yellowish orange	absent or very weak	at middle	transverse medium elliptic	raised	slightly depressed	present
DoNa01	yellowish orange	weak	toward blossom end	trapezoid	flat	flat	absent
DoNa02	yellow	absent or very weak	toward stem end	transverse medium elliptic	flat	slightly depressed	present
BrVt01	yellow	weak	at middle	round	raised	slightly depressed	present
LaDo02	yellow	strong	at middle	round	flat	raised	present
NiTh01	yellowish orange	absent or very weak	at middle	transverse broad elliptic	depressed	slightly depressed	absent
BiTh01	yellow	weak	toward stem end	transverse medium elliptic	raised	slightly depressed	present
BiTh02	yellowish orange	strong	toward blossom end	peanut shape	flat	flat	present
BiDu01	yellowish orange	absent or very weak	at middle	transverse broad elliptic	depressed	moderately depressed	present
QaNg02	yellow	strong	toward stem end	round	depressed	slightly depressed	present
CaTh01	yellow	medium	toward stem end	transverse medium elliptic	flat	moderately depressed	present
HcmC02	yellowish orange	absent or very weak	toward stem end	ovate	raised	flat	present
BiPh02	yellowish orange	medium	toward stem end	transverse medium elliptic	flat	slightly depressed	present
BeTr02	yellowish orange	absent or very weak	at middle	transverse broad elliptic	depressed	slightly depressed	present
DoTh01	yellowish orange	absent or very weak	at middle	transverse broad elliptic	depressed	slightly depressed	present
TaNi01	yellow	strong	at middle	transverse medium elliptic	flat	raised	present
HaGi01	yellowish orange	strong	toward blossom end	peanut shape	flat	flat	present

Appendix 14. Means of 17 continuous variables (QN characteristics) of 22 pumpkin accessions

PNo.	Cr.02	Cr.04	Cr.13	Cr.21	Cr.24	Cr.28	Cr.29	Cr.30	Cr.31	Cr.33	Cr.40	Cr.50	Cr.51	Cr.55	Cr.59	Cr.82	Cr.91
BaLi01	42.8	39.5	26.3	26.8	29.0	40.8	129.0	36.6	33.2	8.6	32.2	10.2	9.2	1878	36.3	3.5	11.3
BeTr01	39.2	50.2	22.6	23.4	23.5	43.2	99.8	47.4	40.2	8.2	63.1	20.1	16.8	2462	13.4	4.2	12.1
TiGi01	46.0	48.1	26.4	26.8	26.7	45.4	95.2	51.8	33.6	7.7	66.4	21.1	13.8	2810	17.8	3.2	13.3
TiGi02	35.8	42.7	24.5	27.1	32.5	92.6	109.6	43.4	37.2	9.2	74.5	23.7	26.0	3190	11.1	4.6	15.3
QuNa02	42.4	43.5	23.2	24.6	28.0	113.0	95.8	50.4	45.6	10.3	23.3	7.4	11.2	722	14.6	2.7	14.3
QuNa03	44.4	38.6	21.9	26.1	27.8	60.4	92.6	65.2	45.4	9.4	56.2	17.9	10.2	1838	13.1	3.3	18.3
DoNa01	40.8	28.8	21.5	23.3	28.4	32.8	101.0	40.8	31.4	12.9	41.7	13.3	12.8	944	11.8	2.4	12.6
DoNa02	37.2	44.3	25.2	24.1	24.3	50.4	105.6	92.6	43.2	13.2	68.4	21.8	13.0	2982	14.7	3.7	15.1
BrVt01	44.6	36.8	25.3	27.9	26.8	63.2	105.4	44.8	40.6	8.8	42.6	13.6	21.6	1018	10.8	2.3	20.7
LaDo02	40.2	43.2	20.2	21.4	20.5	64.2	106.6	60.0	42.4	9.1	62.5	19.9	17.4	2942	17.6	7.1	13.1
NiTh01	41.4	44.1	23.1	22.5	26.4	78.6	95.4	48.8	33.6	10.2	61.4	19.5	8.6	1894	11.6	3.9	12.4
BiTh01	37.8	49.5	29.7	29.3	32.2	82.4	160.2	34.6	32.6	8.6	67.5	21.5	20.8	3076	14.5	3.4	18.0
BiTh02	40.2	48.3	23.5	28.8	29.5	40.8	185.4	32.8	34.0	8.5	33.6	10.7	11.2	1022	15.2	2.4	10.6
BiDu01	48.4	38.6	20.7	21.4	23.0	56.7	108.2	39.2	37.4	8.4	79.1	25.2	19.2	4284	15.2	5.3	15.2
QaNg02	39.8	34.9	29.2	28.3	26.0	46.2	73.4	40.8	38.0	9.2	58.8	18.7	15.6	2206	15.9	2.2	19.8
CaTh01	38.6	39.4	22.4	25.4	26.4	30.8	118.4	28.4	27.4	11.5	65.9	21.0	12.4	2610	11.4	5.2	8.7
HcmC02	39.6	38.2	22.9	25.5	30.1	53.6	112.6	37.0	30.6	11.3	38.5	12.3	9.6	1008	13.5	3.0	13.2
BiPh02	39.4	43.3	25.3	27.5	24.3	67.8	140.0	39.8	36.6	9.8	63.8	20.3	15.4	2426	13.6	3.5	19.0
BeTr02	37.8	32.1	25.4	24.7	25.7	55.6	131.8	33.6	31.4	8.6	68.5	21.8	9.8	2818	11.6	4.2	13.2
DoTh01	37.8	29.5	24.7	23.5	28.3	58.8	106.6	43.2	37.6	9.6	63.7	20.3	15.0	2712	16.5	2.8	16.5
TaNi01	35.6	40.7	24.1	22.9	31.1	47.6	103.4	37.6	39.6	9.3	50.7	16.1	10.2	1724	16.3	2.4	16.2
HaGi01	33.8	39.4	27.8	26.6	38.6	71.4	115.0	48.2	30.2	10.2	38.4	12.2	10.6	1048	13.8	2.1	17.3

Appendix 15. Differentiation of 14 categorical variables (QL, PQ, and QN characteristics) of 32 bottle gourd accessions

PNo.	BiPh01	BiTh01	BrVt02	CaTh01	DaNo01	DoNa01	DoNa02	GiLa01	HaGi01	HaGi02	HaGi03
Origin	Binh Phuoc	Binh Thuan	BR-VT	Can Tho	Daknong	Dong Nai	Dong Nai	Gia Lai	Hau Giang	Hau Giang	Hau Giang
Cr.01	dark	dark	dark	dark	medium	medium	medium	dark	dark	dark	dark
Cr.07	angular	angular	angular	angular	angular	angular	angular	angular	angular	angular	angular
Cr.14	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised
Cr.17	reniform	round	reniform	round	round	reniform	round	round	round	round	round
Cr.20	weak	moderate	weak	weak	moderate	weak	weak	weak	moderate	moderate	moderate
Cr.23	medium	dark	dark	dark	medium	medium	light	dark	dark	medium	medium
Cr.41	green	green	light green	light green	light green	light green	light green	green	green	dark green	light green
Cr.64	medium	medium	medium	medium	medium	matt	matt	medium	medium	glossy	matt
Cr.66	medium	absent or very weak	sparse	absent or very weak	absent or very weak	sparse	absent or very weak	dense	absent or very weak	sparse	absent or very weak
Cr.69	no flared	no flared	no flared	no flared	no flared	no flared	no flared	no flared	flared	no flared	no flared
Cr.74	oblong blocky	oblong	pyriform	oblong	oblong	oblong	pyriform	pyriform	oblong	pyriform	pyriform
Cr.76	round	round	round	pointed	flat	flat	round	pointed	pointed	pointed	round
Cr.77	flat	round	pointed	pointed	flat	flat	flat	pointed	flat	pointed	flat
Cr.80	absent or very weak	medium	absent or very weak	dense	absent or very weak	absent or very weak	absent or very weak	absent or very weak	dense	absent or very weak	absent or very weak

Appendix 15. (Continued)

PNo.	HcmC01	KiGi01	LaDo01	LaDo02	LaDo03	LoAn01	LoAn02	NiTh01	NiTh02	NiTh03	PhYe01
Cr.01	medium	dark	medium	dark	dark	dark	dark	dark	dark	light	dark
Cr.07	angular	angular	angular	angular	angular	angular	angular	angular	angular	angular	angular
Cr.14	entire or very weakly incised	weakly incised	entire or very weakly incised	entire or very weakly incised	weakly incised	entire or very weakly incised	weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised
Cr.17	reniform	reniform	reniform	round	reniform	round	round	round	round	round	reniform
Cr.20	weak	moderate	weak	moderate	weak	moderate	weak	strong	weak	weak	weak
Cr.23	medium	dark	medium	medium	dark	medium	dark	medium	dark	dark	dark
Cr.41	light green	light green	green	green	green	light green	light green	green	green	light green	light green
Cr.64	matt	matt	glossy	glossy	medium	matt	medium	glossy	glossy	medium	matt
Cr.66	absent or very weak	absent or very weak	dense	dense	absent or very weak	sparse	absent or very weak	absent or very weak	absent or very weak	dense	very dense
Cr.69	no flared	flared	no flared	no flared	no flared	no flared	no flared	flared	no flared	no flared	no flared
Cr.74	oblong blocky	oblong	dumbbell	oblong	elliptical	dumbbell	pyriform	pyriform	pyriform	dumbbell	oblong
Cr.76	flat	flat	flat	flat	flat	flat	pointed	round	round	round	round
Cr.77	depressed	round	pointed	round	round	flat	round	pointed	flat	round	flat
Cr.80	absent or very weak	sparse	absent or very weak	absent or very weak	medium	absent or very weak	very dense	absent or very weak	absent or very weak	absent or very weak	absent or very weak

Appendix 15. (Continued)

PNo.	QuNa01	QuNa02	QuNa03	QuNa04	QuNa05	TaNi01	TaNi02	ThHo01	TiGi01	TiGi02
Cr.01	medium	dark	dark	dark	dark	dark	dark	light	dark	dark
Cr.07	angular	angular	angular	angular	angular	angular	angular	angular	angular	angular
Cr.14	smooth	smooth	smooth	smooth	smooth	smooth	smooth	smooth	smooth	smooth
Cr.17	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised	weakly incised	weakly incised	weakly incised	entire or very weakly incised	entire or very weakly incised	entire or very weakly incised
Cr.20	reniform	round	round	round	round	round	reniform	reniform	reniform	round
Cr.23	moderate	moderate	weak	weak	moderate	weak	moderate	moderate	weak	moderate
Cr.41	medium	medium	medium	dark	medium	medium	dark	medium	dark	dark
Cr.64	light green	light green	green	light green	light green	light green	light green	green	light green	green
Cr.66	medium	glossy	glossy	matt	matt	matt	medium	medium	medium	glossy
Cr.69	sparse	absent or very weak	absent or very weak	absent or very weak	absent or very weak	absent or very weak	absent or very weak	very dense	sparse	absent or very weak
Cr.74	flared	flared	no flared	no flared	flared	no flared	no flared	no flared	no flared	no flared
Cr.76	pyriform	pyriform	dumbbell	oblong	pyriform	oblong	elliptical	oblong	pyriform	elliptical
Cr.77	flat	round	round	pointed	round	round	round	round	round	round
Cr.80	round	flat	flat	flat	round	flat	round	flat	flat	depressed

Appendix 16. Means of 14 continuous variables (QN characteristics) of 32 bottle gourd accessions

PNo.	BiPh01	BiTh01	BrVt02	CaTh01	DaNo01	DoNa01	DoNa02	GiLa01	HaGi01	HaGi02	HaGi03	HcmC01	KiGi01	LaDo01	LaDo02	LaDo03
Cr.02	32.4	34.6	34.8	30.6	33.2	30.6	31.8	31.6	33.2	30.2	25.8	36.0	29.2	28.0	30.6	29.2
Cr.04	53.5	41.5	46.7	39.8	50.8	51.7	41.4	54.0	46.9	44.1	56.2	47.6	51.5	39.5	37.6	48.2
Cr.13	24.3	22.0	20.4	22.6	26.2	23.6	24.1	29.4	21.6	23.2	25.5	30.5	26.2	22.2	16.9	24.8
Cr.21	30.0	25.4	24.8	25.8	31.6	28.0	27.0	34.2	23.6	25.2	29.5	31.5	28.2	23.6	22.5	25.2
Cr.24	18.8	16.1	15.6	16.8	19.6	18.8	16.8	22.8	15.5	16.0	17.8	25.2	18.8	15.8	14.5	18.2
Cr.35	44.0	51.0	51.0	51.0	46.0	51.0	39.0	49.0	50.0	52.0	54.0	55.0	51.0	46.0	53.0	53.0
Cr.36	39.0	47.0	49.0	48.0	41.0	44.0	37.0	47.0	47.0	49.0	50.0	50.0	48.0	43.0	50.0	50.0
Cr.40	25.8	21.1	26.2	24.1	27.2	24.3	32.0	23.5	22.7	22.4	27.2	21.4	24.5	32.5	24.4	31.3
Cr.50	11.2	9.7	11.3	10.7	11.7	10.7	13.2	10.5	10.2	10.1	11.7	9.8	10.8	13.3	10.8	13.0
Cr.55	1183	913	1424	1075	942	901	1642	1832	968	1541	1768	937	1109	609	880	1530
Cr.59	31.4	30.4	24.8	36.5	25.9	26.5	26.8	42.1	31.9	32.8	36.1	23.9	38.0	17.9	25.2	23.5
Cr.61	13.8	14.5	19.1	13.9	17.8	15.2	12.4	17.9	14.6	17.6	13.4	14.1	16.3	14.8	13.6	14.2
Cr.83	49.0	57.0	58.0	58.0	51.0	55.0	48.0	55.0	57.0	56.0	59.0	52.0	56.0	52.0	58.0	58.0
Cr.91	10.7	14.3	11.8	16.4	15.3	15.4	10.0	18.2	14.8	17.2	17.3	16.3	23.7	14.8	17.2	19.2

Appendix 16. (Continued)

PNo.	LoAn01	LoAn02	NiTh01	NiTh02	NiTh03	PhYe01	QuNa01	QuNa02	QuNa03	QuNa04	QuNa05	TaNi01	TaNi02	ThHo01	TiGi01	TiGi02
Cr.02	34.4	34.0	30.6	34.2	32.8	33.8	32.8	31.2	26.4	35	34.8	31.6	31.2	38.2	30.8	24
Cr.04	49.2	40.8	48.4	57.5	61.6	48.1	49.5	52	41.8	55.1	60.3	49.6	51.8	51.3	48.8	43.5
Cr.13	21.4	20.6	25	20.5	24.4	25.2	23.8	26.0	23.5	27.4	25.2	28.0	22.8	32.0	26.5	27.6
Cr.21	23.6	23.2	28.2	23.2	28.1	25.3	24.1	30.3	26.2	30.8	28.4	30.6	27.9	34.5	31.2	28.2
Cr.24	15.4	16.0	17.2	15.4	16.8	20.2	17.7	19.0	17.2	20.0	19.5	21.3	15.3	25.4	23.1	19.0
Cr.35	52	50	49	51	52	40	48	50	48	55	52	45	45	46	51	52
Cr.36	43	44	42	43	49	38	44	42	44	51	50	42	42	42	43	51
Cr.40	31.5	24.4	34.1	33.2	44.5	24.5	29.5	36.5	28.1	22.2	28.6	28.1	27.5	23.5	39.5	31.2
Cr.50	13.0	10.8	13.9	13.6	17.2	10.8	12.4	14.6	11.9	10.1	12.1	11.9	11.8	10.5	15.6	12.9
Cr.55	596	1832	1474	1463	1064	972	1913	1740	560	1046	1583	857	1284	910	2100	1536
Cr.59	17.8	41.2	18.7	19.2	43.5	30.3	39	25.8	18.2	36.8	28.1	20.2	18.5	27.8	35.7	23.8
Cr.61	13.2	12.7	14.3	15.9	12.8	18.4	17.4	12.1	12.6	14.8	14.7	18.2	16.4	13.6	13.6	14.5
Cr.83	57	55	55	57	57	46	54	55	53	60	56	55	48	52	57	60
Cr.91	9.9	14.2	16.9	18.1	20.2	10.3	20.4	18.7	14.7	17.6	16.1	16.5	19.6	14.6	17.2	13.6

Appendix 17. Differentiation of 11 categorical variables (QL, PQ, and QN characteristics) of 39 loofah accessions

PNo.	Origin	Cr.12	Cr.17	Cr.23	Cr.37	Cr.38	Cr.41	Cr.43	Cr.69	Cr.74	Cr.76	Cr.77
BaLi01	Bac Lieu	deep	orbicular	dark	sparse	not present or very weak	dark green	dark green	flared	elongate tapered	rounded	flattened
BaLi02	Bac Lieu	deep	reniform	dark	very dense	high	green	dark green	flared	elongate blocky	acute	flattened
BeTr01	Ben Tre	medium	orbicular	dark	medium	high	light green	light green	no flared	oblong blocky	acute	acute
BeTr02	Ben Tre	medium	orbicular	medium	medium	medium	light green	light green	flared	oblong blocky	acute	acute
BiDu01	Binh Duong	shallow	orbicular	dark	very sparse	not present or very weak	light green	light green	flared	oblong blocky	acute	rounded
BiDu02	Binh Duong	medium	reniform	dark	very dense	not present or very weak	green	dark green	flared	elongate blocky	rounded	acute
BiPh01	Binh Phuoc	shallow	reniform	light	very dense	high	light green	light green	flared	elongate blocky	acute	acute
BiTh01	Binh Thuan	medium	orbicular	medium	sparse	not present or very weak	medium	dark green	flared	oblong blocky	acute	acute
BrVt01	BR-VT	deep	orbicular	dark	dense	high	dark green	dark green	no flared	elongate tapered	flattened	rounded
CaTh01	Can Tho	shallow	orbicular	dark	dense	medium	green	dark green	flared	elongate blocky	flattened	rounded
CaTh02	Can Tho	shallow	orbicular	medium	medium	not present or very weak	dark green	dark green	flared	oblong blocky	acute	acute
DoNa01	Dong Nai	shallow	orbicular	dark	very sparse	not present or very weak	green	dark green	flared	elongate tapered	rounded	rounded
DoNa02	Dong Nai	medium	orbicular	medium	very sparse	medium	green	dark green	flared	oblong blocky	acute	acute

Appendix 17. (Continued)

PNo.	Origin	Cr.12	Cr.17	Cr.26	Cr.37	Cr.38	Cr.41	Cr.43	Cr.69	Cr.74	Cr.76	Cr.77
HaGi01	Hau Giang	medium	reniform	medium	sparse	not present or very weak	light green	dark green	no flared	elongate tapered	flattened	acute
HaGi02	Hau Giang	shallow	orbicular	medium	sparse	medium	light green	light green	flared	oblong blocky	acute	acute
HaGi03	Hau Giang	shallow	orbicular	medium	very sparse	not present or very weak	light green	light green	no flared	oblong blocky	acute	rounded
HaGi04	Hau Giang	deep	orbicular	dark	very dense	medium	dark green	dark green	no flared	oblong blocky	rounded	acute
HaGi05	Hau Giang	medium	orbicular	medium	very sparse	not present or very weak	dark green	dark green	flared	oblong blocky	acute	acute
HcmC01	Tp. HCM	medium	orbicular	dark	medium	medium	green	dark green	flared	elongate blocky	rounded	flattened
HcmC02	Tp. HCM	medium	orbicular	medium	dense	not present or very weak	green	greem	flared	oblong blocky	acute	acute
HcmC03	Tp. HCM	medium	orbicular	medium	very dense	not present or very weak	light green	light green	no flared	elongate blocky	rounded	flattened
HcmC04	Tp. HCM	medium	orbicular	light	very dense	medium	light green	green	flared	elongate tapered	rounded	rounded
KiGi01	Kien Giang	medium	reniform	medium	very sparse	high	dark green	dark green	flared	oblong blocky	acute	acute
LoAn01	Long An	medium	orbicular	medium	very sparse	not present or very weak	dark green	dark green	flared	oblong blocky	rounded	rounded
LoAn02	Long An	medium	reniform	dark	dense	not present or very weak	green	light green	flared	oblong blocky	acute	acute
NiTh01	Ninh Thuan	medium	orbicular	dark	very sparse	high	green	dark green	flared	oblong blocky	acute	acute

Appendix 17. (Continued)

PNo.	Origin	Cr.12	Cr.17	Cr.26	Cr.37	Cr.38	Cr.41	Cr.43	Cr.69	Cr.74	Cr.76	Cr.77
NiTh02	Ninh Thuan	deep	orbicular	medium	medium	not present or very weak	dark green	dark green	flared	oblong blocky	acute	acute
NiTh03	Ninh Thuan	deep	orbicular	dark	medium	medium	light green	light green	flared	oblong blocky	acute	acute
NiTh04	Ninh Thuan	medium	orbicular	medium	sparse	high	light green	light green	flared	elongate blocky	rounded	rounded
PhYe01	Long An	medium	orbicular	light	sparse	medium	dark green	dark green	flared	elongate blocky	flattened	acute
QuNa01	Quang Nam	deep	orbicular	dark	very sparse	not present or very weak	green	dark green	flared	oblong blocky	acute	acute
QuNa02	Quang Nam	medium	orbicular	medium	very sparse	not present or very weak	green	green	flared	oblong blocky	rounded	acute
QuNa03	Quang Nam	deep	orbicular	dark	sparse	not present or very weak	green	dark green	flared	oblong blocky	acute	acute
QuNa04	Quang Nam	medium	reniform	medium	dense	medium	light green	light green	flared	oblong blocky	acute	acute
QuNa05	Quang Nam	deep	orbicular	dark	very dense	medium	light green	light green	flared	oblong blocky	acute	acute
QuNa06	Quang Nam	shallow	orbicular	light	sparse	medium	light green	dark green	no flared	elongate tapered	acute	rounded
QuNg01	Quang Ngai	medium	orbicular	dark	dense	medium	light green	light green	flared	oblong blocky	acute	acute
TiGi01	Tien Giang	medium	reniform	medium	very sparse	not present or very weak	medium	dark green	flared	elongate blocky	acute	acute
ViLo01	Vinh Long	medium	reniform	light	dense	not present or very weak	dark green	dark green	flared	oblong blocky	acute	acute

Appendix 18. Means of 12 continuous variables (QN characteristics) of 39 loofah accessions

PNo.	Origin	Cr.02	Cr.04	Cr.13	Cr.21	Cr.24	Cr.35	Cr.36	Cr.40	Cr.55	Cr.59	Cr.61	Cr.91
QuNa01	Quang Nam	40.4	40.8	21.6	21.2	12.3	47	45	12.5	190	24.5	7.2	10.9
QuNa02	Quang Nam	36.8	42.5	20	19.6	14.2	45	45	15.3	296	30.1	11.7	10.2
QuNa03	Quang Nam	31.6	37.9	15.8	16.3	11.6	45	46	14.5	336	37	11.5	8.9
HcmC01	Tp. HCM	37.8	44.1	19.8	19.5	12.3	45	46	16.1	197	22.4	16.1	10.6
HcmC02	Tp. HCM	31	44.5	25.2	24.3	21.2	45	45	12.2	194	32.5	10.8	12
HcmC03	Tp. HCM	42.4	45.5	26.6	26.4	15.3	48	49	11.6	205	35.5	11.2	12.4
BeTr01	Ben Tre	31.6	38.6	19.6	19.1	17.6	47	47	11.7	325	38.1	8.5	8.3
BeTr02	Ben Tre	32.2	47.2	19.7	20.6	17.8	44	46	14.3	317	34.2	7.4	10.9
BiDu01	Binh Duong	28.6	38.7	17.7	18.2	11.4	55	52	13.1	179	21.9	8.7	11.9
HaGi01	Hau Giang	32.8	41.3	22.7	21.1	12.6	48	48	12.7	200	33.6	10.7	10.2
HaGi02	Hau Giang	37.8	34.6	19.1	18.8	11.8	45	46	14.3	227	34.3	7.3	12.9
BiPh01	Binh Phuoc	36.4	36.1	23.5	22.1	14.1	45	44	14.2	321	34.9	5.9	10.6
DoNa01	Dong Nai	38.8	40.5	23.3	24.2	11.7	46	46	13.8	225	28.8	10.2	11.1
BiDu02	Binh Duong	32.4	44.1	24.4	23.1	12	53	54	14.6	202	24.7	4.8	9.8
QuNa04	Quang Nam	37.4	44.8	22.8	21.3	11.8	43	45	13.5	347	41.1	5.4	9.5
BrVt01	BR-VT	39.4	44.2	21.4	21.2	12.6	46	45	13.9	230	29.7	8.6	11.2
NiTh01	Ninh Thuan	34.2	51.4	24.1	23.7	17.6	45	46	13.8	313	34.2	10.8	8.4
NiTh02	Ninh Thuan	32.8	36.2	17.2	17.2	11.2	53	51	13.7	309	33.6	9.8	9.8
NiTh03	Ninh Thuan	33.8	37.8	20.6	21.4	8.9	49	50	14.3	198	31.5	9.6	13.5
QuNa05	Quang Nam	31.2	30.9	16.2	16.2	8.3	46	46	11.8	197	33.6	9.5	9.6
NiTh04	Ninh Thuan	30.4	34.7	18.9	18.7	10.1	54	50	13.9	149	15.2	6.5	10.1

Appendix 18. (continued)

PNo.	Origin	Cr.02	Cr.04	Cr.13	Cr.21	Cr.24	Cr.35	Cr.36	Cr.40	Cr.55	Cr.59	Cr.61	Cr.91
LoAn01	Long An	31	38.4	20.7	21.3	8.6	53	52	13.6	221	28.2	5.7	10.3
LoAn02	Long An	30.8	40.5	19.2	17.9	9.8	44	45	13.9	225	34.2	6.5	11.6
QuNg01	Quang Ngai	30.6	32.4	24.3	25.8	10.5	47	45	10.7	212	28.5	12.7	12.4
CaTh01	Can Tho	29.2	48.5	26.8	28.1	13.9	51	54	11.4	245	33.9	6.8	9.9
HaGi03	Hau Giang	27.2	31.9	17.2	17.6	8.7	44	44	13.7	165	18.5	5.7	8.6
DoNa02	Dong Nai	26.4	37.6	18.3	17.8	9.2	45	46	13.5	227	29.5	8.2	9.8
HaGi04	Hau Giang	29.8	41.4	16.5	16.4	12.5	49	48	12.8	217	28.4	7.1	8.6
HaGi05	Hau Giang	35.8	40.7	19.1	18.4	7.2	45	45	11.5	211	27.6	7.7	10.7
CaTh02	Can Tho	31.2	41.2	19.3	19.5	9.6	52	52	11.2	188	32.1	8.5	10
KiGi01	Kien Giang	34.2	36.4	17.2	16.1	14.1	51	50	12.6	319	36.2	10.5	11.3
BaLi01	Bac Lieu	38	37.3	19.7	19.5	11.5	52	51	13.5	165	18.7	7.9	11
BaLi02	Bac Lieu	29.6	38.5	18	16.5	9.1	49	46	12.5	189	24.3	6.1	8.4
HcmC04	Tp. HCM	30	43.2	18.5	17.9	12	46	47	14.1	178	20.6	6.5	8.3
QuNa06	Quang Nam	36	33.4	20.4	20.2	15.4	46	46	13.8	223	28.4	7.6	9.8
TiGi01	Tien Giang	28.8	34.7	19.8	18.1	10.6	51	49	13.5	220	28.2	5.7	12.2
ViLo01	Vinh Long	32	44.6	22.9	21.2	21.1	44	45	12.4	333	35.5	10.5	8.9
BiTh01	Binh Thuan	34.2	42.3	24.1	24.9	18.5	44	44	13.2	192	24.3	10.4	11.6
PhYe01	Long An	33.4	37.8	23.1	23.5	19.2	48	47	13.7	238	28.4	6.5	10.8

Appendix 19. Differentiation of 17 categorical variables (QL, PQ, and QN characteristics) of 42 bitter gourd accessions

PNo.	BrVt01	DoNa01	BiPh01	TiGi01	AnGi01	SoTr01	HcmC01	QuNa01	QuNa02	BrVt02	BrVt03	NiTh01	NiTh02	NiTh03
Origin	BR-VT	DongNai	Binh Phuoc	Tien Giang	An Giang	Soc Trang	Tp. HCM	Quang Nam	Quang Nam	BR-VT	BR-VT	Ninh Thuan	Ninh Thuan	Ninh Thuan
Cr.01	medium	light	light	light	light	light	medium	light	medium	light	light	light	light	light
Cr.23	medium	dark	medium	dark	medium	medium	dark	medium	dark	dark	medium	dark	dark	medium
Cr.26	light	dark	medium	medium	light	light	medium	light	medium	medium	medium	medium	light	light
Cr.39	medium	weak	weak	weak	weak	weak	weak	weak	medium	weak	weak	medium	weak	medium
Cr.41	light green	dark green	medium green	medium green	white	white	medium green	medium green	medium green	medium green	medium green	medium green	medium green	white
Cr.42	orange	orange	orange	reddish orange	orange	orange	orange	orange	orange	orange	reddish orange	orange	orange	orange
Cr.62	long	short	long	long	long	long	medium	short	short	short	short	long	long	medium
Cr.64	high	medium	medium	high	high	high	neutral	medium	low	high	medium	high	low	low
Cr.74	spindle shape	spindle shape	spindle shape	oblong	ovate	spindle shape	spindle shape	oblong	spindle shape	oblong	spindle shape	spindle shape	spindle shape	spindle shape
Cr.76	obtuse	acute	acute	acute	obtuse	acute	acute	obtuse	obtuse	acute	acute	acute	acute	acute
Cr.77	obtuse	obtuse	obtuse	obtuse	rounded	obtuse	acute	acute	obtuse	obtuse	acute	obtuse	acute	acute
Cr.78	rounded	acute	rounded	rounded	rounded	rounded	acute	obtuse	acute	obtuse	acute	rounded	rounded	rounded
Cr.85	medium	small	medium	large	medium	large	small	medium	small	medium	medium	large	large	medium
Cr.86	medium	many	few	medium	few	medium	many	many	many	many	many	medium	few	many
Cr.88	Light	light	light	light	light	light	dark	medium	medium	medium	medium	medium	light	medium
Cr.89	large	large	large	large	large	large	smooth	large	large	large	large	large	large	large
Cr.90	small	medium	medium	medium	large	large	small	large	large	large	medium	medium	medium	large

Appendix 19. (Continued)

PNo.	QuNa03	DaLa01	BrVt04	HcmC02	TiGi02	TiGi03	TiGi04	BiPh02	AnGi02	BiPh03	BiDu01	BiDu02	BrVt05	BrVt06
Origin	Quang Nam	Daklak	BR-VT	Tp. HCM	Tien Giang	Tien Giang	Tien Giang	Binh Phuoc	An Giang	Binh Phuoc	Binh Duong	Binh Duong	BR-VT	BR-VT
Cr.01	medium	light	medium	light	light	light	light	light	light	light	light	light	light	light
Cr.23	medium	dark	medium	medium	medium	dark	dark	medium	medium	medium	medium	medium	medium	dark
Cr.26	medium	medium	medium	medium	medium	medium	light	medium	medium	light	medium	medium	medium	medium
Cr.39	medium	medium	weak	weak	weak	medium	medium	medium	medium	weak	weak	weak	medium	medium
Cr.41	medium green	dark green	medium green	white	light green	dark green	dark green	light green	light green	medium green	light green	white	medium green	light green
Cr.42	orange	reddish orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	reddish orange	orange	orange
Cr.62	medium	short	short	long	long	medium	medium	long	long	medium	long	medium	long	medium
Cr.64	medium	low	medium	high	high	medium	low	high	high	medium	medium	high	high	high
Cr.74	spindle shape	spindle shape	oblong	spindle shape	spindle shape	spindle shape	spindle shape	spindle shape	spindle shape	spindle shape	spindle shape	spindle shape	oblong	spindle shape
Cr.76	acute	acute	acute	obtuse	acute	acute	obtuse	acute	acute	acute	acute	acute	acute	acute
Cr.77	acute	acute	obtuse	rounded	acute	acute	obtuse	obtuse	acute	acute	obtuse	acute	acute	obtuse
Cr.78	rounded	obtuse	obtuse	rounded	rounded	obtuse	acute	obtuse	obtuse	rounded	obtuse	obtuse	obtuse	rounded
Cr.85	medium	medium	medium	medium	large	medium	small	large	medium	large	small	medium	medium	medium
Cr.86	many	many	many	few	few	medium	medium	medium	few	medium	medium	medium	medium	medium
Cr.88	medium	dark	light	light	light	light	light	light	light	light	light	light	light	light
Cr.89	large	large	large	large	large	large	large	large	large	large	large	large	large	large
Cr.90	large	large	large	medium	medium	large	large	medium	large	large	large	large	large	medium

Appendix 19. (Continued)

PNo.	BiDu03	BiDu04	BiDu05	DoNa02	DoNa03	DoNa04	QuNa04	TiGi05	BiPh04	TaNi01	BiPh05	DoNa05	BiTh01	HcmC03
Origin	Binh Duong	Binh Duong	Binh Duong	Dong Nai	Dong Nai	Dong Nai	Quang Nam	Tien Giang	Binh Phuoc	Tay Ninh	Binh Phuoc	Dong Nai	Binh Thuan	Tp. HCM
Cr.01	light	light	light	light	medium	light	light	light	medium	light	light	light	medium	light
Cr.23	dark	dark	dark	medium	dark	medium	medium	medium	dark	medium	dark	dark	medium	medium
Cr.26	medium	medium	medium	medium	dark	medium	medium	medium	medium	medium	medium	medium	dark	medium
Cr.39	medium	medium	medium	medium	medium	medium	medium	weak	medium	weak	medium	weak	medium	medium
Cr.41	white	medium green	medium green	medium green	white	light green	light green	white	medium green	dark green	medium green	medium green	dark green	light green
Cr.42	reddish orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	orange	reddish orange	orange
Cr.62	short	medium	medium	medium	medium	long	long	long	long	long	short	short	short	long
Cr.64	high	medium	medium	medium	medium	low	low	high	high	high	high	medium	low	medium
Cr.74	oblong	spindle shape	spindle shape	spindle shape	spindle shape	oblong	spindle shape	ovate	spindle shape	oblong	spindle shape	spindle shape	spindle shape	spindle shape
Cr.76	obtuse	obtuse	obtuse	acute	acute	obtuse	obtuse	obtuse	acute	obtuse	acute	obtuse	acute	acute
Cr.77	obtuse	obtuse	acute	obtuse	acute	obtuse	acute	rounded	acute	obtuse	obtuse	acute	acute	acute
Cr.78	obtuse	rounded	rounded	rounded	acute	rounded	rounded	rounded	obtuse	rounded	obtuse	rounded	obtuse	rounded
Cr.85	medium	large	medium	medium	small	medium	medium	large	medium	medium	medium	medium	medium	medium
Cr.86	medium	few	few	few	many	medium	medium	medium	few	medium	many	many	many	medium
Cr.88	light	light	light	light	light	light	light	light	light	light	dark	medium	light	dark
Cr.89	large	large	large	large	large	large	large	large	large	large	large	large	large	large
Cr.90	medium	large	medium	medium	small	large	small	small	medium	large	medium	medium	large	large

Appendix 20. Means of 17 continuous variables (QN characteristics) of 42 bitter gourd accessions

PNo.	Origin	Cr.04	Cr.05	Cr.06	Cr.08	Cr.09	Cr.13	Cr.21	Cr.24	Cr.27	Cr.35	Cr.36	Cr.40	Cr.55	Cr.59	Cr.61	Cr.83	Cr.91
BrVt01	BR-VT	34.3	7	5	15	3.8	12.4	12.1	7.3	22.2	32	29	14.8	109.4	14.3	4.3	57	15.25
DoNa01	Dong Nai	27.2	7	6	14	3.7	10.7	10.5	4.5	18.2	37	30	13.9	98.8	12.6	3.6	59	16.87
BiPh01	Binh Phuoc	31.3	14	7	17	3.6	10.5	11.2	5.4	25.7	37	30	15.3	123.5	14.8	3.5	64	17.23
TiGi01	Tien Giang	38.4	11	5	27	3.8	10.6	10.5	4.8	25.3	36	30	16.1	153.2	17.2	3.4	54	19.55
AnGi01	An Giang	38.2	12	6	20	3.8	8.9	8.5	5.5	17.6	31	29	13.4	85.6	9.9	3.9	52	21.18
SoTr01	Soc Trang	40.9	15	7	18	3.9	11.2	13.4	4.5	23.1	37	30	16.5	137.7	15.8	3.5	58	21.29
HcmC01	Tp. HCM	16.9	19	21	29	4.2	8.8	7.5	2.5	12.1	45	47	5.3	38.6	4.1	4.9	67	4.03
QuNa01	Quang Nam	30.1	18	17	27	4.4	12.5	14.8	4.7	31.5	55	52	18.0	279.2	29.4	15.1	77	23.32
QuNa02	Quang Nam	35.4	14	5	25	3.8	11.4	12.0	5.6	21.8	40	30	16.1	124.4	14.2	5.9	68	20.76
BrVt02	BR-VT	36.8	10	6	30	4.0	11.4	12.6	5.3	24.3	31	28	15.2	122.7	14.7	6.5	54	22.38
BrVt03	BR-VT	34.4	14	6	22	3.7	10.2	10.5	3.7	25.1	32	29	17.6	131.7	14.5	4.3	57	20.3
NiTh01	Ninh Thuan	26.3	16	6	14	3.8	10.2	10.7	4.2	22.2	39	28	18.3	160.5	16.8	4.9	59	18.04
NiTh02	Ninh Thuan	38.5	14	6	17	3.7	9.5	9.3	4.4	20.3	39	28	13.5	142.2	17.6	5.7	61	17.52
NiTh03	Ninh Thuan	21.6	25	14	26	3.9	9.7	9.8	3.9	19.8	55	51	12.4	91.8	20.2	5.5	73	21.46
QuNa03	Quang Nam	19.2	15	12	23	3.8	11.3	12.1	4.7	16.8	42	38	15.1	122.7	14.8	4.7	62	22.09
DaLa01	Daklak	18.2	14	12	24	3.6	10.8	10.7	4.1	17.1	50	45	15.4	122.3	14.4	5.1	68	20.81
BrVt04	BR-VT	34.7	17	5	28	3.8	12.5	13.1	5.1	24.2	36	27	14.6	112.9	12.9	4.8	57	20.67
HcmC02	Tp. HCM	31.5	15	6	21	3.8	11.5	12.4	6.1	21.2	37	28	14.7	151.8	18.5	5.8	55	15.65
TiGi02	Tien Giang	32.5	19	7	25	3.7	10.8	10.3	4.4	25.3	38	30	14.6	145.8	17.3	5.3	56	18.87
TiGi03	Tien Giang	32.8	14	4	31	3.8	9.2	9.2	3.8	21.2	35	29	16.8	128.5	14.5	3.9	54	20.52
TiGi04	Tien Giang	38.4	16	7	21	4.0	10.8	10.9	4.5	20.4	39	28	14.5	154.1	19.2	5.5	56	24.09

Appendix 20. (Continued)

PNo.	Origin	Cr.04	Cr.05	Cr.06	Cr.08	Cr.09	Cr.13	Cr.21	Cr.24	Cr.27	Cr.35	Cr.36	Cr.40	Cr.55	Cr.59	Cr.61	Cr.83	Cr.91
BiPh02	Binh Phuoc	24.5	13	4	27	3.8	12.5	12.9	5.1	21.8	37	28	15.4	121.5	14.2	4.2	60	15.83
AnGi02	An Giang	41.6	10	4	18	3.9	12.5	11.5	5.2	22.3	38	28	13.3	110.8	13.7	5.5	56	22.24
BiPh03	Binh Phuoc	23.4	13	4	22	3.6	8.7	8.6	3.8	21.2	34	28	18.4	155.9	15.7	4.5	54	24.53
BiDu01	Binh Duong	31.5	14	5	25	3.8	10.6	10.4	4.4	22.2	35	27	15.1	145.8	16.8	5.6	56	22.05
BiDu02	Binh Duong	28.7	8	5	16	3.9	12.8	11.5	6.3	13.9	33	27	17.9	132.6	14.4	4.3	55	22.55
BrVt05	BR-VT	36.5	12	9	19	4.0	11.1	11.5	4.6	28.3	37	27	15.4	123.5	14.7	4.9	56	23.2
BrVt06	BR-VT	29.4	16	4	22	3.9	12.4	11.5	5.3	22.6	36	28	17.2	148.1	15.2	4.8	57	19.85
BiDu03	Binh Duong	33.5	14	3	28	3.7	10.6	10.8	3.3	22.8	30	28	16.7	160.5	18.4	4.8	51	17.2
BiDu04	Binh Duong	29.1	13	3	16	3.8	11.5	12.4	3.9	22.3	37	28	18.2	130.1	13.5	3.9	59	21.47
BiDu05	Binh Duong	26.5	16	6	13	3.9	10.5	10.3	3.2	19.2	38	30	16.4	126.0	14.3	4.8	59	18.54
DoNa02	Dong Nai	27.8	13	7	22	3.9	9.7	9.5	4.1	26.8	38	30	14.5	117.4	14.1	4.2	62	19.11
DoNa03	Dong Nai	32.3	13	5	23	3.7	10.5	11.6	6.2	25.4	35	28	14.3	119.4	14.8	5.7	57	15.19
DoNa04	Dong Nai	33.4	15	11	16	3.7	11.4	11.8	3.7	25.2	38	33	12.8	134.4	16.6	4.9	60	20.88
QuNa04	Quang Nam	33.7	15	6	14	3.6	11.3	11.2	3.5	23.7	37	28	14.1	137.6	16.0	4.1	61	13.08
TiGi05	Tien Giang	23.2	9	7	15	3.8	9.6	9.7	3.2	22.4	35	27	16.7	129.3	14.8	5.0	61	13.74
BiPh04	Binh Phuoc	36.3	17	8	22	3.7	10.6	10.5	4.7	22.1	39	29	13.2	130.3	15.3	5.3	61	19.25
TaNi01	Tay Ninh	28.6	13	7	15	3.9	9.6	10.2	4.9	15.2	38	29	12.9	107.5	13.3	5.4	64	20.67
BiPh05	Binh Phuoc	33.5	16	6	26	3.9	11.2	11.5	3.6	20.2	39	28	15.9	141.7	15.1	3.5	63	19.92
DoNa05	Dong Nai	37.5	10	7	18	3.7	11.5	10.8	4.2	19.2	35	30	15.2	119.0	13.8	4.6	57	16.97
BiTh01	Binh Thuan	18.7	12	13	25	3.7	9.5	9.3	3.6	16.2	54	46	14.2	99.8	12.3	5.8	70	21.07
HcmC03	Tp. HCM	35.1	13	7	18	3.9	9.2	10.1	3.4	20.4	38	35	17.5	130.9	14.4	4.7	62	22.25