Studies on agronomy and crop physiology of *Plectranthus edulis* (Vatke) Agnew

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Studies on agronomy and crop physiology of *Plectranthus edulis* (Vatke) Agnew

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Abstract

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Plectranthus edulis (Vatke) Agnew (Lamiaceae) is an ancient Ethiopian tuber crop grown in mid and high altitude areas in the north, south and south-west of Ethiopia. Cultivation dates back from c. 3000 BC, but in recent years its acreage and production have declined. Renewed interest to conserve the crop and increase its production is limited by absence of accurate information on growth, development and cultural practices of *P. edulis.* This project aimed at providing the basic knowledge needed to direct further applied research.

A standard production technique was developed after interviewing farmers in Chencha and Wolaita in southern Ethiopia, and was used in later experiments. The standard planting material chosen were de-sprouted tuber pieces, prepared from a medium (12–15 cm) sized mother tuber broken into three pieces. Three pieces were planted per hole, at a hole spacing of 75 × 90 cm. Shoot tipping (pinching; the removal of the apices with 1–2 leaf pairs) was carried out when the crop was 10–15 cm high.

The general structure of the crop was similar to that of Irish potato. Plant components were: the seed tuber pieces, sprouts, main stems, branches, leaves, inflorescences, fruits, seeds, roots, stolons and tubers. The crop had a long growing period. In two growth studies, maximum fresh tuber yields were attained c. 34 weeks after planting (WAP). Above-ground development was characterised by a late emergence (c. 4 weeks), a slow development of the canopy after emergence until full ground cover was attained (c. 20 weeks), a very short period during which ground cover was full (c. 2 weeks) and a relative fast decline in ground cover thereafter (6−8 weeks). Primary and secondary branches constituted the major part of the canopy. The first stolons were formed c. 10–12 WAP on below-ground nodes of main stems and primary branches. Tubers were first recorded at 18 WAP as a swelling on the tip of the stolon and sometimes as a swelling of the middle part of stolons. Tubers attained a maximum length of 20–25 cm, and a maximum diameter of c. 2 cm. Aerial stolons were initiated 12−16 weeks later than below-ground stolons and could be up to 2.5 m long.

The increase in tuber fresh weight with time was realized by an increase in both number of tubers and in average weight per tuber over the entire tuber formation period. Fresh tuber yields at 34 WAP were 45–49 Mg ha^{-1}. Yield levels in other sets of experiments in which the harvest date was chosen arbitrarily were c. 21 Mg ha^{-1} (29.7 WAP) and c. 30 Mg ha^{-1} (34.7 WAP). Experimental yields were very high compared to those reported by farmers.

Nevertheless, in growth studies, the average daily dry matter production of the crop over the whole growing period was only 4.2−4.6 g m^{-2} day^{-1}. The dry matter production was limited by a poor radiation interception by the canopy – only one third of the incident radiation was intercepted − and a low radiation use efficiency (RUE) – on average only 1.59 g MJ^{-1} photosynthetically active radiation (PAR). RUE gradually increased after emergence to about 2.7 g MJ^{-1} PAR when tuber formation was still in an early stage (24−26 WAP), but then declined because of a stagnation or decline in total crop dry weight, that lasted several weeks. Dry matter production decreased in that period because the decrease in canopy dry matter – especially stem dry matter − was not yet compensated for by the increase in tuber dry matter. This was attributed partly to a still limited capacity of the tubers to convert and / or store assimilates in this stage. Later this changed and total dry weight and RUE increased again. Harvest index was 81–99% at the moment when tuber yield was maximum.

Shoot tipping significantly increased ground cover and delayed canopy senescence. Tipping also had a positive – though not always significant – effect on tuber yield. Tipping enhanced early stolon formation, but did not consistently affect the number of stolons later in the growing season Because differences among tipped treatments were not large, limiting the tipping frequency to one will help to save time, labour and money.

Across experiments in which the number and size of the tuber pieces planted per hole were varied, the tuber fresh weight increased when the number of main stems per m^2 increased up to 2.5–3 main stems per m^2. This sufficiently high stem number could usually be achieved by planting sufficient seed tuber material (equalling at least one medium-sized mother tuber per hole) and breaking it into two or three pieces. This confers with the farmers practice. Over all treatments, an increase in fresh tuber yield was never realized by merely increasing the individual tuber weight, but either by combined effects on number of tubers and individual tuber fresh weight or by an effect on number of tubers alone.

A further increase in radiation interception by advancing and improving canopy development could likely be achieved by planting larger seed pieces, pre-sprouting the seed tuber pieces and using a higher plant density. However, the below ground development should be geared to that. At present the late initiation and formation of tubers already seems to limit production, and this should be improved when an enhanced canopy cover should result also in higher tuber yield.

On short term notice, however, the major constraints to concentrate on will be the shortage of seed tubers and the poor storability of the progeny tubers. Shortage of seed tubers was mentioned by the interviewed *P. edulis* farmers as a major constraint and the principle reason for the decline in production of *P. edulis.* The present practice by farmers of storing tubers *in situ* in the ground was shown to reduce tuber fresh weights by 36–59% and the number of tubers by 18–48% in 6 weeks.

Keywords: Development, morphology, plant density, potato, radiation interception, radiation use efficiency, seed size, seed tuber, spacing, stolon, tipping, tuber

Preface

This thesis is about the indigenous orphan crop *Plectranthus edulis*. It was written based on survey data collected from the southern region of Ethiopia and experiments that were carried out in two localities in south Ethiopia. The thesis has attempted to understand the production practices, major production problems, and also the physiology and agronomy of the crop. It is hoped that the results obtained during the research will serve as a base in an effort to improve the tuber production of this crop. During my research work several organizations and individuals contributed to the realization of this thesis.

I am very grateful to Crop and Weed Ecology of the Plant Sciences Group, Wageningen University, for giving me the opportunity to work on my PhD on this crop. I am also thankful to the Ethiopian Science and Technology Commission and the Norwegian Agency for Development Cooperation (NORAD) for their financial assistance.

I am heavily indebted to Professor dr Paul C. Struik, first for considering my application as a PhD candidate, and then for his unreserved assistance to realize my work. Paul, I thank you for all the effort you made to realize the completion of my work. I am really grateful for all activities including checking, analysing, developing ideas and editing the papers. Paul, I hope you have enjoyed the time you had in Ethiopia and particularly in Wolaita where the farmers tried to explain how the crop is grown.

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Back to Ethiopia, I thank the administrative offices of the Awassa College of Agriculture and Hawassa University. I am also particularly thankful to the Departments of Horticulture and Plant Sciences staffs for their cooperation. Without their cooperation I know I would not have been successful. I thank you all. I want to make special thanks to Admasu Tsegaye, Tesfaye Teshome, Tesfaye Abebe, Awdenegest Moges, Ayele Taye, Firdu Azerefegn, Bizuayehu Tesfaye Yibrah Beyene, Kefyalew Beryihun and Amsalu Gobena. I also thank the Wondogenet Forestry College and Research Institute Dean’s office and administration for providing me an experimental area for my research, and I am particularly indebted to Genene Asfaw for facilitating land for my research.

I also would like to thank the International Livestock Research Institute (ILRI), the Ethiopian Health and Nutrition Institute (EHNRI), the Ministry of Agriculture of Wolaita and Chencha, the Soil laboratory and the Biodiversity Research Institute. I want to make special thanks to the Biodiversity Research Institute for providing me with planting material to start my research.

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Mulugeta Taye
Wageningen, March 2008

Contents

CHAPTER 1

General introduction

Ethiopia: geographical location, climate and population

Ethiopia is a country situated in the Horn of Africa. It is located at a latitude of 3−15 °N and longitude of 33−48 °E. Ethiopia encompasses massive highland complexes of mountains and dissected plateaus divided by the Rift Valley (running generally southwest to northeast), surrounded by lowlands, steps, and (semi-)desert. The highest point in Ethiopia is Ras Dashen mountain (4500 masl) in the northwest and the lowest point is the Danakil (Afar) depression (120 mbsl) in the northeast. The total area of Ethiopia is 1,120,000 km^2, of which about 8% is used by smallholder famers (Alemayehu, 2006). Essentially, the climate is diverse ranging from a semi-arid desert type in the lowlands to a humid and warm type in the southwest (NMSA, 2001). Traditionally, the Ethiopian climate zones are grouped into five categories: *wurch* (cold climate over 3000 masl), *dega* (temperate-like climate; highlands at 2500–3000 masl), *woina dega* (warm; 1500–2500 masl), *kola* (hot and arid type, less than 1500 masl), and *berha* (hot and hyper-arid) (NMSA, 2001). However, because the distribution and amount of rainfall are also important, the zones are grouped into eight agro-ecological zones as indicated in Table 1 (MoA, 2000; Alemayehu, 2006). Generally, in Ethiopia there are three seasons: the dry season (October–January), a short rainy season (February–May) and a long rainy season (June–September) (NMSA, 2001).

The population of Ethiopia was estimated − based on projecting the 1994 census − to be 77,127,000 persons in July 2007, of which 64,438,000 are rural and 12,689,000

Table 1. Traditional Ethiopian agro-ecological zones, based on altitude, rainfall and temperature.

Zones	Altitude (m)	Annual rainfall (mm)	Temperature (°C)
Berha (dry-hot)	500–1500	< 900	> 22
Erteb kola (sub moist-warm)	500–1500	900–1000	18–24
Woina dega (dry-warm)	1500–2500	< 900	18–20
Woina dega (sub moist-cool)	1500–2500	900–1000	18–20
Erteb woina dega (moist-cool)	1500–2500	> 1000	18–20
Dega (cold)	2500–3500	900–1000	14–18
Erteb dega (moist-cold)	2500–3500	> 1000	10–14
Wurch (very cold or alpine)	> 3500	> 1000	< 10

Source: Alemayehu (2006), modified from MoA (2000). Spelling adopted from NMSA (2001).

are urban (CSA, 2006). About 85% of the Ethiopian population lives in rural areas and the male to female ratio is almost one to one (CSA, 1999). Ethiopia is the third most highly populated country in Africa in terms of total population after Nigeria and Egypt (Alemayehu, 2006).

Ethiopian economy, land use and agriculture

The Ethiopian economy is mainly based on agriculture, which accounts for half of the gross domestic product, 90% of the exports, and 85% of the total population employment (NMSA, 2001). Smallholders are the backbone of the agricultural sector. They cultivate 95% of the cropped area and produce 90−95% of the cereals, pulses and oil seeds (Alemayehu, 2006). Most of the arable land is cropped to cereals (85%), followed by pulses (11%) and other crops (4%) (Alemayehu, 2006). Cereals include teff (*Eragrostis tef*), maize, sorghum, barley, and wheat; pulses grown are chick pea, beans and peas; oil crops include sunflower, safflower, rape, neug (Niger seed, *Guizotia abyssinica*) and groundnut (CSA, 2006). Root and tuber crops such as potato, sweet potato, yam, cassava, enset, and *Plectranthus edulis* are also grown in several places in Ethiopia (Westphal, 1975).

Westphal (1975) distinguished four major agricultural systems in Ethiopia: pastoralism, shifting cultivation, the seed-farming complex and the enset-planting complex. Due to many transitions and a great diversity within each of the systems, their border lines are not always clear. However, the grouping mentioned below forms the basis for understanding the systems:

(a) The pastoral complex. This is practised usually in the lower and drier parts of the country, where large herds of cattle, sheep and goats are kept. Locations include areas in the north, east, north-west and southern parts of Ethiopia. Farmers in these areas also grow sorghum, cotton, ginger, cabbage, pumpkin, maize, and also peas and beans. Most pastoralists in these areas are nomadic.

(b) The shifting cultivation. This is practised mostly in the western and south-western fringes of the highlands and in the lowlands. The shifting cultivation practices vary from place to place.

(c) The seed-farming complex. The characteristic of this system is the reproduction of nearly all crops (mainly cereals, pulses, and oil crops) by seed, whereas tuber crops are much less important. This complex is found in the Ethiopian north and in the eastern highlands, and is subdivided into the following three complexes:

    (c1) The grain-plough complex: grain is dominant and there are hardly any fruit trees, green vegetables or tuber crops;

    (c2) The barley-hoe complex: barley is dominant, with some wheat, and also other

crops like legumes;
(c3) The sorghum complex: exists in the highlands in eastern and southern Ethiopia where sorghum is dominant.
(d) The enset-planting complex. This is subdivided into four systems:
  (d1) Enset as a staple food;
  (d2) Enset as a co-staple with cereals and tuber crops;
  (d3) Enset not as co-staple with tuber crops such as yam and taro dominant and cereals of secondary importance;
  (d4) Enset not as co-staple, with cereals dominant and tuber crops of secondary importance.

The tuber crop *Plectranthus edulis*

Plectranthus edulis (Vatke) Agnew, syn. *Coleus edulis* Vatke is an ancient Ethiopian tuber crop (Greenway, 1944; Siegenthaler, 1963). It is locally known by different names such as Dinicha Oromo, Wolaita dono, Gamo dinich, Gurage dinich, Agaw dinich, Ethiopian potato, etc. It belongs to the family Lamiaceae (Labiatae). The genus *Plectranthus* comprises over 350 non-tuber and tuber-bearing species that grow predominantly in Africa, Asia and Australia (Codd, 1985). In addition to *P. edulis* several tuber-bearing *Plectranthus* species are cultivated in many parts of the world. The most common ones of these are *P. barbatus* Andr. [syn. *C. barbatus* (Andr.) Benth., *P. comosus* Sims] (Greenway, 1944; Jansen, 1996); *P. rotundifolius* (Poiret) Sprengel [syn. *C. tuberosus* (Blume) Bentham, *C. parviflorus* Benth., *Solenostemon rotundifolius* (Poiret) J.K. Morton, *C. rotundifolius* Chev. and Perrot, *C. dysentericus* Baker, *P. tuberosus* Blume, Hausa potato, Madagascar potato, country potato] (Greenway, 1944; Kay, 1973; Westphal, 1975; Tindall, 1983; Kay and Gooding, 1987; Jansen, 1996) and *P. esculentus* N. E. Brown [syn. *C. dazo* A. Cheval., *C. esculentus* (N.E. Brown) G. Taylor, *P. floribundus* N.E. Brown, Livingstone potato, Tzenza] (Greenway, 1944; Tindall, 1983; Jansen, 1996; Dhliwayo, 2002; Allemann and Hammes, 2003).

Siegenthaler (1963) suggested *P. edulis* to be one of the Ethiopian highland tribesmen's ancient food crops. The coming of *P. edulis* was related with the coming of the negroid people in 3000 BC, who penetrated the plateau from the west, bringing with them agriculture of the Sudanic type (sorghum, cowpea, yam, okra, sesame) (Murdock, 1959). Westphal (1975) reported the crop to be grown in the northern, southern and south-western parts of Ethiopia.

P. edulis is cultivated primarily for its tubers and is consumed after cooking (Westphal, 1975; Zemede and Zerihun, 1997). The raw tuber is rich in carbohydrate (Table 2). The boiled tuber has a slightly higher carbohydrate concentration than Irish potato, but both have comparable low protein and fat concentrations (Table 2). The leaf is cooked and eaten as vegetable in some western parts of Ethiopia, particularly in the Kefa area (Zemede and Zerihun, 1997). Its leaf is also used as a traditional medicine to cure different diseases.

Farmers grow *P. edulis* mainly from seed tuber pieces (Westphal, 1975). They start planting following the advent of the rain mainly from April onwards. During its growth, farmers carry out several cultural practices including tipping, earthing up, and manuring. Farmers start harvesting the tubers mostly between September and November (Westphal, 1975).

Problem statement

For years, *P. edulis* has been a major traditional food crop in several regions of Ethiopia (Westphal, 1975). However, in recent years its acreage and production have declined considerably, due to problems associated with shortage of seed tubers, land scarcity and market problems. This has led to replacement of the crop by maize, sweet potato and potato, but also to the loss of knowledge on optimal cultural practices.

At present, there is a huge interest from the farmers, government and non-governmental organizations to maintain the crop and increase its production, firstly because humans require only little amounts of this crop to satisfy their energy needs as compared to the amounts required from potato and sweet potato, secondly because the

Table 2. Food composition of *Plectranthus edulis* tubers. Data per 100 g edible portion.

	Plectranthus edulis		Irish potato
	Raw	Boiled	Boiled with skin
Energy (calories)	69	101	84
Moisture (%)	81.9	73.8	77.2
Nitrogen (g)	0.30	0.24	0.24
Protein (g)	1.50	1.00	1.50
Fat (g)	0.20	0.20	0.20
CHO (incl. fibre) (g)	15.3	23.7	19.8
Fibre (g)	0.70	1.00	0.70
Ash (g)	1.10	1.30	1.30
Calcium (mg)	29.0	19.0	18.4
Phosphorous (mg)	90.0	62.0	74.3
Iron (mg)	9.30	1.10	3.60

Source: Food composition table for use in Ethiopia, Ethiopian Health and Nutrition Research Institute [EHNRI, 1997 (*Plectranthus* data) and 1998 (potato data)].

crop is little attacked by disease and insect pests as compared to potato and sweet potato, and thirdly because it is also seen as a traditional food. Because of these reasons, farmers have started to replant *P. edulis* in their farmyards. However, absence of any information in the country and elsewhere on the growth and development of the *P. edulis* crop is limiting further progress. Even basic knowledge on the crop was missing at the start of this research. No yield data existed and there was no detailed description of the cultural practices carried out. Among these are some crop-specific practices like tipping (the removal of the apical part of main stems and branches including 1–2 leaf pairs) and the use of tuber pieces for planting. Knowledge about such indigenous practices is important for it may provide some useful clues concerning the potential future direction of scientific research (DeWalt, 1994). In addition there is no knowledge on the rationale behind the different cultural practices and the mechanisms by which they influence crop production.

This project wants to provide the basic knowledge needed to direct further applied research. The study will be carried out on various aspects of the crop. The findings are believed to contribute a great deal to the increment of the productivity of the crop.

Objectives

The first objective of this thesis is to establish and analyse how and why the traditional cultural production practices are carried out in important growing areas of the crop in southern Ethiopia.

A description of the traditional production practices will provide general information on the crop, cultural practices and production constraints, but is also essential to design a ‘‘standard’’ production method for future experiments. In addition, it will identify important differences in cultivation techniques between locations, provide information on the rationale of different cultural techniques in the perception of the farmers, and on the ways by which they assume these cultural techniques will affect tuber yield and tuber size distribution.

The second objective is to characterize the growth and development of the crop with time.

Absence of any information on the development and growth of the crop is limiting further progress in crop yield and area expansion. The first step is increasing insight into the description of the structure of the crop and characterisation of the development and growth with time after planting. This will reveal which plant organs are initiated where and when, and which developmental stages the crop passes through. Characterisation of the development and growth with time will allow establishing the basic growth parameters that determine the yield of the crop, and reveal which processes are limiting production.

The third objective of the project is to understand the mechanisms by which "tipping" and its frequency affect growth, development and tuber size distribution of the crop.

The yield of a crop is a function of the interception of light by the canopy, the efficiency with which the intercepted radiation is converted into dry matter, and the distribution of the dry matter over different plant organs. The tuber size distribution may depend on the number of tubers and the tuber yield. Because the number of sinks may limit production, the number of tubers or the timing of tuber initiation may also have an effect on yield. An important question is whether a higher number of tubers per unit area will increase yield or only reduce average tuber size. The different cultural practices affect yield along these processes.

Amongst the most characteristic cultural practices of the *Plectranthus* crop is ''tipping'', i.e. the removal of the tip of the shoot apex around one month after emergence. Depending on the time and labour availability, this practice can be repeated one and two months later. Farmers believe that tipping encourages growth and increases tuber production.

It is unknown how tipping actually affects the crop. It is likely to break apical dominance, thus stimulating development of shoots from axillary buds (e.g., Salisbury and Ross, 1992). The tipping may stimulate above ground branching and thereby increase light interception by the canopy. Alternatively it may also limit the immediate above ground growth potential and stimulate below-ground development. In potato, the induction of tubers and stimulation of tuber growth are known to enhance the level of photosynthesis. Tuber growth, therefore, may increase light use efficiency. Tipping probably also affects the number of tubers and tuber size distribution, e.g., by stimulating both above-ground and below-ground branching or increasing the number of stems, thus resulting in more stolons per unit area and more tubers per unit area.

The fourth objective of the project is to understand the mechanisms by which different planting practices affect growth, development and tuber size distribution of the crop.

Besides tipping, also other cultural practices may result in changes in numbers of stems and light interception, with potential effects on total tuber production, number of tubers and tuber size distribution.

In many farming areas, farmers use cut pieces or very small-sized whole tubers that are remnants of the previous harvest or that are purchased from the local market. They cut the bigger whole tuber into 2−4 pieces or take some 2−4 small whole tubers and plant them together in a hole. The tuber size is assumed to affect the number of stems, their growth, the number of tubers and the tuber size distribution on a per plant basis. In potato, bigger seed tubers result in more stems per seed tuber, relatively larger sizes of progeny tubers and more progeny tubers. This has been confirmed by several workers including Struik and Lommen (1999).

Thesis structure

The main part of the thesis consists of a general introduction (Chapter 1), five research chapters (Chapters 2−6), and a general discussion (Chapter 7). Chapter 1 gives background information on Ethiopia: geography, climate, population; economy, land use and agriculture; information on *Plectranthus edulis*; describes the research problem and objectives and describes the thesis structure.

The research part of the thesis first concentrates on the indigenous production practices. Chapter 2 describes the results of a survey on the farmers' production practices, the opinions of the farmers on the rationale behind them, and the major production constraints.

The next two chapters concentrate on the characterization of crop development and growth. Chapter 3 deals with the structure of the crop and the development of the numbers of stems and branches, leaves, stolons and tubers with time. Chapter 4 deals with the growth dynamics, particularly in relation to light interception. It identifies which processes are limiting production.

The final two research chapters study the mechanisms behind the important agronomic practices. Chapter 5 deals with the effect of tipping and the frequency of tipping on crop development and tuber yield. Chapter 6 deals with four experiments meant to examine the effect of seed tuber piece size, number and arrangement on crop development and tuber yield. The first of these four experiments deals with breaking mother tubers into different numbers of tuber pieces before planting them in a planting hole, the second experiment deals with the effect of planting tuber pieces with different sizes, experiment 3 deals with planting different numbers of seed tuber pieces of the same size per planting hole, and experiment 4 deals with the effect of the planting arrangement.

In the general discussion (Chapter 7) the opinions of the farmers on how cultural practices affect yield are related to the insights obtained by the experiments. Finally it is discussed what should and could be done to make the crop more successful.

CHAPTER 2

Indigenous multiplication and production practices for the tuber crop *Plectranthus edulis* in Chencha and Wolaita, southern Ethiopia[*]

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Abstract

Plectranthus edulis (syn. *Coleus edulis*) is a tuber-bearing Labiatae species cultivated in parts of southern Ethiopia. To learn about traditional cultural practices and their rationale a survey was conducted among farmers from Chencha and Wolaita, experienced in growing this crop. A pre-tested questionnaire was used to interview 48 family heads categorized into three wealth groups per site. Information was checked through group discussions and field observations. In Wolaita, poorer farmers cropped a larger portion of their land to *P. edulis* than richer farmers. Land was usually prepared for planting between January and April. In Wolaita, the crop was mostly grown in a furrow. In Chencha, growing in patches and on flat land also occurred. Farmers mostly used a digging hoe for land preparation. Tuber pieces were planted about 5 cm deep. According to farmers, using tuber pieces resulted in more stems, more progeny tubers and higher yields compared to using whole tubers. Tubers were broken in pieces 0–1 day before planting. Tuber pieces were planted with sprouts or after desprouting. Crops were usually fertilized with manure, but in Wolaita sometimes also with compost. Applying fertilizer was thought to give more and bigger tubers. Earthing up took place 1–3 times (usually twice), to increase yield. Tipping was also done 1–3 times (usually once), to increase the number of stems. Based on the survey, an overview of the practices and their rationale is compiled for use in further research into this orphan crop.

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Introduction

Owing to the diverse climatic and cultural conditions, numerous groups of crops such as cereals, legumes, leafy vegetables, fruits, and root and tuber crops are grown in southern Ethiopia. Root and tuber crops include enset, Irish potato, sweet potato, yam, cassava, taro and *Plectranthus edulis* (Vatke) Agnew (syn. *Coleus edulis* Vatke). Depending on the place where *P. edulis* is grown it is known under different names, e.g., Wolaita dono, Gamo dinich, Dinicha Oromo, Agaw dinich, Gurage dinich, etc.

P. edulis is a diploid, dicotyledonous plant, with a height up to 150 cm belonging to the Labiatae (Lamiaceae) family. The genus *Plectranthus* consists of over 350 tuber bearing and non-tuber bearing species distributed predominantly in Africa, Asia and Australia (Codd, 1985). Some of the non-tuber bearing species are grown for their leaves and flowers as ornamental or medicinal plants while the tuber-bearing species are cultivated mainly for their tubers. Besides *P. edulis,* tuber-bearing species include *Plectranthus parviflorus* (syn. *Coleus tuberosus*), *Coleus rotundifolius* and *Plectranthus esculentus* (Kay, 1973; Tindall, 1983).

P. edulis is said to be originated in Ethiopia, and has been grown in different mid and high altitude areas (Greenway, 1944; Ryding, 2000). Siegenthaler (1963) reported it to be a major highland tuber crop in the southwestern parts of Ethiopia. Westphal (1975) stated that it is an indigenous crop in the northern, southern, and southwestern parts of Ethiopia. Zemede and Zerihun (1997) reported it to be a major carbohydrate source in Ethiopia. Farmers and the Ministry of Agriculture claim that the total tuber production has declined considerably over the last few decades for reasons unknown. Recently, farmers and governmental and non-governmental organizations have shown a renewed interest in *P. edulis*, for the crop is a traditional food, a major source of energy, and not seriously attacked by diseases and insect pests.

However, information on the growth and development of *P. edulis* and on the optimal cultural practices is scarce. Even basic knowledge on the crop is not available. Knowledge on how and why farmers carry out the different cultural practices and information on the production constraints are essential. As described by DeWalt (1994), knowledge about such indigenous practices is important for it may provide useful clues concerning the potential future direction of scientific research on such orphan crops.

The objectives of this survey study are to establish and analyse what the traditional cultural production practices are in some parts of southern Ethiopia, how they are carried out and how farmers rationalize them. The study will also provide information on production constraints, and will allow farmer's production methods to be assessed. It also provides information on important differences in cultural techniques among farmers

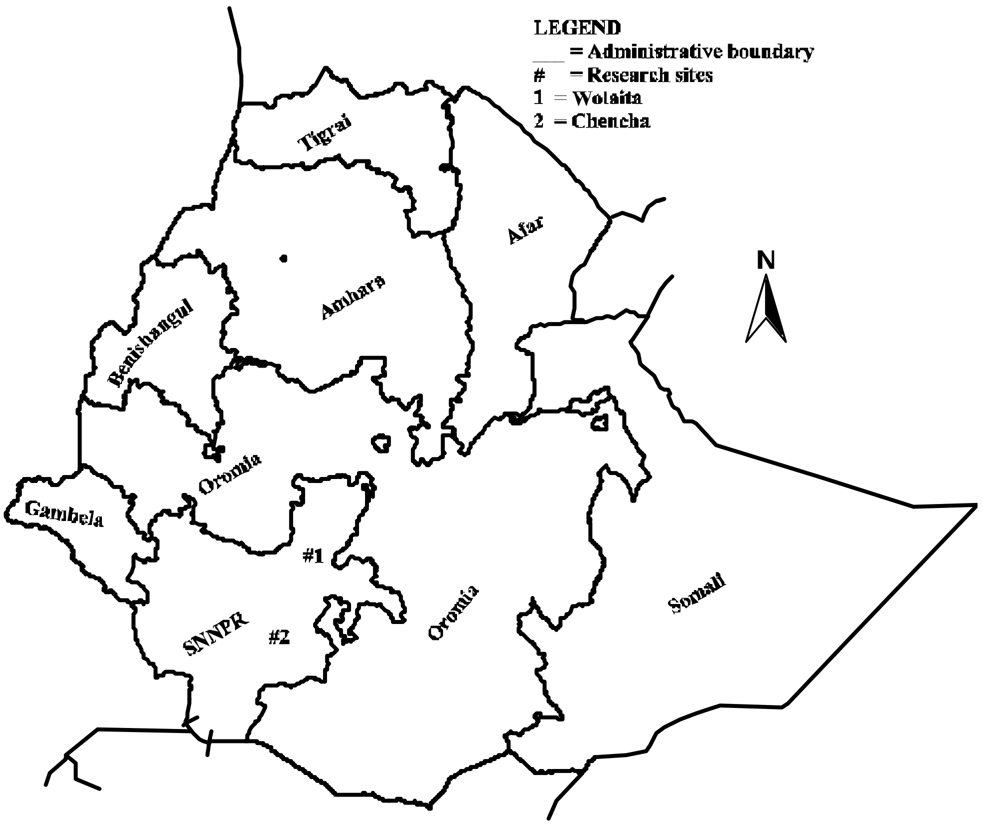

Fig. 1. Map of Ethiopia showing the areas where the survey was carried out. SNNPR: Southern Nations, Nationalities and People's Region.

and on ways by which the farmers assume cultural techniques will affect tuber yield and tuber-size distribution. The information can be used to develop a research agenda.

Materials and methods

Study area

A formal survey was conducted in two *P. edulis* growing areas in southern Ethiopia, namely Chencha and Wolaita (Fig. 1). These areas are among the many places where the crop has been grown widely as a traditional food for many years. Both areas are located in the highlands. Chencha is located 2000–3000 masl with an average temperature of 18 °C, Wolaita is located 1800–2000 masl with an average temperature of 23 °C. Both areas receive 1500–2000 mm rainfall in a bimodal pattern, i.e. short rains from March – May and long rains from July – September. Chencha has a total area of 365 km^2 and a population density of about 301 per km^2. The people in Chencha are mainly engaged in agriculture and crafting (CSA, 2000). Wolaita has a total area of 429 km^2 and a population density of about 629 per km^2. The people in Wolaita are mainly engaged in agriculture (CSA, 2000). In both Chencha and Wolaita there are different ethnic groups. The dominant ethnic groups in both areas belong to the Omotic linguistic family.

Questionnaire and interviewing

A pre-tested questionnaire was used to interview farmers growing *P. edulis*. From a list provided by the Bureau of the Ministry of Agriculture, 48 households were randomly selected from four peasant associations from both Chencha and Wolaita. One family head from each household was questioned on belongings, production practices, perception, problems and constraints encountered, and future plans for the production of *P. edulis.* Both closed and open-ended questions were included in the survey. The latter were only used when more information was desired. The interviewing started on June 28, 2002, in Wolaita and two weeks later in Chencha, and ended after about three months. Specially trained enumerators were taking the interviews. In addition, the researchers very closely followed the cultural practices, from land preparation up to time of harvest and storage, particularly in the Wolaita area.

Group discussions

After analyzing the interview data, discussions with groups of farmers in both areas took place between November 20 and 25, 2002. The groups consisted both of farmers who at the time were growing and who had stopped growing *P. edulis.* During the discussions, several questions were raised with particular emphasis on production practices and constraints. The discussions helped to clarify some points that remained vague during the interviews.

Wealth categories

The respondents were grouped into three wealth categories, namely poor, medium and rich. The wealth categories were based on Aresawem (1993), FARM Africa (1999) and Admasu Tsegaye and Struik (2002). In this categorization, land area cropped, and animals owned (including oxen, dairy cows, sheep, mules and donkeys) were the criteria (Table 1).

Data analysis

Descriptive statistics including percentages and chi-square were carried out using the

Table 1. Criteria for categorizing *P. edulis* growers in Chencha and Wolaita into three wealth categories.

	Chencha			Wolaita		
	Poor	Medium	Rich	Poor	Medium	Rich
Land area (ha)	< 0.25	0.25–1.00	> 1.00	< 0.25	0.25–1.00	> 1.00
Animals						
Oxen	0	0	1–2	0	1–2	2–3
Dairy	0	1	2–3	0	2–3	5–7
Sheep [a]	0	2–3	5–7			
Mule [a]				0	0	1–2
Donkey [a]				0	1	4

[a] Mule and donkey were not considered in Chencha while sheep was not considered in Wolaita.

statistical program SPSS 10.0. Chi-square on numbers of farmers was used to establish differences between locations or wealth categories in cultural practices and opinions of farmers; data were recalculated to percentages for presentation.

Results

Household characteristics

Over 90% of the respondents in Chencha and Wolaita had lived in the area for over 20 years, and 88% of the respondents in Chencha and 79% in Wolaita had grown the crop for over 10 years. Table 2 indicates the land proportion allotted to grow *P. edulis* by different wealth groups. Over 50% of the farmers allotted ≤ 5% of their land to *P. edulis,* around 10% of the farmers more than 15%. The chi-square test showed no significant differences among the wealth groups in the land proportion allotted to *P. edulis* in Chencha. In Wolaita, poorer farmers allotted a relatively larger proportion of land to the crop than richer farmers.

Crop cultivation

In addition to *P. edulis,* respondents in Chencha and Wolaita cultivated cereals (wheat, barley, maize and/or teff), leguminous crops (bean and/or pea), and root and tuber crops (enset, Irish potato, sweet potato, cassava and/or taro). Of the root and tuber crops, 85% and 15% of the respondents in Chencha indicated that they mostly consumed enset and Irish potato, respectively, while in Wolaita 77% and 19%

indicated that they mostly consumed sweet potato and Irish potato, respectively (data not shown). About 75% of the respondents in Chencha and 25% in Wolaita indicated that they consumed less *P. edulis* than the above-mentioned cereals, legumes and tuber and root crops, mainly because of the low yields (data not shown).

In both areas all respondents indicated that they grew *P. edulis* alone as a monocrop for it did not perform very well both in terms of growth and yield when planted as an intercrop.

Table 2. Percentage of respondents in different wealth categories classified according to the percentage land cropped with *P. edulis* in Chencha (n = 48) and Wolaita (n = 48).

Percentage land	Chencha				Wolaita			
cropped to *P. edulis*	Poor	Medium	Rich	χ^2 [a]	Poor	Medium	Rich	χ^2 [a]
≤ 5	33	63	50	3.9	0	56	80	10.4
6–15	50	31	50	(P = 0.422)	83	35	10	(P = 0.033)
≥ 16	17	6	0		17	9	10	
n [b]	12	32	4		6	32	10	

[a] χ^2-analysis was carried out on numbers in different categories per site.

[b] Number of respondents in each wealth category.

Land races of P. edulis

Most respondents knew three to four land races (data not shown). In total, six land races were known in Chencha: Lofuwa, Unnuka, Chankua, Merchia, Dalakuwa and Kaytaria; five were known in Wolaita: Lofuwa, Unnuka, Chankua, Merchia Nech, and Kaytaria. In Wolaita there was a tendency that poor farmers knew fewer land races than farmers that had more resources.

Farmers used various characteristics to identify the land races. Almost all farmers used tuber characteristics and 40–60% also used leaf characteristics, time of maturity or storage duration to identify land races (data not shown). This was similar for Chencha and Wolaita.

Land preparation

The land was usually prepared for planting between January and the end of April, with preparation starting earlier in Chencha than in Wolaita (Table 3). During the discussions, some farmers – particularly those with more land – mentioned that they prepared their land twice, i.e. they carried out the first preparation in October or November and the second one in February. In October and November they used the remnant soil moisture of the main rainy season for turning up the soil, and consequently kill weeds, pathogens and insect pests.

The land was prepared in different forms including furrow, flat (like cereals), patch and raised bed (Table 3). The patch mode was a kind of spot digging, which was done mostly on virgin land or on land that was not cultivated for several years, and the digging was made on a space with a depth of 5–10 cm and diameter of about 50–70 cm. In Chencha, furrows and patches were most often used whereas 13% used flat planting. In Wolaita, the vast majority of the respondents used the furrow method, and 6% used raised beds (Table 3).

Digging hoe (Toyle), spade and ox-pulled plough were used to dig the land (Table 3). The digging hoe is a kind of forked digging tool with two long ‘‘fingers’’. It was mostly used on small plots, while an ox-pulled plough was mostly used on large plots and plain terrain. The digging hoe was the most frequently used tool in both Chencha and Wolaita, and was even more frequently used in Chencha than in Wolaita (Table 3).

Table 3. Percentages of respondents using the indicated months of starting land preparation, mode of land preparation and kind of tool for digging/ploughing before planting *P. edulis* in Chencha (n = 48) and Wolaita (n = 48).

	Chencha	Wolaita	χ^2
Months for preparing the land			
January	31	2	27.0 ($P < 0.001$)
February	13	56	
March	23	21	
April	33	21	
Mode of preparing the soil			
Furrow	46	94	36.9 ($P < 0.001$)
Flat	13	0	
Patch	42	0	
Raised bed	0	6	
Kind of tool [a]			
Ox-pulled plough	17	33	6.7 ($P = 0.035$)
Digging hoe (Toyle)	83	60	
Spade	19	35	

[a] Note that the sum of all kinds of tools is larger than 100% in both areas, because some farmers used several tools.

Planting material

P. edulis was grown from tuber pieces, whole tubers, stem cuttings and sprout cuttings (Table 4). Stem cuttings are the top part of the branches with a length that varied up to 50 cm, while sprout cuttings are the young outgrowths originating from the tuber, about 10–15 cm in length. Tuber pieces were most frequently used while the other types of planting material generally were used only occasionally by a few respondents in Wolaita (Table 4). Farmers did not use true seed.

Table 4. Percentage of farmers using the indicated types of planting material with different frequencies in Chencha (n = 48) and Wolaita (n = 48).

Type of planting material	Chencha			Wolaita			χ^2
	Often	Occasionally	Never	Often	Occasionally	Never	
Whole tubers	0	0	100	2	17	81	10.0 (*P* = 0.007)
Tuber pieces	100	0	0	100	0	0	0
Stem cuttings	0	0	100	0	6	94	3.1 (*P* = 0.213)
Sprout cuttings	0	0	100	0	4	96	2.0 (*P* = 0.360)
True seed	0	0	100	0	0	100	0

On average for the two sites, about 45% of the respondents used tuber pieces primarily to increase the number of stems and about 30% of the respondents indicated that using tuber pieces also increased the number of progeny tubers (data not shown). About 12% of the respondents indicated that they used tuber pieces because they thought it would give them higher yields. In Chencha a few respondents used tuber pieces merely because it was considered a traditional practice.

Number of tuber pieces

From one whole tuber, 2–4 pieces were prepared. The vast majority of respondents broke the medium (10−15 cm) and small (5−10 cm) tubers into two pieces and the big tubers (> 15 cm) into three pieces (Fig. 2). In Chencha, the number of tuber pieces prepared from whole tubers of different sizes was lower than in Wolaita (Fig. 2).

Time for breaking the whole tuber and treatment after breaking

In Chencha, most respondents broke the seed tubers one day before planting or on the day of planting, while in Wolaita the vast majority of respondents broke the tubers on the day of planting (Table 5).

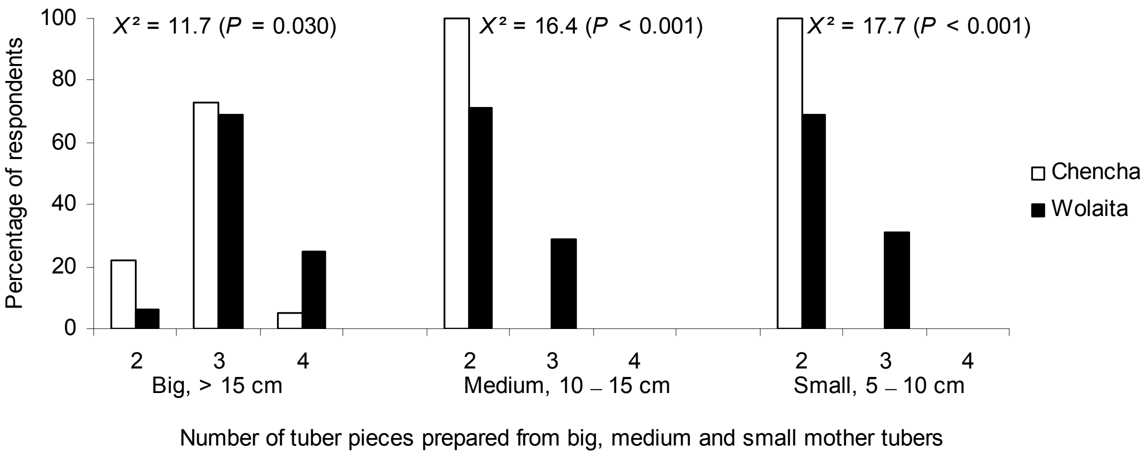

Fig. 2. Percentage of respondents preparing 2, 3 or 4 tuber pieces from big, medium and small sized tubers in Chencha (n = 48) and Wolaita (n = 48).

Table 5. Percentage of farmers breaking seed tubers into pieces for planting at the indicated time and adopting the indicated treatment of the tuber pieces between breaking and planting in Chencha (n = 48) and Wolaita (n = 48).

	Chencha	Wolaita	χ^2
Time of breaking seed tubers into pieces for planting			
Day of planting	48	73	9.9 ($P = 0.019$)
One day before planting	52	23	
Two days before planting	0	2	
Three or four days before planting	0	2	
Treatment of seed tuber pieces between breaking and planting			
Spreading tubers on dry place in the house	42	0	26.9 ($P < 0.001$)
Mixing with ash	2	0	
No treatment	56	100	

Respondents in Wolaita planted the tuber pieces without subjecting them to any treatment (Table 5). In Chencha, almost half of the respondents kept the tubers in a dry place in the house, while one respondent mixed the tuber with ash (Table 5).

Planting the tuber pieces

The tuber pieces could be planted with sprouts, which were produced during storage, or after de-sprouting. In Chencha 67% of the respondents planted the tuber pieces after de-sprouting; in Wolaita this was 46%. The remaining farmers planted their seed

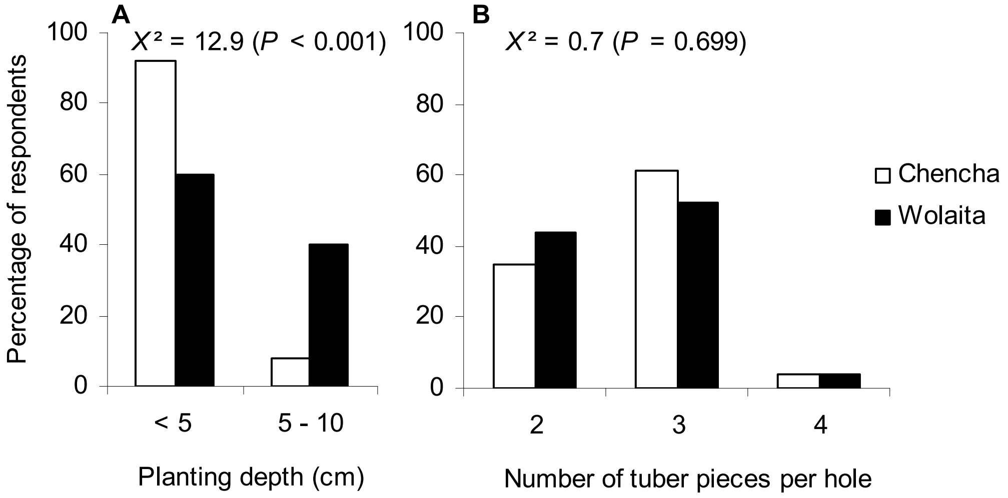

Fig. 3. Percentage of respondents in Chencha and Wolaita indicating planting of seed tubers or seed tuber pieces at a depth of < 5 cm or 5–10 cm (A) and planting 2, 3 or 4 tuber pieces per hole (B).

tubers with sprouts. Those respondents who used de-sprouted tubers did so to get more stems, whereas respondents who used sprouted tuber pieces, mainly did so to improve growth (data not shown).

Planting tuber pieces took place most of the time in April, following the short rain that occurred in this month. During the group discussions some farmers indicated that they planted their tubers in March, and relied on the coming of adequate rain.
Tuber pieces were usually planted at an approximate spacing of 60−100 cm between rows (furrows) and 40−75 cm within a furrow row. A wide spacing was preferred because *P. edulis* has a branchy growth habit and because a wide spacing allows carrying out practices including earthing up and tipping (see below).

Almost all respondents in Chencha covered the seed tuber pieces with less than 5 cm soil (Fig. 3A), whereas in Wolaita 40% of the respondents covered the tuber pieces with 5–10 cm soil in order to protect the progeny tubers from strong and direct sun shine (Fig. 3A).

Most respondents planted three or two tuber pieces at one planting position (hole) (Fig. 3B). The tuber pieces were planted at some distance from each other within one hole to reduce competition during early growth.

Fertilization

When fertilizing, respondents in Chencha relied entirely on animal manure while in Wolaita 37% used compost, alone or in addition to manure (Table 6).

Most respondents in Chencha indicated that they applied manure one time or regularly (four times or more) while in Wolaita they generally applied it three times (Table 6). Farmers applied manure any time until earthing up and placed it around the root system. If the manure was a fresh dung, farmers did not place it close to the root system. Because of the fear of ‘‘burning’’ the farmers usually kept the fresh dung on top of the soil for some time and then incorporated it with some soil thus putting it closer to the root system. The amount of manure varied approximately between 20–30 Mg ha^{-1}. During the group discussions farmers indicated that they kept on applying manure particularly as the temperature got higher for they thought that this could help to cool down the soil**.**

Most respondents indicated that fertilization resulted in more and larger tubers (Table 6), with even more respondents indicating the positive effects in Chencha than in Wolaita (Table 6).

Table 6. Percentage of respondents indicating the different fertilization practices and effects of fertilization in Chencha (n = 48) and Wolaita (n = 48).

	Chencha	Wolaita	χ^2
Type of fertilizer			
Manure only	94	63	24.0 ($P < 0.001$)
Compost only	0	6	
Manure and Compost	0	31	
None	6	0	
Number of applications			
0	0	0	77.4 ($P < 0.001$)
1	40	0	
2	13	10	
3	4	90	
≥ 4	44	0	
Effects on tuber number			
More tubers	94	75	6.8 ($P = 0.034$)
No effect	6	21	
Less tubers	0	4	
Effects on tuber size			
Larger tubers	94	63	13.9 ($P = 0.001$)
No effect	6	33	
Smaller tubers	0	4	

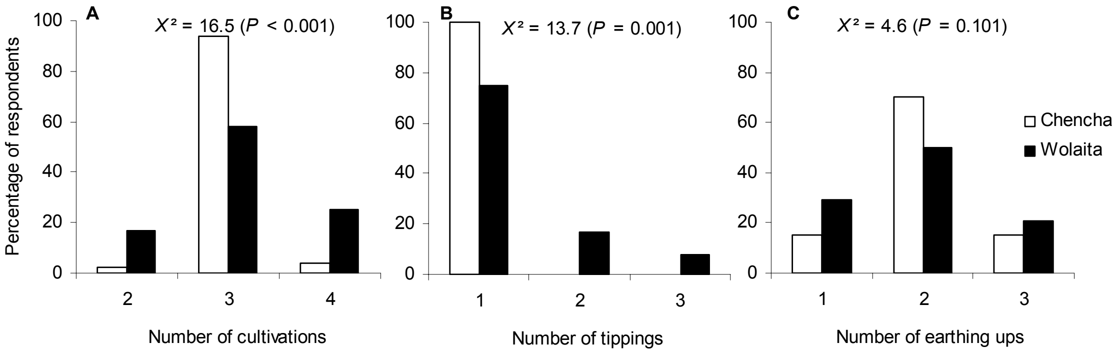

Fig. 4. Percentage of respondents in Chencha and Wolaita indicating that they cultivated the soil 2, 3 or 4 times (A), that they carried out 1, 2 or 3 tippings (B) and that they earthed up 1, 2 or 3 times (C). For definition of cultivation see text.

Cultivation

Cultivation is a shallow digging around the root system. More than 90% of the respondents in Chencha cultivated three times while in Wolaita about 50% of the respondents cultivated three times and the remaining two and four times (Fig. 4A). During the group discussions with the farmers, they indicated that they carried out the first cultivation following the emergence of the shoot. The other cultivations depended on the occurrence of weeds around the stem. Cultivation was carried out for various reasons including for the production of more stems, more tubers, higher yield and to overcome weeds (Table 7). Most mentioned more stems as the principal reason for cultivation.

Tipping

Tipping is the removal of one or two pairs of leaves from the tip part of the main stem and branches. The number of tippings varied significantly between Chencha and Wolaita, with only one tipping being carried out in Chencha, and 1–3 in Wolaita (Fig. 4B). During group discussions, the farmers mentioned that they carried out the first tipping as soon as the plant reached about 15 cm or had produced 2–3 pairs of leaves, the second tipping 1 month after the first and the third 2 months after the second. Most farmers at both sites were convinced that tipping increased the number of stems (Table 7). In addition, some farmers at both sites mentioned it increased yield (Table 7), but – given the labour requirement of this practice – the percentage of respondents who had this opinion was relatively low.

Table 7. Percentage of respondents mentioning the indicated principle rationale for cultivation, tipping, and earthing up carried out on *P. edulis* in Chencha (n = 48) and Wolaita (n = 48).

	Chencha	Wolaita	χ^2
Rationale for cultivation			
More stems	42	46	8.9 ($P = 0.063$)
More tubers	10	0	
Bigger tubers	4	0	
Higher yield	29	27	
Protect from weeds	15	27	
Rationale for tipping			
More stems	67	81	5.1 ($P = 0.163$)
More tubers	4	0	
Bigger tubers	0	0	
Higher yield	25	19	
Short, broad canopy	4	0	
Rationale for earthing up			
More stems	10	19	13.2 ($P = 0.0.10$)
More tubers	13	21	
Bigger tubers	17	13	
Higher yield	60	33	
Others [a]	0	15	

[a] Other reasons include protection of plants from sun burn and burying stolons.

Earthing up

Earthing up refers to the piling up of the soil around the stems. Most respondents piled up the soil around the stem twice while some piled up the soil once or three times (Fig. 4C). Most respondents carried out the first earthing up in the first 45 days from planting, the second between 90−135 days and the third between 135−180 days from planting (data not shown). Farmers carried out the earthing up principally to increase yield, whereas some mentioned more stems, more tubers and bigger tubers as reason for earthing up (Table 7). During the group discussions farmers indicated that they earthed up their crop more than three times in order to cover the stolons that appeared above the soil and to support the branches from a heavy wind.

Diseases, insect pests and weeds

Diseases were reported to occur only in Wolaita, by about 60% of the respondents, of which the majority mentioned that diseases reduced the number and/or size of the progeny tubers and a few claimed that diseases increased the number and/or size of the progeny tubers (Table 8). Insect pests were reported to occur by almost half of the respondents and were reported to have negative effects on number and size of progeny tubers (Table 8). Weed problems were reported by all respondents. In Chencha, 10% of the respondents claimed weeds had no effect on tuber size, whereas in Wolaita 10% of the respondents claimed weeds had no effect on number of progeny tubers (Table 8).

Table 8. Percentage farmers reporting no occurrence of diseases, insect pests and weeds in *P. edulis* crops, and occurrence with different effects on tuber number and size in Chencha (n = 48) and Wolaita (n = 48).

	Chencha				Wolaita				χ^2
	No occurrence	Type of effect[a]			No occurrence	Type of effect			
		+	0	–		+	0	–	
Effects on tuber number									
Disease	100	0	0	0	42	13	0	46	39.5 (*P* < 0.001)
Insect pest	44	0	0	56	58	4	0	38	6.3 (*P* = 0.430)
Weed	0	0	0	100	0	0	10	90	26.9 (*P* < 0.001)
Effects on tuber size									
Disease	100	0	0	0	40	10	0	50	41.5 (*P* = 0.001)
Insect pest	44	0	0	56	63	4	0	33	9.7 (*P* = 0.290)
Weed	0	0	10	90	0	0	0	100	26.9 (*P* < 0.001)

[a] +: positive (more or bigger tubers), 0: no effect, –: negative (fewer or smaller tubers).

Harvesting tubers and yield

Harvesting for consumption started earlier in Wolaita than in Chencha (Fig. 5). The majority of the respondents in Wolaita started harvesting in October while in Chencha they started in November (Fig. 5).

Tubers were harvested by digging them up with a digging hoe. Harvesting took place gradually depending upon the need of the family. The number of hills (plants from one planting hole) that were dug depended on the family size. During the group discussions it became clear that farmers with large families harvested the tubers from

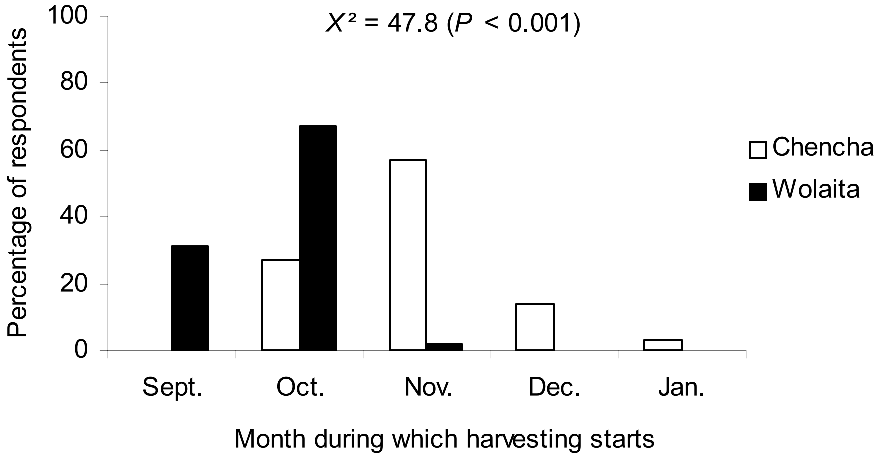

Fig. 5. Percentage of respondents indicating different months of starting harvesting tubers for consumption in Chencha and Wolaita.

2–3 hills while farmers with a small family only harvested from one hill. Farmers also indicated that the yield collected from a hill varied depending on various factors including temperature, rainfall, and crop management. They indicated that the number of progeny tubers from well managed farms varied from 80 to 120 per hole and from poorly managed farms varied up to 20 per hole. The fresh tuber yield per hole varied from 500 to 1000 g in weight.

Harvesting tubers for use as seeds started much later than when tubers were to be used for consumption. Harvesting seed tubers was usually done just before planting. When the land was not adequately covered with plant material or debris, seed tubers could start to sprout long before use. In such cases, seed tubers were dug up and transferred to a cooler place (see storage section).

Storing tubers for consumption and for planting

Tubers for consumption were stored *in situ* in the ground, i.e. in the place where the crop was planted, for a maximum period of 5 months, but usually shorter (Fig. 6). During group discussions with the farmers, they indicated that storing for several months was not desirable for it led to changes in flavour, increased the fibre content, and increased the energy needed for cooking. The maximum storage duration was shorter in Chencha than in Wolaita.

Tubers meant for planting, commonly known as ‘‘seed tubers’’, often were left in the place where they were grown until planting. While they were in the ground they were covered with enset and banana leaves, manure or debris to protect the tuber from

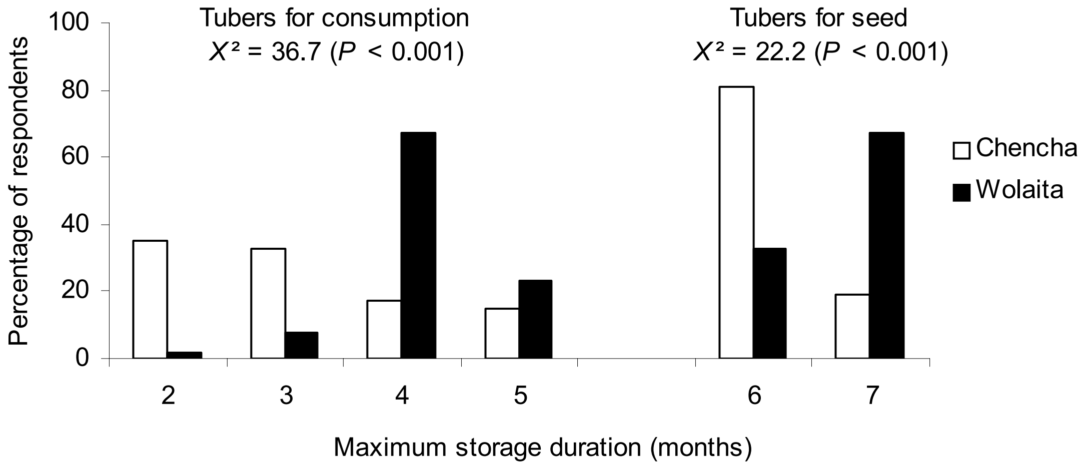

Fig. 6. Percentage of respondents indicating the maximum duration of storage of tubers used for consumption or for seed in Chencha and Wolaita.

strong sunshine. In some instances, however, particularly when high temperature prevailed, farmers moved the seed tubers to other places where there was shade, and placed them in a dug furrow or hole and covered the soil with grasses, enset, banana leaves or any debris. Seed tubers were stored for a shorter period in Chencha than in Wolaita (Fig. 6).

Seed tuber acquisition

Most farmers used at least a quarter of their plants as a source of seed tubers for the next planting season. During the group discussions, farmers indicated that those who did not grow the crop before purchased seed tubers from the local market or directly bought them from the producer farm. They bought different sizes depending on their preferences and stored them in the soil or in their houses. They mostly bought the tuber when the planting time was approaching. Because the availability of seed tubers at the time of planting was lower the price per kg was higher. As learned from the group discussions those farmers who were relatively rich preferred bigger tubers while those who did not have adequate money bought smaller ones. Bigger seed tuber sizes cost an average of 7–8 US$/100 kg while smaller seed tubers cost 4–5 US$/100 kg.

Reasons for the decline in production

Several production constraints including shortage of seed tubers, shortage of land, water shortage, poor storage ability and poor market opportunity were indicated as reasons for the decline in production (Table 9). In both Chencha and Wolaita shortage of seed tubers was indicated as the major contributing factor by respondents from all wealth categories. During the discussions, farmers indicated that a high price of seed tubers, long duration (6–8 months) of the crop to reach maturity and high temperature which causes more loss of moisture during crop growth also greatly contributed to the decline in production.

Despite these problems, however, all respondents in both areas wanted to continue growing and consuming the tubers with their families and almost all respondents also wanted to increase the proportion of area cropped to *P. edulis* on their farm (Table 10).

Table 9. Percentage of respondents in the three wealth categories mentioning the indicated principle rationale for the decline of *P. edulis* in Chencha (n = 48) and Wolaita (n = 48)

	Chencha				Wolaita			
Rationale	Poor	Medium	Rich	χ^2	Poor	Medium	Rich	χ^2
Shortage of seed tubers	83	72	100	6.5 ($P = 0.586$)	100	91	70	13.4 ($P = 0.099$)
Shortage of land	0	6	0		0	3	0	
Water shortage	0	9	0		0	0	10	
Poor storage duration	8	12	0		0	0	20	
Poor market	8	0	0		0	6	0	
n [a]	12	32	4		6	32	10	

[a] Number of respondents in each wealth category.

Table 10. Percentage of farmers mentioning the indicated attitudes towards future production of *P. edulis* in Chencha (n = 48) and Wolaita (n = 48).

	Chencha	Wolaita	χ^2
Farmers want to continue growing the crop	100	100	0
Farmers' families want to continue consuming tubers	100	100	0
Farmers expect an increase of the area of *P. edulis* on the farm	100	83 [a]	8.6 ($P = 0.003$)

[a] All other farmers expected the area to remain at least constant.

Discussion

Farmers interviewed

The farmers interviewed were taken at random from a long list of farmers growing the crop obtained through the proper authorities. Therefore, farmers interviewed in each area were considered to be representative for the farmers of those areas growing the crop, both in terms of wealth status, level of knowledge, variation in cultural practices, etc. The group discussions contributed significantly to the understanding of the answers provided by individual farmers. These discussions were always lively and intensive.

Indigenous production practices to grow P. edulis

Understanding the indigenous production practices is a basic tool to promote a certain crop. Knowing the practices would enable one to grow the crop, understand yield gaps and make the necessary investigations. Table 11 lists the major practices involved in the production of *P. edulis* in Chencha and Wolaita. Most of the practices were similar in both areas. Explanations of the activities have been given in the remark column when necessary (Table 11).

Table 11. Standard practices in the production of *P. edulis* in Chencha and Wolaita.

Activity	Description	Remarks
I Land preparation		
Digging / ploughing time	January – April	Digging/ploughing takes place following the advent of rain.
Means of digging/ploughing	Tools and animal pulled plough: digging hoe, spade and ox	The digging hoe (toyle) is a common traditional tool and most commonly used. Oxen are used on large plots.
Mode of preparing the land	Furrow, flat, patch and raised bed	Furrow is widely used. The patch method is used by many people in Chencha on virgin and fertile soil.
Spacing and population/ha	60–100 cm between furrows, 40–75 cm within a furrow, 41,666–13,333 plants/ha	
Furrow depth	15–20 cm	Personal observation
II Type of planting material, and preparation		
Type of planting material	Tuber pieces, whole tubers, sprout cuttings and stem cuttings	Tuber pieces are used by most growers. The other planting materials are used by few farmers.

Table 11 continued.

Number of tuber pieces prepared from one mother tuber		
Big mother tuber (> 15 cm)	3 tuber pieces	
Medium mother tuber (10–15 cm)	2 tuber pieces	
Small mother tuber (5–10 cm)	2 tuber pieces	
Time for preparing tuber pieces	One day before and on the day of planting	Farmers with large areas start breaking the mother tubers in pieces when one day is left for planting.
Sprouting/de-sprouting of tuber pieces	Both are used by many farmers	It is highly possible that there would be breakage of sprouts during transportation and planting.
Number of tuber pieces planted per hole	2–3 pieces	
III Planting and subsequent field practices		
Planting time	Mostly in April	Planting in this month is carried out by many as there is adequate rain during this month.
Planting depth	< 5 cm and 5–10 cm	Tubers are placed deeper in the ground as the temperature gets higher.
Fertilization		
Type of fertilizer	Manure	In Wolaita also combined with compost
Number of applications	1–> 3 times	
Time of applying fertilization	Application mostly continues until earthing up	
Cultivation		
Number of cultivations	2–4 times	Most common is to cultivate three times.
Time of cultivation		
1st cultivation	One month after emergence	
2nd–4th cultivation	Depending on the weed infestation	

Table 11 continued.

Tipping		
Number of tippings	1–3	One tipping is mostly done.
Time of tipping	As the young plants reach 10–15 cm height or have produced 2–3 pairs of leaves. Later tippings may be carried out depending on the growth, and most commonly with 1–2 months difference.	
Earthing up		
Number	1–3	Two times earthing up is mostly practised.
Time of earthing up		
1st	Within 45 days from planting	
2nd	90–135 days from planting	
3rd	135–180 days from planting	
Diseases and insect control	None	Disease problems only occur at some fields in Wolaita, insect pests occur in some fields at both sites.
IV Harvesting and storage		
Months when harvesting tubers for consumption starts	September – January	Most farmers in Wolaita start harvesting tubers for consumption in October and in Chencha in November. Tubers mature later in Chencha than Wolaita because of lower temperatures.
Storage method for tubers for consumption	*In situ* (field)	
Maximum storage duration for tubers for consumption	2–5 months	Many keep tubers in the ground for 2–3 months.
Storage method for seed tubers	*In situ* (field)	As the temperature gets higher tubers are taken to a shady area and buried in the ground.
Maximum storage duration for seed tubers	6–7 months	A greater proportion of the tubers would decay and be lost when stored longer.

Differences in cultural practices between Chencha and Wolaita

Farmers in Chencha tended to start land preparation earlier than farmers in Wolaita (Table 3). The soils in Chencha were often more fertile than those in Wolaita and often were used for the first time by farmers. This had significant consequences for the types of land preparation and for the amount of fertilizer applied. On virgin soil farmers in Chencha did not plough but prepared patches for planting (Table 3). Wolaita farmers on the other hand applied more frequently manure to the crop than most farmers in Chencha (Table 6). Chencha farmers tended to cut the seed tubers longer before planting and consequently more Chencha farmers paid attention to drying of the seed tubers than in Wolaita (Table 5). Farmers in Chencha tended to tip only once (Fig. 4B) with the same frequency of earthing up (Fig. 4C) compared to farmers in Wolaita. Note that the agronomic purposes of tipping and earthing up are very similar and that both activities require a lot of labour. When this labour requirement is also in the same part of the growing season and coincides with labour demands in other crops the decision to carry out a tipping will have to be made in line with the decision on earthing up. Tipping may be less effective without earthing up as the extra stems and stolons produced will hardly produce extra tubers in that case.

Use of tuber pieces

The respondents in both areas broke whole tubers into pieces before planting to encourage production of more stems, more tubers and a higher yield. In other crops propagated from tubers, for instance in Irish potato, tuber pieces are primarily used to increase the number of propagules (Beukema and van der Zaag, 1979) and also to break dormancy, enhance sprout growth and increase stem numbers (Beukema and van der Zaag, 1979; Struik and Wiersema, 1999). In *P. edulis*, however, since mother tubers are cut into 2–3 pieces (depending on the size of the tuber; Fig. 2) and 2–3 tuber pieces again are planted per hole (Fig. 3B), breaking is likely to enhance the production per hole. Breaking may also stimulate a uniform emergence of stems per hole, and increase the number of stems, branches and leaves, and as a result increase the ground cover and total production per hole. In addition the high number of stems may give rise to more progeny tubers. Because none of the respondents indicated that using tuber pieces increased the size of progeny tubers (data not shown), effects on tuber number are likely more prominent.

Planting seed pieces

On average over the two areas almost half of the respondents planted the tubers with their sprouts and the others after de-sprouting. Most users of sprouted tuber pieces favoured the presence of sprouts for it advances and enhances growth and increases yield while most users of de-sprouted tubers favoured de-sprouting for it stimulates more stems to be formed. The effect of planting tubers with their sprouts or after de-sprouting them is known from other crops. For instance, in Irish potato planting de-sprouted tubers increases the number of stems and final tuber yield (Beukema and van der Zaag, 1979; Struik and Wiersema, 1999). However, these effects strongly depend on physiological age of the seed tuber, the period of pre-sprouting and several other factors.

The vast proportion of the respondents in both areas planted the tuber in a furrow at a depth of < 5 cm soil layer (Fig. 3A). Farmers put on top of the tuber a thicker layer of soil of 5–10 cm when high temperature prevailed. It is unknown, however, whether temperature affects the growth and tuber production of *P. edulis.*

Manuring

Manuring is a widely used practice in both areas and respondents used it to obtain more and larger progeny tubers (Table 6). In Irish potato, both manure and chemical fertilizers have been used to enhance the growth and tuber production (Beukema and van der Zaag, 1979; Borgel et al., 1980). However, in both study areas farmers did not use chemical fertilizer on *P. edulis* (Table 6).

Tipping

Tipping is a crop specific practice employed by all farmers in both areas, although the practice is considered time-consuming by most farmers (see also above). It is thus likely to have a significant effect on crop performance. The vast majority of the respondents in Chencha indicated that tipping enhanced stem number (Table 7). However, the mechanism through which tipping affects the crop's performance is still unknown. Removing the stem apex will break apical dominance and will likely result in extra above-ground branches. This increased branching may enhance light interception by the canopy and thus increase dry matter production. It is still unknown how tipping affects the below-ground parts of the crop. For example, it is not known whether tipping causes more main stems, more stolons and more tubers to be formed. The proportion of respondents indicating that tipping increased yield was also low. This is surprising given the amount of labour required for this practice.

Earthing up (piling up soil)

Piling up of soil around the stem was a common practice and the majority of respondents carried it out twice (Fig. 4C). Respondents in both areas piled up soil around the stem to increase yield (Table 7). They also mentioned that this practice would increase the number of stems, the number of tubers, or the tuber size (Table 7).

This practice is also carried out in Irish potato with a purpose to bury the stolons, increase the production by increasing the number of tubers and to avoid tuber greening (chlorophyll formation) (Beukema and van der Zaag, 1979). It is unknown in *P. edulis* how the piling up affects the above- and below-ground growth. As the piling up is a hard task, knowing the optimum number and the time of piling is essential.

There was not really a good positive correlation between number of tippings and number of earthing up. On the contrary, these activities might compete for the amount of labour available. However, both activities serve similar goals.

Major production constraints

In identifying the possible causes for the decline in the production of *P. edulis* (see introduction), respondents in both study areas indicated as possible reasons: shortage of seed tubers, long storage duration, water shortage and poor market (Table 9). All wealth groups in both areas indicated shortage of seed tubers as a major constraint. This constraint may be alleviated by designing multiplication systems and methods with higher rates of multiplication than the 1:4 in *P. edulis*. Other important constraints indicated were long storage duration in Wolaita (to be solved by improving storage facilities and techniques) and shortage of land in Wolaita (Table 9). Farmers also mentioned the long growing period and introduction of new crops such as Irish potato and sweet potato as constraints.

To alleviate similar problems in Irish potato several studies were carried out. For instance, to overcome shortage of seed tubers different experiments were carried out using *in vitro*-produced propagation material (Lommen, 1999; Struik and Lommen, 1999), on the effect of storage conditions on tuber production (Moorby, 1978; Ronsen, 1978; Beukema and van der Zaag, 1979) and on problems related with diseases, insects and weeds (Struik and Wiersema, 1999). In almost all cases techniques, methods, and cultural practices have been designed through which the problems could be overcome in an economic way. However, *P. edulis* is an orphan crop in national and international research; research to overcome the production constraints in this crop does not exist. We have initiated a research project to (at least partly) fill this gap by studying the crop physiology and ecology of *P. edulis* and by analysing the agronomic and crop physiological effects of tipping, different sizes of tuber pieces and the physiological age of mother tubers.

Conclusions and recommendations

- *P. edulis* has been grown and used as a major source of food in many parts of

Ethiopia and is liked as a tasty source of carbohydrates.

- In Chencha and Wolaita, cultural practices in this crop are laborious and time consuming. In most cases the techniques used in the two areas are the same.
- Information on the farmers' production practices in this crop was basically lacking and that in itself is an important constraint in developing the crop.
- We have described the general cultural practices of the crop to provide the scientific community with information needed to further evaluate and investigate the crop. Our research may also assist agronomists, extensionists and breeders to improve the crop.
- The major production constraints are shortage of seed tubers, poor storability, and water shortage.
- Farmers do report attacks by diseases and insect pests in *P. edulis*.
- Traditional cultural practices include time-consuming and laborious techniques such as tipping and earthing up, which both are supposed to increase stem number and thus yield. These techniques may also increase tuber number. The physiology behind this and especially the reasons why *P. edulis* produces so few tubers without these stimulating techniques need to be studied in detail.

CHAPTER 3

Major structure and development of *Plectranthus edulis*

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Abstract

Plectranthus edulis (Vatke) Agnew (Lamiaceae) is an ancient Ethiopian tuber crop grown in mid and high altitude areas in the north, south and west of Ethiopia. The structure of this plant and its development have not yet been described in detail. Two similar experiments were carried out at Awassa and Wondogenet (southern Ethiopia) in a split-plot design with five blocks and cultivar (Lofuwa and Chankua) as main factor and harvest date (20 harvests from 14 to 280 days after planting (DAP)) as split factor. The plants were grown from seed tuber pieces and attained a maximum height of about 1.50 m. Plants produced main stems and primary, secondary and tertiary branches, with primary and secondary branches and their leaves constituting the main part of the canopy. Plant components were the seed tuber pieces, sprouts, main stems, branches, leaves, flowers, fruits, seeds, roots, stolons and tubers.

Stolons were formed on main stems and primary branches and originated below ground or above ground (aerial stolons). Aerial stolons were initiated later than below-ground stolons and were much longer (up to 2.5 m). Tubers usually were produced as a swelling on the tip of the stolon and sometimes as a swelling of the middle part of stolons. Tubers were stem tubers with pairs of ‘‘eyes’’ being arranged in the same pattern as the axillary buds on stolons and stems. Tubers of cv. Lofuwa were up to 25 cm in length, those of cv. Chankua up to 20 cm, both with a diameter of about 2 cm. The tubers in the middle of the stolon were longer than the ones at the tip.

After tuber initiation, the number of tubers increased almost linearly during a period of 12–14 weeks, and maximum numbers of tubers were attained around 238 DAP, at crop senescence. Also the number of smaller tubers (< 10 or 20 g) increased until this moment. In the period of tuber initiation also the average weight per tuber increased up to 20–25 g per tuber around 238 DAP. The increase in tuber fresh weight with time was therefore realized by an increase in both tuber number and in average weight per tuber.

After crop maturity, farmers store the tubers *in situ* in the soil until they need them. This research showed that this practice dramatically reduces tuber yield and number, because decreases of 36–59% were found in total tuber fresh weight per hole and of 18–48% in number of tubers when tubers were kept in the soil in the 6-week period between 238 and 280 DAP.

Keywords: Branches, development, Ethiopia, leaves, *Plectranthus edulis*, stolons, tubers

Introduction

Plectranthus edulis (Vatke) Agnew, (Lamiaceae, Labiateae) is an ancient Ethiopian tuber crop (Greenway, 1944; Siegenthaler, 1963; Westphal, 1975). It is locally known as Wolaita dono, Gamo dinich, Dinicha Oromo, Agaw dinich, etc., and also as Ethiopian potato (Mulugeta et al., 2007). It is grown in mid and high altitude areas in the north, south and west of Ethiopia and is primarily cultivated for its tubers which are consumed after cooking but to some extent also for its leaves as a cooked vegetable in some western Ethiopian regions (Westphal, 1975; Zemede and Zerihun, 1997; Mulugeta et al., 2007). *P. edulis* is mainly propagated by planting 2−3 tuber pieces of a broken seed tuber in one planting hole. Cultural practices include tipping, earthing up and manuring (Mulugeta et al., 2007). Tubers are usually harvested following the ceasing of the main rainy season; for instance in Wolaita and Chencha crop harvesting starts in October and November, respectively (Mulugeta et al., 2007).

The structure of this plant and its components has not been described in detail yet. Understanding its structure is essential in order to understand how to increase a crop's productivity. Struik and Wiersema (1999) underlined the importance of understanding the structure of a potato to influence its physiology and agronomy. Several researchers including Allemann et al. (2003) working with *P. esculentus* also carried out morphological studies as the basis for their subsequent studies. Such information is also very basic for *P. edulis.* Equally important is the understanding of the development of a crop for it has both physiological (understanding the dynamics of organ appearance) and agronomic (knowing when to perform certain practices) relevance (McMaster, 2004). The sequence of the different crop stages can be considered as a series of discrete periods, each identified by a process of change in the structure, size or mass of specific organs (Squire, 1990). Temperature has profound effects on such developmental stages, for instance in cotton (Reddy et al., 1991) and enset (Admasu and Struik, 2003).

The objectives of this study were to identify the major structural components, and to describe and understand the development of the canopy and underground parts. Emphasis was on the vegetative parts of the crop. Inflorescences of *P. edulis* were earlier described by Siegenthaler (1963).

Materials and methods

Experimental sites

A similar experiment was carried out at two sites in the southern region of Ethiopia, i.e. at Hawassa University, Awassa, from April 4, 2003 – January 9, 2004; and at Wondogenet College of Forestry and Natural Resources, Wondogenet, from April 11, 2003 – January 16, 2004. The Awassa field was located at 7°03' N latitude and 38°30' E longitude while the Wondogenet field was at 7°06' N latitude and 38°37' E longitude. Awassa is located at an altitude of 1650 masl, Wondogenet at an altitude of 1850 masl. Wondogenet is relatively cooler and more humid than Awassa. The daily average temperature in Awassa during the experimental period ranged between 17−25 °C and that of Wondogenet between 14−24 °C. Average temperatures during the experimental period were 19.9 and 18.4 °C, average global radiation was 16.07 and 12.95 MJ m^{-2} day^{-1} and total rainfall 671 and 888 mm at Awassa and Wondogenet, respectively. The course of weather data during the experiments is indicated in Fig. 1. Daylength fluctuated between 11.59 h (21 December) and 12.41 h (21 June) at both sites. The soil texture at both sites was sandy loam.

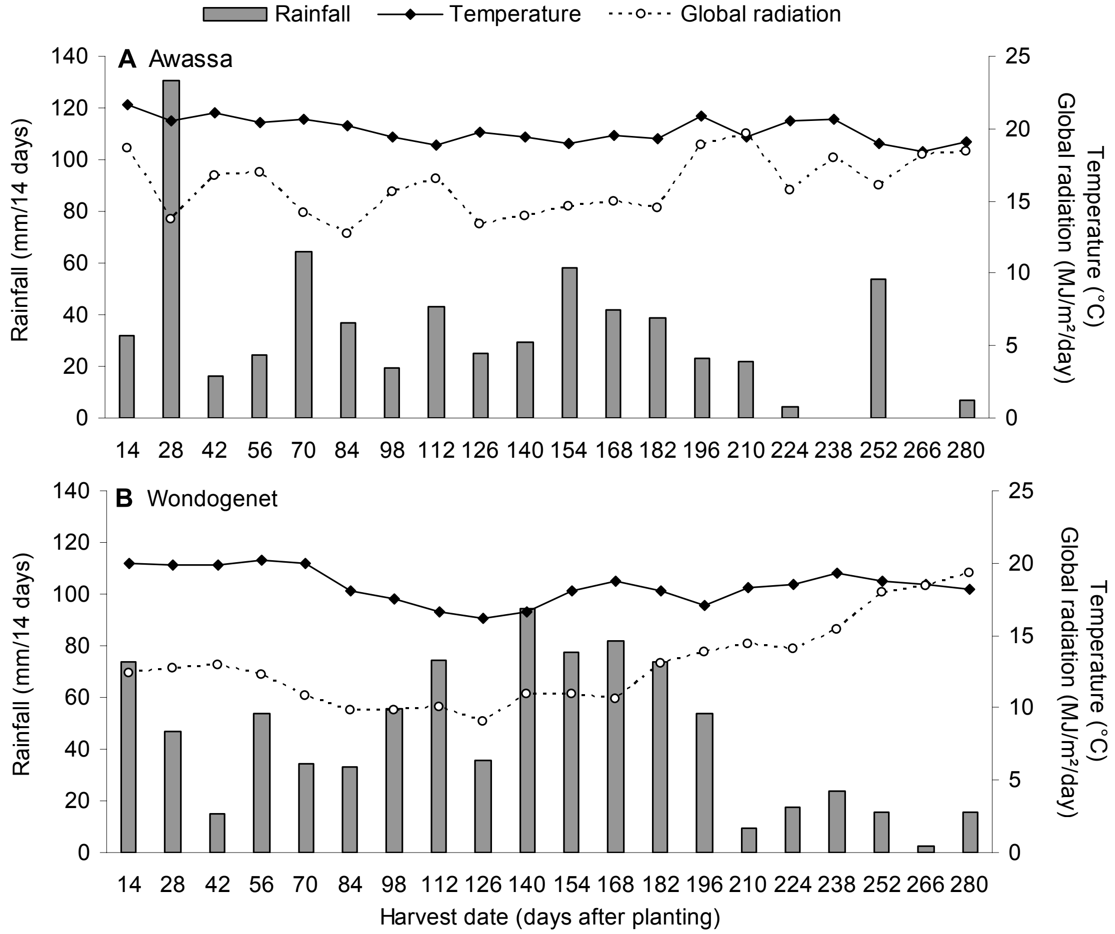

Fig. 1. Weather data during the experiments in Awassa (A, 4 April 2003 – 8 January 2004) and Wondogenet (B, 11 April 2003 – 15 January 2004). Data for 14-day periods preceding harvest dates.

Design and treatments

A split-plot design was used with five blocks and with cultivars as the main factor and harvest date as split factor. There were 20 planting holes per plot of 3.60 × 2.75 m, consisting of four rows spaced at 90 cm, and with a within-row planting distance of 75 cm. The middle three holes in the middle two rows (6 holes) were used for observations, and the remaining 14 holes were used to grow guard plants. The two cultivars used were Lofuwa and Chankua. Cv. Lofuwa is considered early maturing and cv. Chankua late maturing. Harvests were carried out each fortnight, starting after planting. The total number of harvests was 20.

Crop management

The experimental field was ploughed, and furrowed until a depth of 20 cm. Tuber pieces for planting were prepared by breaking a de-sprouted whole tuber of about 10–12 cm into about three equal pieces. Three tuber pieces were planted in a triangle with sides of about 5 cm in a planting hole in a furrow, and covered by a layer of soil of about 5 cm thick. During crop growth the soil was tilled about three times to remove and cover the weeds. Tipping, i.e. removing the tip (the apex plus one or two pairs of visible leaves) of the main stems and branches, was carried out when plants reached about 15 cm height, i.e., 61 days after planting (DAP) in Awassa and 63 DAP in Wondogenet. Earthing up, i.e. piling soil around the roots, was done at least three times in order to cover the stolons and support the stems.

Observations

The major above-ground and below-ground plant parts of each cultivar were visually examined to describe the different structures. Numbers of main stems, branches, leaves and stolons from six holes were counted every 14 days up to the moment when no counting was possible anymore because of plant senescence. The numbers of tubers from six holes were counted every 14 days until 280 DAP. Green leaves from different stem types were counted. The number of stolons was counted for each type of stem separately but later counting per type stem discontinued for it became very difficult to identify the origin of the stolons. Also, stolons were grouped into aerial and below-ground stolons depending on their origin. In these experiments, only stolons that were still connected to the stem were counted. Tubers were divided into different weight classes. Tuber fresh yield per hole was determined and the average weight per tuber was calculated.

Statistical analysis

Means and standard deviations were calculated per cultivar per harvest date using GenStat release 9.2 or Excel 2003.

Results

Major structural components

General. The plants grown from the seed tuber pieces were ascending, herbaceous, and bushy with a maximum height of about 1.50 m. Each plant was composed of several parts: the mother tuber piece, sprouts, main stems, branches, leaves, flowers, fruits, seeds, roots, stolons, and tubers. The colour of the vegetative parts, stolons and tubers varied depending on the cultivar. The leaves and stems of cv. Lofuwa were green and the stolons and the skin of the tubers were creamish, with incidentally a flush of red. The stem, stolons and the tuber skin of cv. Chankua were reddish, while the leaves were a mixture of red and green, turning redder under high irradiation levels. Fig. 2 shows the crop and details of the plant and its structural components.

Sprouts. A sprout is defined as a young growth of the buds of the tuber pieces with a soft stem, with or without leaves, yellowish and directly originating from a mother tuber. The soft stem might be short or lengthy, erect or crippled. More than one sprout could arise from a single eye.

Main stems and branches. The changing of colour of the sprouts from yellowish to green in cv. Lofuwa and to reddish in cv. Chankua after emergence marked the establishment of the true plant. Stems that directly originated from a mother tuber piece were considered main stems. Branches that arose from main stems were primary branches, those from primary branches were secondary branches, and those from secondary branches were tertiary branches. Primary branches were produced starting from the first node immediately (about 2−5 cm) above the eye of the seed tuber piece, and its internodes were very close to each other at the beginning but later increased in length as the height increased. In some axils of leaves more than one branch was produced. Main stems and branches were hairy, swollen at and above each node and quadrangular. Branches were arranged in an opposite, decussate pattern following the phyllotaxis of the leaves. The length of the individual internodes varied between 6 and 8 cm under normal growth.

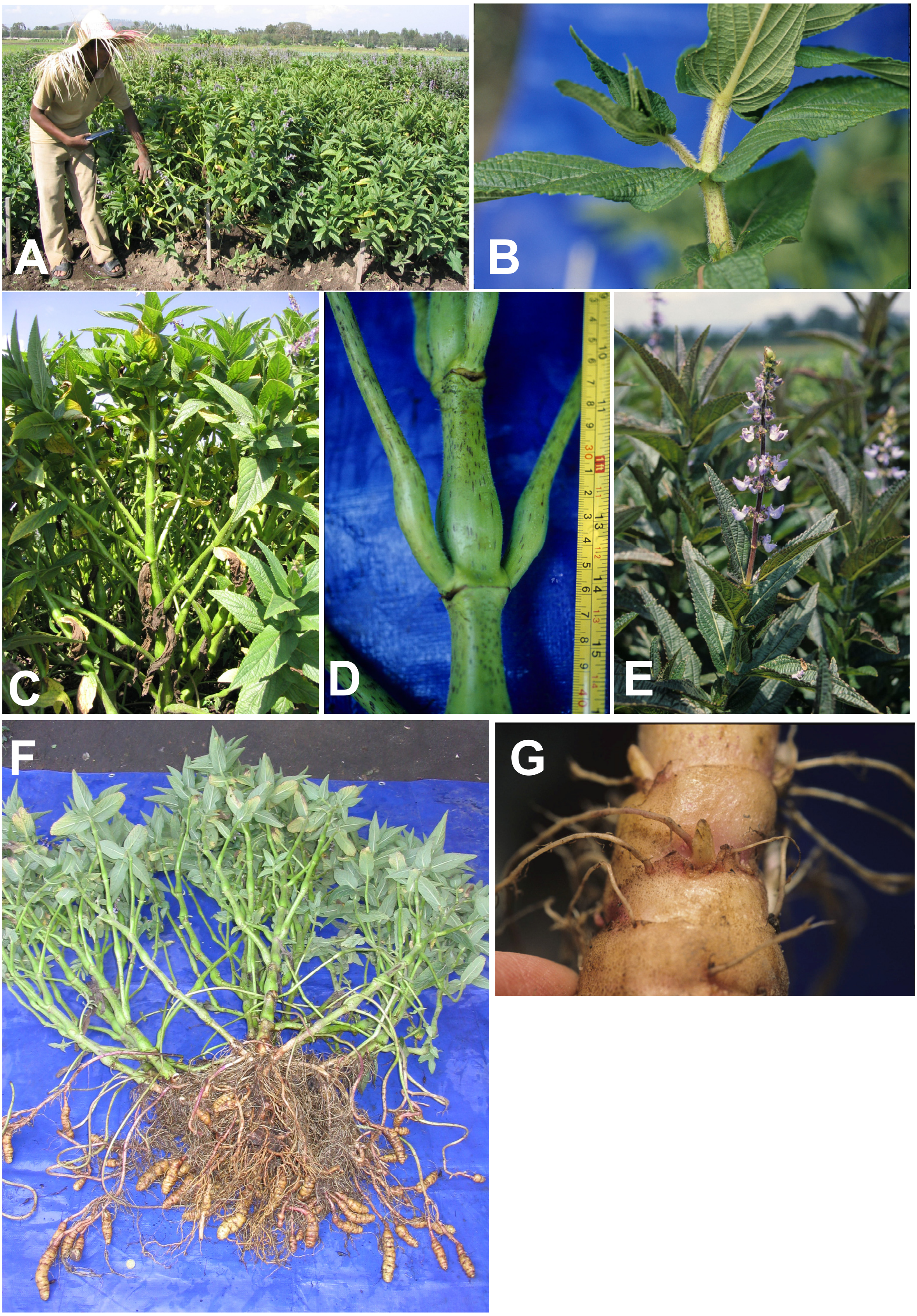
A
B
C
D
E
F
G

Fig. 2. The *P. edulis* crop and details of the plant and its components. (A) *P. edulis* crop in Awassa, 6.5 months after planting; (B) upper part of a primary branch showing sessile leaves, the opposite, decussate phyllotaxis, and a secondary branch developing in the axil of one of the two leaves of a pair; (C) branching pattern in the inner part of the field crop from A; (D) detail of an older part of a primary branch showing the quadrangular stems, swollen at and above a node, and secondary branches being formed from both axillary buds at a node in an opposite decussate pattern; leaf scars are visible below the secondary branches; (E) inflorescence of cv. Chankua, 6 months after planting; (F) plant dug out of the soil, 6.5 months after planting, showing tubers on stolons, dense, fibrous roots, branches with leaves, and many aerial stolons arising from the primary branches, some bearing tubers. Most below-ground stolons are covered by the root mass; (G) detail of a tuber, 6 months after planting the crop, showing a tuber "eye" with the main bud producing a small sprout, small scale leaves covering the eye, roots being developed at the node around the eye, and the relatively larger swelling of internodes compared to the nodes of a tuber.

Leaves. The leaves were oval to elliptical in shape, dentate, sessile, pubescent, slightly bent outward at the tip and on the margin, and with conspicuous veins. The phyllotaxis was opposite, with leaf pairs decussate. Leaves started to appear from the 1st node of the branches. The mature leaf length was about 10 cm long and the width of the widest middle part was 5 cm.

Inflorescences. Terminal inflorescences were produced at the tip of main stems and on most primary and secondary branches. The panicle-like inflorescences were branched with several blue flowers in clusters of bisexual flowers. Flowers were typical for the family, with five sepals united in a calyx and five petals united to a two-lipped corolla.

Seeds and fruits. Seeds were brown/black, ovoid-shaped and smaller than 1 mm. The fruit consisted of four seeds included in the persistent calyx.

Stolons. Stolons originated from main stems and the lower primary branches. We call stolons that originated from main stems main stem stolons, while those from primary branches are called primary branch stolons. Stolons were also categorized as below-ground and aerial stolons. The length of the aerial stolons varied, in some cases they grew to more than 2.5 m. Aerial stolons also were leafy and greenish or deep red. However, below-ground stolons sometimes grew above ground (became ‘‘wild’’) whereas aerial stolons or branches from aerial stolons grew into the soil and formed tubers. Measuring the length of the below-ground stolons was difficult for they were buried in the soil. Stolons were branched opposite at a node – although also only one main bud at a node could develop – and were hairy.

Tubers. Tubers were produced as a swelling of the tip part of the stolon and sometimes also as a swelling of the middle part of stolons. The first swelling of stolons to tubers seemed to occur at the nodes, whereas later the internodes swelled and in older tubers the internodes were more swelled than the nodal parts. Tubers were also produced without stolons from the mother tuber piece (sessile tubers). Tubers had pairs of ‘‘eyes’’ (i.e., compound axillary buds) being arranged in the same pattern as the axillary buds on stolons and stems. The tuber dimensions varied. Tubers of cv. Lofuwa were up to 25 cm in length while those of cv. Chankua were up to 20 cm, both with a diameter of about 2 cm. The tubers in the middle of the stolon were longer than the ones at the tip. The flesh colour of both cultivars was creamish. Tubers from both cultivars were slender like carrots but there were also some curved ones.

Roots. Fibrous roots were produced at the nodes of main stems, primary branches, stolons, and tubers. The roots were thin and dense and varied in length. Some were as long as 60 cm.

Canopy development

Sprouts. The first sprouts were produced between 14 and 28 DAP in both Awassa and Wondogenet. They emerged between 28 and 42 DAP, developing into main stems.

Number of main stems and branches. After emergence, the number of main stems increased during the earlier growth stages in both genotypes at Awassa and Wondogenet but later settled to between 1 and 2 main stems per hole (Figs 3A and B).

The first primary branches appeared around 50 DAP. The number of primary branches increased thereafter to about 20 primary branches per hole in Awassa and 20–25 in Wondogenet (Figs 3C and D). A decrease in the number of primary branches in both cultivars took place after about 200 DAP in Wondogenet and slightly later in Awassa (Figs 3C and D).

The first secondary branches appeared at about 70 DAP. The number of secondary branches increased substantially from about 100 DAP onwards to about 40–45 secondary branches per hole (Figs 3E and F). The decrease in secondary branch number started earlier than the decrease in primary branch number. In cv. Chankua the increase in the number of secondary branches was slightly slower and the decrease slightly earlier than in cv. Lofuwa.

A variable number of tertiary branches arose from some of the secondary branches and the first appeared after about 125 DAP in cv. Lofuwa and slightly later in cv. Chankua (Figs 3G and H). Maximum numbers of tertiary branches varied between

5–10 and about 30, with lower numbers being produced in Wondogenet than in Awassa and lower numbers being produced in cv. Chankua than in cv. Lofuwa.

The maximum total number of main stems plus branches was 80–100 per hole in both Awassa and Wondogenet (Figs 3I and J).

Number of leaves. The first green leaves appeared when the first plants emerged between 28 and 42 DAP. Thereafter, the number of green leaves from main stems increased until about 140 DAP to about 60 per hole and then decreased again (Figs 4A and B). Some leaves from primary branches might have been counted as main stem green leaves because for some of the primary branches closer to the ground it was difficult to differentiate them from main stems.

The number of green leaves from the primary branches increased until about 4 weeks later than the number of green leaves on main stems in Awassa and until 0–2 weeks later in Wondogenet and then decreased (Figs 4C and D). The maximum number of green leaves on primary branches was 350–400 per hole.

The number of green leaves from secondary branches increased up to about 400 in Awassa and 200–250 in Wondogenet (Figs 4E and F). The maximum number of green leaves on secondary branches was obtained at about the same moment as the maximum number of green leaves on primary branches in cv. Lofuwa, but slightly later in cv. Chankua in Wondogenet. Green leaves on secondary branches stayed slightly longer around the maximum than green leaves on primary branches before they started to decrease considerably in number.

The number of green leaves on tertiary branches increased until a slightly later date than the number of green leaves on secondary branches except for cv. Chankua in Wondogenet, where the dates on which the maximum was achieved, coincided (Figs 4G and H). Maximum numbers of green leaves on tertiary branches were about 30 per hole for cv. Chankua and 40 (Wondogenet) to 100 (Awassa) per hole for cv. Lofuwa.

The maximum total number of green leaves per hole was in general higher in Awassa than in Wondogenet (Figs 4I and J). There were no green leaves present anymore at 252 DAP in Awassa and 2 weeks earlier in Wondogenet. Leaves that senesced in the later growth stages normally dropped from the plant immediately after their colour had changed to yellowish. Senescing leaves on the main stems and lower parts of the primary branches could change colour to brown and remain on the stem.

Number of stolons. The first stolons appeared from below-ground nodes of main stems and primary branches about 70 DAP in Awassa and 70–84 DAP in Wondogenet (Fig. 5, Tables 1 and 2). The number of below-ground stolons initially increased as time progressed but decreased later, particularly closer to maturity in Wondogenet (Tables 2

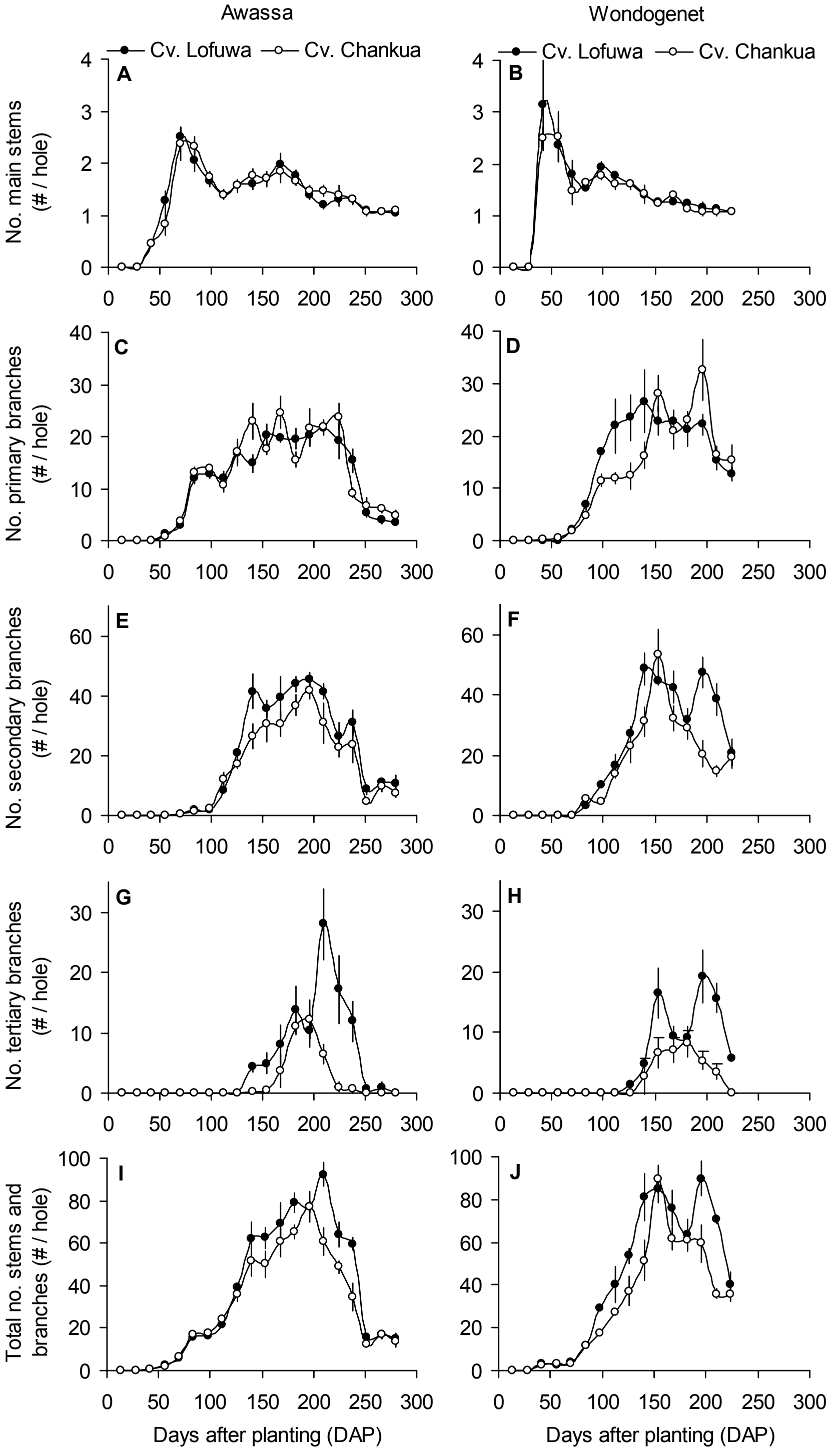

Fig. 3. Number of main stems and branches per hole at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) main stems, (C) primary branches, (E) secondary branches, (G) tertiary branches, (I) total number of main stems and branches in Awassa; (B) main stems, (D) primary branches, (F) secondary branches, (H) tertiary branches, and (J) total number of main stems and branches in Wondogenet. Bar = standard deviation.

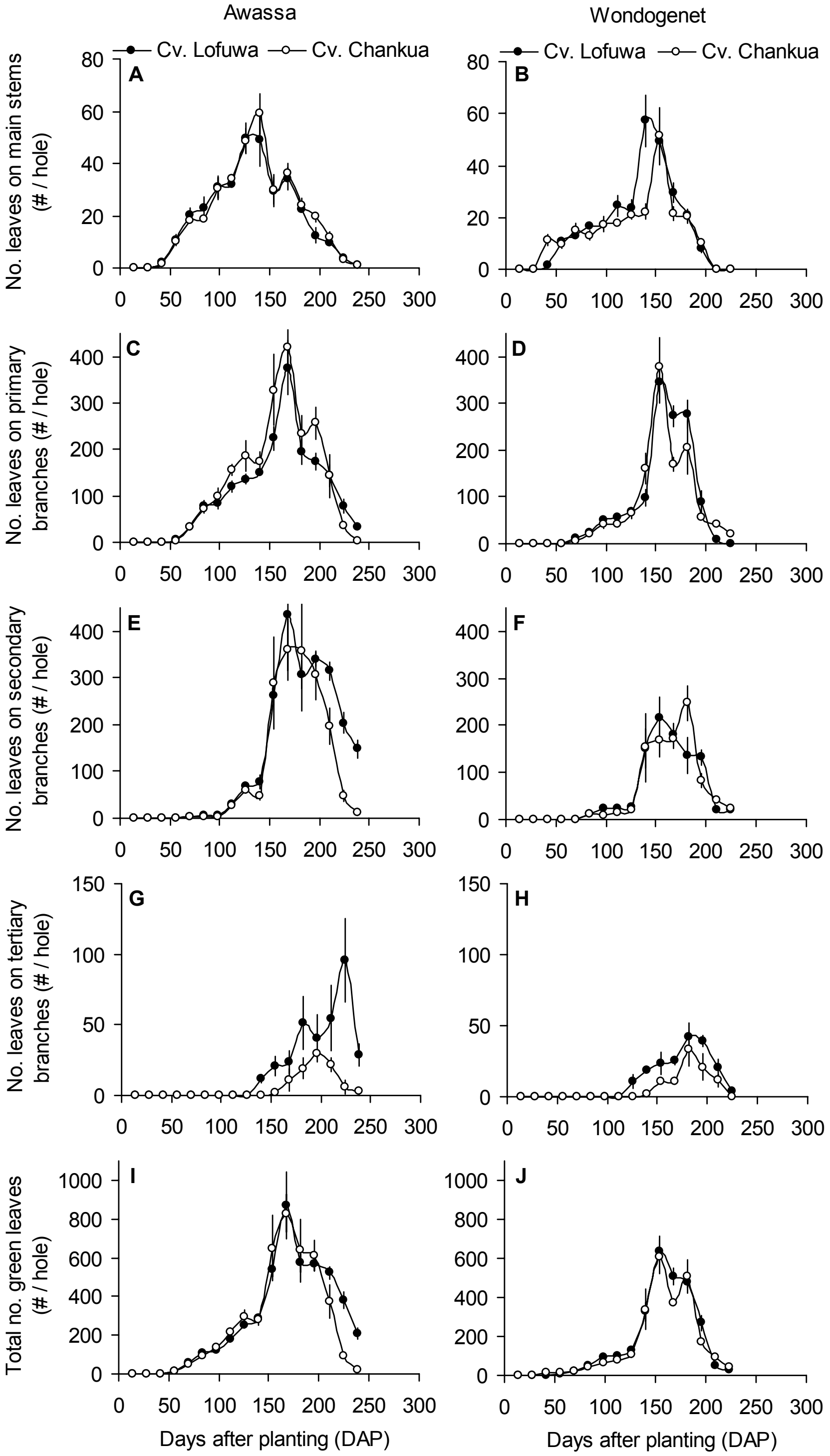

Fig. 4. Number of green leaves per hole from main stems and branches at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) number of green leaves on main stems, (C) number of green leaves on primary branches, (E) number of green leaves on secondary branches, (G) number of green leaves on tertiary branches, (I) total number of green leaves on main stems plus branches in Awassa; (B) number of green leaves on main stems, (D) number of green leaves on primary branches, (F) number of green leaves on secondary branches, (H) number of green leaves on tertiary branches, (J) total number of green leaves on main stems plus branches in Wondogenet. Bar = standard deviation.

Table 1. Development with time of the numbers of below-ground and aerial stolons from main stems and primary branches for cvs Lofuwa and Chankua in Awassa. Mean ± SD (n = 5). No SD is presented when no stolons were present.

	Below-ground stolons (# / hole)			Aerial stolons (# / hole)		
DAP	Main stems	Primary branches	Total	Main stems	Primary branches	Total
Cv. Lofuwa						
14	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0
70	0.4 ± 0.30	0.7 ± 0.44	1.1 ± 0.33	0.0	0.0	0.0
84	2.4 ± 0.93	1.9 ± 0.69	4.3 ± 0.97	0.0	0.0	0.0
98	3.0 ± 0.85	1.9 ± 0.56	4.9 ± 1.32	0.0	0.0	0.0
112	11.9 ± 2.46	3.1 ± 0.64	15.0 ± 2.38	0.0	0.0	0.0
126	14.7 ± 6.57	5.8 ± 2.31	20.5 ± 4.71	0.0	0.0	0.0
140	14.5 ± 7.28	10.1 ± 4.14	24.5 ± 10.96	0.0	0.0	0.0
154	13.3 ± 7.19	11.9 ± 1.91	25.2 ± 8.22	0.0	0.0	0.0
168	14.7 ± 14.70	12.5 ± 4.53	27.2 ± 17.59	0.0	0.0	0.0
182	10.4 ± 5.74	4.5 ± 4.31	14.9 ± 9.93	5.0 ± 3.21	8.9 ± 6.12	13.9 ± 9.07
196	22.4 ± 12.59	8.7 ± 2.44	31.2 ± 11.43	4.6 ± 3.62	6.6 ± 3.26	11.2 ± 5.44
210	17.3 ± 3.53	4.3 ± 1.93	21.6 ± 3.77	2.6 ± 3.41	6.3 ± 1.82	8.9 ± 2.23
224	1.5 ± 3.43	6.8 ± 3.26	8.4 ± 4.46	0.4 ± 0.89	4.9 ± 1.69	5.3 ± 1.77
238	11.3 ± 5.61	14.0 ± 11.15	25.2 ± 15.50	2.1 ± 2.88	5.3 ± 3.27	7.3 ± 5.68
Cv. Chankua						
14	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0
70	0.6 ± 0.48	0.7 ± 0.30	1.3 ± 0.64	0.0	0.0	0.0
84	0.0	0.0	0.0	0.0	0.0	0.0
98	2.6 ± 0.48	2.0 ± 0.53	4.6 ± 0.48	0.0	0.0	0.0
112	7.5 ± 2.71	2.2 ± 0.62	9.7 ± 2.80	0.0	0.0	0.0
126	10.3 ± 4.39	5.7 ± 2.49	16.0 ± 5.79	0.0	0.0	0.0
140	13.7 ± 6.18	13.0 ± 5.79	26.7 ± 11.81	0.0	0.0	0.0
154	8.6 ± 6.26	13.1 ± 8.60	21.7 ± 13.68	0.0	0.0	0.0
168	10.0 ± 5.49	19.5 ± 11.79	29.5 ± 15.08	0.0	0.0	0.0
182	7.7 ± 4.33	4.8 ± 2.66	12.5 ± 6.25	9.2 ± 5.13	3.5 ± 1.69	12.7 ± 6.46
196	8.9 ± 6.68	7.8 ± 3.69	16.7 ± 7.45	2.4 ± 3.36	10.5 ± 3.58	12.9 ± 3.08
210	13.4 ± 10.31	9.7 ± 12.38	23.1 ± 21.23	1.5 ± 1.18	5.6 ± 5.31	7.1 ± 4.38
224	6.9 ± 2.74	6.8 ± 2.04	13.7 ± 3.14	5.3 ± 9.24	2.0 ± 1.91	7.2 ± 8.35

DAP days after planting

Table 2. Development with time of the numbers of below-ground and aerial stolons from main stems and primary branches for cvs Lofuwa and Chankua in Wondogenet. Mean ± SD (n = 5). No SD is presented when stolons were not present.

	Below-ground stolons (# / hole)			Aerial stolons (# / hole)		
DAP	Main stems	Primary branches	Total	Main stems	Primary branches	Total
Cv. Lofuwa						
14	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0
84	2.3 ± 0.64	2.5 ± 0.99	4.8 ± 0.69	0.0	0.0	0.0
98	4.6 ± 0.66	11.7 ± 2.10	16.3 ± 2.61	0.0	0.0	0.0
112	8.9 ± 2.75	15.1 ± 2.94	24.0 ± 3.03	0.0	0.0	0.0
126	15.0 ± 9.40	7.0 ± 8.66	22.0 ± 17.43	0.0	0.0	0.0
140	21.4 ± 17.92	26.4 ± 14.80	47.8 ± 24.67	0.0	0.0	0.0
154	35.9 ± 22.25	29.7 ± 16.99	65.6 ± 38.21	0.0	0.0	0.0
168	43.0 ± 21.98	37.6 ± 10.76	80.6 ± 30.87	6.7 ± 3.51	20.8 ± 5.99	27.5 ± 6.59
182	30.5 ± 25.14	4.8 ± 2.22	35.3 ± 26.68	9.5 ± 7.30	6.5 ± 3.59	16.0 ± 8.97
196	31.0 ± 14.84	26.3 ± 14.24	57.3 ± 28.65	4.5 ± 3.19	11.2 ± 11.77	15.6 ± 11.84
210	12.0 ± 2.75	12.5 ± 6.63	24.6 ± 8.80	6.8 ± 5.91	5.0 ± 3.05	11.8 ± 7.51
Cv. Chankua						
14	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0
84	1.6 ± 0.72	2.2 ± 0.90	3.8 ± 0.77	0.0	0.0	0.0
98	4.9 ± 1.30	11.6 ± 3.88	16.5 ± 4.53	0.0	0.0	0.0
112	6.8 ± 2.79	11.0 ± 2.17	17.8 ± 1.21	0.0	0.0	0.0
126	8.3 ± 5.64	8.0 ± 9.03	16.3 ± 12.88	0.0	0.0	0.0
140	15.4 ± 9.42	9.8 ± 9.70	25.2 ± 18.82	0.0	0.0	0.0
154	31.9 ± 10.38	38.2 ± 19.16	70.1 ± 27.41	0.0	0.0	0.0
168	38.1 ± 17.44	39.3 ± 8.22	77.4 ± 14.25	0.0	0.0	0.0
182	11.7 ± 13.12	5.3 ± 2.92	17.0 ± 12.39	3.2 ± 2.14	7.8 ± 3.32	11.0 ± 2.84
196	15.2 ± 5.35	24.1 ± 10.32	39.3 ± 13.24	5.5 ± 3.82	3.0 ± 2.59	8.5 ± 4.21
210	7.5 ± 3.39	9.7 ± 5.42	17.3 ± 7.58	1.7 ± 2.64	5.1 ± 3.02	6.8 ± 3.90

DAP days after planting

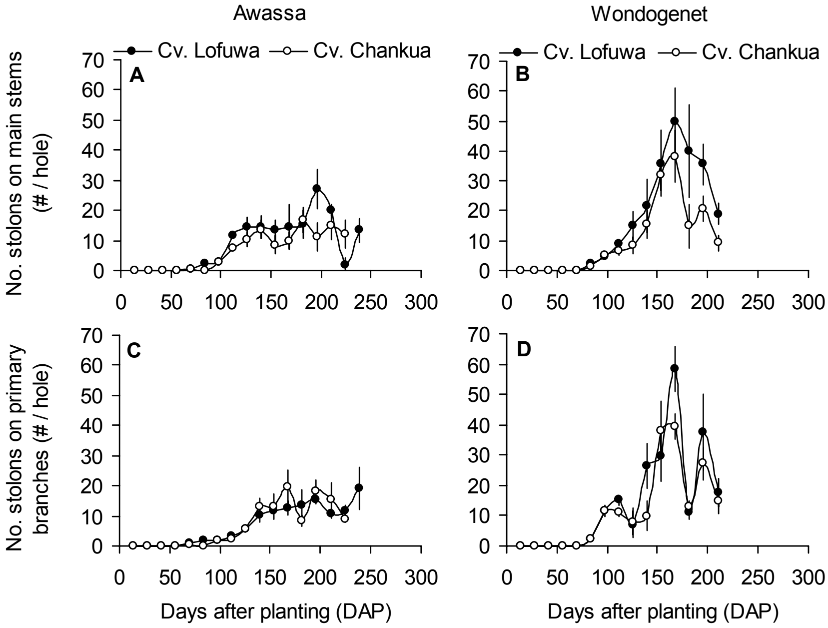

Fig. 5. Number of stolons originating from main stems and primary branches per hole at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) stolons on main stems, (C) stolons on primary branches in Awassa; (B) stolons on main stems, (D) stolons on primary branches in Wondogenet. Bar = standard deviation.

and 3). Aerial stolons appeared 168−182 DAP, much later than below-ground stolons, also from main stems and primary branches (Tables 1 and 2). Aerial stolons were small in number as compared to below-ground stolons in both places. The total number of stolons from main stems and primary branches were comparable (Fig. 5). The increase in number of stolons continued longer in Wondogenet than in Awassa, and the maximum numbers of stolons were about 30–40 per hole in Awassa and 80−100 per hole in Wondogenet (Figs 6A and B). This number of stolons remained stable in Awassa until no further assessment of the number of stolons was possible anymore, but the increase in number of stolons in Wondogenet was followed by a decrease.

Number of tubers. Tubers started to appear about 126 DAP on stolons from main stems and from primary branches (Fig. 7). Tubers of different sizes were formed but the numbers of tubers in the weight classes 0−10 g and 10–20 g were higher than the numbers of the heavier ones (Fig. 8). The heaviest tubers were found in the size class 70–80 g in Awassa and in the class 80–90 g in Wondogenet. The latter size, however, was found only now and then (1−2 tubers per 30 holes). The total number of tubers

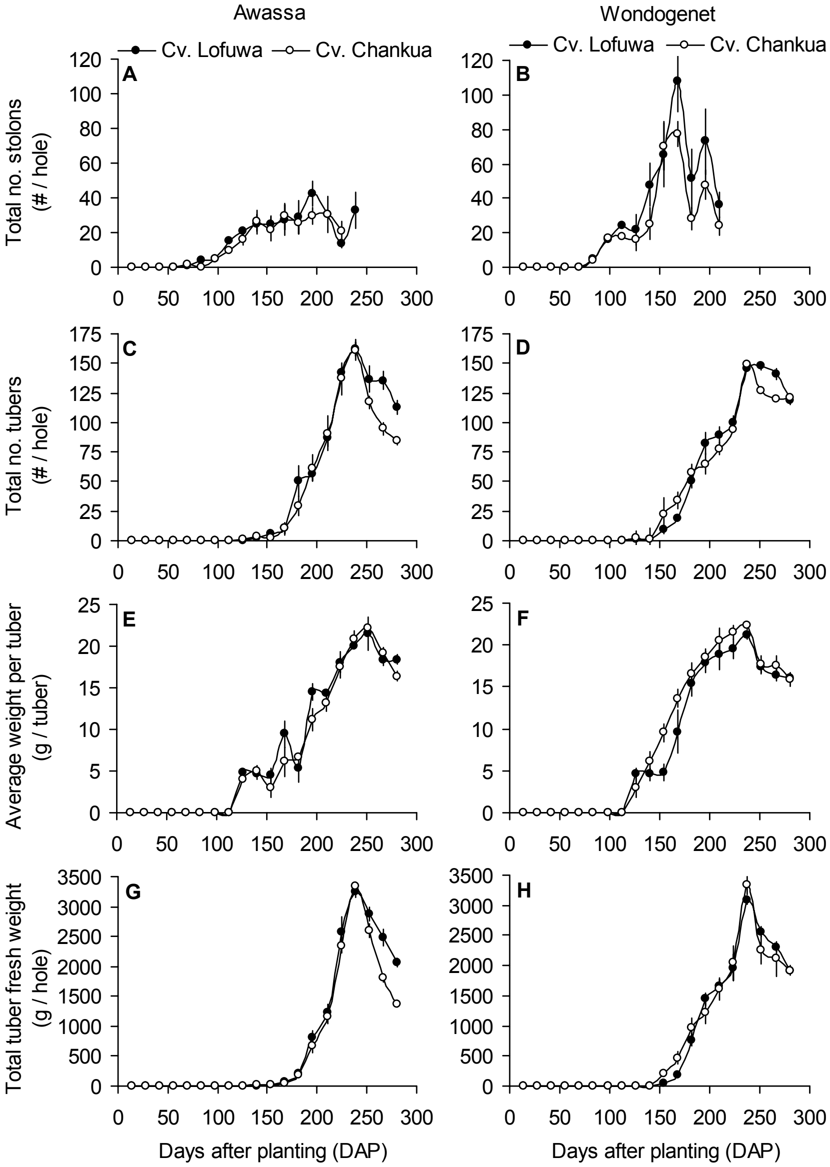

Fig. 6. Total number of stolons and tubers per hole, average weight per tuber and total tuber fresh weight per hole at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) number of stolons, (C) number of tubers, (E) average weight per tuber, (G) total tuber fresh weight in Awassa; (B) number of stolons, (D) number of tubers, (F) average weight per tuber and (H) total tuber fresh weight in Wondogenet.

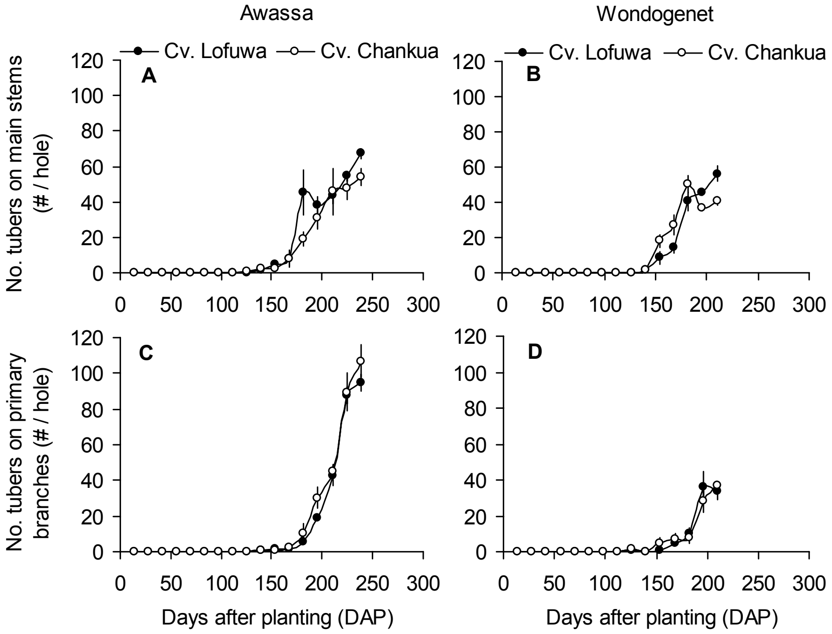

Fig. 7. Number of tubers originating from main stems and primary branches per hole at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) tubers on main stems, (C) tubers on primary branches in Awassa; (B) tubers on main stems, (D) tubers on primary branches in Wondogenet. Bar = standard deviation.

increased up to 140–160 tubers per hole at about 238 DAP but then decreased in both cultivars and places (Figs 6C and D). The average weight per tuber increased to a maximum average weight of 20–25 g per tuber, as time progressed up to about 252 DAP in Awassa and 238 DAP in Wondogenet. The tuber fresh weight per hole reached about 3000–3500 g in both cultivars and places at 238 DAP and thereafter decreased strongly (Figs 6G and H).

Discussion

Structural components

The tubers of *P. edulis* are clearly stem tubers with pairs of ‘‘eyes’’ (i.e., compound axillary buds) being arranged in the same alternating pattern as the axillary buds on stolons and stems. *P. edulis* therefore consists of similar structural components as other crops producing stem tubers on stolons, such as the common potato (*Solanum tuberosum*) (Beukema and van der Zaag, 1979; Struik and Wiersema, 1999). *P. esculentus* differs from *P. edulis* because *P. esculentus* produces stem tubers that are sessile and clustered around the stem (Allemann et al., 2003). The stolons of *P. edulis*

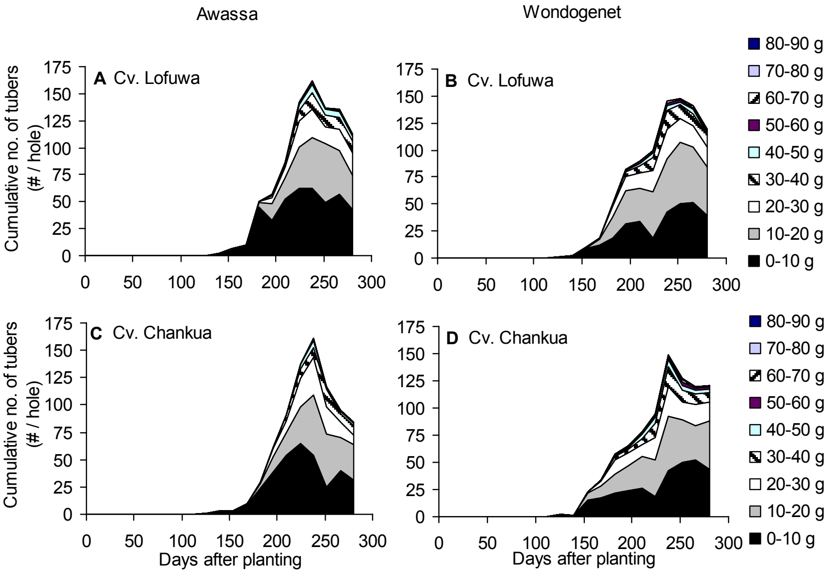

Fig. 8. Cumulative number of tubers per hole in different tuber weight classes at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) cv. Lofuwa, Awassa; (B) cv. Lofuwa, Wondogenet; (C) cv. Chankua, Awassa; (D) cv. Chankua, Wondogenet. Bar = standard deviation.

were much longer than those of Irish potato and particularly the aerial stolons behaved differently from those of Irish potato. They were very ‘‘aggressive’’, growing fast over the soil surface, and could achieve a length of more than 2 m. The aerial stolons produced several branches and bore tubers after the branches entered into the ground.

Tubers were formed upon swelling both at the tip and in the middle of the stolon. In Irish potato, tubers in the middle of the stolon are only observed when secondary growth occurs, i.e. the growth of the apex changes from tuber-like to stolon-like due to a switch in external conditions to those that are not conducive to tuberization and tuber bulking, e.g., warm temperatures or rainfall after a dry period (e.g., Bodlaender et al., 1964; Lugt et al., 1964). For *P. edulis*, the exact nature of the tuber formation in the middle of the stolon still has to be established, but most likely it results from thickening of an existing stolon part and not just from a secondary growth like phenomenon.

P. esculentus differed also in other aspects from *P. edulis,* like the flower colour which was blue in *P. edulis* while *P. esculentus* has yellow flowers (Tindall, 1983), but also by the fact that tubers of *P. esculentus* show a clear positively gravitropic growth (Allemann et al., 2003). We did not record the exact growth direction of *P. edulis* tubers and stolons, but the wide spread of the stolons suggests it was mainly plagiotropic for the stolons (with the exception of the branches from aerial stolons entering the soil).

Canopy development

Several yellowish sprouts per hole were produced from each tuber piece at the beginning of the growing period but after emergence all except a few sprouts changed to green or reddish (depending on the cultivar). The emerged main stems were tipped at 61−63 DAP. The total number of main stems stopped to increase (soon) thereafter. Primary branches then started to develop (Fig. 3), while the number of main stems decreased to c. 1.5 per hole, likely because of inter-stem competition. This implies that at maximum half of the tuber pieces planted per hole actually produced a main stem surviving until the tuber stage. The majority of the canopy of *P. edulis* was formed by primary and secondary branches and the leaves on these branches (Figs 3 and 4). Canopy development was gradually arrested by the initiation of terminal inflorescences at the apices of the stems, especially the primary and secondary branches, and the ending of further initiation of new branches. First inflorescences were observed 112 DAP and 126 DAP for cvs Lofuwa and Chankua, respectively in Awassa, and 154 DAP for both cultivars in Wondogenet. The total number of green leaves started to decline after c. 154–168 DAP (Fig. 4), with complete leaf senescence being attained 238−252 DAP. There was no prove for the assumption that cv. Lofuwa was earlier maturing than cv. Chankua.

Number of stolons, number of tubers and tuber yield

The pattern of stolon formation differed greatly between sites. In Awassa, the total number of stolons levelled off after tubers were initiated (c. 150 DAP) and remained at a more or less stable level. Counting the number of stolons was difficult because some were broken while harvesting, and only those that remained connected with main stems and primary branches were included in the counts. The total number of stolons in Awassa stayed around 25–30 per hole until 200–250 DAP when reliable counting of stolons was no longer possible (Fig. 6A). The stable level was surprising, because aerial stolons were initiated from 182 DAP onwards, but this initiation was apparently accompanied by an overall decrease in the number of below-ground stolons (Table 1). It is unlikely that the two types of stolons were mixed because the aerial stolons were longer than the below-ground tubers, leafy and more coloured, and the two types of stolons therefore could be clearly distinguished.

In Wondogenet the total number of stolons had increased to higher levels than in Awassa at the moment tuber initiation had commenced well (Fig. 6B). This was found for stolons from both main stems and primary branches (Fig. 5). It is possible that the higher numbers of stolons were related to the overall lower temperature in

Wondogenet than in Awassa. The increase in number of stolons also continued longer in Wondogenet than in Awassa, but was followed by a decrease, taking place in the period that tubers were still being initiated (Figs 6B and D). Also in Wondogenet the appearance of aerial stolons was accompanied by a decrease in the number of below-ground stolons (Table 2).

The difference in number of stolons between sites was not reflected in the number of tubers, which at maximum was 150–160 per hole at both sites. After tuber initiation, the number of tubers increased almost linearly during a period of 12–14 weeks, and maximum numbers of tubers were attained around 238 DAP, at crop senescence. This is very unlike the pattern of tuber formation that is common in Irish potato, in which most tubers are initiated within a period of a few weeks (Vreugdenhil and Struik, 1989; Struik, 2007), after which during the tuber bulking phase the number of tubers declines due to resorption of the smallest, non-competitive tubers (Struik, 2007). In *P. edulis* also the number of smaller tubers (< 10 or 20 g) increased until senescence (Fig. 8). In the period of tuber initiation also the average weight per tuber increased up to 20–25 g per tuber around 238 DAP (Figs 6E and F). The increase in tuber fresh weight with time until senescence was therefore realized by an increase in both tuber number and in average weight per tuber (Fig. 6).

In situ *storage*

There was a sharp peak in number of tubers and especially in tuber fresh weight per hole at 238 DAP (Fig. 6). From an agronomical point of view it is important to identify this moment to maximize yield. Tuber yield per hole still increased before, and losses occurred thereafter. It was not possible, however, to relate this moment consistently over sites and cultivars to the number of green leaves: In Wondogenet, the last counts of green leaves were made 2 weeks before this moment and at 238 DAP no green leaves were present anymore, whereas in Awassa the number of green leaves was negligible at 238 DAP in cv. Chankua but still more than 200 per hole in cv. Lofuwa (Fig. 4).

After crop maturity, farmers store the tubers *in situ* in the soil until they need them (Mulugeta et al., 2007). This research shows that this dramatically reduces the number of tubers and their weight, with decreases being observed of 36–59% in total tuber fresh weight per hole and of 18–48% in number of tubers in 6 weeks (between 238 and 280 DAP; cf. Fig. 6). Losses not only took place in the lightest tuber classes (< 10 or 10–20 g) but also in the heavier tuber classes. Some weight losses may have been caused by further respiration of the tubers, by loss of water and by losses of complete tubers. Declines in the number of tubers might have been caused by resorption of the least competitive tubers, probably the smallest tubers and tubers in the middle part of the stolons. In addition, some tubers might not have been found back anymore, some of which could be lost because of rotting or by exhausting of all reserves by respiration. No obvious rotting of tubers was observed however.

CHAPTER 4

Light interception, radiation use efficiency, growth and tuber production of *Plectranthus edulis*

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Abstract

Plectranthus edulis (Vatke) Agnew (Lamiaceae) is an ancient Ethiopian crop that produces edible tubers on stolons below ground. There is thus far no quantitative information on growth and parameters determining growth and yield. The objective of this study was to understand and quantify the growth of *P. edulis*, and identify the processes limiting yield. A similar experiment was carried out in Awassa and Wondogenet (southern Ethiopia) in a split-plot design with five blocks and cultivar (Lofuwa and Chankua) as main factor and harvest date (20 harvests from 14 to 280 days after planting (DAP)) as split factor.

The moment at which tuber weights were maximal was achieved in both cultivars and at both sites at 238 days after planting (DAP), when fresh tuber yields were 45−49 Mg ha^{-1} and tuber dry matter concentrations 19−21%. Although these yields are very high compared to farmers' yields, average daily dry matter production of the crop was only 4.2−4.6 g m^{-2} day^{-1}. Two processes limited the dry matter production: the radiation interception by the crop and the efficiency by which the intercepted radiation was converted into dry matter. Only about one third of the incident radiation was intercepted by the crop's canopy. This was due to a late emergence (c. 4 weeks), a slow development of the canopy after emergence until full ground was attained (c. 20 weeks), a very short period at which ground cover was complete (c. 2 weeks) and a sharp decline in ground cover thereafter (6−8 weeks). The average radiation use efficiency (RUE) was only 1.59 g MJ^{-1} PAR for the crop in Wondogenet. RUE increased after emergence until early after tuber formation to about 2.7 g MJ^{-1} PAR in Wondogenet, but then declined because of a stagnation (cv. Chankua in Awassa) or decline (all other cultivar × site combinations) in total crop dry weight, starting after 168 DAP in Awassa and 182 DAP in Wondogenet and lasting for several weeks. Dry matter production decreased because the loss in canopy dry matter – especially stem dry matter − was not yet compensated by the increase in tuber dry matter. Later the tuber production more than outweighed the decrease in canopy dry weight, and total dry weight and RUE increased again. The relative allocation of the total dry matter produced to the tuber varied between 81 and 99% at the moment when tuber yield was maximal and was not limiting production. Keeping the tubers in the soil for more than 238 DAP drastically reduced tuber dry weights.

Keywords: Dry matter allocation, ground cover, growth rate, harvest index, LAI, light use efficiency, radiation interception, radiation use efficiency, soil cover, tuber crops

Introduction

Plectranthus edulis (Vatke) Agnew (Lamiaceae) is a tuber crop indigenous to Ethiopia. It is locally known by different names such as Wolaita dono, Gamo dinich, Dinicha Oromo, Agaw dinich, Gurage dinich, and currently Ethiopian potato (Mulugeta et al., 2007). It is cultivated in the southwestern, southern and northern parts of Ethiopia for its tuber (Westphal, 1975; Zemede and Zerihun, 1997; Mulugeta et al., 2007). The crop is grown from seed tubers which are broken into tuber pieces before planting. Planting the tuber pieces takes place as the short rain starts in the beginning of April and the tuber harvesting time varies but starts in October − November (Mulugeta et al., 2007). The crop is grown as a monocrop; normal cultural practices include cultivation, tipping, earthing up, and manuring (Mulugeta et al., 2007). The crop was shown to produce stem tubers below ground, on stolons that originated from main stems and primary branches, either below or above ground (Chapter 3). Up to about 175 tubers were produced per planting hole.

Understanding the physiological response of a crop as practised for instance on common potato (Kooman, 1995) helps to improve its productivity. In *P. edulis*, there is thus far no quantitative information on growth and parameters determining growth and yield. This limits further progress in its production and expansion.

The solar radiation intercepted by a crop's canopy and the efficiency of utilizing that intercepted radiation for CO_2 fixation are the primary factors affecting dry matter production (Monteith, 1977; Sinclair and Muchow, 1999). Studies on different crops showed that the amount of radiation intercepted by the canopy during the growing season is directly related to the dry matter production (Monteith, 1977; Lommen, 1999; Admasu and Struik, 2003). Radiation use efficiency (RUE), which is the total dry matter production per unit of intercepted radiation, is a variable used to analyse the productivity of crops in different environments (Idinoba et al., 2002). In general, a higher dry matter production can result from more solar radiation being intercepted, higher radiation use efficiency, or a combination of the two (Willey, 1990). This analytical approach can be extended by studying the allocation of the total dry matter over the organs of interest and the remaining plant organs. In tuber crops such as Irish potato, tuber dry matter production thus results from the total dry matter production and the harvest index, the proportion of the total dry matter in the harvested tubers (e.g., Spitters, 1990; Struik and Lommen, 1999; Tadesse et al., 2001a, b). Tuber fresh weight is then obtained by dividing tuber dry weight by the tuber dry matter concentration.

An important step in increasing insight into the functioning of *P. edulis* is a proper description and quantification of growth. This will allow establishment of the basic growth parameters that determine the yield of the crop. Therefore, the objective of this study was to understand and quantify the growth of *P. edulis*, and identify the processes limiting yield.

Materials and methods

Experimental sites

A similar experiment was carried on two locations in southern Ethiopia. The first location was the main campus of Hawassa University, Awassa (7°03' N, 38°30' E) and the second the Wondogenet College of Forestry and Natural Resources, Wondogenet (7°06' N, 38°37' E). The experiment at Awassa was conducted from April 4, 2003 – January 9, 2004 and the experiment in Wondogenet from April 11, 2003 – January 16, 2004. Awassa is located at about 1650 masl, Wondogenet at 1850 masl. The average temperature over the experimental period was 19.9 °C in Awassa and 18.4 °C in Wondogenet, total rainfall was 671 and 888 mm at the respective sites. For more weather details, see Chapter 3. The soil texture in both places was sandy loam.

Experimental design

A split-plot design with five blocks and with two cultivars (Lofuwa and Chankua) as main factor and 20 harvests (every 14 days from 14 until 280 days after planting (DAP)) as sub factor was used in the experiments. Each plot had four rows spaced at 90 cm with 75 cm within-row distance between holes in an area of 12.6 m^2 (3.60 m × 3.75 m). Twenty holes were planted in each plot from which the plants from the middle six holes (three holes in two rows) were used for observations, and the plants from the remaining 14 holes were guard plants. Cultivar Lofuwa had a green leaf and stem colour and its stolon and tuber skin was creamish, while Chankua's leaves, stems, and stolon and tuber's skin colour was reddish (Chapter 3).

Crop management

The experimental field was ploughed, and furrowed until a depth of 20 cm. A whole seed tuber of about 10–12 cm was broken into three equal pieces and these pieces were planted in a small hole in a furrow (Chapter 3). After placing them in the hole they were covered with a layer of soil of about 5 cm thick. During crop growth the plots were cultivated about three times to remove weeds. Tipping, i.e. removing the tip part of the main stem and branches, was carried out when plants had reached about 15 cm height, i.e. at 61 DAP in Awassa and 63 DAP in Wondogenet. Earthing up, i.e. piling soil around the stem base, was done three times in order to cover the stolons and to support the stem.

Ground cover

Ground cover (%) was measured every 7 days by means of a frame with a size of 0.90 m × 0.75 m that was divided into 100 grids each having an area of 67.5 cm^2 (9 cm × 7.5 cm). The number of grids filled with > 50% green leaves was counted by looking vertically from the top. A value of 1 was given for a grid that was covered with > 50% green leaves and zero for < 50% green leaves. The ground cover percentage was based on the green leaves only and did not include green stems. Records were taken from four plants per plot, of which two plants were taken from each row. The grid method provides a non-destructive measurement, which correlates well with the proportion of intercepted photosynthetically active radiation as measured with a tube solarimeter (Haverkort et al., 1991). Only ground cover data from Wondogenet were used.

Radiation

Because the meteorological stations at the experimental sites were not recording radiation directly, radiation was calculated indirectly from sunshine hours in Awassa, and cloudiness hours in Wondogenet. The formula, $Rs = w\ (0.24 + 0.59\ n/N)\ Ra$, in which Rs is solar radiation that reaches the earth surface per 24 h, n = the bright sunshine hours per day recorded at the meteorological stations, N = maximum possible sunshine hours per day, Ra = radiation received at the top of the atmosphere and w = weighting factor which reflects the effect of temperature and latitude on the relationship between Rs and evapo-transpiration (ET) was used to convert the sunshine hour into solar radiation (Doorenbos and Pruitt, 1977; Admasu and Struik, 2003). The values for w, N, Ra, and the coefficients 0.24 and 0.59 were taken from Doorenbos and Pruitt (1977) and Admasu and Struik (2003). The cloudiness hours, which were recorded in Octa 1–8 at the meteorological station in Wondogenet, were converted into n/N (Doorenbos and Pruitt, 1977) and finally the solar radiation was estimated using the above formula.

Cumulative intercepted radiation

Daily ground cover was calculated by linear intrapolation of the weekly data and was multiplied by the daily radiation to determine the radiation intercepted per day. Intercepted radiation is the difference between solar radiation received at the surface of the canopy and that transmitted to the soil (Squire, 1990). The daily intercepted radiation was summed up to produce the cumulative intercepted radiation at each harvest. PAR was calculated as 50% of the incident global solar radiation.

Growth and related measurements

Fresh leaf and tuber weights were recorded. Dry matter weights of leaves, main stems and branches, stolons and tubers were recorded after drying them at 72 °C for about 48 h. Tubers were broken into pieces before placing them in an oven. A leaf sample of 12–15 leaves per plot was taken to determine the relationship between leaf fresh weight and leaf area as measured by a video type leaf area meter. Leaf area index (m^2 m^{-2}), harvest index ($g\ g^{-1}$), tuber dry matter concentration (TDMC, $g\ g^{-1}$) and total dry weight ($g\ m^{-2}$) were calculated. Roots, sprouts and inflorescences were not included in the total dry weight. Leaves and stolon dry weights were not determined anymore at later stages when most leaves had littered and most stolons were found to be detached from the stem. Their weight was negligible at that moment.

Statistical analysis

Means and standard deviations were calculated per cultivar per harvest date using GenStat release 9.2 or Excel 2003.

Results

Dry matter of main stems and branches

The dry weights of main stems, primary branches and secondary branches and the total stem dry weight increased up to about 168 DAP in Awassa (Figs 1A, C, E and I) and up to 168 DAP (primary branches and total stem weight of cv. Chankua) or 182 DAP (other cultivars × stem type combinations) in Wondogenet (Figs 1B, D, F and J). Tertiary branches usually developed slightly later than lower order branches, and their weight was almost negligible (Figs 1G and H). Maximum total stem dry weight was between 380–500 $g\ m^{-2}$, with the primary branches being the most important constituents producing more than 60% of the stem dry mass. Cv. Lofuwa generally produced more stem dry matter than cv. Chankua.

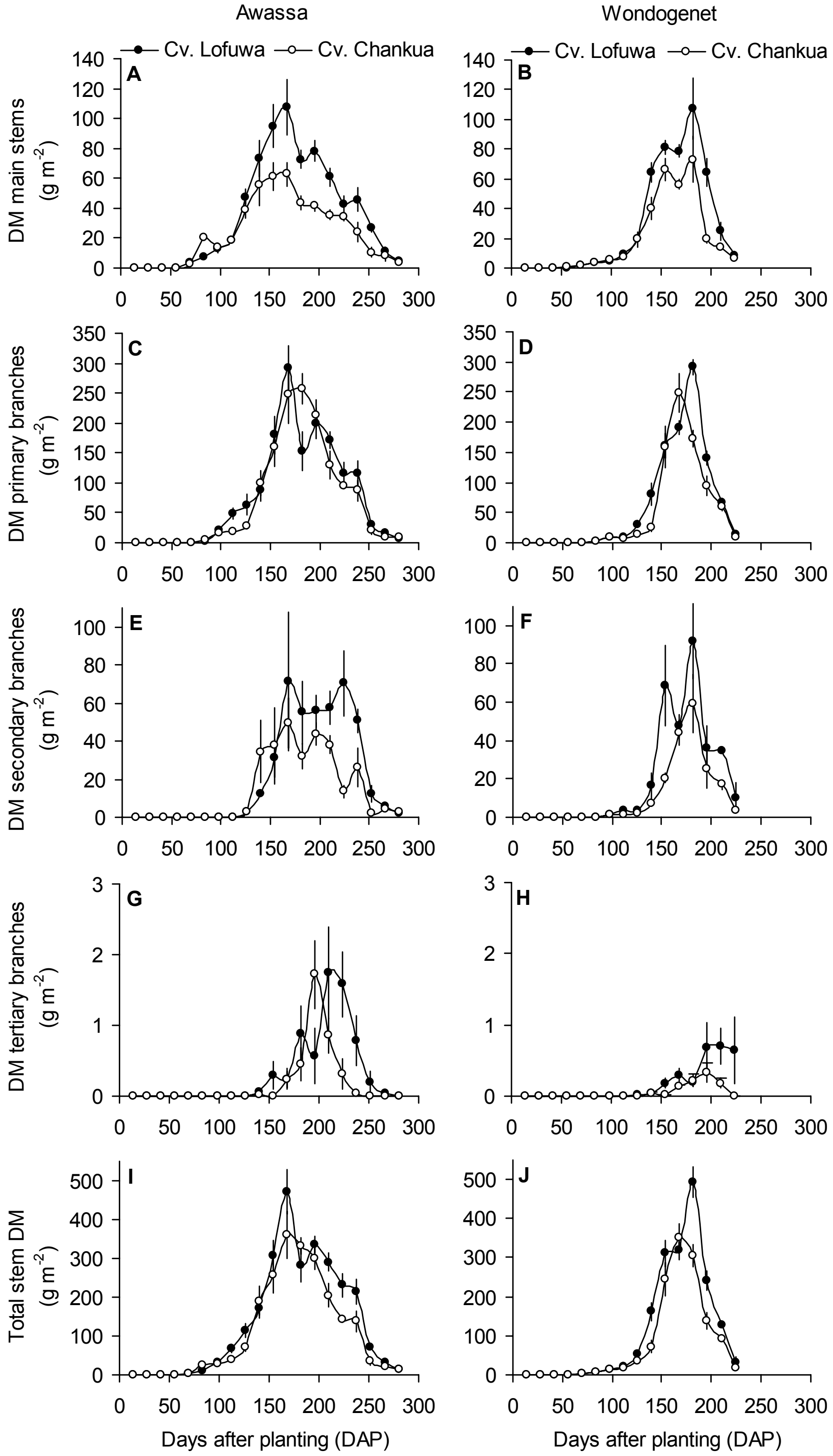

Fig. 1. Dry weight per m² of main stems and branches at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) main stems, (C) primary branches, (E) secondary branches, (G) tertiary branches, (I) total dry weight of main stems and branches in Awassa; (B) main stems, (D) primary branches, (F) secondary branches, (H) tertiary branches, and (J) total dry weight of main stems and branches in Wondogenet. Bar = standard deviation.

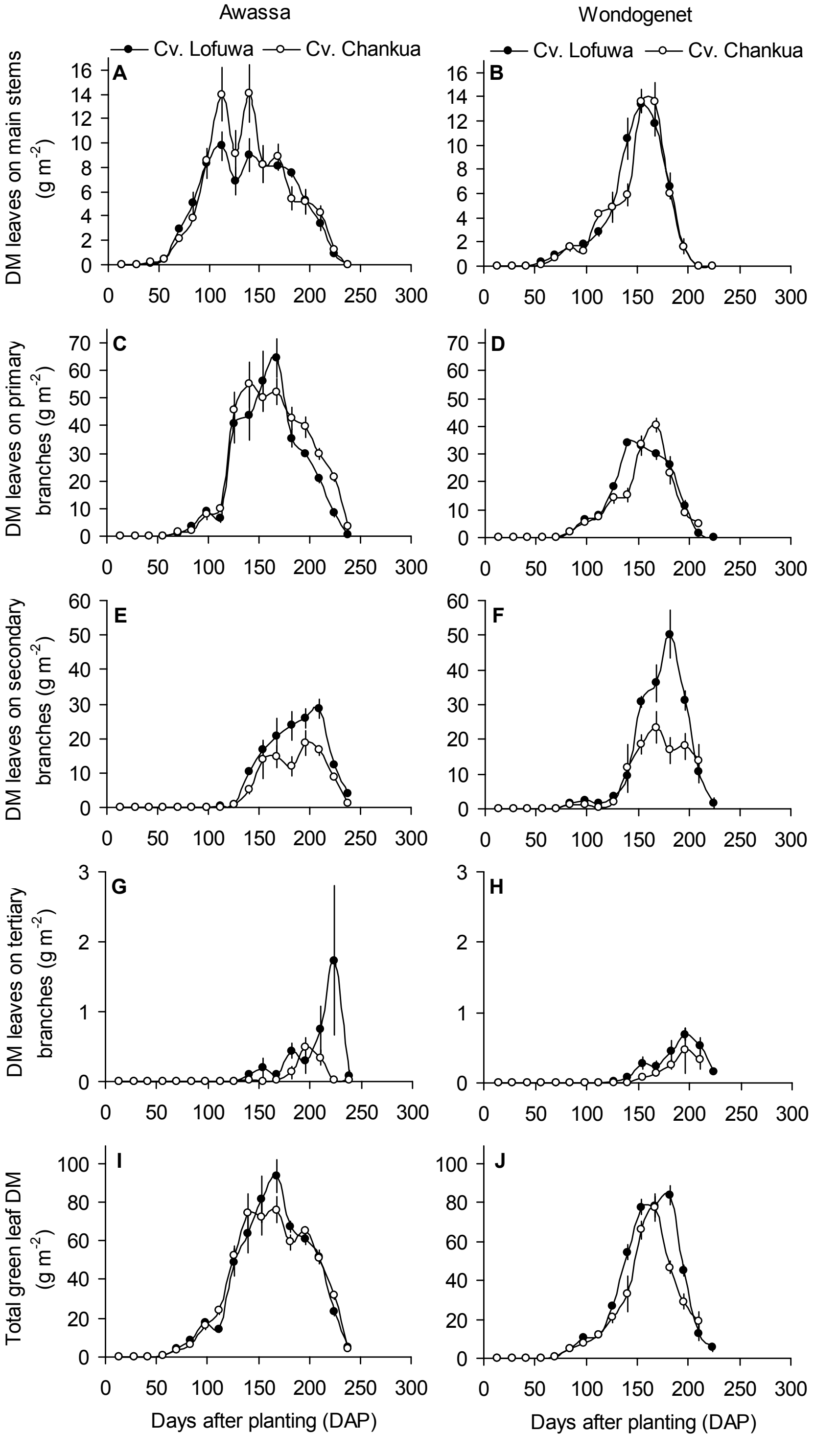

Fig. 2. Dry weight per m² of green leaves from main stems and branches at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) green leaves on main stem, (C) green leaves on primary branches, (E) green leaves on secondary branches, (G) green leaves on tertiary branches, (I) total dry weight of green leaves on main stems plus branches in Awassa; (B) green leaves on main stems, (D) green leaves on primary branches, (F) green leaves on secondary branches, (H) green leaves on tertiary branches, (J) total dry weight of green leaves on main stems plus branches in Wondogenet. Bar = standard deviation.

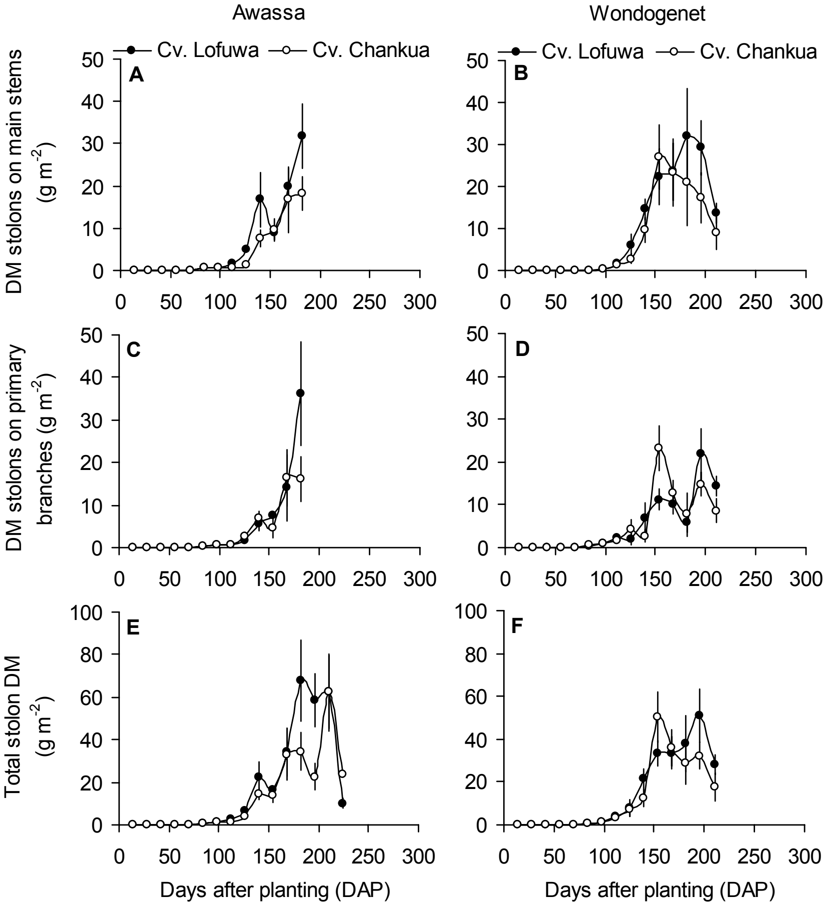

Fig. 3. Dry weight per m² of stolons originating from main stems and primary branches and total stolon weight at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) stolons on main stems, (C) stolons on primary branches, (E) total stolon dry weight in Awassa; (B) stolons on main stems, (D) stolons on primary branches, (F) total stolon dry weight in Wondogenet. Bar = standard deviation.

Dry matter of leaves

The moments at which during the growth cycle of *P. edulis* the maximum dry weights of green leaves on different stem fractions were attained varied between 112 and 224 DAP, and in general were later for green leaves from higher order branches (Fig. 2). The maximum total dry weight of green leaves was 80–100 g m^{-2} (Figs 2I and J), attained 140–168 DAP in Awassa and 168–182 DAP in Wondogenet. At both sites the maximum was achieved later for cv. Lofuwa than for cv. Chankua (Figs 2I and J). Green leaves from primary branches contributed most to the total green leaf mass in Awassa and in cv. Chankua in Wondogenet, but in cv. Lofuwa in Wondogenet also leaves from secondary branches were important, although during a smaller timeframe. Leaves from tertiary branches were relatively unimportant.

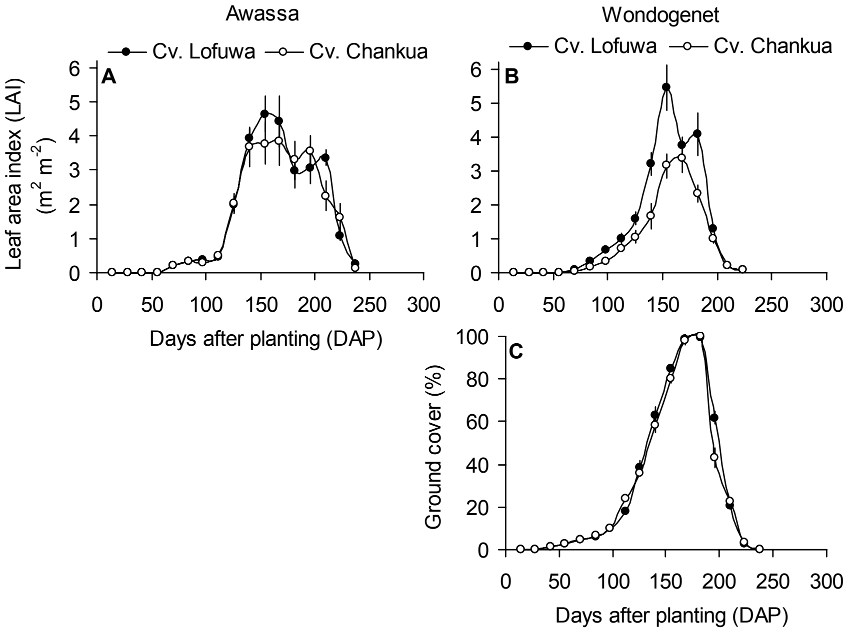

Fig. 4. Development of leaf area index (LAI) and ground cover (GC) by the canopy at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) LAI in Awassa; (B) LAI, (C) GC in Wondogenet. Bar = standard deviation.

Dry matter of stolons

Stolon data were usually very variable. Stolons were produced on main stems and primary branches (Fig. 3). The stolon dry matter from main stems and primary branches separately was recorded up to 182 DAP in Awassa and up to 210 DAP in Wondogenet. Determining from which branch they grew was discontinued thereafter for it became very difficult to separate them. Maximum stolon dry weights recorded were 50–60 g m^{-2}, and were obtained 182–224 DAP in Awassa and 154–196 DAP in Wondogenet. The total stolon dry matter in general decreased as the plant got older.

Leaf area index

Leaf area index (LAI) increased up to 3.8−4.7 in Awassa and up to 3.4–5.5 in Wondogenet (Figs 4A and B). LAI remained at least 3 up to 196 and 210 DAP for cv. Chankua and Lofuwa, respectively in Awassa, and up to 168−182 DAP for the respective cultivars in Wondogenet and then decreased.

Ground cover

Ground cover data are only presented for Wondogenet. Ground cover in Wondogenet seemed to increase almost linearly after emergence until about 100−120 DAP, when there seemed to be a switch to a higher rate of linear increase (Fig. 4C). Maximum ground cover was only maintained for a short period of c. 2 weeks around 175 DAP, after which ground cover decreased sharply.

Yield formation

During the growing period, accumulated radiation interception by the crop increased to c. 430−450 MJ PAR m^{-2} in Wondogenet, after which PAR-interception did not increase further because of crop senescence (Tables 3–4). The radiation use efficiency (RUE), the efficiency by which this intercepted radiation was converted into crop dry matter, on average in Wondogenet was 1.59 g MJ^{-1} PAR, but, surprisingly, strongly changed with time. After emergence RUE increased gradually, attaining maximum values of 2.55−2.81 g MJ^{-1} PAR in the early stages of tuber formation (Tables 3–4). Thereafter the RUE declined and only restored at the end of the growing period.

Dry matter production first increased up to 168 DAP in Awassa and up to 182 DAP in Wondogenet, when tuber formation had commenced, but then was arrested (cv. Chankua in Awassa) or even declined (other cultivar × site combinations) (Tables 1–4, Fig. 5) because of the decrease in dry weight of the canopy, especially the stems (Fig. 5). After several weeks the increase in tuber dry weight became larger than the decrease in canopy weight and total dry weight increased again until crop maturity at 238 DAP (Tables 1–4). Maximum values attained were 1002−1110 g dry matter per m^2. Prolonged keeping of the crop in the soil without harvesting reduced the total dry matter to 447−619 g m^{-2} in 6 weeks. Harvest index (the fraction of tuber dry mass in the total dry mass) and tuber dry weight increased over the entire growing period until crop maturity at 238 DAP (Tables 1–4). Harvest index at that moment had attained values of 80.5 and 87.4%, respectively, for cvs Lofuwa and Chankua in Awassa and 97.5 and 98.9% for the respective cultivars in Wondogenet.

The dry matter concentration of the tubers increased during the growing period to 18.6–21.4% at maturity. Tuber fresh yield increased up to 4556−4933 g m^{-2}, or 45−49 Mg ha^{-1} at 238 DAP. Prolonged keeping of the crop in the soil for 6 weeks reduced the tuber fresh weight to 2041−3055 g m^{-2}.

Discussion

The moment at which tuber weights were maximal was achieved in both cultivars and at both sites at 238 DAP (7.5−8 months after planting), when fresh tuber yields attained 4556–4933 g m^{-2}, or 45–49 Mg ha^{-1}. These yields are extremely high

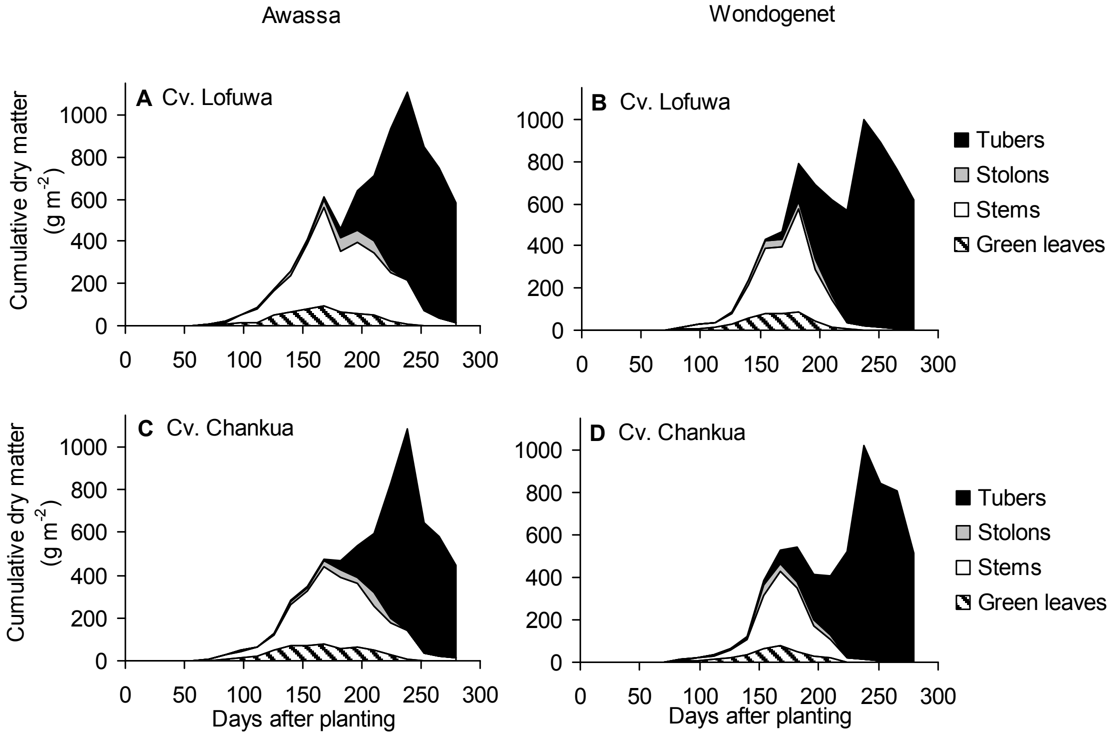

Fig. 5. Cumulative dry weight of green leaves, stems, stolons and tubers with time at Awassa and Wondogenet for cvs Lofuwa and Chankua. (A) cv. Lofuwa, Awassa; (B) cv. Lofuwa, Wondogenet; (C) cv. Chankua, Awassa; (D) cv. Chankua, Wondogenet.

compared to the yields reported by farmers (500–1000 g per hole; Mulugeta et al., 2007; 1.48 holes per m^2) or the average yield of Irish potato recorded in Ethiopia (7.85 Mg ha^{-1}, P. Gildemacher, personal communication). This is probably partly because farmers harvest relatively early. Farmers reported to start harvesting the crop in October in Wolaita and in November in Chencha, whereas maximum yield in our experiments was attained late November in the Awassa experiment and early December in the Wondogenet experiment, both at 238 DAP. When our final harvest would have been 4 weeks earlier, only 37% of the final yield would have been attained in Awassa and 51% of the final yield in Wondogenet. The higher yield of *P. edulis* as compared to Irish potato is partly caused by the length of the growing period that is much shorter for Irish potato (120 DAP; cf. Admasu and Struik, 2001). It is still unknown how the different climatic conditions in Wolaita and Chencha as compared to Awassa and Wondogenet – where the experiments were carried out – would affect the optimum harvest date. Temperatures in Chencha are lower than in Awassa and Wondogenet, temperatures in the Wolaita area investigated, likely slightly higher. When comparing our experiments, the crop development in the relatively cooler and more humid Wondogenet seemed more advanced than in Awassa, but maximum yield was attained at the same moment.

Table 1. Yield determining variates in time for cv. Lofuwa in Awassa. Mean ± SD.

DAP	Total incident PAR (MJ m^{-2})	Total dry matter (g m^{-2}) ×	Harvest index (g g^{-1}) =	Tuber dry matter (g m^{-2}) /	Tuber dry matter concentration (g g^{-1}) =	Tuber fresh yield (g m^{-2})
14	130	0	0	0	n.d.	0
28	226	0	0	0	n.d.	0
42	344	0.24 ± 0.055	0	0	n.d.	0
56	463	0.68 ± 0.263	0	0	n.d.	0
70	562	8.91 ± 1.078	0	0	n.d.	0
84	651	18.4 ± 4.62	0	0	n.d.	0
98	760	52.2 ± 10.35	0	0	n.d.	0
112	876	86.0 ± 18.14	0	0	n.d.	0
126	970	170 ± 34.3	0.0011 ± 0.0015	0.21 ± 0.284	0.035 ± 0.0483	2.37 ± 3.264
140	1067	260 ± 66.9	0.0043 ± 0.0078	1.23 ± 2.192	0.061 ± 0.0559	11.2 ± 19.16
154	1169	409 ± 100.1	0.0097 ± 0.0061	4.24 ± 3.297	0.104 ± 0.0052	40.3 ± 30.20
168	1274	611 ± 151.7	0.0204 ± 0.0076	13.2 ± 8.22	0.126 ± 0.0078	104 ± 61.9
182	1375	457 ± 119.6	0.0903 ± 0.0195	39.9 ± 6.30	0.131 ± 0.0040	303 ± 44.9
196	1507	637 ± 106.0	0.2832 ± 0.0470	183 ± 53.5	0.149 ± 0.0098	1218 ± 319.4
210	1645	707 ± 77.5	0.4138 ± 0.0579	304 ± 50.6	0.166 ± 0.0069	1837 ± 359.3
224	1755	936 ± 164.8	0.7155 ± 0.0566	672 ± 145.4	0.176 ± 0.0044	3817 ± 747.5
238	1881	1110 ± 68.7	0.8052 ± 0.0517	892 ± 52.2	0.186 ± 0.0056	4792 ± 255.7
252	*1993*	*851 ± 109.1*	*0.9177 ± 0.0095*	*781 ± 96.7*	*0.185 ± 0.0332*	*4260 ± 367.1*
266	*2121*	*751 ± 61.0*	*0.9571 ± 0.0148*	*718 ± 52.4*	*0.197 ± 0.0217*	*3681 ± 405.5*
280	*2249*	*581 ± 72.9*	*0.9735 ± 0.0053*	*566 ± 73.0*	*0.186 ± 0.0260*	*3055 ± 187.8*

DAP days after planting.

Data in italics were taken after crop maturity during *in situ* storage.

Table 2. Yield determining variates in time for cv. Chankua in Awassa. Mean ± SD.

DAP	Total incident PAR (MJ m^{-2})	Total dry matter (g m^{-2}) ×	Harvest index (g g^{-1}) =	Tuber dry matter (g m^{-2}) /	Tuber dry matter concentration (g g^{-1}) =	Tuber fresh yield (g m^{-2})
14	130	0	0	0	n.d.	0
28	226	0	0	0	n.d.	0
42	344	0.08 ± 0.022	0	0	n.d.	0
56	463	0.12 ± 0.132	0	0	n.d.	0
70	562	4.04 ± 0.694	0	0	n.d.	0
84	651	23.9 ± 3.86	0	0	n.d.	0
98	760	29.2 ± 5.70	0	0	n.d.	0
112	876	38.2 ± 5.84	0	0	n.d.	0
126	970	70.9 ± 21.13	0.0039 ± 0.0054	0.36 ± 0.491	0.004 ± 0.0503	3.90 ± 5.428
140	1067	193 ± 77.8	0.0121 ± 0.0028	2.27 ± 1.039	0.091 ± 0.0231	25.7 ± 9.84
154	1169	260 ± 98.1	0.0049 ± 0.0078	1.81 ± 3.240	0.063 ± 0.0574	17.4 ± 31.31
168	1274	368 ± 124.1	0.0206 ± 0.0052	7.48 ± 2.656	0.124 ± 0.0065	60.1 ± 20.72
182	1375	372 ± 29.0	0.1080 ± 0.0711	39.8 ± 24.95	0.135 ± 0.0066	288 ± 164.1
196	1507	453 ± 68.4	0.3353 ± 0.1047	153 ± 56.3	0.153 ± 0.0067	1005 ± 381.3
210	1645	480 ± 100.1	0.5803 ± 0.0424	276 ± 43.0	0.162 ± 0.0096	1713 ± 329.5
224	1755	771 ± 71.8	0.8126 ± 0.0211	628 ± 68.6	0.181 ± 0.0027	3473 ± 342.4
238	1881	1084 ± 99.7	0.8740 ± 0.0408	944 ± 53.0	0.191 ± 0.0080	4933 ± 200.9
252	*1993*	*649 ± 88.6*	*0.9486 ± 0.0256*	*615 ± 76.6*	*0.160 ± 0.0116*	*3836 ± 333.1*
266	*2121*	*585 ± 54.7*	*0.9627 ± 0.0155*	*563 ± 51.5*	*0.211 ± 0.0110*	*2671 ± 167.7*
280	*2249*	*447 ± 34.2*	*0.9680 ± 0.0088*	*433 ± 33.9*	*0.214 ± 0.0262*	*2041 ± 180.2*

DAP days after planting.

Data in italics were taken after crop maturity during *in situ* storage.

Table 3. Yield determining variates in time for cv. Lofuwa in Wondogenet. Mean ± SD.

DAP	Total incident PAR (MJ m^{-2})	PAR intercepted (MJ m^{-2}) ×	RUE (g MJ^{-1})	= Total dry matter (g m^{-2})	× Harvest index (g g^{-1})	= Tuber dry matter (g m^{-2})	/ Tuber dry matter concentration (g g^{-1})	= Tuber fresh yield (g m^{-2})
14	87	0	n.d.	0	0	0	n.d.	0
28	176	0	n.d.	0	0	0	n.d.	0
42	266	0.43 ± 0.299	0.38 ± 0.419	0.25 ± 0.167	0	0	n.d.	0
56	352	1.87 ± 0.877	0.46 ± 0.227	0.72 ± 0.172	0	0	n.d.	0
70	428	4.11 ± 1.036	0.90 ± 0.325	3.50 ± 0.889	0	0	n.d.	0
84	497	7.84 ± 1.671	1.49 ± 0.357	11.3 ± 1.02	0	0	n.d.	0
98	566	12.3 ± 2.91	2.23 ± 0.659	26.4 ± 6.16	0	0	n.d.	0
112	636	22.1 ± 2.70	1.72 ± 0.404	37.7 ± 7.12	0	0	n.d.	0
126	700	39.3 ± 2.73	2.24 ± 0.508	88.6 ± 23.6	0.0029 ± 0.0052	0.21 ± 0.358	0.018 ± 0.0266	4.35 ± 6.309
140	777	97.1 ± 6.89	2.45 ± 0.340	239 ± 45.6	0.0025 ± 0.0025	0.64 ± 0.715	0.039 ± 0.0407	10.1 ± 10.50
154	853	153 ± 8.4	2.81 ± 0.333	430 ± 68.4	0.0213 ± 0.0311	8.53 ± 11.528	0.102 ± 0.0363	73.5 ± 82.17
168	927	224 ± 7.9	2.09 ± 0.218	467 ± 35.7	0.0824 ± 0.0401	38.2 ± 17.10	0.152 ± 0.0334	264 ± 130.2
182	1019	312 ± 10.9	2.53 ± 0.350	791 ± 125.8	0.2229 ± 0.0297	177 ± 43.2	0.156 ± 0.0054	1140 ± 285.5
196	1116	399 ± 17.3	1.72 ± 1.140	687 ± 51.5	0.5088 ± 0.0455	350 ± 41.5	0.164 ± 0.0076	2145 ± 312.7
210	1217	432 ± 17.8	1.43 ± 0.164	617 ± 52.8	0.7263 ± 0.0282	449 ± 46.8	0.183 ± 0.0093	2457 ± 306.2
224	1315	449 ± 16.7	1.25 ± 0.191	562 ± 99.2	0.9320 ± 0.0518	527 ± 116.4	0.181 ± 0.0049	2916 ± 671.6
238	1423	439 ± 12.0	2.28 ± 0.218	1002 ± 119.1	0.9751 ± 0.0067	977 ± 114.0	0.214 ± 0.0210	4556 ± 207.3
252	*1549*	*453 ± 13.7*	*1.96 ± 0.174*	*888 ± 85.7*	*0.9864 ± 0.0064*	*876 ± 88.2*	*0.230 ± 0.0158*	*3802 ± 233.7*
266	*1677*	*449 ± 27.7*	*1.70 ± 0.294*	*758 ± 79.8*	*0.9873 ± 0.0044*	*749 ± 77.9*	*0.220 ± 0.0117*	*3402 ± 181.9*
280	*1813*	*446 ± 9.6*	*1.39 ± 0.314*	*619 ± 132.3*	*0.9907 ± 0.0039*	*613 ± 131.9*	*0.217 ± 0.0471*	*2836 ± 126.5*

DAP days after planting.

Data in italics were taken after crop maturity during *in situ* storage.

Table 4. Yield determining variates in time for cv. Chankua in Wondogenet. Mean ± SD.

DAP	Total incident PAR (MJ m^{-2})	PAR intercepted (MJ m^{-2})	× RUE (g MJ^{-1})	= Total dry matter (g m^{-2})	× Harvest index (g g^{-1})	= Tuber dry matter (g m^{-2})	/ Tuber dry matter concentration (g g^{-1})	= Tuber fresh yield (g m^{-2})
14	87	0	n.d.	0	0	0	n.d.	0
28	176	0	n.d.	0	0	0	n.d.	0
42	266	0.66 ± 0.424	0.28 ± 0.158	0.14 ± 0.052	0	0	n.d.	0
56	352	1.87 ± 0.507	0.47 ± 0.225	0.79 ± 0.216	0	0	n.d.	0
70	428	4.05 ± 0.675	0.78 ± 0.146	3.16 ± 0.854	0	0	n.d.	0
84	497	8.01 ± 1.926	1.45 ± 0.452	10.9 ± 0.92	0	0	n.d.	0
98	566	13.1 ± 1.38	1.88 ± 0.142	24.6 ± 3.01	0	0	n.d.	0
112	636	23.1 ± 2.98	1.43 ± 0.203	32.5 ± 2.45	0	0	n.d.	0
126	700	41.6 ± 2.17	1.52 ± 0.297	63.0 ± 12.05	0.0080 ± 0.0083	0.53 ± 0.525	0.038 ± 0.0354	8.35 ± 8.182
140	777	95.1 ± 6.32	1.25 ± 0.556	119 ± 53.1	0.0053 ± 0.0044	0.77 ± 0.815	0.041 ± 0.0231	15.9 ± 16.99
154	853	151 ± 5.78	2.55 ± 0.660	386 ± 108.7	0.0677 ± 0.0437	24.6 ± 12.63	0.077 ± 0.0248	304 ± 142.2
168	927	218 ± 8.76	2.42 ± 0.503	528 ± 111.1	0.1198 ± 0.0353	64.8 ± 31.44	0.095 ± 0.0101	687 ± 303.4
182	1019	310 ± 5.5	1.75 ± 0.364	543 ± 114.3	0.2902 ± 0.0572	162 ± 63.7	0.111 ± 0.0119	1440 ± 434.3
196	1116	388 ± 12.5	1.06 ± 0.277	413 ± 113.4	0.5066 ± 0.0690	212 ± 72.8	0.116 ± 0.0075	1810 ± 577.9
210	1217	417 ± 10.4	0.98 ± 0.266	408 ± 102.9	0.6756 ± 0.0722	281 ± 98.6	0.115 ± 0.0221	2393 ± 527.9
224	1315	434 ± 33.6	1.21 ± 0.345	524 ± 144.4	0.9610 ± 0.0132	505 ± 144.3	0.167 ± 0.0033	3022 ± 856.0
238	1423	430 ± 13.0	2.38 ± 0.352	1023 ± 143.5	0.9893 ± 0.0020	1012 ± 140.4	0.205 ± 0.0210	4930 ± 413.4
252	*1549*	*440 ± 18.6*	*1.90 ± 0.764*	*840 ± 358.0*	*0.9920 ± 0.0030*	*833 ± 356.3*	*0.243 ± 0.0657*	*3341 ± 659.7*
266	*1677*	*429 ± 26.0*	*1.89 ± 0.746*	*809 ± 306.4*	*0.9922 ± 0.0033*	*803 ± 306.0*	*0.253 ± 0.0282*	*3123 ± 838.8*
280	*1813*	*439 ± 13.9*	*1.17 ± 0.229*	*512 ± 93.8*	*0.9898 ± 0.0040*	*507 ± 94.6*	*0.179 ± 0.0347*	*2840 ± 229.4*

DAP days after planting.

Data in italics were taken after crop maturity during *in situ* storage.

As already treated by Mulugeta et al. (Chapter 3), delaying harvest to 6 weeks beyond the moment of maximum yield dramatically reduced fresh tuber yields with 36−59%, partly because of a reduction in the number of tubers. The present data show that both the fresh and dry weights of tubers declined during this *in situ* storage (Tables 1–4) and that the decrease in fresh yield during *in situ* storage was thus not mainly water loss, but must also have been caused by respiration. Also the dry matter concentration of the tubers changes during *in situ* storage, but not consistently in the same way across sites and cultivars (Tables 1–4).

Processes limiting production

During the total experimental period, the maximum crop dry weight was attained at 238 DAP, when also tuber dry and fresh weights were maximal (Tables 1–4). Maximum dry weights were 1000−1100 g m^{-2}, which corresponds to an average daily dry matter production of 4.2−4.6 g m^{-2} day^{-1}. Although the fresh tuber yields obtained under our experimental conditions are promising, the low daily growth rates suggest that considerable improvement is still possible.

Two processes clearly limited the dry matter production: the radiation interception by the crop and the efficiency by which the intercepted radiation was converted into dry matter (Tables 3–4). A third process, the allocation of the dry matter produced to the organ of interest, the tuber, seemed not limiting because of the high harvest index at the later harvest dates (Tables 1–4).

Improving radiation interception. The poor radiation interception was caused by (a) late emergence, (b) slow development of the crops' canopy, (c) an extremely short period at which ground cover was full, and (d) a sharp decline in soil cover during senescence. There was thus hardly a period during which ground cover was full and growth rates could be maximal.

The first plants emerged late, i.e. between 4 and 6 weeks after planting (Chapter 3), whereas the tuber pieces planted only produced sprouts between 2 and 4 weeks after planting (Chapter 3). This probably could be improved by planting tuber pieces with sprouts or by pre-sprouting pieces before planting. In our experiments, the seed tubers from which the seed tuber pieces were prepared were de-sprouted before being broken into tuber pieces, meaning that the sprouts produced during storage of the seed tubers were removed. This de-sprouting of seed tubers was practised by slightly more than 50% of the farmers interviewed by Mulugeta et al. (2007), whereas the other farmers planted the tuber pieces with sprouts. De-sprouting of old sprouts is common practice in Irish potato. Pre-sprouting in common potato advances crop development (e.g., Haasse et al., 2007), with longer sprouts reducing the time to emergence (e.g., Headford, 1962; Firman et al., 1992), especially in smaller tubers (Lommen, 1994). Emergence probably could also be accelerated by planting slightly larger tuber pieces. Larger tubers were shown to accelerate emergence in Irish potato (e.g., Lommen, 1994; Lommen and Struik, 1994).

Except by advancing emergence, radiation interception of the crop could also be enhanced by a faster increase in ground cover by the canopy after emergence. This in theory could be improved by planting larger seed tuber pieces (cf. Wiersema and Cabello, 1986; Allen et al., 1992; Lommen and Struik, 1994 for different sized Irish potato tubers), by planting more pieces per area (e.g., Spitters, 1990) or by cultural practices that stimulate the canopy development. Farmers growing *P. edulis* in Chencha and Wolaita use tipping, i.e. the removal of the apex plus one or two pairs of leaves from the main stems and branches, as a means to increase the number of stems. Our plants were tipped according to farmers' practice, i.e. when the plants reached about 15 cm (61−63 DAP). Tipping is likely to arrest and even decrease soil cover by the canopy on a short term basis, but thereafter may stimulate soil cover by producing extra branches. The transition from a slow linear increase to a faster linear rate of increase in soil cover in Wondogenet observed at 100−120 DAP (Fig. 4D) was associated with the development of leaves on primary and secondary branches (Fig. 2, Chapter 3). Optimizing the tipping timing and frequency thus might increase the rate of increase in soil cover. However, the objectives of tipping and earthing up (hilling – another practice carried out by the farmers to support the plant and cover the stolons) must be balanced given the fact that both practices require a lot of labour during the same time span.

Farmers generally used manure or compost on *P. edulis* (Mulugeta et al., 2007), whereas in our experiments no manure was applied because there was not enough available. Manuring might favour canopy growth. Nitrogen, for instance, is well known to enhance leaf area growth and stimulate branching in Irish potato (cf. Burton, 1989; Harris, 1992; Vos and Biemond, 1992). However, too high applications of nitrogen in potato are known to stimulate vegetative development too long, and reduce the allocation of dry matter to the tubers. It is still unknown how this may affect yield in *P. edulis*, but our fresh tuber yields obtained were higher than those reported by farmers.

Plant density is well known to affect ground cover (e.g., Spitters, 1990). Increasing the number of holes or seed tuber pieces planted per m^2 may, therefore, also fasten the achievement of full soil cover and increase yield per unit area.

The very short period of full ground cover and the fast decline in soil cover after achieving the maximum might be fully explained by the senescence of the plants because of the termination of canopy growth. It is less likely that drought has hastened senescence, because the dry period in Wondogenet started only after ground cover had already started to decline. Because of the dryer conditions later in the season, it seems more useful to increase soil cover in an earlier growth stage than to try to keep the canopy green longer.

Improving the radiation use efficiency. The values for the radiation use efficiency found (on average 1.59 g MJ^{-1} PAR in Wondogenet, which is only 0.8 g MJ^{-1} global radiation) were low compared to the values found by many others. Monteith (1977) indicated that the RUE was approximately 1.4 g MJ^{-1} global radiation over a range of crops and also Squire (1990) reported a value of 1.4 g MJ^{-1} (2.5 g MJ^{-1} PAR) for sole crops in full sunlight.

One reason for the low RUE might be the higher radiation intensity during the daylight period in Ethiopia than at locations at higher latitudes. This higher radiation intensity cannot be used as efficiently for photosynthesis as radiation with lower intensity, because the photosynthetic system of a larger part of the canopy will be saturated (cf. Kooman et al., 1996). However, Admasu and Struik (2003), working with enset in the same region found radiation use efficiencies varying from 1.43–2.67 g MJ^{-1} PAR for enset (on average 2.14), which is closer to, but still higher than the average found for *P. edulis*. Normally, low radiation use efficiencies indicate abiotic or biotic stress (e.g., Squire, 1990). A striking result from our work, however, was the fact that the RUE was not constant over the growing season. RUE increased until early in the tuber formation phase to about 2.7 g MJ^{-1} PAR in Wondogenet, which is in line with the values reported by Monteith (1977) and Squire (1990), but then declined (Tables 3–4). This decline was associated with a surprising, temporary halt or decline in total crop dry weight starting after 168 DAP in Awassa and after182 DAP in Wondogenet and lasting for several weeks. This decline was associated with a faster decrease in canopy dry matter – especially stem dry matter – than the increase in tuber dry matter (cf. Fig. 5). Later the tuber production outweighed the decrease in canopy dry weight, and total dry weight and RUE increased again (Tables 1–4). It is unknown if a strong formation of roots might have interfered with the decline in dry matter and the later increase in tuber dry matter in a stage that the LAI was declining to low values. Roots were not included in the total dry matter, as is common in this type of research (e.g., Squire, 1990). *P. edulis*, however, produced appreciable amounts of roots (Fig. 2, Chapter 3). In addition, the stems might have contributed to keep up production until 238 DAP, because stems stayed green longer than leaves stayed on the crop, but were not included in the ground cover measurements.

CHAPTER 5

Effects of shoot tipping on growth and yield of *Plectranthus edulis*

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Abstract

Plectranthus edulis is an indigenous tuber crop, cultivated in Ethiopia. It produces below-ground tubers on stolons originating from the stems. Farmers apply several laborious cultural practices to enhance shoot growth and yield, among which shoot tipping is very common. Tipping (pinching) is the removal of the shoot apex with one or two pairs of leaves from the main stems and branches. The rationale of this practice, especially when repeated more than once during one cropping season, is not fully understood. One experiment with two cultivars was carried out in each of Awassa and Wondogenet in Ethiopia to assess and analyse the effects of shoot tipping and its frequency on crop development and tuber production. Tipping treatments included zero tipping, tipping once, tipping twice and tipping thrice, with the first tipping taking place 68 days after planting, a stage at which most of the stems reached a height of about 15 cm, and the next ones following at intervals of 44−46 days. Tipping significantly increased the number of main stems per hole at both sites, but reduced the number of stolons per main stem in Awassa. Tipping enhanced early stolon formation, but did not consistently affect the number of stolons per hole later in the growing season. The number of tubers per stolon, the number of tubers per hole and the average individual tuber fresh weight were not significantly affected by tipping. In Awassa, soil cover increased with an increase in the frequency of the tipping because of the tipping effects on the different canopy development variables. However, tuber fresh and dry matter yield at the final harvest (208 days after planting) were not significantly affected by tipping. In Wondogenet, tipping enhanced the soil cover, but the crop did not benefit extra from a third tipping. Tipping (independent of its frequency) enhanced tuber fresh and dry matter yield at the final harvest compared to the control at this site. Because senescence was slightly delayed by tipping, yield effects of tipping might be increased by harvesting later. In general, there was a positive effect of tipping on canopy development and tuber yield, but the latter could only be established as significant in Wondogenet. Limiting the tipping frequency to one will help to save time, labour and money.

Keywords: *Coleus edulis*, decapitation, genotypes, pinching, *Plectranthus edulis*, radiation interception, tipping, tuber crop, yield component analysis

Introduction

Plectranthus edulis (Vatke) Agnew (syn. *Coleus edulis* Vatke), locally called Wolaita dono, Dinicha Oromo, Gamo dinich, Agaw dinich or Ethiopian potato, is a diploid, dicotyledonous plant, belonging to the Labiatae (Lamiaceae) family. It can grow up to a height of 150 cm and produces edible tubers on below-ground stolons. The below-ground habit of the plant resembles that of the Irish potato. *P. edulis* is grown as an indigenous tuber crop at mid to high altitudes (Greenway, 1944; Zemede and Zerihun, 1997) in the southern, western and northern parts of Ethiopia (Westphal, 1975; Mulugeta et al., 2007).

Tipping (pinching), i.e. the removal of the shoot apices with one or two pairs of leaves, is a common element of the crop husbandry applied by farmers. Some farmers claim that tipping increases tuber yield (Mulugeta et al., 2007). In a survey carried out in the regions Chencha and Wolaita in Ethiopia, Mulugeta et al. (2007) found the number of tippings to vary between one and three, depending on the availability of time and labour. Most growers carried out the first tipping when the plants reached a height of 15 cm, which is 1−1.5 months after planting. If farmers tipped more frequently, the second and third tippings were carried out about one and two months after the first tipping, respectively.

Shoot tipping or decapitation is well known to stimulate branching in many plant species (e.g., Dun et al., 2006) by breaking apical dominance. Tipping is carried out in various ornamentals, including *Plectranthus*, *Angelonia* and *Calibrachoa* species, and ornamental sweet potato (Smith, 2003) to make the plant bushy. For the same reason, tipping may also increase the number of stolons, and thus the number of potential tuber sites. However, the practice only makes sense if the size of the canopy or the number of potential tuber sites are indeed factors limiting production.

Although tipping has been practised in *P. edulis* for years, it is unknown how it affects crop development and tuber yield. Therefore, we carried out field experiments to assess and analyse the effects of tipping and tipping frequency on canopy branching and soil cover, yield components, and tuber production of *P. edulis.*

Materials and methods

Experimental sites

A similar experiment was carried out at two sites in southern Ethiopia, namely Awassa and Wondogenet between April 19 and November 13 2003 (Awassa) and between April 20 and November 14 2003 (Wondogenet). The Awassa field was located at

7° 03' N and 38° 30' E and the Wondogenet field at 7°06' N 38°37' E'. Awassa lies at an altitude of 1650 masl, Wondogenet at 1750 masl. Wondogenet is relatively cooler and more humid than Awassa. Average temperatures were 20.2 °C and 18.4 °C at the respective sites. Daily average temperatures during the experiments ranged between 17.4–23.7 °C and 14.9–21.6 °C in Awassa and Wondogenet, respectively. Rainfall was not limiting.

Experimental design and treatments

The experiments had a complete split-split-plot design with three factors, namely cultivar, number of tippings, and harvesting time, replicated in six blocks. Four harvesting times were randomized within four tipping practices and the latter within two cultivars. The two cultivars were Lofuwa and Chankua. The leaf and stem colours of Lofuwa are green and its tuber skin is dull white, whereas the leaf, branch and the tuber skin of Chankua are red or reddish. Farmers consider Lofuwa as relatively early maturing and Chankua as late maturing. The four tipping treatments included zero tipping, tipping once [the first tipping carried out 68 days after planting (DAP), when most shoots attained a height of about 15 cm], tipping twice (in which the first tipping was followed by a second tipping 114 DAP i.e. 46 days after the first tipping), and tipping thrice (in which the third tipping was carried out 158 DAP, i.e. 44 days after the second tipping). While tipping, the top parts (i.e. the apex with one or two pairs of visible leaves) were removed from those main stems and branches that were developed to such an extent that at least one pair of leaves remained on the stem or branch. In the second and third tipping, only outgrowths were tipped from stems that had been tipped in the previous tipping.

Crop management

Before planting, the experimental field was ploughed, disc harrowed, and furrowed with a depth of 20 cm and a width of 50 cm. The crop was planted on April 19, 2004 (Awassa) or on April 20, 2004 (Wondogenet). Planting holes of 5 cm depth were made in furrows. Three de-sprouted, broken tuber pieces (prepared by breaking a mother tuber of 10−15 cm length into three) were planted per hole in a triangle with sides of about 5 cm, and covered with soil. Hole spacing was 75 cm within a row and 90 cm between rows, consistent with common practice. Each experimental unit consisted of an area of 3.60 m × 3.75 m comprising four rows of five holes. Of the 20 holes in a plot, plants from the inner six holes (three holes × two rows) were used for observation, while the plants from the remaining 14 holes were guard plants. During growth the soil was cultivated two to three times in order to control weeds, and plants were earthed up thrice, i.e. piling up of soil around the stem, in order to support the stems and also cover the stolons. These are farmer practices as indicated in Mulugeta et al. (2007). Manure or chemical fertilizer was not applied.

Observations and calculations

Ground cover. Ground cover was estimated at harvest (1st and 2nd harvest) or one day before harvest (3rd and 4th harvest), using a frame of 0.90 m × 0.75 m that was divided into 100 cells of 9 cm × 7.5 cm each. The number of cells filled for at least 50% with green leaves was counted, the observer looking down from above to avoid parallax. Two measurements were taken per net plot, one from each inner row. This grid method provides a non-destructive measurement, which correlates well with the proportion of intercepted photosynthetically active radiation as measured with a tube solarimeter (Haverkort et al., 1991).

Crop analysis and related measurements. Data from above-ground and below-ground parts were recorded during each harvest. The number of main stems from six holes and the number of branches (primary, secondary and tertiary) from three holes were recorded. Main stem refers to each stem that originated from the bud of a mother tuber piece, primary branches originated from main stems, secondary branches from primary branches, and tertiary branches from secondary branches. Stolon number was recorded from main stems and primary branches from three holes. Secondary and tertiary branches produced no stolons. Tuber yield was determined from six holes.

The 1st harvest was on June 26–27 (68 DAP), the 2nd harvest on August 11–12 (114 DAP), the 3rd harvest on September 25–26 (159 DAP) and the 4th harvest on November 13–14 (208 DAP) in Awassa and Wondogenet, respectively. Harvests took place on the day of the 1st and 2nd tipping (immediately after tipping), one day after the 3rd tipping and 50 days after the 3rd tipping.

Statistical analysis

ANOVA was carried out on the data using GenStat, release 9.2, separately for the data from each harvest date. Relationships between number of secondary branches (*x* variate) and the total number of green leaves (*y* variate) over tipping treatments within sites and cultivars were determined by Excel 2003.

Results

Because tipping was carried out at the 1st, 2nd and 3rd harvests, plants were not treated differently until the 1st harvest, except for the removal of the tipped leaves in treatments T1−T3 on the harvest date. Similarly, plants of treatments T1−T3 were not treated differently until the 2nd harvest except for removal of the tips of treatment T2−T3 just prior to harvest, and plants from treatments T2 and T3 were not treated different until the 3rd harvest except for the removal of the tips one day before harvest in treatment T3.

Canopy development

Number of main stems. The number of main stems per hole was significantly increased by the tipping treatments in the 2nd, 3rd and 4th harvests at Awassa (Table 1), with no difference in the number of main stems between the frequencies of tipping. It was also significantly increased by tipping in the 2nd harvest at Wondogenet, but not affected furthermore by tipping in the 3rd harvest and was lower for higher frequencies of tipping at the 4th harvest (Table 2). There were no significant differences between cultivars in the number of main stems except in the 4th harvest at Wondogenet, when Chankua still had more stems than Lofuwa (Tables 1 and 2).

Number of branches. For all types of branches, the number of branches per hole was maximum at the 3rd harvest and had decreased at the 4th harvest due to crop senescence. Tipping significantly increased the number of primary branches per hole in almost all harvests as compared to zero tipping at both sites (Tables 1 and 2). It is unclear why effects sometimes were already noted in the 1st harvest, because the tipping treatments were applied at the harvest day. Tipping also increased the number of secondary branches in the 2nd and 3rd harvests, but had no consistent effect anymore on the number of secondary branches remaining in the final harvests (Tables 1 and 2). The number of tertiary branches at the 3rd harvest was increased by tipping twice or thrice in Awassa and in cv. Lofuwa in Wondogenet, and by all tipping frequencies in cv. Chankua in Wondogenet (Tables 1 and 2), but there were no consistent effects anymore in the final harvests.

Number of green leaves. The number of green leaves per hole was maximum at the 3rd harvest (Table 3). At this harvest, the number of leaves per hole both at Awassa and Wondogenet showed significant interaction between cultivar and tipping. The more frequent the tipping was, the more green leaves per hole, especially for Chankua.

Table 1. Number of main stems and different order branches per hole of the *P. edulis* cultivars Lofuwa and Chankua as affected by zero (T0), one (T1), two (T2) and three tippings (T3) for four harvests in Awassa.

Tipping treatment	Main stems				Primary branches				Secondary branches				Tertiary branches			
	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)
Cultivar Lofuwa																
T0	1.22	1.32	1.53	1.25	4.56	6.0	22.3	4.44	0[b]	8.1	50.1 a	10.4 bc	0	0	35.2	23.2
T1 (68 DAP)	1.22	2.22	2.00	2.06	7.72	20.4	23.5	8.33	0	11.9	94.6 b	5.1 a	0	0	35.7	16.6
T2 (68+114 DAP)	1.19	2.19	2.17	1.94	6.72	20.1	25.0	7.00	0	10.2	123.0 c	9.6 b	0	0	84.8	26.0
T3 (68+114+158 DAP)	1.19	2.06	2.00	2.06	7.06	22.5	31.7	7.44	0	10.4	116.8 c	23.3 e	0	0	103.9	19.9
Cultivar Chankua																
T0	1.22	1.19	1.42	1.31	4.89	8.0	25.9	4.56	0	7.5	46.7 a	13.2 cd	0	0	34.6	19.0
T1 (68 DAP)	1.31	2.03	2.03	1.83	6.33	23.6	31.0	8.00	0	13.2	99.6 b	6.6 a	0	0	33.1	13.7
T2 (68+114 DAP)	1.31	2.03	2.22	1.89	6.44	24.8	32.4	7.06	0	11.1	149.3 d	15.8 d	0	0	76.3	25.4
T3 (68+114+158 DAP)	1.31	2.28	2.03	2.33	6.33	23.9	34.7	6.61	0	12.9	172.6 e	10.0 bc	0	0	78.1	26.8
Average over cultivars																
T0	1.22	1.25 a	1.47 a	1.28 a	4.72 a	7.0 a	24.1a	4.50 a	0	7.8 a	48.4	11.8	0	0	34.9 a	21.1 b
T1 (68 DAP)	1.26	2.13 b	2.01 b	1.94 b	7.03 b	22.0 b	27.3 ab	8.17 b	0	12.6 b	97.1	5.8	0	0	34.4 a	15.1 a
T2 (68+114 DAP)	1.25	2.11 b	2.19 b	1.92 b	6.58 b	22.4 b	28.7 b	7.03 b	0	10.6 b	136.2	12.7	0	0	80.5 b	25.7 b
T3 (68+114+158 DAP)	1.25	2.17 b	2.01 b	2.19 b	6.69 b	23.2 b	33.2 c	7.03 b	0	11.6 b	144.7	16.6	0	0	91.0 b	23.3 b
Statistical analysis[a]																
Cultivar (CV)	ns	ns	ns	ns	ns	***	*	ns		ns	*	ns			ns	ns
Tipping (T)	ns	***	***	***	***	***	***	***		**	***	***			***	***
CV × T	ns	ns	ns	ns	ns	ns	ns	ns		ns	**	***			ns	ns

DAP days after planting.

Different *letters* within a column indicate significant differences according to the $\mathrm{LSD}_{0.05}$ test.

[a] Significance: *** = $P < 0.001$; ** = $0.001 \le P < 0.01$; * = $0.01 \le P < 0.05$; ns = not significant ($P \ge 0.05$).

[b] Not present.

Table 2. Number of main stems and different order branches per hole of the *P. edulis* cultivars Lofuwa and Chankua as affected by zero (T0), one (T1), two (T2) and three tippings (T3) for four harvests in Wondogenet.

Tipping treatment	Main stems				Primary branches				Secondary branches				Tertiary branches			
	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)
Cultivar Lofuwa																
T0	1.61	1.67	1.61	1.19	5.00	6.6 a	21.9	3.44	0[b]	4.8	56.1 a	8.4 a	0	0	39.2 a	20.9
T1 (68 DAP)	2.83	2.50	1.86	1.28	6.11	19.6 bcd	27.0	6.44	0	12.2	88.6 b	8.8 a	0	0	35.8 a	15.8
T2 (68+114 DAP)	2.53	2.56	1.83	1.03	6.56	20.8 cd	28.2	6.56	0	12.1	126.3 c	8.4 a	0	0	82.7 c	24.9
T3 (68+114+158 DAP)	2.86	2.36	1.67	1.17	5.78	19.4 bc	28.8	5.89	0	9.4	125.4 c	21.7 b	0	0	82.2 c	19.8
Cultivar Chankua																
T0	1.69	1.78	1.61	1.89	5.00	7.0 a	21.5	3.89	0	5.4	43.9 a	8.3 a	0	0	36.5 a	18.9
T1 (68 DAP)	2.83	2.44	1.64	1.67	6.06	17.5 b	28.9	4.89	0	11.3	112.6 c	9.9 a	0	0	57.3 b	21.9
T2 (68+114 DAP)	2.61	2.22	1.61	1.39	6.44	21.2 cd	27.8	5.56	0	10.8	127.9 c	9.0 a	0	0	119.4 d	25.9
T3 (68+114+158 DAP)	2.44	2.53	1.61	1.36	5.39	21.5 d	28.8	5.44	0	11.0	128.3 c	7.7 a	0	0	85.8 c	21.9
Average over cultivars																
T0	1.65 a	1.72 a	1.61	1.54 b	5.00 a	6.8	21.7 a	3.67 a	0	5.1 a	50.0	8.4	0	0	37.9	19.9 a
T1 (68 DAP)	2.83 b	2.47 b	1.75	1.47 b	6.08 b	18.6	27.9 b	5.67 b	0	11.8 b	100.6	9.3	0	0	46.6	18.9 a
T2 (68+114 DAP)	2.57 b	2.39 b	1.72	1.21 a	6.50 b	21.1	28.0 b	6.06 b	0	11.5 b	127.1	8.7	0	0	101.1	25.4 b
T3 (68+114+158 DAP)	2.65 b	2.44 b	1.64	1.26 a	5.58 ab	20.5	28.8 b	5.67 b	0	10.2 b	126.9	14.7	0	0	84.0	20.9 a
Statistical analysis[a]																
Cultivar (CV)	ns	ns	ns	**	ns	ns	ns	ns		ns	ns	**			**	ns
Tipping (T)	***	***	ns	***	*	***	***	***		***	***	***			***	*
CV × T	ns	ns	ns	ns	ns	*	ns	ns		ns	*	***			***	ns

DAP days after planting.

Different *letters* within a column indicate significant differences according to the $LSD_{0.05}$ test.

[a] Significance: *** = $P < 0.001$; ** = $0.001 \leq P < 0.01$; * = $0.01 \leq P < 0.05$; ns = not significant ($P \geq 0.05$).

[b] Not present.

Table 3. Total number of green leaves on main stems and branches per hole of the *P. edulis* cultivars Lofuwa and Chankua as affected by zero (T0), one (T1), two (T2) and three (T3) tippings for four harvests in Awassa and Wondogenet.

Tipping treatment	Awassa				Wondogenet			
	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)
Cultivar Lofuwa								
T0	12.4 ab	192	411 a	89 a	13.3	196	431 a	88
T1 (68 DAP)	20.9 d	217	646 b	118 b	15.7	208	631 b	129
T2 (68+114 DAP)	14.0 b	180	936 c	136 bc	13.3	176	896 d	142
T3 (68+114+158 DAP)	14.1 b	176	1069 d	146 cd	14.1	181	1053 f	130
Cultivar Chankua								
T0	11.2 a	173	430 a	120 b	13.7	176	430 a	93
T1 (68 DAP)	17.1 c	209	623 b	169 d	18.5	196	734 c	170
T2 (68+114 DAP)	16.9 c	191	1013 d	143 bcd	16.1	198	972 e	143
T3 (68+114+158 DAP)	14.3 b	185	1228 e	125 bc	13.6	189	1166 g	139
Average over cultivars								
T0	11.8	183 a	421	104	13.5 a	186	431	91 a
T1 (68 DAP)	19.0	213 b	635	144	17.1 b	202	683	150 b
T2 (68+114 DAP)	15.4	185 a	975	139	14.7 a	187	934	142 b
T3 (68+114+158 DAP)	14.2	180 a	1148	135	13.9 a	185	1110	134 b
Statistical analysis [a]								
Cultivar (CV)	ns	ns	***	*	ns	ns	**	ns
Tipping (T)	***	*	***	***	**	ns	***	** *
CV × T	**	ns	**	**	ns	ns	*	ns

DAP days after planting.

Different *letters* within a column indicate significant differences according to the $LSD_{0.05}$ test.

[a] Significance: *** = $P < 0.001$; ** = $0.001 \leq P < 0.01$; * = $0. 01 \leq P < 0.05$; ns = not significant ($P \geq 0.05$).

There were significant exponential relations between the number of secondary branches at harvest 3 and the total number of leaves ($R^2 = 0.918–0.995$).

Ground cover. As first tipping was practiced 68 days after planting, significant differences due to tipping only appeared later during the growing season (Fig. 1). This

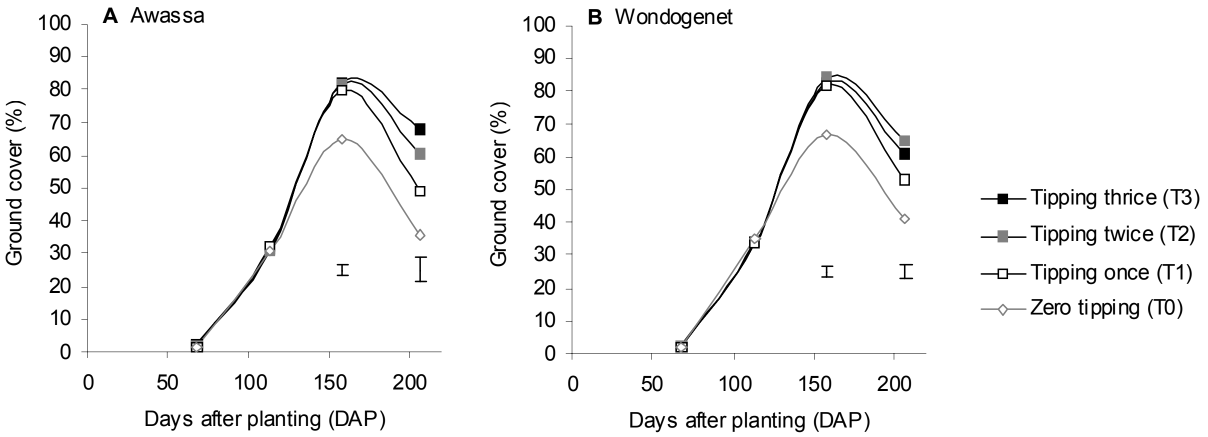

Fig. 1. Effect of zero, one, two and three tippings on development of ground cover percentage of *P. edulis* with time in Awassa (A) and Wondogenet (B) Average values over two cultivars. The interaction between cultivar and tipping was not significant. Bars: $LSD_{0.05}$ for dates on which the main effect of tipping was significant.

was true for both sites. Tipping increased both the maximum ground cover recorded and the ground cover during the period during which leaves senesced.

Below-ground development

Number of stolons. Stolons generally did not appear until after the 1st harvest (Table 4). At the second harvest in Awassa a small number of stolons had appeared and the number was significantly higher in tipped plants than in control plants (Table 4). At Wondogenet in the 2nd harvest, a non-significant difference was evident between the control and most tipping treatments in cv. Lofuwa but a higher stolon number for tipped treatments in cv. Chankua. Stolon numbers were maximum at the 3rd harvest. Tipping no longer had any effect on stolon number in the 3rd harvest in Wondogenet and in cv. Chankua in Awassa. For Lofuwa in the third harvest at Awassa tipping once resulted in more stolons than the control whereas tipping more than once resulted in fewer stolons than zero tipping (Table 4).

Number of tubers. Tubers did not appear until after the 2nd harvest. The number of tubers was not significantly affected by tipping, although more tubers tended to be produced with an increase in the frequency of tipping at both sites (Table 4). At the final harvest in Wondogenet, the number of tubers was significantly higher for Chankua than for Lofuwa (Table 4).

Table 4. Number of stolons and tubers per hole of the *P. edulis* cultivars Lofuwa and Chankua as affected by zero (T0), one (T1), two (T2) and three (T3) tippings in four harvests in Awassa and Wondogenet.

Tipping treatment	Number of stolons per hole								Number of tubers per hole							
	Awassa				Wondogenet				Awassa				Wondogenet			
	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)	1st harvest (68 DAP)	2nd harvest (114 DAP)	3rd harvest (159 DAP)	4th harvest (208 DAP)
Cultivar Lofuwa																
T0	0.056	5.1	26.6 b	3.2	0.111	9.7 ab	35.9	13.4	0	0	6.5	112	0	0	5.5	122
T1 (68 DAP)	0	6.1	32.7 c	2.7	0	10.2 ab	39.9	7.1	0	0	7.7	135	0	0	6.6	109
T2 (68+114 DAP)	0	6.2	20.8 a	2.7	0	10.4 ab	34.4	9.2	0	0	8.7	137	0	0	5.6	132
T3 (68+114+158 DAP)	0	7.3	20.7 a	3.1	0	14.6 c	30.0	9.1	0	0	7.2	147	0	0	5.1	144
Cultivar Chankua																
T0	0	4.7	18.3 a	3.3	0	8.8 a	28.6	11.7	0	0	5.9	136	0	0	5.1	117
T1 (68 DAP)	0	5.8	17.4 a	3.1	0	15.4 c	28.6	14.0	0	0	7.4	122	0	0	5.6	145
T2 (68+114 DAP)	0	7.8	21.0 a	3.3	0	13.0 bc	35.0	5.6	0	0	6.9	132	0	0	5.1	141
T3 (68+114+158 DAP)	0	6.6	19.7 a	3.2	0	12.9 bc	29.0	12.7	0	0	7.9	135	0	0	6.0	145
Average over cultivars																
T0	0.028	4.9 a	22.4	3.2	0.056	9.2	32.2	12.6	0	0	6.2	124	0	0	5.3	120
T1 (68 DAP)	0	5.9 ab	25.1	2.9	0	12.8	34.2	10.5	0	0	7.6	128	0	0	6.1	127
T2 (68+114 DAP)	0	7.0 b	20.9	3.0	0	11.7	34.7	7.4	0	0	7.8	134	0	0	5.4	136
T3 (68+114+158 DAP)	0	6.9 b	20.2	3.2	0	13.7	29.5	10.9	0	0	7.5	141	0	0	5.5	144
Statistical analysis [a]																
Cultivar (CV)	ns	ns	**	ns	ns	ns	ns	ns			ns	ns			ns	*
Tipping (T)	ns	**	ns	ns	ns	**	ns	ns			ns	ns			ns	ns
CV × T	ns	ns	**	ns	ns	*	ns	ns			ns	ns			ns	ns

DAP days after planting.

Different *letters* within a column indicate significant differences according to the $LSD_{0.05}$ test.

[a] Significance: *** = $P < 0.001$; ** = $0.001 \leq P < 0.01$; * = $0.01 \leq P < 0.05$; ns = not significant ($P \geq 0.05$).

Table 5. Yield characteristics of the *P. edulis* cultivars Lofuwa and Chankua as affected by zero (T0), one (T1), two (T3) and three (T3) tippings in Awassa. Stem and stolon data from the 3rd harvest (159 DAP), tuber data from the 4th harvest (208 DAP).

Cultivar	Number of main stems per hole (# / hole)	× Number of stolons per main stem (# / main stem)	= Number of stolons per hole (# / hole)	× Number of tubers per stolon (# / stolon)	= Number of tubers per hole (# / hole)	× Average weight per tuber (g / tuber)	= Tuber fresh weight per hole (g / hole)	× Number of holes per m^2 (# / m^2)	= Tuber fresh yield per m^2 (g / m^2)	× Tuber dry matter concentration (g / g)	= Tuber dry weight per m^2 (g / m^2)
Cultivar Lofuwa											
T0	1.53	18.4	26.6 b	4.33	112	11.7	1288	1.48	1906	0.159	302
T1 (68 DAP)	2.00	15.2	32.7 c	4.50	135	10.8	1406	1.48	2081	0.161	335
T2 (68+114 DAP)	2.17	9.9	20.8 a	6.65	137	10.4	1401	1.48	2074	0.155	321
T3 (68+114+158 DAP)	2.00	10.9	20.7 a	7.16	147	9.8	1439	1.48	2130	0.156	340
Cultivar Chankua											
T0	1.42	13.0	18.3 a	8.88	136	10.0	1342	1.48	1986	0.159	316
T1 (68 DAP)	2.03	9.0	17.4 a	7.71	122	10.6	1293	1.48	1914	0.157	298
T2 (68+114 DAP)	2.22	9.4	21.0 a	6.49	132	11.2	1468	1.48	2173	0.169	368
T3 (68+114+158 DAP)	2.03	10.2	19.7 a	7.07	135	11.0	1453	1.48	2150	0.163	352
Average over cultivars											
T0	1.47 a	15.7 b	22.4	6.61	124	10.9	1315	1.48	1946	0.159	309
T1 (68 DAP)	2.01 b	12.1 a	25.1	6.11	128	10.7	1350	1.48	1997	0.159	317
T2 (68+114 DAP)	2.19 b	9.6 a	20.9	6.57	134	10.8	1435	1.48	2123	0.162	344
T3 (68+114+158 DAP)	2.01 b	10.6 a	20.2	7.12	141	10.4	1445	1.48	2140	0.162	346
Statistical analysis [a]											
Cultivar (CV)	ns	*	**	*	ns	ns	ns		ns	ns	ns
Tipping (T)	***	**	ns	ns	ns	ns	ns		ns	ns	ns
CV × T	ns	ns	***	ns	ns	ns	ns		ns	ns	ns

DAP days after planting.

Different *letters* within a column indicate significant differences according to the $LSD_{0.05}$ test.

[a] Significance: *** = $P < 0.001$; ** = $0.001 \leq P < 0.01$; * = $0.01 \leq P < 0.05$; ns = not significant ($P \geq 0.05$).

Table 6. Yield characteristics of the *P. edulis* cultivars Lofuwa and Chankua as affected by zero (T0), one (T1), two (T3) and three (T3) tippings in Wondogenet. Stem and stolon data from the 3rd harvest (159 DAP), tuber data from the 4th harvest (208 DAP).

Cultivar	Number of main stems per hole (# / hole) ×	Number of stolons per main stem (# / main stem) =	Number of stolons per hole (# / hole) ×	Number of tubers per stolon (# / stolon) =	Number of tubers per hole (# / hole) ×	Average weight per tuber (g / tuber) =	Tuber fresh weight per hole (g / hole) ×	Number of holes per m^2 (# / m²) =	Tuber fresh yield per m^2 (g / m^2) ×	Tuber dry matter concentration (g / g) =	Tuber dry weight per m^2 (g / m^2)
Cultivar Lofuwa											
T0	1.61	22.8	35.9	3.44	122	10.5	1258	1.48	1864	0.144	268
T1 (68 DAP)	1.86	23.2	39.9	3.64	109	13.9	1465	1.48	2170	0.137	298
T2 (68+114 DAP)	1.83	19.2	34.4	3.80	132	10.7	1374	1.48	2036	0.146	298
T3 (68+114+158 DAP)	1.67	18.5	30.0	5.23	144	10.7	1329	1.48	1969	0.165	330
Cultivar Chankua											
T0	1.61	18.4	28.6	4.53	117	10.2	1195	1.48	1771	0.164	291
T1 (68 DAP)	1.64	18.2	28.6	5.36	145	10.2	1462	1.48	2167	0.169	368
T2 (68+114 DAP)	1.61	22.3	35.0	4.18	141	11.2	1561	1.48	2313	0.170	393
T3 (68+114+158 DAP)	1.61	18.3	29.0	5.71	145	10.2	1455	1.48	2155	0.170	366
Average over cultivars											
T0	1.61	20.6	32.2	3.99	120	10.4	1227 a	1.48	1818 a	0.154	280 a
T1 (68 DAP)	1.75	20.7	34.2	4.50	127	12.0	1463 b	1.48	2168 b	0.153	333 b
T2 (68+114 DAP)	1.72	20.7	34.7	3.99	136	10.9	1468 b	1.48	2174 b	0.158	345 b
T3 (68+114+158 DAP)	1.64	18.4	29.5	5.47	144	10.4	1392 b	1.48	2062 b	0.167	348 b
Statistical analysis [a]											
Cultivar (CV)	ns	ns	ns	ns	*	*	ns		ns	**	**
Tipping (T)	ns	ns	ns	ns	ns	ns	**		**	ns	**
CV × T	ns	ns	ns	ns	ns	ns	ns		ns	ns	ns

DAP days after planting.

Different *letters* within a column indicate significant differences according to the $LSD_{0.05}$ test.

[a] Significance: *** = $P < 0.001$; ** = $0.001 \leq P < 0.01$; * = $0.01 \leq P < 0.05$; ns = not significant ($P \geq 0.05$).

Yield components and dry matter production. In Awassa, tipping increased the number of main stems per hole, decreased the number of stolons per main stem, but had no effect on the number of stolons per hole in cv. Chankua and an inconsistent effect in cv. Lofuwa (Table 5). In Wondogenet, tipping increased the number of main stems per hole, but did not affect the number of stolons per main stem or per hole (Table 6). The number of tubers per stolon, the number of tubers per hole, the average weight per tuber and the tuber dry matter concentration were not affected significantly by tipping (Tables 5 and 6). The tuber fresh and dry weight per hole was not significantly increased by tipping in Awassa (Table 5), but was increased in Wondogenet (Table 6).

In Awassa, the number of stolons produced per main stem was significantly higher for cv. Lofuwa than for cv. Chankua, and so was the number of stolons per hole in the T0 and T1 treatments. Number of tubers produced per stolon, however, was significantly higher for cv. Chankua than for cv. Lofuwa. There were no differences between cultivars in any of the other production components in Awassa. At Wondogenet cv. Chankua produced more tubers per hole than Lofuwa, had a smaller average tuber size, and had a higher tuber dry matter concentration and a higher tuber dry matter yield (Table 6).

Discussion

Growth and development

Tipping enhanced the number of main stems (Tables 1 and 2), as it affected the inter-stem competition. In Awassa the number of main stems increased over time, and this increase was stronger in tipped plants than in non-tipped plants.

There were also more branches produced on tipped plants than on control plants (Tables 1 and 2), most likely due to the breaking of apical dominance, which stimulates branching in many crops (e.g., Dun et al., 2006). Due to increased branching there were also more leaves (Table 3). This enhanced branching and leaf production increased the canopy cover and delayed crop senescence (Fig. 1).

Tipping increased stolon numbers in the earlier phases of growth, whereas by the time of the 3rd harvest (when stolon numbers were maximum) no effects of tipping on stolon numbers were visible anymore (Table 4). The number of tubers obtained from these stolons also was not significantly affected. There was, however, a tendency towards an increased number of tubers in tipped treatments at both experimental sites (Table 4), which is consistent with the positive effect found by Menzel (1981) on number of tubers in Irish potato after decapitating potato plants growing at high temperatures. This effect was attributed by Menzel (1981) to lowering of the gibberellin concentrations in the stolon, where they inhibit tuberization. Obviously, tipping affected above-ground development more than it affected below-ground development. More main stems also tended to reduce the number of stolons per stem, thus counterbalancing the positive effect of tipping on the number of main stems, except at very early stages of stolon or tuber formation.

Intercepted radiation and yield

More leaves were produced on tipped plants than on non-tipped plants (Table 3) and, as a result, more light was intercepted by tipped plants (Fig. 1). The heavy foliage formed by the tipping treatments increased tuber dry matter yield at Wondogenet by an accumulation of small effects on tuber fresh yield and tuber dry matter concentration, but did not contribute to significantly more dry matter being allocated to the tubers at Awassa (Tables 5 and 6).

Practical implications

Tipping stimulated the production of stems and branches and thus contributed to leaf area development and radiation interception and may have reduced weed problems. Tipping also resulted in a higher tuber yield in Wondogenet, whereas the same trend was visible in Awassa without being significant. Harvesting slightly later in time might have increased the differences in tuber yield between the tipped treatments and the control, because ground cover of tipped plants was still higher than that of control plants at our final harvest. The results obtained in our experiments confirm the farmers’ perception that tipping will not only stimulate canopy development but also increase tuber yield. Limiting the tipping frequency to one might suffice as this would save time and labour.

CHAPTER 6

Effects of seed tuber piece size, number and planting arrangement on the tuber yield, yield components and tuber weight distribution of *Plectranthus edulis*

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Abstract

Plectranthus edulis is a locally important tuber crop on which agronomic information is scarce. Four field experiments were carried out, each at both locations Awassa and Wondogenet (Ethiopia), to examine the effects of the size of the seed tuber piece and the planting arrangement on the crop development, yield components, yield and tuber weight distribution of *Plectranthus edulis.* Exp. 1 dealt with the effects of breaking the same seed tuber size into different numbers of seed tuber pieces, Exp. 2 assessed the effects of differences in weight of the seed tuber pieces, planting only one seed tuber piece per hole, Exp. 3 investigated the effects of planting different numbers of seed tuber pieces per hole at the same size of seed tuber pieces, and Exp. 4 studied the effects of planting arrangement. In Awassa, cv. Lofuwa was planted whereas in Wondogenet cv. Chankua was used. In general, responses to experimental factors were similar for the two sites. Exp. 1 showed that breaking seed tubers resulted in more stems, more progeny tubers, smaller individual progeny tubers at both sites, and larger tuber yields in Wondogenet. Exp. 2 indicated that, when only one seed tuber piece was planted per hole, larger seed tuber piece sizes gave more stems, more stolons and more tubers per m^2, larger tubers and higher tuber yields. Exp. 3 showed that more seed tuber pieces per hole at constant seed tuber piece size gave more stems, more stolons (on which tubers are produced), and more tubers per m^2 thus increasing tuber fresh yield. Exp. 4 indicated that plant arrangement had little effect, but that planting individual tuber pieces in a line increased tuber yield in Wondogenet as compared to planting them together in one hole. Across all experiments, the tuber fresh weight increased when the number of main stems per m^2 increased up to 2.5–3 main stems per m^2. Yield levels of about 30 Mg ha^{-1} were attained. An increase in tuber fresh weight was either achieved by combined effects on number of tubers and individual tuber fresh weight or by an effect on number of tubers alone. The number of small progeny tubers per hole, per stem or per stolon was high in all experiments, suggesting that agronomic tools to increase individual progeny tuber weight deserve attention in further research.

Keywords: *Coleus edulis*, number of stems, number of tubers, plant density, *Plectranthus edulis*, seed piece, seed size, seed tuber, seed weight, spacing, tuber crop

Introduction

Plectranthus edulis (Vatke) Agnew (Family: Lamiaceae or Labiatae), syn. *Coleus edulis* Vatke, is one of the economical important tuber-bearing species of the genus *Plectranthus*, together with *P. parviflorus* (Sudan Potato; e.g., Tindall, 1983), *P. rotundifolius* (Madagaskar Potato; e.g., Jansen, 1996) and *P. esculentus* (Livingstone Potato; Tindall, 1983; Allemann et al., 2003; Allemann and Hammes, 2006). *P. edulis* is cultivated mainly for its tubers. It is grown in the mid and high altitude areas (> 1000 masl) in Ethiopia (Westphal, 1975), for example in Chencha and Wolaita (Mulugeta et al., 2007). Depending on the area where it is grown it is called Wolaita dono, Dinicha Oromo, Gamo dinich, Gurage dinich, Agaw dinich or Ethiopian potato.

In Ethiopia, *P. edulis* is mainly propagated through the use of seed tuber pieces, obtained by breaking whole tubers in 2–4 pieces (Mulugeta et al., 2007). Planting patterns may vary. Most farmers in Wolaita and Chencha planted 2–3 tuber pieces closely together in a small hole. Using cut or broken tuber pieces and planting them in clusters is also a common practice in growing *P. esculentus* in countries such as South Africa and Zimbabwe (Tindall, 1983; Dhliwayo, 2002) and in growing Irish potato (*Solanum tuberosum)* (Beukema and van der Zaag, 1979).

Seed piece size and the number of seed pieces planted per hole may affect the performance of a tuber crop through their effects on number of stems and the quantity of reserves available for early growth per individual stem. The two are often interrelated. For instance, in Irish potato, a smaller seed tuber size decreases the number of main stems per seed tuber and the growth vigour of the individual stems and consequently the number of tubers per plant and the tuber yield per hectare (Struik and Wiersema, 1999). Earlier studies by Wurr (1974) also showed that small sized seed tubers resulted in a small number of stems but more tubers per stem as compared to big sized seed tubers. Bremner and Taha (1966) reported lower yield per stem but higher tuber yield per plant from larger sized seed tubers than from small sized seed tubers.

There is no scientific information available for *P. edulis* on the effect of seed piece size, number and planting arrangement on tuber yield, yield components and tuber weight distribution. Therefore, the objective of this chapter is to analyse the effect of tuber piece size, number of seed tuber pieces, and planting arrangement on the yield components, yield and tuber weight distribution of *P. edulis.*

Materials and methods

Experimental sites

Four experiments were carried out each at both locations Awassa and Wondogenet, in southern Ethiopia. The Awassa field was located at 7°03' N and 38°30' E and the Wondogenet field at 7°06' N 38°37' E. Awassa lies at an altitude of 1650 masl and Wondogenet at 1750 masl. Wondogenet is relatively cooler and more humid than Awassa. The average temperature during the experimental period was 20.2 °C and 18.4 °C at the respective sites. The average daily temperature ranged between 15.3−23.7 °C and 14.9−21.6 °C in Awassa and Wondogenet, respectively, while the rainfall was 819 mm in Awassa and 989 mm in Wondogenet. The soil in both experimental sites was a sandy loam.

General experimental design

In all experiments a split-plot design was used. The seed tuber treatments (see below) were the main factor and harvest time was the split factor. There were five blocks in experiment 1 in Awassa and six blocks in all other experiments.

Each experimental unit had a gross size of 3.60 m × 3.75 m with rows at 90 cm and a distance of 75 cm between holes within a row. The basic seed tubers had a length of 12−15 cm and an average fresh weight of 65−70 g. Tubers were de-sprouted and broken (when required) a few hours before planting. Seed tuber pieces were planted and covered with a layer of c. 5 cm soil. Cv. Lofuwa was grown in Awassa and cv. Chankua in Wondogenet.

Treatments in the different experiments

In *Experiment 1,* the effects of breaking one whole mother tuber into different numbers of seed tuber pieces were investigated. Treatments were: (a) one whole tuber per hole (b) one whole tuber broken into two pieces planted in the same hole; (c) one whole tuber broken into three pieces planted in the same hole; (d) one whole tuber broken into four pieces planted in the same hole.

In *Experiment 2*, the effects of the size of the seed tuber piece when only one seed tuber piece was planted per hole were investigated. Treatments were: (a) one whole seed tuber planted per hole; (b) one tuber piece per hole of a seed tuber broken into two pieces (1/2 tuber); (c) one tuber piece per hole of a seed tuber broken into three pieces (1/3 tuber); (d) one tuber piece per hole of a seed tuber broken into four pieces (1/4 tuber).

In *Experiment 3*, the effects of different numbers of seed tuber pieces of the same size planted per hole were investigated. Seed tubers were broken into equal size (about 4 cm length each) and were randomly picked for planting for each treatment. Treatments were: (a) one seed tuber piece per hole; (b) two seed tuber pieces per hole; (c) three seed tuber pieces per hole; (d) four seed tuber pieces per hole.

Experiment 4 was on the effects of planting arrangement. Treatments included: (a) placing three seed tuber pieces (size as in Exp. 3) together in a single hole, and (b) placing three tuber pieces in a row with a spacing of about 25 cm between the seed tuber pieces. In both treatments the same number of pieces was planted per unit area.

Crop management

The experimental fields were ploughed and disked until a depth of 20 cm. A narrow furrow of about 25 cm was made by hand to place the seed tuber pieces as practiced by the farmers. Planting took place on April 21, 2004 in Awassa and on April 22 (Exp. 1) and 23 (Exps 2–4), 2004 in Wondogenet in a plant arrangement of 90 × 75 cm. Plants were tipped 73–75 days after planting (DAP). Tipping is the removal of the apex of the main stems and larger primary branches including one or two leaf pairs. At least one leaf pair per branch remained after tipping. Cultivation was done twice to remove weeds and earthing up, i.e. piling of soil around the below part of the stem to support the branches and cover the stolons, was done thrice. Manure or chemical fertilizer was not applied.

Harvesting was carried out twice. The first harvest was carried out on September 1, 2004 (133 DAP) in Awassa and on September 2, 2004 (132 and 133 DAP) in Wondogenet; the second harvest was carried out on December 20, 2004 (243 DAP) in Awassa and December 21, 2004 (242 and 243 DAP) in Wondogenet.

Observations and calculations

Number of main stems, primary, secondary and tertiary branches, stolons and progeny tubers were recorded as well as progeny tuber weight. Records on main stems and tubers were taken from six holes per plot, while records on numbers of branches and stolons were from three holes. Tubers were also graded into classes 0–30 and > 30 g and numbers and yields in these classes were also recorded. We report on numbers of main stems, branches and stolons from the 1st harvest and on tuber numbers and weights from the second harvest. Because of plant senescence, numbers of stems and stolons could not be assessed reliably at the final harvest.

Data were transformed before subjecting them to ANOVA using the statistical package GenStat 9.2. Transformations used were square root transformations for numbers and average weights per tuber and ^{10}log transformations for fresh tuber yield. Data presented in tables are the untransformed data; statistical information was based on transformed data.

Table 1. Effects of different seed tuber piece sizes and planting patterns on the number of primary, secondary and tertiary branches per hole in four experiments in Awassa (cv. Lofuwa) and Wondogenet (cv. Chankua).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m²	Awassa Primary branches	Awassa Secondary branches	Awassa Tertiary branches	Wondogenet Primary branches	Wondogenet Secondary branches	Wondogenet Tertiary branches
Experiment 1								
1	1/1	1.48	32.7	51.9 a	4.1	36.2 a	85.1 b	0.0
2	1/2	1.48	36.2	91.6 b	13.0	48.9 b	65.2 a	0.0
3	1/3	1.48	36.1	62.7 a	6.2	54.3 b	65.2 a	0.8
4	1/4	1.48	36.9	61.4 a	7.1	55.3 b	72.2 a	0.0
Significance			ns	*	ns	*	**	ns
Experiment 2								
1	1/1	1.48	34.7 c	129.0	26.2	36.6	64.8	0.0
1	1/2	1.48	31.8 bc	141.1	25.8	26.7	94.6	4.0
1	1/3	1.48	26.8 b	106.7	21.0	24.0	94.1	0.0
1	1/4	1.48	17.3 a	124.2	10.5	31.8	82.7	2.2
Significance			***	ns	ns	ns	ns	ns
Experiment 3								
1	1/3	1.48	18.4 a	80.6	32.7	17.4 a	85.6	2.0
2	1/3	1.48	22.8 a	91.8	31.8	32.3 b	74.3	0.0
3	1/3	1.48	33.6 b	142.1	41.1	31.0 b	77.8	5.2
4	1/3	1.48	38.7 b	95.0	34.7	39.8 c	91.2	13.8
Significance			***	ns	ns	***	ns	ns
Experiment 4								
1	1/3	3 × 1.48	32.1	78.7	15.0	34.4	80.3	19.9 b
3	1/3	1.48	29.3	76.7	19.9	31.6	91.3	10.6 a
Significance			ns	ns	ns	ns	ns	***

[a] Size is expressed as the proportion of one whole mother tuber, in which 1/1 = one unbroken mother tuber, 1/2 = a halve mother tuber, etcetera.

Significances were established after square root transformation of the data; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after square root transformation of the data.

Results

Experiment 1: Effect of breaking one whole mother tuber into different numbers of seed tuber pieces

Branch development. Breaking the mother tuber into pieces did not affect the number of primary branches in the Awassa experiment, but increased the number in the Wondogenet experiment (Table 1). The number of secondary branches per hole differed significantly amongst treatments with the largest numbers being found for mother tubers broken into two seed pieces in the Awassa experiment and the unbroken seed tubers in the Wondogenet experiment (Table 1).

Yield components. Breaking one mother tuber into an increasing number of seed tuber pieces and planting them in a single hole significantly increased the number of main stems per hole and per m^2 in both the Awassa and Wondogenet experiments; significantly decreased the number of stolons per main stem in the Awassa experiment but not in the Wondogenet experiment; and significantly increased the number of tubers per stolon in the Wondogenet experiment but not in the Awassa experiment. As a result, breaking the mother tuber significantly increased the number of tubers per m^2 in both Awassa and Wondogenet (Table 2). Effects were generally stronger the more seed pieces were produced from one seed tuber. Individual fresh weight of the tubers harvested was significantly reduced by breaking. The combined effect of these effects on yield components was that the fresh tuber yield per m^2 was not affected in Awassa, but significantly increased in Wondogenet by breaking one mother tuber into 2−4 seed tuber pieces (Table 2).

Effects on tuber weight distribution. The number of progeny tubers of the weight class 0−30 g per hole was significantly increased when mother tubers were broken into more pieces while the number of the tuber weight class > 30 g per hole was significantly decreased in both Awassa and Wondogenet (Tables 3a and b). The total number of tubers per hole significantly increased when the mother tuber was broken into more pieces in both the Awassa and the Wondogenet experiment (Tables 3a and b).

Also fresh tuber yield per hole of the weight class 0−30 g significantly increased in Awassa and Wondogenet after breaking the mother tuber into pieces, whereas the yield per hole of the weight > 30 g significantly decreased (Tables 3a and 3b). The total tuber weight per hole significantly increased by breaking the mother tuber into tuber pieces in the Wondogenet experiment but not in the Awassa experiment (Tables 3a and b).

Table 2. Yield component analysis for the effects of planting one mother tuber broken into different numbers of tuber pieces per hole (Exp. 1) in Awassa (cv. Lofuwa) and Wondogenet (cv. Chankua). Numbers of tubers were derived from the 2nd harvest (243 DAP), numbers of main stems and of stolons from the 1st one (133 DAP).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Number of main stems per hole	Number of main stems per m^2	Number of stolons per main stem	Number of stolons per m^2	Number of tubers per stolon	Number of tubers per m^2	Weight per tuber (g)	Fresh tuber yield (g/m^2)
Awassa										
1	1/1	1.48	1.70 a	2.52 a	30.4 b	75.5	1.44	102.6 a	26.7 b	2679
2	1/2	1.48	2.27 b	3.36 b	15.2 a	52.2	3.24	144.0 b	19.9 a	2815
3	1/3	1.48	2.50 bc	3.70 bc	17.3 a	63.8	2.61	159.5 b	17.8 a	2824
4	1/4	1.48	2.67 c	3.95 c	12.0 a	46.9	3.48	148.1 b	18.6 a	2661
Significance			***	***	**	ns	ns	*	**	ns
Wondogenet										
1	1/1	1.48	1.81 a	2.67 a	21.1	56.7	1.23 a	63.3 a	28.9 b	1827 a
2	1/2	1.48	2.06 ab	3.05 ab	23.4	68.5	1.62 a	109.3 b	28.6 b	2960 b
3	1/3	1.48	2.25 bc	3.33 bc	21.8	71.4	2.12 b	155.3 c	19.2 a	2826 b
4	1/4	1.48	2.61 c	3.87 c	18.4	69.5	2.52 b	171.4 c	16.5 a	2690 b
Significance			**	**	ns	ns	***	***	***	***

[a] Size is expressed as the proportion of one whole mother tuber, in which 1/1 = one unbroken mother tuber, 1/2 = a halve mother tuber, etcetera.

Significances were established after square root transformation of the data on numbers and weight per tuber and after ^{10}log transformation of the fresh tuber yield data; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

Table 3(a). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, > 30 g, total) after planting one mother tuber broken into different numbers of tuber pieces per hole in Awassa (Exp. 1, cv. Lofuwa). Numbers of tubers were derived from the 2nd harvest (243 DAP), numbers of main stems and of stolons from the 1st one (133 DAP).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Data per hole			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/1	1.48	56.1 a	13.1 c	69.2 a	33.1	7.77 d	40.9	1.17 a	0.27 ab	1.44
2	1/2	1.48	85.6 b	11.6 c	97.2 b	38.1	5.17 c	43.2	2.86 b	0.38 b	3.24
3	1/3	1.48	100.0 b	7.6 b	107.6 b	40.2	3.04 b	43.2	2.43 ab	0.18 a	2.61
4	1/4	1.48	95.1 b	4.9 a	100.0 b	36.8	1.87 a	38.7	3.32 b	0.17 a	3.48
Significance			**	***	*	ns	***	ns	*	*	ns
Tuber fresh weight (g)											
1	1/1	1.48	1195 a	614 c	1808	716	363 d	1080 c	24.5	12.8 ab	37.3
2	1/2	1.48	1376 ab	524 c	1900	614	234 c	848 b	47.8	17.1 b	65.0
3	1/3	1.48	1562 b	344 b	1906	626	138 b	764 ab	38.4	8.2 a	46.6
4	1/4	1.48	1577 b	219 a	1796	604	84 a	688 a	54.4	7.7 a	62.1
Significance			**	***	ns	ns	***	**	ns	*	ns

[a] Size is expressed as the proportion of one whole mother tuber, in which 1/1 = one unbroken mother tuber, 1/2 = a halve mother tuber, etcetera.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

Table 3(b). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, > 30 g, total) after planting one mother tuber broken into different numbers of tuber pieces per hole in Wondogenet (Exp. 1, cv. Chankua). Numbers of tubers were derived from the 2nd harvest (243 DAP), numbers of main stems and of stolons from the 1st one (133 DAP).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Data per hole			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/1	1.48	31.5 a	11.2 c	42.7 a	17.9 a	6.33 d	24.2 a	0.90 a	0.32 c	1.23 a
2	1/2	1.48	64.2 b	9.6 bc	73.8 b	33.5 b	4.82 c	38.3 b	1.40 b	0.22 b	1.62 a
3	1/3	1.48	96.6 c	8.1 b	104.8 c	46.6 c	3.67 b	50.5 c	1.96 c	0.17 ab	2.12 b
4	1/4	1.48	110.5 c	5.1 a	115.7 c	42.9 bc	2.01 a	44.9 bc	2.41 d	0.11 a	2.52 b
Significance			***	***	***	***	***	**	***	***	***
Tuber fresh weight (g)											
1	1/1	1.48	611 a	622 c	1233 a	343 a	350 c	693	17.3 a	17.28 c	34.6
2	1/2	1.48	1488 b	510 bc	1998 b	779 b	263 bc	1041	33.3 b	11.36 bc	44.6
3	1/3	1.48	1505 b	402 b	1908 b	679 b	182 b	861	31.5 b	8.43 b	39.9
4	1/4	1.48	1533 b	282 a	1816 b	599 b	110 a	709	33.5 b	6.11 a	39.6
Significance			***	***	***	***	***	ns	**	***	ns

[a] Size is expressed as the proportion of one whole mother tuber, in which 1/1 = one unbroken mother tuber, 1/2 = a halve mother tuber, etcetera.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

The number of tubers per stem of the weights 0−30 g was not significantly different in Awassa but significantly increased in Wondogenet with an increase in the number of seed tuber pieces in which the mother tuber was broken. The weight > 30 g, however, significantly decreased as the number of pieces increased in both experiments (Tables 3a and b). The resulting total number of tubers per stem was not significantly affected in Awassa, but was higher in Wondogenet when mother tubers were broken.

As for numbers, also the weight of tubers per stem in the weight class 0−30 g was not significantly affected in Awassa by breaking a mother tuber into more pieces, but increased in Wondogenet (Tables 3a and b). The weight of tubers > 30 g per stem decreased in both experiments. The resulting total tuber weight per stem decreased as the number of tuber pieces increased in Awassa, but was not affected in Wondogenet (Table 3b).

The number of tubers of the weight class 0−30 g per stolon increased as the number of tuber pieces in a hole increased (Tables 3a and b). The number of tubers of the weight class > 30 g per stolon, however, significantly decreased as the number of pieces increased in a hole in Wondogenet (Table 3b). In Awassa, trends were less clear and not significant (Tables 3a and 3b). The total number of tubers per stolon increased significantly when mother tubers were broken into more pieces in Wondogenet, but the trend was not significant in Awassa (Table 3a and 3b).

Tuber fresh weight of the weight class 0−30 g per stolon significantly increased when a mother tuber was broken into tuber pieces in Wondogenet, but not significantly in Awassa (Tables 3a and b). The fresh tuber weight of the weight class > 30 g per stolon decreased in Wondogenet when a mother tuber was broken into more than two pieces, but not significantly in Awassa (Tables 3a and b). The total tuber weight per stolon was not significantly affected by breaking the mother tuber (Table 3b).

Experiment 2: Effect of the weight of the seed tuber piece when only one was planted per hole

Branch development. Significantly more primary branches were produced from bigger tuber pieces in Awassa (Table 1) while the other branches did not show significant differences in both places.

Yield components. The number of main stems per hole and per m^2, the number of stolons per m^2, the number of tubers per m^2 and the average individual tuber weight significantly decreased with a decrease in the individual seed piece weight in both the Awassa and the Wondogenet experiment (Table 4). Although not significantly so, the

Table 4. Yield component analysis for the effects of planting one mother tuber piece of different sizes per hole (Exp. 2) in Awassa (cv. Lofuwa) and Wondogenet (cv. Chankua). Numbers of tubers were derived from the 2nd harvest (243 DAP in Awassa, 242 DAP in Wondogenet), numbers of main stems and of stolons from the 1st one (133 DAP in Awassa, 132 DAP in Wondogenet).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Number of main stems per hole	Number of main stems per m^2	Number of stolons per main stem	Number of stolons per m^2	Number of tubers per stolon	Number of tubers per m^2	Weight per tuber (g)	Fresh tuber yield (g/m^2)
Awassa										
1	1/1	1.48	1.50 b	2.22 b	34.1	69.3 b	2.79	174.6 c	22.7 c	3925 d
1	1/2	1.48	1.14 ab	1.69 ab	33.1	55.2 ab	1.81	89.5 b	24.5 c	2146 c
1	1/3	1.48	1.11 a	1.65 a	25.3	39.0 a	2.23	74.2 b	17.3 b	1261 b
1	1/4	1.48	0.97 a	1.44 a	23.0	33.6 a	1.67	47.3 a	8.9 a	422 a
Significance			*	*	ns	*	ns	***	***	***
Wondogenet										
1	1/1	1.48	2.06 c	3.05 c	18.1 a	51.7 d	2.40	120.2 d	26.4 b	3105 b
1	1/2	1.48	1.11 b	1.65 b	26.3 b	42.9 c	1.84	76.1 c	30.4 b	2275 b
1	1/3	1.48	1.06 b	1.56 b	17.1 a	26.4 b	1.69	41.6 b	15.6 a	663 a
1	1/4	1.48	0.81 a	1.19 a	14.3 a	15.8 a	1.68	24.7 a	15.8 a	365 a
Significance			***	***	*	***	ns	***	***	***

[a] Size is expressed as the proportion of one whole mother tuber, in which 1/1 = one unbroken mother tuber, 1/2 = a halve mother tuber, etcetera.

Significances were established after square root transformation of the data on numbers and weight per tuber and after ^{10}log transformation of the fresh tuber yield data; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

Table 5(a). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, > 30 g, total) after planting one different sized tuber piece per hole in Awassa (Exp. 2, cv. Lofuwa). Numbers of tubers were derived from the 2nd harvest (243 DAP), numbers of main stems and of stolons from the 1st one (133 DAP).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Data per hole			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/1	1.48	89.9 c	27.92 c	117.8 c	65.6 c	20.6 c	86.1 c	2.13	0.66 b	2.79
1	1/2	1.48	55.1 b	5.31 b	60.4 b	49.4 bc	4.7 b	54.1 b	1.65	0.16 a	1.81
1	1/3	1.48	47.8 b	2.28 a	50.1 b	43.3 ab	2.0 ab	45.3 ab	2.12	0.11 a	2.23
1	1/4	1.48	30.7 a	1.28 a	31.9 a	31.8 a	1.4 a	33.2 a	1.59	0.07 a	1.67
Significance			***	***	***	**	***	***	ns	***	ns
Tuber fresh weight (g)											
1	1/1	1.48	1559 d	1091 c	2649 d	1146 c	816 c	1963 c	35.6 b	26.1 b	61.7 b
1	1/2	1.48	1183 c	266 b	1449 c	1064 c	236 b	1301 c	36.6 b	8.3 a	45.0 b
1	1/3	1.48	737 b	114 a	851 b	685 b	103 a	738 b	34.2 b	5.5 a	39.7 b
1	1/4	1.48	217 a	68 a	285 a	225 a	73 a	298 a	10.3 a	3.9 a	14.2 a
Significance			***	***	***	***	***	***	***	**	**

[a] Size is expressed as the proportion of one whole mother tuber, in which 1/1 = one unbroken mother tuber, 1/2 = a halve mother tuber, etcetera.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

Table 5(b). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, > 30 g, total) after planting one different sized tuber piece per hole in Wondogenet (Exp. 2, cv. Chankua). Numbers of tubers were derived from the 2nd harvest (242 DAP), numbers of main stems and of stolons from the 1st one (132 DAP).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Data per hole			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/1	1.48	70.4 d	10.75 d	81.1 d	35.8 b	5.42 c	41.2 b	2.08	0.316	2.40
1	1/2	1.48	44.0 c	7.42 c	51.4 c	40.2 b	6.80 c	47.0 b	1.58	0.269	1.84
1	1/3	1.48	24.6 b	3.50 b	28.1 b	23.3 a	3.34 b	26.7 a	1.47	0.220	1.69
1	1/4	1.48	14.9 a	1.56 a	16.7 a	19.9 a	1.94 a	22.1 a	1.47	0.193	1.68
Significance			***	***	***	**	***	**	ns	ns	ns
Tuber fresh weight (g)											
1	1/1	1.48	1539 c	561 c	2100 c	791 b	286 c	1077 b	44.9 b	16.3	61.2 b
1	1/2	1.48	1185 c	355 c	1540 c	1085 b	324 c	1409 b	43.6 b	12.8	56.5 b
1	1/3	1.48	289 b	163 b	452 b	276 a	156 b	431 a	17.3 a	9.7	27.1 a
1	1/4	1.48	164 a	72 a	251 a	210 a	87 a	315 a	16.2 a	8.9	26.1 a
Significance			***	***	***	***	***	***	***	ns	***

[a] Size is expressed as the proportion of one whole mother tuber, in which 1/1 = one unbroken mother tuber, 1/2 = a halve mother tuber, etcetera.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the LSD$_{0.05}$ after transformation of the data.

number of tubers per stolon in both the Awassa and the Wondogenet experiment also decreased as the size of the seed tuber piece decreased. The resulting effect on fresh tuber yield was that the yield declined with a decrease in individual seed piece size over the entire range of sizes and in both the Awassa and Wondogenet experiment (Table 4).

Effects on tuber weight distribution. The tuber number of the weight classes 0–30 g and > 30 g per hole, and their total significantly decreased as the seed tuber piece size decreased in both the Awassa and the Wondogenet experiment (Tables 5a and b). Similarly, the tuber weight of both weight groups per hole, and their total, significantly decreased as the seed tuber piece size decreased in both experiments (Tables 5a and b).

The number of tubers of the weight classes 0–30 g, and > 30 g per stem, and their total, significantly decreased as the sizes of the seed pieces decreased in both Awassa and Wondogenet (Tables 5a and b). Similarly, the fresh tuber weight of both categories and their totals per stem considerably decreased as the seed tuber piece size per hole decreased in both the Awassa and Wondogenet experiment, with effects in Wondogenet showing only in the smaller ranges of mother tuber piece sizes (Tables 5a and b).

The number of tubers of the weight classes 0–30 g and > 30 g per stolon, and their total, seemed to decrease as the tuber piece size decreased in both the Awassa and Wondogenet experiment, but the reduction was significant only in the weight class > 30 g in Awassa (Tables 5a and b). Similarly, the tuber weights per stolon in all weight classes decreased significantly when the size of the mother tuber pieces decreased (Tables 5a and b), except in Wondogenet where the decrease in tuber weight per stolon for tubers > 30 g was not significant.

Experiment 3: Effect of the number of seed tuber pieces of the same size planted per hole

Branch development. The number of primary branches per hole in both experiments was significantly higher when more mother tuber pieces were planted together in one hole (Table 1). The numbers of secondary and tertiary branches were not significantly affected.

Yield components. The number of main stems per hole and per m^2 was increased by planting more tuber pieces per hole in Wondogenet, whereas the increase was not significant ($P = 0.067$) in Awassa (Table 6). The number of stolons per main stem was not significantly affected by the number of seed tuber pieces planted. The

Table 6. Yield component analysis for the effects of planting different numbers of similar sized mother tuber pieces per hole (Exp. 3) in Awassa (cv. Lofuwa) and Wondogenet (cv. Chankua). Numbers of tubers were derived from the 2nd harvest (243 DAP in Awassa, 242 DAP in Wondogenet), numbers of main stems and of stolons from the 1st one (133 DAP in Awassa, 132 DAP in Wondogenet).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Number of main stems per hole	Number of main stems per m^2	Number of stolons per main stem	Number of stolons per m^2	Number of tubers per stolon	Number of tubers per m^2	Weight per tuber (g)	Fresh tuber yield (g/m^2)
Awassa										
1	1/3	1.48	1.33	1.98	20.3	36.0 a	1.73 a	54.6 a	16.1	830 a
2	1/3	1.48	1.33	1.98	27.9	48.9 ab	2.37 ab	106.3 b	20.2	2082 b
3	1/3	1.48	1.61	2.39	29.7	65.4 b	2.97 b	189.4 c	16.0	3093 c
4	1/3	1.48	2.11	3.13	23.3	59.8 b	3.32 b	187.5 c	19.5	3599 c
Significance			ns	ns	ns	**	*	***	ns	***
Wondogenet										
1	1/3	1.48	1.11 a	1.65 a	20.6	32.3 a	2.69 ab	64.2 a	13.7 a	846 a
2	1/3	1.48	1.75 b	2.59 b	24.8	64.0 b	1.76 a	85.9 a	29.1 b	2364 b
3	1/3	1.48	1.78 b	2.63 b	21.8	54.7 b	3.69 b	197.9 b	15.7 a	3112 c
4	1/3	1.48	2.17 b	3.21 b	20.4	65.3 b	3.70 b	213.7 b	17.3 a	3589 c
Significance			**	**	ns	*	*	***	***	***

[a] The weight of each tuber piece was 15–18 g. To create similar-sized tuber pieces, one mother tuber was broken into three pieces. Each piece was therefore 1/3 of a mother tuber. The larger mother tubers (c. 30% of all tubers), however, were broken into four pieces.

Significances were established after square root transformation of the data on numbers and weight per tuber and after ^{10}log transformation of the fresh tuber yield data; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

Table 7(a). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, > 30 g, total) after planting different numbers of similar sized seed tuber pieces per one hole in Awassa (Exp. 3, cv. Lofuwa). Numbers of tubers were derived from the 2nd harvest (243 DAP), numbers of main stems and of stolons from the 1st one (133 DAP).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Data per hole			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/3	1.48	35.0 a	1.9 a	36.9 a	31.2 a	1.69 a	32.9 a	1.64	0.092 a	1.73 a
2	1/3	1.48	67.6 b	4.1 a	71.8 b	57.7 b	3.42 a	61.1 b	2.23	0.132 a	2.37 ab
3	1/3	1.48	108.1 c	19.8 b	127.8 c	73.3 b	13.49 b	86.8 b	2.50	0.468 b	2.97 b
4	1/3	1.48	105.0 c	21.6 b	126.6 c	54.7 b	11.57 b	66.2 b	2.74	0.570 b	3.32 b
Significance			***	***	***	**	***	**	ns	***	*
Tuber fresh weight (g)											
1	1/3	1.48	459 a	101 a	560 a	394 a	95 a	489 a	20.4 a	4.9 a	25.3 a
2	1/3	1.48	1169 b	237 b	1405 b	958 b	197 b	1155 b	37.7 b	7.6 a	45.3 b
3	1/3	1.48	1277 bc	811 c	2088 c	931 b	620 c	1551 b	28.3 ab	18.1 b	46.1 b
4	1/3	1.48	1447 c	983 c	2429 c	792 b	541 c	1332 b	38.6 b	25.7 b	64.3 b
Significance			***	***	***	***	***	***	*	***	**

[a] The weight of each tuber piece was 15–18 g. To create similar-sized tuber pieces, one mother tuber was broken into three pieces. Each piece was therefore 1/3 of a mother tuber. The larger mother tubers (c. 30% of all tubers), however, were broken into four pieces.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

Table 7(b). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, > 30 g, total) after planting different numbers of similar sized seed tuber pieces per one hole in Wondogenet (Exp. 3, cv. Chankua). Numbers of tubers were derived from the 2nd harvest (242 DAP), numbers of main stems and of stolons from the 1st one (132 DAP).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Data per hole			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/3	1.48	42.2 a	1.14 a	43.3 a	39.7 a	1.02 a	40.8 a	2.62 ab	0.069 a	2.69 ab
2	1/3	1.48	50.8 a	7.17 b	58.0 a	29.3 a	4.03 b	33.4 a	1.52 a	0.237 b	1.76 a
3	1/3	1.48	116.9 b	16.64 c	135.6 b	67.9 b	9.60 c	77.5 b	3.23 b	0.461 c	3.69 b
4	1/3	1.48	128.0 b	16.28 c	144.3 b	60.4 b	7.70 c	68.1 b	3.37 b	0.426 c	3.70 b
Significance			***	***	***	***	***	***	*	***	*
Tuber fresh weight (g)											
1	1/3	1.48	522 a	49 a	571 a	478 a	44 a	522 a	33.7	3.1a	36.8
2	1/3	1.48	1274 b	322 b	1596 b	776 b	187 b	963 b	36.4	10.3 b	46.7
3	1/3	1.48	1469 b	632 c	2100 c	843 b	367 c	1210 b	41.0	17.4 b	58.4
4	1/3	1.48	1807 c	616 c	2422 c	861 b	286 c	1146 b	47.0	15.9 b	62.9
Significance			***	***	***	**	***	***	ns	**	ns

[a] The weight of each tuber piece was 15–18 g. To create similar-sized tuber pieces, one mother tuber was broken into three pieces. Each piece was therefore 1/3 of a mother tuber. The larger mother tubers (c. 30% of all tubers), however, were broken into four pieces.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

number of stolons per m^2 increased only when the number of seed tuber pieces planted per hole increased from 1 to 2–3, and then levelled off. The number of tubers per stolon usually showed higher values when more seed tuber pieces were planted per hole. The number of progeny tubers per m^2 significantly increased as the number of seed tuber pieces of similar size per hole increased up to 3, and the tuber fresh weight per m^2 seemed to increase over the whole range, in both the Awassa and Wondogenet experiment (Table 6).

Effects on tuber weight distribution. The number of tubers of the weight classes 0–30 g and > 30 g per hole, and their total, significantly increased as the number of seed tuber pieces of similar size increased up to 3, in both experiments and then levelled off (Tables 7a and b). The tuber fresh weight significantly increased in all weight groups including the total as the number of seed tuber pieces per hole increased in both places (Tables 7a and b).

The number of tubers per stem in the weight classes 0–30 and > 30 g, and their total, also increased as the number of seed tuber pieces increased up to 3 and thereafter seemed to decrease again although this decrease was never significant. The tuber weight per stem of these classes followed the same trend (Tables 7a and 7b).

Overall, the number and weight of tubers per stolon of the individual weight classes and their total seemed higher when more tuber pieces were planted per hole. However, trends were not always significant and increases were not always gradual (Tables 7a and 7b).

Experiment 4: Effects of planting arrangement

Branch development. There was no significant effect of planting arrangement on the number of primary, secondary or territory branches per hole, except in Wondogenet where more tertiary branches were recorded when tuber pieces were planted in a line than when they were planted together in one hole.

Yield components. Main stem numbers seemed higher when tuber pieces were planted in a line instead of together in one hole, but differences were just not significant, both in Awassa ($P = 0.083$) and Wondogenet ($P = 0.058$) (Table 8). Number of stolons per main stem and per m^2, number of tubers per stolon, and weight per tuber were not significantly different between the treatments (Table 8). The number of tubers per m^2 was significantly higher for line planting in Wondogenet, and just not significant ($P = 0.098$) in Awassa. The fresh tuber yield was significantly higher for line planting in Wondogenet, but not significantly in Awassa (Table 8).

Table 8. Yield component analysis for the effects of planting similar sized mother tuber pieces of *P. edulis* in different planting patterns[1] (Exp. 4) in Awassa (cv. Lofuwa) and Wondogenet (cv. Chankua). Numbers of tubers were derived from the 2nd harvest (243 DAP in Awassa, 242 DAP in Wondogenet), numbers of main stems and of stolons from the 1st one (133 DAP in Awassa, 132 DAP in Wondogenet).

Number of tuber pieces per hole	Size per tuber piece[a]	Number of holes per m^2	Number of main stems per hole or 3 holes[b]	Number of main stems per m^2	Number of stolons per main stem	Number of stolons per m^2	Number of tubers per stolon	Number of tubers per m^2	Weight per tuber (g)	Fresh tuber yield (g/m^2)
Awassa										
1	1/3	3 × 1.48	2.22	3.29	18.9	61.6	3.11	187.4	16.3	3016
3	1/3	1.48	1.69	2.51	24.9	61.4	2.62	157.5	18.5	2891
Significance			ns	ns	ns	ns	ns	ns	ns	ns
Wondogenet										
1	1/3	3 × 1.48	2.06	3.05	27.3	78.8	2.83	204.0	15.9	3218
3	1/3	1.48	1.64	2.43	30.6	72.4	2.43	161.1	15.7	2465
Significance			ns	ns	ns	ns	ns	*	ns	*

[a] The weight of each tuber piece was 15–18 g. To create similar-sized tuber pieces, one mother tuber was broken into three pieces. Each piece was therefore 1/3 of a mother tuber. The larger mother tubers (c. 30% of all tubers), however, were broken into four pieces.

Significances were established after square root transformation of the data on numbers and weight per tuber and after ^{10}log transformation of the fresh tuber yield data; ns: not significant, *: $0.05 > P \geq 0.01$.

[b] One hole with three tuber pieces at 90 × 75 cm or three holes with one piece spaced at 25 × 75 cm.

Effects on tuber weight distribution. The number of progeny tubers per hole of both the 0−30 g and > 30 g weight classes, and their total, was not significantly different in Awassa (Table 9a). The tuber yield per hole in the weight class 0−30 and the total tuber yield per hole, however, were significantly higher for crops from seed pieces placed widely at Wondogenet (Table 9b).

The tuber fresh weight of the weight class 0−30 g and the total tuber fresh weight were also significantly higher when the seed tuber pieces were placed wider as compared to placing them in a hole in Wondogenet. In Awassa, these effects were not significant (Table 9a).

The number of tubers per stem was not significantly affected except for the number of tubers > 30 g in Awassa, that was lower at wider spacing (Tables 9a and b). The tuber weight per stem was not significantly affected in both places (Tables 9a and b).

There were also no significant effects on the numbers of tubers or the fresh weights of tubers per stolon in any weight class (Tables 9a and b).

Discussion

The tuber of *P. edulis* is a stem tuber and possesses (compound) ‘‘eyes’’ with buds that can sprout and produce stems comparable to the Irish potato (*Solanum tuberosum* L.). The performance of the plants in the experiments described in this chapter must be the result of differences between the seed tuber pieces planted per hole in amount of reserves and number of buds available for initial stem growth, the intra-plant competition between main stems from the same tuber piece, and the inter-plant competition between the plants produced from the different pieces planted in one hole.

Main stem formation from seed tuber pieces

Breaking a mother tuber of 12–15 cm into 2–4 pieces before planting increased the total number of tuber buds that grew successfully into main stems (Exp. 1, Table 2). This practice is also applied in other tuber crops like Irish potato and sweet potato (*Ipomoea batatas* (L.) Lam.) to increase the number of stems by circumventing the dominance of nearby stems (e.g., Vander Zaag and Demagante, 1989). Breaking a medium-sized *Plectranthus* tuber into more than two pieces (3 × 1/3 or 4 × 1/4 tuber) before planting, however, reduced the success rate of an individual seed tuber piece to produce a surviving main stem to < 1: the number of main stems per hole was lower than the number of pieces planted per hole (Table 2). Even planting two 1/3-sized pieces (2 × 1/3 tuber) in Exp. 3 already reduced the success rate to < 1 main stem per seed piece (cf. Table 6). It is likely that this was mainly caused by the weakness of the stems from smaller (1/3- and 1/4-sized) seed tuber pieces, that were more prone to not surviving the early inter-plant competition. It is less likely that the low main stem number for smaller pieces was caused merely by a lack of buds on the seed tuber piece that were still capable to produce a new stem, because planting the same size of tuber pieces in patterns without early competition, e.g. one 1/3 tuber piece per hole, resulted in > 1 main stem (Table 4). Also spacing 1/3-sized tuber pieces wider as compared to clustering them in one hole (Table 8, Experiment 4) increased the number of surviving main stems over experiments, although the difference could not be established as significant within the individual sites. However, it cannot be excluded that also lack of buds or seed piece decay might have limited stem production, because several tuber buds had already produced sprouts during storage and these sprouts were removed before planting. The observation that 1/4-sized tuber pieces not all produced a main stem when planted individually in one hole supports this idea (Table 4).

Over all experiments, the number of main stems ranged between 1.19 (Table 4) and 3.95 per m^2 (Table 2). More main stems per unit area were achieved by planting more pieces per hole, either by breaking the mother tuber or planting more similar-sized pieces (Exps 1 and 3, Tables 2 and 6), by planting larger-sized pieces (Exp. 2, Table 4) or by spacing individual pieces wider instead of clustering them in one hole (Exp. 4, Table 8), although this last effect was only significant over sites (data not shown), and not within sites.

Relations between numbers of main stems, number of stolons, number of tubers and tuber yield

Over all experiments, more main stems per unit area resulted in more stolons up to about 2 main stems per m^2 and thereafter levelled off (Fig. 1a). The effects of breaking (Exp. 1, Table 2) and of clustering (Exp. 4, Table 8) on number of stolons were therefore small: most of the treatments in those experiments already resulted in a sufficiently high number of stems. In all these treatments a relatively high quantity of mother tuber material was planted, equaling one tuber per hole or more. Numbers of stolons were reduced when smaller tuber pieces were planted at one per hole (Table 4), or when fewer 1/3-sized tuber pieces were planted per hole (Table 6). These treatments concomitantly resulted in fewer stolons and fewer stems.

More main stems resulted also in more tubers, but in this case the increase with number of stems seemed to level off at a higher number of stems than was the case for number of stolons: about three stems per m^2 (Fig. 1b). Relations between numbers of tubers and stems were visible in all experiments (Tables 2, 4, 6 and 8), but there was a

Table 9(a). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, >30 g, total) after planting similar sized mother tuber pieces in different planting patterns[a] in Awassa (Exp. 4, cv. Lofuwa). Numbers of tubers were derived from the 2nd harvest (243 DAP), numbers of main stems and of stolons from the 1st one (133 DAP).

Number of tuber pieces per hole	Size per tuber piece[b]	Number of holes per m^2	Data per hole or 3 holes[a]			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/3	3 × 1.48	121.3	5.22	126.5	28.1	1.199	29.2	2.99	0.125	3.11
3	1/3	1.48	100.4	5.94	106.3	30.0	1.795	31.8	2.47	0.143	2.62
Significance			ns	ns	ns	ns	*	ns	ns	ns	ns
Tuber fresh weight (g)											
1	1/3	3 ×1.48	1783	253	2036	414	57.5	472	44.3	5.98	50.3
3	1/3	1.48	1692	260	1951	502	77.8	580	41.7	6.31	48.0
Significance			ns	ns	ns	ns	ns	ns	ns	ns	ns

[a] One hole with three tuber pieces at 90 × 75 cm or three holes with one piece spaced at 25 × 75 cm.

[b] The weight of each tuber piece was 15–18 g. To create similar-sized tuber pieces, one mother tuber was broken into three pieces. Each piece was therefore 1/3 of a mother tuber. The larger mother tubers (c. 30% of all tubers), however, were broken into four pieces.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the $LSD_{0.05}$ after transformation of the data.

Table 9(b). Distribution of tuber number and weight per hole, per main stem and per stolon over different weight classes (0–30 g, >30 g, total) after planting similar sized mother tuber pieces in different planting patterns[a] in Wondogenet (Exp. 4, cv. Chankua). Numbers of tubers were derived from the 2nd harvest (242 DAP), numbers of main stems and of stolons from the 1st one (132 DAP).

Number of tuber pieces per hole	Size per tuber piece[b]	Number of holes per m^2	Data per hole or 3 holes[a]			Data per main stem			Data per stolon		
			0–30 g	> 30 g	Total	0–30 g	> 30 g	Total	0–30 g	> 30 g	Total
Tuber number											
1	1/3	3 x 1.48	129.2	8.50	137.7	63.9	4.36	68.3	2.66	0.170	2.83
3	1/3	1.48	100.4	8.31	108.7	61.5	5.18	66.7	2.24	0.187	2.43
Significance			**	ns	**	ns	ns	ns	ns	ns	ns
Tuber fresh weight (g)											
1	1/3	3 x 1.48	1809	363	2172	906	186	1092	37.1	7.40	44.5
3	1/3	1.48	1306	359	1664	816	224	1039	28.9	7.93	36.8
Significance			**	ns	*	ns	ns	ns	ns	ns	ns

[a] One hole with three tuber pieces at 90 × 75 cm or three holes with one piece spaced at 25 × 75 cm.

[b] The weight of each tuber piece was 15–18 g. To create similar-sized tuber pieces, one mother tuber was broken into three pieces. Each piece was therefore 1/3 of a mother tuber. The larger mother tubers (c. 30% of all tubers), however, were broken into four pieces.

Significances were established after square root transformation of tuber numbers and ^{10}log transformation of tuber weights; ns: not significant, $P \geq 0.05$; *: $0.05 > P \geq 0.01$; **: $0.01 > P \geq 0.001$; ***: $P < 0.001$.

Different letters refer to significant differences according to the LSD$_{0.05}$ after transformation of the data.

considerable influence of the experiment on the relationship.

It is unclear why the numbers of stolons and tubers were differentially related to number of stems. Numbers of stolons peaked at an earlier moment than numbers of tubers (unpublished data from other experiments). At the same time the number of stolons seemed to respond more to an increase in between-stem competition than the number of tubers.

Tuber fresh yield increased with an increase in the number of main stems up to about 2.5–3 stems per m² and then levelled off (Fig. 1c). Below that, the interception of radiation was likely limiting tuber production. Radiation interception was not measured in our experiments, but the significant effects on primary branch numbers in Exps 2 and 3 (Table 1) following the same trends as tuber yields in these experiments (Table 4 and 6) indicate the relevance of proper haulm development. In addition, the higher number of tuber sinks in treatments with high numbers of stems may have enhanced net assimilation rates and tuber yield.

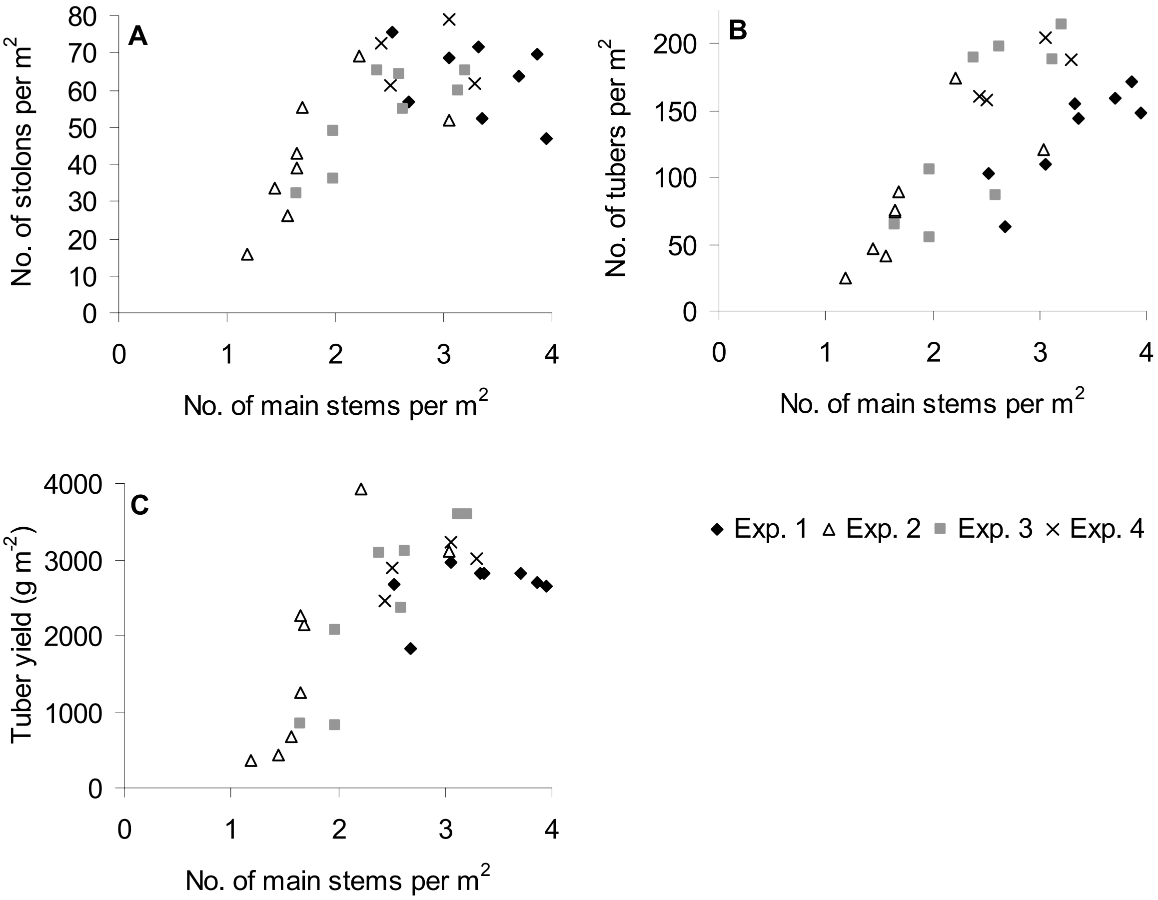

Fig. 1. Scatter plots showing the associations across experiments between number of main stems and number of stolons (A), number of tubers (B), and tuber fresh yield (C). Data from Tables 2, 4, 6 and 8.

Tuber-weight distribution and its manipulation is complex in many tuber crops, including Irish potato (cf. Struik et al., 1990, 1991). In Irish potato, the average weight of the tubers, the variability of tuber weight and the number of tubers together determine the yield and the tuber-weight distribution (Struik et al., 1991). In Irish potato, both the average tuber weight and its relative variability are closely related with number of tubers. There usually is a negative relationship between number of tubers and average tuber weight, at least when variation in number of tubers is associated with agronomic factors such as water supply and number of stems per unit area. In contrast, for *Plectranthus,* the relations between number of tubers, average tuber weight and fresh tuber yield were complex (Fig. 2). The negative relationship between number of tubers and average tuber weight often observed in Irish potato was not common in our data set (Fig. 2c). A negative association was only observed in the higher range of tuber numbers, whereas at low tuber numbers also the average weight per tuber was relatively low. The latter typically occurred in those treatments in which

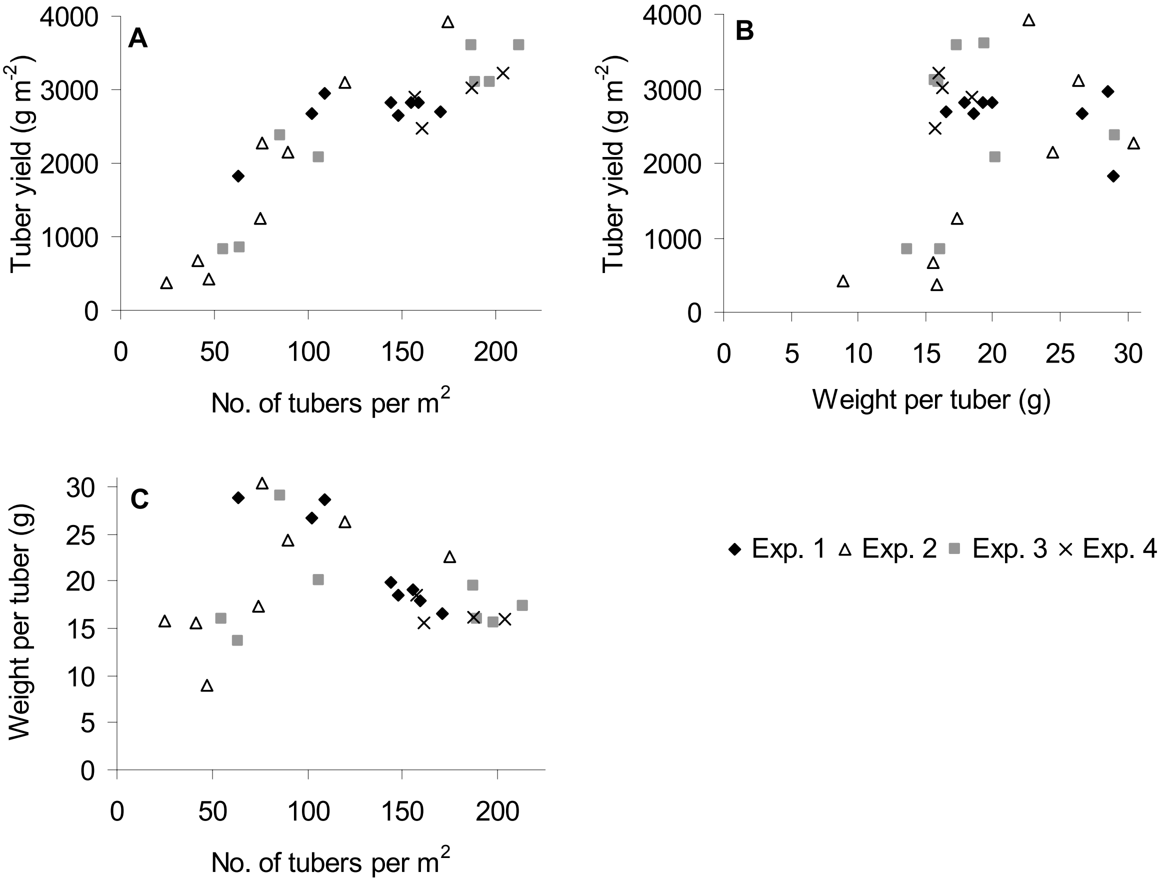

Fig. 2. Scatter plots showing the overall relationships across experiments between number of tubers, average weight per tuber and tuber yield. (A) number of tubers versus tuber yield, (B) average weight per tuber versus tuber yield, (C) number of tubers versus average weight per tuber. Data from Tables 2, 4, 6 and 8.

the total tuber piece weight planted per hole was small (1 × 1/4 or 1 × 1/3) (Fig. 2c, Tables 4 and 6). However, when significant effects on fresh tuber yield were observed then these effects were never realized by merely increasing the individual tuber weight (Figs 2a and b). An increase in tuber fresh weight was either achieved by combined effects on number of tubers and individual tuber fresh weight or by an effect on number of tubers alone. In several cases, the effects on numbers of tubers and individual tuber weight were cancelling each other out.

Comparison to farmers yields

The fresh tuber yield level obtained in this set of experiments was very promising and 2−4 times higher than the yields reported by farmers, who traditionally plant 2 or 3 pieces per hole of a size of 1/2 of tuber of 10 – 15 cm (2−3 × 1/2 tuber) and report yields of 500–1000 g per hole (Mulugeta et al., 2007). Our treatments that were closest to these traditional practices were: breaking a tuber in two pieces in Exp. 1 (2 × 1/2 tuber) and – to a lesser extent − planting 3 pieces of 1/3 tuber in one hole in Exps 1, 3 and 4 (3 × 1/3 tuber). These treatments resulted in respectively 2815, 2814, 3093 and 2891 g fresh weight m^{-2} in Awassa and 2960, 2826, 3112 and 2465 g fresh weight m^{-2} in Wondogenet, on average 2872 g m^{-2} or 1939 g per hole. These relatively high yields also show that refraining from manure application in this set of experiments had not reduced yield as compared to farmers' yields.

Implications

The optimum for farmers would be to strive towards a number of stems of more than 2.5 main stems per m^2 in order to maximize yield. This is usually achieved by planting sufficient seed tuber material (equaling at least 1 medium-sized mother tuber per hole) and breaking it into two or three pieces. This practice confers with the farmers practice (Mulugeta et al., 2007). An increase in yield might be achieved by spacing the pieces wider instead of clustering them in one hole (Table 8) as this increases the probability of getting sufficiently high stem numbers. More than c. 2.5 stems per m^2 may not lead to higher yield, but may increase the number of (small) tubers and reduce the average tuber weight (Table 2, Tables 3 a, b).

CHAPTER 7

General discussion

At the start of the research described in this thesis, little was known about the tuber crop *Plectranthus edulis*. Even basic knowledge was missing: there were no yield data and there was no description of cultural practices common in the crop. In this thesis it is described how and why the traditional cultural production practices are carried out (Chapter 2), and the development and growth of the crop with time are characterised (Chapters 3 and 4). Also the mechanisms behind the important agronomical practices are described for shoot tipping (Chapter 5) and different sizes, numbers and arrangements of seed tuber pieces (Chapter 6).

This general discussion will first focus on the present insight into the ontogeny of the crop as obtained by the experiments, and how this is related to the cultural practices and the perceptions and opinions of the farmers on how cultural practices affect yield (Section 7.1). The second part of the discussion will focus on why the crop is attractive, what are the main constraints endangering the crop despite its attractiveness, and what should be done to make the crop more successful (Section 7.2).

7.1 *Plectranthus edulis*: Crop ontogeny and cropping practices

7.1.1 Morphology and development

General morphology and development

A plant of *P. edulis* is composed of: the mother tuber piece, sprouts, main stems, branches, leaves, inflorescences, fruits, seeds, roots, stolons, and tubers. The stolons are very long and are initiated on buds of main stems and primary branches, first only on below-ground nodes, but later also on the lower aerial nodes. Tubers are produced upon swelling of the tip or middle part of stolons. Most of the tubers that are formed along the stolon are longer than tubers formed at the stolon tip. The tubers of *P. edulis* are stem tubers, like those of Irish potato.

The crop passes through the following ontogenetic phases:

1. emergence, resulting in an established crop;
2. canopy development, ending gradually through the initiation of terminal inflorescences;
3. a phase in which stolons are initiated and develop from below-ground and aerial

buds, and that ends in stolon senescence;
4. a phase of tuber initiation and growth;
5. a phase of canopy senescence and tuber maturation.

These five phases are partly overlapping each other and are not as well attuned to one another and to weather conditions as is the case in the much further domesticated and improved Irish potato.

The total growing period of *P. edulis* is long: in our experiments, maximum fresh tuber yields of 45–49 Mg ha^{-1} were achieved in 7.5−8 months after planting (238 days after planting, DAP) (Chapters 3 and 4). We therefore will pay more attention to the phases of canopy development and tuber initiation and growth. We also address the temporary dip in total dry matter production observed after 5.5−6 months after planting (Chapter 4).

Canopy development

The crop uses the first half of the growing period extremely inefficiently by a very slow emergence, establishment and canopy development. Emergence takes at least 1 month and after emergence it takes another 3−4 months to reach a leaf area index (LAI) of 3. Given the temperature during these phases the development is very slow. The long time needed to establish a full canopy cover, might be related to the practice adopted in the experiments of using small tuber pieces, de-sprouting them and planting them at a wide spacing. Slow canopy development can probably be prevented to some extent by using larger seed pieces, having seed pieces of an optimal physiological condition and planting them more densely than we did. Moreover, some cultural practices after emergence can stimulate canopy cover; these include manuring, tipping and tillage (see 7.1.2).

Canopy growth stops c. 5.5−6 months after planting (168−182 DAP) after which leaf and stem dry weights and LAI and ground cover decrease. The major reason for the decrease in LAI and ground cover must be the termination of the growth of individual stems by the induction of terminal inflorescences. The first inflorescences are visible 112−126 DAP in Awassa and 154 DAP in Wondogenet. Inflorescences are formed on most primary and secondary branches and on main stems that are not tipped. However, we have not monitored the flowering events of the different types of stems and branches precisely. It seems that tertiary branches are continued to be formed even during canopy decline, but their contribution to the total leaf area is rather small.

It is unknown what triggers flowering in *Plectranthus edulis*. Within the Lamiaceae family, several types of flowering induction responses exist. When flowering limits further canopy expansion and/or even maintenance of a green leaf area, it is important to achieve a full canopy early enough before flowering.

Tuber initiation and growth

In our experiments, first tubers were initiated slightly later than 4 months after planting (126 DAP), 6−8 weeks after the first stolons had been initiated below ground. By contrast, the complete crop cycle of for instance Irish Potato in Ethiopia only lasts about 4 months (120 days; cf. Admasu and Struik, 2001). In our experiments, initiation of new tubers continued until the end of tuber growth. It is unknown what triggers the initiation of the first tubers. Photoperiod is well known to influence storage organ formation in many crops. Short days are known to promote tuber initiation in Irish potato (Ewing and Struik, 1992). Allemann and Hammes (2006) identified a photoperiod between 12.5 and 13 h as the critical photoperiod at and below which tuberization was induced in a genotype of the Livingstone potato, *Plectranthus esculentus.* Daylength fluctuated only slightly between planting and tuber initiation at 126 DAP at the experimental sites where the growth studies were carried out: from 12.08 h at planting to 12.41 h at 21 June back to 12.27 h at 126 DAP in Awassa, and from 12.13 h to 12.41 h and back to 12.24 in Wondogenet. Besides inducing tubers, a short photoperiod in Irish potato may also enhance the allocation of dry matter to the tubers. Temperatures, however, may well modify the response to photoperiod (Ewing and Struik, 1992).

The initiation or further growth of tubers might also be related to flower induction and initiation (cf. Almekinders and Wiersema, 1991; Almekinders and Struik, 1996; Celis-Gamboa et al., 2003). In our field experiments, the first inflorescences were observed at tuberization or slightly before the first tubers appeared in Awassa, but 4 weeks later than the first tubers in Wondogenet (Chapter 3). When terminal inflorescences are formed, as is the case in *P. edulis*, this limits the possibility for further canopy growth, and the plant may have to redirect its allocation of assimilates. The weight of the inflorescences and seeds was not determined in our experiments, but it was negligible compared to other canopy components.

A temporary dip in dry matter production

A stagnation or decrease was observed in total dry matter production after c. 5.5−6 months after planting (168 DAP in Awassa and 182 DAP in Wondogenet) that lasted several weeks. This was associated with a faster decrease in canopy dry matter – especially stem dry matter – than the increase in tuber dry matter (Chapter 4). At this stage, tuber production may have been limited by a low capacity of absorbing photosynthates. This could be due to the still low number of small tubers and/or by a rate limiting step in the conversion of assimilates to the storage compounds in the tubers, e.g., starch synthetase assuming starch to be the major carbohydrate in *P. edulis* tubers. The exact composition of the carbohydrates stored in *P. edulis* tubers, however, is still unknown. The low number of tubers and their low sink activity at that early moment may well have been limiting. This is supported by the continued initiation of new tubers throughout the growing season and the initiation and growth of aerial stolons – accommodating extra tuber forming possibilities − during this period.

Another reason explaining part of the stagnation in total dry matter production might be increased root production. Roots were not included in the total dry matter as is common in this type of research (e.g., Squire, 1990), but were formed in considerable amounts (Fig. 2, Chapter 3) also at later stages of crop growth.

Later the tuber production outweighed the decrease in canopy dry weight again, and total dry weight and radiation use efficiency (RUE) increased again (Chapter 4).

7.1.2 Cropping practices

In this section we discuss the effects of the various cultural practices carried out by farmers on tuber formation and tuber yield directly.

Size of tuber pieces for planting

Farmers normally break medium sized (10−15 cm) and small sized (5−10 cm) mother tubers in two pieces and larger mother tubers (> 15 cm) in three, and usually plant three tuber pieces per hole (Chapter 2). Breaking is done primarily to increase the number of stems. Breaking a mother tuber of 12–15 cm into 2−4 pieces before planting indeed increased the total number of tuber buds that grew successfully into main stems (Chapter 6). Breaking into more than two pieces (3 × 1/3 or 4 × 1/4 tuber), however, reduced the success rate of an individual seed tuber piece to produce a surviving main stem to < 1. Tuber pieces should therefore not become too small. The tubers pieces planted in the experiments described in Chapters 2−5 were prepared from breaking a medium sized tuber in three and therefore were relatively small. Larger tuber pieces might not only have a higher success rate, but may also lead to a slightly earlier emergence and a faster initial canopy growth.

Pre-sprouting

The tuber pieces can be planted with sprouts, which were produced during storage, or after de-sprouting. The tuber pieces in the experiments described in Chapters 3−6 were de-sprouted. This was in conformity with what was done by the majority of farmers interviewed in Chapter 2. In Chencha 67% of the respondents planted the tuber pieces after de-sprouting; in Wolaita this was 46%. De-sprouting was applied to get more stems, whereas respondents who used sprouted tuber pieces, mainly did so to improve initial growth. De-sprouting may increase the number of stems by removing the dominance of the most advanced sprout. Removing sprouts that are formed during storage is common practice in Irish potato to enhance uniformity and facilitate mechanical planting. Using sprouted tubers, however, may enhance emergence and early growth.

Planting density

The standard hole spacing used in the experiments described in Chapters 3–6 was 75 × 90 cm (14,815 holes per ha). This was low, but within the range used by farmers, i.e. 40–75 cm within a furrow and 60–100 cm between furrows (varying between 13,333 and 41,666 holes per ha). Increasing the plant density, e.g., doubling it, may well lead to a much higher canopy cover in the first part of the growing period. Given the slow and linear increase in ground cover with time (Chapter 4; with rates of increase of c. 10% (absolute) per week in the interval covering the major increase), doubling the hole density may well lead to full canopy cover being attained more than 4 weeks earlier than in the present experiments.

Fertilization

As discussed in Chapter 4, also fertilization may increase canopy growth. Farmers generally use manure or compost on *P. edulis* (Chapter 2), whereas in the experiments described in this thesis no manure was applied because there was not enough available. Nitrogen, for instance, is well known to enhance leaf area growth, stimulate branching and increase the leaf area duration in Irish potato (cf. Burton, 1989; Harris, 1992; Vos and Biemond, 1992). Farmers believe that fertilization results in more and larger tubers (Chapter 2). The higher and longer canopy cover may result in higher total dry matter yield and, therefore, higher individual tuber weights whereas the longer period until senescence may lead to a longer period of tuber initiation and, therefore, more tubers. High applications of nitrogen in potato, however, can also delay the allocation of dry matter to the tubers and, therefore, reduce tuber yield if the growing season is limited in time. It is still unknown how fertilization may affect yield in *P. edulis*, but our fresh tuber yields obtained were higher than those reported by farmers. Farmers also reported that they applied manure particularly as it became warmer as they thought this could help to keep the soil cool (Chapter 2). Except for a direct mulching effect of the manure this may also result from a larger canopy and consequently less irradiation of the soil. Apparently cooling of the soil was regarded important by the farmers. It is unknown if this was due to a direct effect of temperature on the below-ground processes of stolon and tuber formation.

Tipping

Tipping is the removal of one or two pairs of leaves from the tip part of the main stem and branches. Farmers in Chencha carried out one tipping, farmers in Wolaita carried out 1–3 tippings (Chapter 2). The first tipping takes place as soon as the plant reaches about 15 cm or has produced 2–3 pairs of leaves, the second tipping 1 month after the first and the third 2 months after the second. Most farmers at both sites were convinced that tipping increases the number of stems. Some farmers mentioned it increased yield, but − given the labour requirement of this practice − the percentage of respondents who had this opinion was relatively low. Chapter 5 showed that tipping indeed affected above-ground development more than it affected below-ground development. It increased the number of main stems, the number of branches, and the number of leaves and it increased the canopy cover and delayed crop senescence. It, therefore, may also have reduced weed problems.

It would be logical when the increased canopy cover would also lead to higher tuber yield, but tipping also resulted in a higher tuber yield only in Wondogenet, whereas the same trend was visible in Awassa without being significant. Limiting the number of tippings to one might suffice as this would save time and labour (Chapter 5). Tipping needs to be fine-tuned with other cultural practices, especially with earthing up.

Earthing up

Farmers piled up the soil around the stem twice (in the first 45 days from planting and 90–135 days from planting), while some piled up the soil thrice (also 135–180 DAP) (Chapter 2). Earthing up is the toughest task in *P. edulis* farming and is primarily used to support the branches of the plant against strong wind and to bury the stolons. Farmers earthed up primarily to increase yields, whereas some mentioned more stems, more tubers and bigger tubers (Chapter 2).

When the stolon length can be reduced by breeding, earthing up can probably be done less frequent. A first obvious breeding goal for stolons is to shorten them like breeders have done in common potato. Shorter stolons in *P. edulis* would help to reduce labour costs and would allow farmers to lessen the tillage and earthen up practices.

Weed control

Weed problems were reported by all respondents of the interviews described in Chapter 2 and soil tillage was carried out to control them. Soil tillage in this case refers to a shallow digging around the root system, mostly carried out three times, with the first being carried out following the emergence of the shoot (Chapter 2). The others depended on the occurrence of weeds around the stem. Most farmers mentioned ‘‘more stems’’ as the principal reason for tillage and secondary reasons were ‘‘more tubers’’, ‘‘higher yields’’ and ‘‘overcoming weeds’’ (Chapter 2). Soil tillage will increase the number of stems through reducing the competition between crop stems and weeds in an early phase. In the first weeks after emergence there was also competition between the different main stems produced per hole from the tuber pieces, leading to a die back of main stems later on (Chapter 3). Weeds will increase this competition and will result in a greater die back with fewer surviving stems. Chapter 6 showed that tuber yield increased with an increase in the number of main stems up to 2.5–3 stems per m^2. A high number of stems per m^2 is thus essential to guarantee a high yield. In addition, weeds may reduce yield by increased competition for light.

The late emergence of the crop (Chapter 3) and the slow increase in ground cover by the canopy (Chapter 4) will enhance weed problems. This may be overcome through using good seed tubers, which will speed up emergence and ensure early canopy cover. This practice also reduces the effort needed for tillage.

7.2 *Plectranthus edulis*: an attractive traditional vegetable, its constraints and their solutions

In this section the following issues are addressed: why is the crop attractive, what are the main problems endangering the crop despite its attractiveness, and what should and could be done to make the crop more successful.

7.2.1 Why is Plectranthus edulis *attractive?*

Plectranthus edulis is one of Ethiopia's most ancient tuber crops, with cultivation dating back from about 3000 BC (cf. Murdock, 1959; cited by Westphal, 1975). The crop is primarily grown for its tubers in northern, southern and south-western parts of Ethiopia (Westphal, 1975).

In some places in the south its leaf is also consumed as cooked vegetable (e.g., Westphal, 1975). The *P. edulis* culture matches the definition of traditional vegetables as defined by FAO (1988), which refers to the categories of plants whose leaves, fruits or roots are acceptable and used as vegetables by rural and urban communities through custom habit or tradition.

P. edulis is a main source of energy for the farming community. The *P. edulis* tuber is rich in energy and has a slightly higher carbohydrate concentration after cooking than Irish potato (EHNRI, 1997). Moreover, farmers highly appreciate *P. edulis* and indicate it satisfies one’s hunger better than other tuber crops (personal observation of the author). In relation to its energy, farmers also describe the tuber as ‘‘very important’’ for it makes them energetic, and leads them to have more children. In this regard, Dhliwayo (2002) indicated also for *P. esculentus* that consuming the tubers increases potency.

All farmers interviewed in the surveys described in Chapter 2 indicated that they wanted to continue growing and consuming the tubers with their families. Almost all wanted to increase the area of *P. edulis* on their farm.

7.2.2 Constraints

Despite the fact that *P. edulis* is an important source of energy and highly appreciated by the farming community, even the *P. edulis* farmers interviewed in Chapter 2 consumed more of other tuber crops than of *P. edulis.*

P. edulis faces several *agronomic* constraints. Shortage of seed tubers was mentioned by the interviewed *P. edulis* farmers of all wealth groups in both study areas in Chapter 2 as a major constraint and the principal reason for the decline in production of *P. edulis*. Other constraints identified were the long storage duration, the high price of seed tubers and poor market, the long duration of the crop to reach maturity, water shortage and high temperatures. The first three of these are related to the shortage of seed tubers.

The late emergence of the crop (Chapter 3) and the slow increase in ground cover by the canopy (Chapter 4) will enhance weed problems. This may be overcome through using good seed tubers, which speed up emergence and ensure early canopy cover, which in turn also reduces efforts for tillage.

Although the crop at the start of research was regarded as not susceptible to pests and diseases, this view proved to be incorrect. Diseases were only reported to occur in Wolaita, by about 60% of the respondents, but not in Chencha (Chapter 2). Insect pests were reported by almost half of the respondents. The cooler climate in Chencha and the fact that many farmers in Chencha used virgin land or land that had not been used for many years might have prevented occurrence of diseases. At Wolaita, nematode and some leaf diseases were a problem in some areas. Root-knot nematode-like symptoms were observed in the experiments described in Chapters 3–6 incidentally, but an experiment planted in Areka (Wolaita) planned to be carried out alongside the experiments in Awassa and Wolaita (Chapters 2 and 3) was completely ruined by severe nematode infestation. Nematode problems, esp. *Meloidogyne* sp., are well known in other *Plectranthus* species (e.g., Dhliwayo, 2002; Nisha and Sheela, 2006). Identifying the insect pests and other disease organisms, and also determining their economic effect will considerably help farmers. Based on that knowledge, control methods could be developed, varying from design of crop rotations to (bio)chemical control methods. The danger of nematode infestation should also be taken into account when transferring seed from one area to another.

Another serious problem is that tipping, earthing up, manuring, and tillage are all laborious, costly and time taking. While looking for solutions for these problems it may be important to involve farmers in solving the problems as this approach would make the acceptance of the finding easier. Several workers including Warren and Cashman (1988) have emphasized the importance of considering indigenous knowledge and societal preferences, without which it would lead to failure. Zannou et al. (2004) emphasized the importance of considering the perception of stakeholders including the farmers in order to be successful with the research results.

Also important might be a *psychological effect*, which leads the farming community and others to consider *P. edulis* as “a wild and weed crop” because it has been cultivated for many years in the rural areas while considering the new crops as “modern crop”. This attitude is considered a serious problem in several other indigenous crops (Mnzava, 1993).

Finally, the *knowledge on the physiological behaviour* of the different cultivars is only poor. Six cultivars were known in Chencha: Lofuwa, Unnuka, Chankua, Merchia, Dalakuwa and Kaytaria; five were known in Wolaita: Lofuwa, Unnuka, Chankua, Merchia Nech, and Kaytaria (Chapter 2). More genotypes may be grown in other parts of the country. Farmers, however, used mainly morphological characteristics to identify the different land races. Almost all farmers used tuber characteristics and 40–60% also used leaf characteristics, time of maturity or storage duration to identify genotypes. The cultivars used in later studies (Chapters 3–6), Lofuwa and Chankua, were thought to differ in maturity, with Chankua being later maturing than Lofuwa. However, we found no evidence in our experiments to support this opinion. A proper description of the physiological characteristics of cultivars and their response to external conditions will be helpful to farmers and could serve as a basis for future genetic improvement of *P. edulis.*

7.2.3 What should be done to make the crop more successful?

Any attempt to make the crop more successful should start with solving two major problems: the shortage of seed tubers and the poor storability of the progeny tubers (see above).

Shortage of seed tubers

Shortage or absence of seed tubers was the main production constraint and the primary reason for the decline in production. The farmers needed at least a quarter of their plants as a source of seed tubers for the next planting season (multiplication rate 1:4; Chapter 2). For farmers that do not grow *P. edulis* themselves or when *P. edulis* farmers consume or sell a larger portion of tubers than intended, there is a severe shortage of seed tubers. They then have to be obtained from the markets or from neighbouring farmers. Around planting time, the quality of the tubers is poor, and prices – when tubers are available − are high. In addition, the storability of the seed tubers is poor. To overcome these problems alternative multiplication methods or systems of seed production with higher rates of multiplication than 1:4 should be designed.

Increasing the use of alternative propagation methods such as stem cuttings and sprout cuttings may be helpful. Stem cuttings are the top parts of the branches with a length that varies up to 50 cm, sprout cuttings are the young sprouts removed from the tuber, about 10–15 cm in length. Stem and sprout cuttings were occasionally used by about 5% of the interviewed farmers in Wolaita but were not used in Chencha (Chapter 2). However, because stem cuttings have to be ready for planting early in the rainy season the source seed tuber has to be planted earlier in a separate area before the normal planting time and has to be irrigated until the rain is coming. Taking stem cuttings from plants grown from seed tubers planted during the main rain season may not result in adequate tuber production, because the cuttings would be exposed to hot conditions and less moisture after planting. Use of rapid multiplication techniques by means of tissue culture may also be considered, but might be costly at the moment.

Ways to increase the multiplication rate of seed tubers to more than 1:4, would be by improving the storability (see below) in order to save more tubers from deterioration during storage, or by developing special ways to grow seed tubers with a high storability, e.g., through techniques increasing yield of the most useful classes of tubers. At present, farmers use all classes of tubers for multiplication, but prefer the medium and larger size tubers (data not shown) that they break into different numbers of tuber pieces. The most efficient seed tuber size and the most efficient number of pieces to prepare from different sized seed tubers still have to be established. It is obvious that there are still great improvements possible in optimizing the quantity of planting material used for planting. In many of the experiments described in Chapters 3–6, the number of main stems arising from one hole was lower than the number of pieces planted, which was attributed to early competition between stems. This implies that savings in the quantity of planting material are possible, as long as the quality of the material is good enough to produce sufficient strong stems. Another option that could be considered for improving the quantity and quality of seed tubers available is for some farmers to concentrate specifically on low-cost seed production. This might take place in cooler regions (e.g., Chencha) − where the storage period is relatively short and temperatures during storage are relatively low, thus decreasing ageing of the seed tubers and deterioration during storage − or even outside the traditional growing areas of *P. edulis*.

Thus far it is unknown if the physiological ageing of the seed tubers that occurs during growth and storage has a great impact on the crop grown from it. In Irish potato the physiological age of the seed tuber has a strong impact on crop growth (e.g., Struik and Wiersema, 1999).

It is highly recommended to initiate a research programme on seed tuber production of *P. edulis* and on the effect of seed quality on the performance of the crop grown from that seed.

Storability of tubers

From the research it became clear that the storability of the tubers was a serious problem for both tubers intended for consumption and for tubers reserved as seed tubers. Tubers for consumption were stored *in situ* in the ground, i.e. in the place where the crop was planted, for a maximum period of 5 months, but usually shorter (Chapter 2). Farmers indicated that storing for several months was not desirable for it led to changes in flavour, increased the fibre content, and increased the energy needed for cooking. Our experimental results (Chapters 3 and 4) showed that this method of storage leads to dramatic losses. Decreases of 36−59% were found in tuber fresh weight per hole and of 18−48% in number of tubers when tubers were kept in the soil for 6 weeks after the maximum tuber yield was obtained. The reduction in tuber dry weight found while stored *in situ* in the soil (Chapter 3) equalled the expected losses when tubers had an average respiration rate of 1−1.5% per day.

Also seed tubers were commonly left in the place where they were grown until planting. They have to be stored up to the beginning of the next planting season and therefore longer than tubers intended for consumption (Chapter 3). While they were in the ground they were covered with enset (*Ensete ventricosum* (Welw.) Cheesman) and banana leaves, manure or debris to protect the tubers from strong sunshine. In some instances, however, particularly when high temperatures prevailed, farmers moved the seed tubers to other places where there was shade, and placed them in a dug furrow or hole and covered the soil with grasses, enset or banana leaves, or any debris (Chapter 2).

Thus far, no research has been published on the effect of different storage conditions on the seed tuber performance, but preliminary investigations in 2003–2004 showed that seed tubers were kept physiologically younger when stored at 4 °C as compared to keeping them in the dark (a box) at ambient temperatures, or in the ground. Tubers stored under diffused light – which is a very successful way of storing seed tubers under relatively high temperatures in areas without cooling facilities in Irish potato (cf. Wiersema and Struik, 1999) − were completely destroyed within 15 days of storage. More study is still required to develop a better storage method that suits the farmers and can keep the seed tubers physiologically younger. Improvements best act along the lines of avoiding a too low relative humidity around the tubers to prevent evaporation while on the other hand reducing tuber respiration by keeping the temperatures of the tubers as low as possible and suppressing sprouting and the growth of sprouts. Covering the soil as for seed tubers probably will also improve the storability of tubers for consumption. It is still unknown if there is a special period needed in *P. edulis* tubers for hardening and would-healing, as in common potato.

It is recommended to carry out a research programme on behaviour of seed and ware tubers of *P. edulis* during storage and on appropriate technologies to store these tubers.

7.3 Closing remarks

A big step forward has been made in understanding the ontogeny of the crop *P. edulis* and the way in which cultural practices affect development and growth of the crop. The research also has identified the most important production constraints.

Major constraints to solve at a short term notice are the shortage of seed tubers and the poor storability of the tubers. Research should be initiated on seed production of *P. edulis* and on the effect of seed quality on the performance of the crop grown from that seed. In addition a research programme should be initiated on the behaviour of seed and ware tubers of *P. edulis* during storage and on appropriate technologies to store these tubers.

The crop uses the first part of the growing period inefficiently. Several options have been given to enhance emergence and soil cover, but these only will successfully increase yield when also tuber formation can be advanced: the below-ground parts must be able to use the assimilates produced. It is thus far unknown if and how the moment of tuber initiation can be advanced, but practices aiming at increasing early stolon formation (e.g., tipping) and stolon branching will set the stage to produce as many tubers as possible in an early stage, thus improving the capacity to absorb assimilates. Conditions and ways to increase the absorbing capacity per tuber require further investigation. Detailed understanding of stolon behaviour and the physiological mechanisms of tuberization is also needed in order to develop strategies to improve the productivity of the stolons.

A proper description of the physiological characteristics of the present cultivars and their response to environmental conditions should be carried out and could then be the basis for selection of genotypes depending on the cultivation site and for breeding of improved genotypes.

Thereafter, research into disease and pest management and fine-tuning the different agronomical practices to the physiology of the crop will help to increase the economical benefit to the farmers and the reliability with which the crop can be grown.

In addition to improving agro-physiological knowledge, it would also be welcomed to improve the knowledge on the nutritional value and other possible effects of the tubers on human well-being.

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Summary

Plectranthus edulis (Vatke) Agnew, syn. *Coleus edulis* Vatke is an ancient Ethiopian tuber crop, with cultivation dating back to at least 3000 BC. It is locally known by different names such as Dinicha Oromo dinich, Wolaita dono, Gamo dinich, Gurage dinich, Agaw dinich, Ethiopian potato, etc. It belongs to the family Lamiaceae (Labiatae). The crop is grown in the northern, southern and south-western parts of Ethiopia. *P. edulis* is cultivated primarily for its tubers and is consumed after cooking. The boiled tubers have a slightly higher carbohydrate concentration than those of Irish potato (*Solanum tuberosum* L.), but comparably low protein and fat concentrations. In some western parts of Ethiopia, particularly in the Kefa area, also the leaf is cooked and eaten as a vegetable.

P. edulis is a traditional food crop, but in recent years its acreage and production have declined considerably. There is now a renewed interest from farmers, government and non-governmental organizations to conserve the crop and increase its production. However, absence of accurate information on the growth and development of *P. edulis* is limiting further progress in yield increase and area expansion. No yield data existed at the start of this research and there was no detailed description of its cultural practices or its growth.

This project aimed at providing the basic knowledge needed to direct further applied research. More specifically, the aims of the project were:

- to establish and analyse how and why the traditional cultural production practices were carried out in important growing areas of the crop in southern Ethiopia;
- to characterize the growth and development of the crop with time in order to know which plant organs are initiated where and when, which developmental stages the crop passes through, and which crop processes are limiting tuber production;
- to understand the mechanisms by which important cultural practices affect the growth, development and yield of the crop, concentrating on “tipping” and planting practices.

The findings are believed to contribute to the increment of the productivity of the crop and the setting up of a research agenda.

Indigenous multiplication and production practices

In Chapter 2, it was established by interviewing farmers what the traditional cultural production practices were in some parts (Chencha and Wolaita) of southern Ethiopia, how they were carried out and how farmers rationalized them. The crop was grown as a monocrop. Land was usually prepared for planting between January and April. In

Wolaita, the crop was mostly grown in furrows. In Chencha, the crop was also grown in patches and on flat land. Farmers mostly used a digging hoe for land preparation. The crop was grown from tuber pieces, prepared by breaking a mother tuber into 2–3 pieces. According to the farmers, using tuber pieces resulted in more stems, more progeny tubers and higher yields compared to using whole tubers. Tubers were broken in pieces 0–1 day before planting. Tuber pieces were planted 5 cm deep, either with sprouts that had been produced during storage and were still on the tuber, or after desprouting. Usually three tuber pieces were planted per planting hole, with planting holes spaced at 40–75 cm within a furrow and 60–100 cm between furrows (13,333–41,666 holes per ha). Crops were usually fertilized with manure, but in Wolaita sometimes also with compost. Applying fertilizer was thought to give more and bigger tubers. Earthing up (hilling) took place 1–3 times (usually twice) to support the plants and cover the stolons, and was thought to increase yield. Tipping (pinching) is the removal of the shoot apex with one or two pairs of leaves from the main stems and branches. Plants were tipped 1–3 times (usually once), to increase the number of stems. Typical yield levels reported by farmers were 500–1000 g tuber fresh weight per hole. Practices like tipping, earthing up and soil tillage to remove weeds were regarded as time consuming. Shortage of seed tubers was mentioned by the interviewed *P. edulis* farmers as a major constraint and the principle reason for the decline in production of *P. edulis*. Other constraints identified were the long storage duration, the high price of seed tubers, the ‘‘poor market’’, the long duration of the crop to reach maturity, water shortage and high temperatures. The first three of these are related to the shortage of seed tubers.

From the knowledge obtained, a standard production technique was developed that was used in later experiments. The standard planting material chosen were desprouted tuber pieces, prepared from a medium (12–15 cm) sized mother tuber broken into three pieces, a number of three pieces were planted per hole, a hole spacing of 75 × 90 cm (14,815 holes per ha) was applied and tipping was carried out once, when the crop had achieved a height of 10–15 cm. All practices were within the range used by farmers. No manure was applied because this was not available.

Major structure and development of Plectranthus edulis

In Chapter 3, the structure and development of the crop was studied, using two cultivars, cv. Lofuwa and cv. Chankua. Plant components were: the seed tuber pieces, sprouts, main stems, branches, leaves, inflorescences, fruits, seeds, roots, stolons and tubers. The general structure was similar to that of Irish potato.

The plants attained a maximum height of c. 1.50 m. Plants produced main stems and primary, secondary and tertiary branches, with primary and secondary branches and their leaves constituting the main part of the canopy.

The first stolons were formed c. 70−84 days after planting (DAP) on below-ground nodes of main stems and primary branches. Aerial stolons were initiated 12−16 weeks later than below-ground stolons and were much longer (up to 2.5 m). Tubers were first recorded at 126 DAP and usually were produced as a swelling on the tip of the stolon and sometimes as a swelling of the middle part of stolons. They attained a maximum length of 20–25 cm depending on the cultivar, and a maximum diameter of c. 2 cm. The tubers in the middle of the stolon were longer than the ones at the tip. Tubers were stem tubers with pairs of ‘‘eyes’’ being arranged in the same pattern as the axillary buds on stolons and stems.

After tuber initiation had started, the number of tubers increased almost linearly during 12–14 weeks, and maximum numbers of tubers (c. 150−160 per hole in these experiments) were attained around 238 DAP, at crop maturity. Also the number of smaller tubers (< 10 or 20 g) increased until this moment. The average weight per tuber increased in the same period up to 20–25 g per tuber. The increase in tuber fresh weight with time was therefore realized by an increase in both number of tubers and in average weight per tuber. Fresh tuber yields at 238 DAP were 45−49 Mg ha^{-1} and tuber dry matter concentrations 19−21% (Chapter 4). These yields were very high compared to those reported by farmers.

Light interception, radiation use efficiency, growth and tuber production

Despite the high fresh tuber yield in comparison with farmers’ yields, the average daily dry matter production of the crop over the whole growing period was only 4.2−4.6 g m^{-2} day^{-1}. The experiments described in Chapter 4 showed that two processes limited this dry matter production: the radiation interception by the crop and the efficiency by which the intercepted radiation was converted into dry matter. Only about one-third of the incident radiation was intercepted by the crop’s canopy. This was due to a late emergence (c. 4 weeks), a slow development of the canopy after emergence until full ground cover was attained (c. 20 weeks), a very short period at which ground cover was full (c. 2 weeks) and a sharp decline in ground cover thereafter (6−8 weeks). The average radiation use efficiency (RUE) was only 1.59 g MJ^{-1} photosynthetically active radiation (PAR), as established for the crop in Wondogenet. RUE gradually increased after emergence to about 2.7 g MJ^{-1} PAR when tuber formation was still in an early stage, but then declined because of a stagnation (cv. Chankua in Awassa) or decline (other cultivar × site combinations) in total crop dry weight, that lasted several weeks. Dry matter production decreased because the decrease in canopy dry matter – especially stem dry matter − was not yet compensated by the increase in tuber dry matter. Later this changed and total dry weight and RUE increased again. Harvest index was 81–99% at the moment when tuber yield was maximum.

In situ *storage*

After crop maturity, farmers store the tubers *in situ* in the soil until they need them. It was shown in Chapters 3 and 4 that this practice dramatically reduced numbers and weight of tubers. When tubers were stored *in situ* for 6 weeks, total tuber fresh weight decreased by 36–59% and the number of tubers by 18–48%. Both respirational losses and water losses contributed to that.

Effects of shoot tipping

The effects of shoot tipping were studied in Chapter 5. The number of tippings was varied between zero and three, with the first tipping taking place when most stems had a height of c. 15 cm, and the next ones following at intervals of 44–46 days. In general, there was a positive effect of tipping on canopy development and a positive – though not always significant – effect on tuber yield. Tipping significantly increased the number of main stems, the number of branches and the number of leaves. Tipping enhanced early stolon formation, but did not consistently affect the number of stolons later in the growing season. The number of tubers per stolon, the number of tubers per hole and the average individual tuber fresh weight were not significantly affected by tipping. In Awassa, soil cover increased with an increase in the frequency of the tipping, due to the tipping effects on branch and leaf number. However, the increases by tipping in tuber fresh (+7%) and tuber dry matter yield (+9%) as compared to the control at the final harvest were not significant. In Wondogenet, tipping enhanced the soil cover, but the crop did not benefit extra from a third tipping. On average, tipping enhanced tuber fresh (+17%) and dry matter yield (+22%) at the final harvest compared to the control at this site. Typical tuber fresh yield levels observed in these experiments were c. 21 Mg ha^{-1} at the final harvest (208 DAP). Because senescence was slightly delayed by tipping and ground cover of the tipped plants was still higher than that of zero tipped plants at the final harvest, yield effects of tipping might have been more pronounced when the crops would have been harvested later. Because differences among tipped treatments were not large, limiting the tipping frequency to one will help to save time, labour and money.

Effects of seed tuber piece size, number and planting arrangement

The effects of the number and size of the seed tuber pieces and the planting arrangement on the crop development, yield components, yield and tuber weight distribution were studied in Chapter 6. Breaking a mother tuber of 12–15 cm into 2–4 pieces before planting increased the total number of tuber buds that grew successfully into main stems. Breaking the tuber into more than two pieces before planting, however, reduced the success rate of an individual seed tuber piece to produce a surviving main stem to < 1, likely because tuber pieces became too small and had not enough reserves to produce highly competitive stems. Breaking also increased the number of progeny tubers, decreased the average size of the individual progeny tubers, and increased fresh tuber yield in one out of the two experiments carried out. When only one seed tuber piece was planted per hole, larger seed tuber piece sizes gave more stems, more stolons and more tubers per m^2, larger tubers and higher tuber yields. Planting more seed tuber pieces per hole at constant seed tuber piece size gave more stems, more stolons, and more tubers per m^2 thus increasing tuber fresh yield. Spacing the tuber pieces in a line instead of planting them together in a hole had little effect on yield components, but increased tuber yield in Wondogenet.

Across experiments, the tuber fresh weight increased when the number of main stems per m^2 increased up to 2.5–3 main stems per m^2. Under the production conditions used, the optimum for farmers would be to strive towards this number in order to maximize yield. This could usually be achieved by planting sufficient seed tuber material (equaling at least 1 medium-sized mother tuber per hole) and breaking it into two or three pieces. This confers with the farmers practice. An increase in yield might be achieved by spacing the pieces wider instead of clustering them in one hole as this increases the probability of getting sufficiently high stem numbers. More than c. 2.5–3 stems per m^2 may not lead to higher yield, but may increase the number of (small) tubers and reduce the average tuber weight.

Typical yield levels attained were c. 30 Mg ha^{-1} at 243 DAP. Over all treatments, an increase in fresh tuber yield was never realized by merely increasing the individual tuber weight. An increase in tuber fresh weight was either achieved by combined effects on number of tubers and individual tuber fresh weight or by an effect on number of tubers alone.

Relating crop ontogeny to cultural practices

The first part of the general discussion (Chapter 7) related the present insight into the ontogeny of the crop to the cultural practices.

The long time needed for the crop to establish a full canopy cover (c. 5 months), might be related to the practice of using small tuber pieces, de-sprouting them and planting them at a wide spacing. Larger tuber pieces may lead to an earlier emergence and faster initial canopy growth, and in addition will have a higher success rate. Also using sprouted tubers – either with sprouts produced during storage or pre-sprouted after sprout removal – may enhance emergence and early growth. Increasing the plant density will lead to a higher canopy cover in the first part of the growing period. Given the slow increase in ground cover with time, doubling the hole density may well lead to full canopy cover being attained more than 4 weeks earlier than in the present experiments. Some cultural practices carried out by farmers also stimulate canopy cover; these include manuring, tipping and tillage. Nitrogen, for instance, is well known to enhance leaf area growth, stimulate branching and increase the leaf area duration in Irish potato. Tipping increased the number of main stems, branches and leaves, the canopy cover, and it delayed crop senescence.

Canopy growth stopped after c. 5.5−6 months, likely because the induction of terminal inflorescences limited further canopy expansion and finally also maintenance of a green leaf area. When terminal inflorescences are formed, this limits the possibility for further canopy growth, and plants have to redirect the allocation of assimilates.

Options to enhance emergence and early soil cover thus will only successfully increase yield when also tuber formation can be advanced: the below-ground parts must be able to use the assimilates produced. First tubers now were initiated slightly later than 4 months after planting, 6−8 weeks after the first stolons had been initiated. By contrast, the complete crop cycle of for instance Irish potato in Ethiopia only lasts about 4 months. Tuber production at an early stage seemed to be limited by a low capacity of absorbing photosynthates. This could be due to the still low number of small tubers, there sink activity, and/or by a rate limiting step in the conversion of assimilates to the storage compounds. Evidence for this was found in (1) the check or temporary decrease observed in the total dry matter production in the period that the decrease in canopy dry matter was not yet balanced by an increase in tuber dry matter, (2) that tubers were continuously initiated throughout the growing season and (3) that initiation and growth of aerial stolons took place during this period, accommodating extra tuber forming possibilities. It is thus far unknown if and how the moment tuber initiation can be advanced, but practices aiming at increasing early stolon formation (e.g., tipping) and stolon branching will set the stage/prerequisites to produce as many tubers as possible in an early stage, thus improving the capacity to absorb assimilates. Conditions and ways to increase the absorbing capacity per tuber require further investigation.

Constraints and a research agenda

The second part of the general discussion focussed on the constraints endangering the crop despite its attractiveness, and what should be done to make the crop more successful. Any attempt to make the crop more successful should start with solving two major constraints: *the shortage of seed tubers* and the *poor storability* of the progeny tubers.

The shortage of seed tubers results from the extremely low multiplication rates (25% of the area had to be reserved as seed) combined with the poor storability of the tubers. Improvement might act along developing alternative multiplication methods and/or designing seed production systems. Alternative propagation methods might include the use of stem and sprout cuttings. Use of rapid multiplication techniques by means of tissue culture may also be considered, but might be costly at the moment.

Ways to increase the multiplication rate of seed tubers to more than 1:4, would be by improving the storability in order to save more tubers from deterioration during storage, or by developing special ways to grow high quality seed tubers. There are still great improvements possible in optimizing the quantity of planting material used for planting. Seed might also be produced by specialized growers within a region, in the cooler regions, or even outside the traditional growing area's of *P. edulis*. It is highly recommended to initiate a research programme on seed tuber production of *P. edulis* and on the effect of seed quality on the performance of the crop grown from that seed.

The storability of the tubers was a serious problem for both tubers intended for consumption and for tubers reserved as seed tubers. The *in situ* storage method used for ware tubers led to fresh weight losses of 36–59% within 6 weeks. Also seed tubers were commonly left *in situ*, although they were covered with enset and banana leaves, manure or debris to protect them against strong sunshine, and sometimes were moved later to shaded places in a dug furrow or hole and covered again.

Improvement of the storability best acts along preventing evaporation by avoiding a too low relative humidity, reducing tuber respiration by keeping the temperature as low as possible and suppressing (early) sprouting. It is recommended to carry out a research programme on behaviour of seed and ware tubers of *P. edulis* during storage and on appropriate technologies to store these tubers.

In addition to these major constraints, research into diseases and pests and their management and research into the fine-tuning of different agronomical practices to the physiology of the crop will help to increase the economical benefit for the farmers and the reliability with which the crop can be grown. A proper description of the physiological characteristics of the present cultivars and their response to environmental conditions should be carried out as a basis for selection and breeding of improved genotypes. Finally also the composition and nutritional value of *P. edulis* tubers should be better documented.

Samenvatting

Plectranthus edulis (Vatke) Agnew, syn. *Coleus edulis* Vatke is een oud Ethiopisch knolgewas, dat zeker al vanaf 3000 voor Christus wordt geteeld. Lokaal is het bekend onder verschillende namen zoals Dinicha Oromo, Wolaita dono, Gamo dinich, Gurage dinich, Agaw dinich, en de Ethiopische aardappel. Het hoort tot de Lamiaceae (Labiatae) familie. Het gewas wordt geteeld in het noorden, zuiden en zuidwesten van Ethiopië. *P. edulis* wordt voornamelijk geteeld voor de knollen, die worden gegeten na koken. De gekookte knollen hebben een iets hoger koolhydraatgehalte dan die van de gewone aardappel (*Solanum tuberosum* L.), maar vergelijkbaar lage eiwit- en vetgehaltes. In sommige streken in westelijk Ethiopië, in het bijzonder in de Kefa regio, wordt ook het blad van de plant gekookt en gegeten als groente.

P. edulis is een traditioneel voedselgewas, maar in de laatste jaren zijn het areaal en de productieomvang van het gewas sterk gedaald. Er is nu een hernieuwde interesse van boeren, regering en NGO’s om het gewas te behouden en om de productieomvang te verhogen. Gebrek aan precieze informatie over de groei en ontwikkeling van *P. edulis* belemmert echter de vooruitgang in opbrengstverhoging en areaaluitbreiding. Er bestonden bij aanvang van dit onderzoek zelfs geen opbrengstgegevens en er was geen gedetailleerde beschrijving van de gebruikte teelttechnieken of de groei van het gewas.

Het doel van dit onderzoeksproject was de basiskennis te verwerven die nodig was om richting te geven aan verder, toepassingsgericht onderzoek. De specifieke doelstellingen van het project waren:

- vast te stellen en te analyseren hoe en waarom de traditionele teelthandelingen worden uitgevoerd in belangrijke teeltgebieden in het zuiden van Ethiopië;
- de groei en ontwikkeling van het gewas in de tijd te beschrijven om na te gaan welke plantorganen waar en wanneer worden geïnitieerd, welke ontwikkelingsstadia het gewas doorloopt en welke groeiprocessen de knolproductie beperken;
- te begrijpen via welke mechanismen belangrijke teelthandelingen de groei, ontwikkeling en knolopbrengst van het gewas beïnvloeden, met de nadruk op de invloed van toppen, het gebruikte pootmateriaal en de pootmethode.

De resultaten worden geacht bij te dragen aan een productiviteitsstijging en aan het opstellen van een onderzoeksagenda.

Inheemse vermeerderings- en productiemethoden

In Hoofdstuk 2 is door het interviewen van boeren vastgesteld wat de traditionele teelhandelingen waren in enkele delen (Chencha en Wolaita) van zuidelijk Ethiopië, hoe deze teelthandelingen worden uitgevoerd en hoe de boeren deze motiveerden. Het gewas werd uitsluitend geteeld in monocultuur. Het land werd tussen januari en april gereed gemaakt voor poten. In Wolaita werd het gewas voornamelijk in voren geteeld, in Chencha ook op aparte plantplekken of op vlak land. De boeren gebruikten meestal een zogenaamde toyle, een 2-tandige graafhark, om de grond te bewerken. Als pootgoed werden knolstukken gebruikt, die werden gemaakt door een moederknol in 2–3 stukken te breken. Volgens de boeren leidde het gebruik van knolstukken in vergelijking met hele knollen tot meer stengels, meer dochterknollen en een hogere opbrengst. De moederknollen werden 0–1 dag voor het poten in stukken gebroken. De knolstukken werden 5 cm diep gepoot, òf met de kiemen die tijdens de bewaring geproduceerd waren nog op de knolstukken, òf na afkiemen. Meestal werden drie knolstukken per plantgat gepoot, terwijl de afstand tussen plantgaten 40–75 cm in de rij was en 60–100 cm tussen rijen (13.333–41.666 plantgaten per ha). De gewassen werden meestal bemest met dierlijke mest, maar in Wolaita soms ook met compost. Bemesting werd verondersteld meer en grotere knollen te geven. Het gewas werd 1–3 keer aangeaard (meestal twee keer) om steun te geven aan de stengels en om de stolonen te bedekken. Aanaarden werd verondersteld de opbrengst te verhogen. Toppen is het verwijderen van het groeipunt plus 1–2 bladparen van de hoofd- en zijstengels. Planten werden 1–3 keer getopt (normaliter eenmaal) om het aantal stengels te verhogen. Typische opbrengstniveaus die door de boeren werden genoemd waren 500–1000 g knollen per plantgat. Teelthandelingen als toppen, aanaarden en onkruidbestrijding werden tijdrovend gevonden. Een gebrek aan pootgoed werd door de geïnterviewde boeren genoemd als een belangrijke beperking en de voornaamste reden voor de achteruitgang in de productie van *P. edulis*. Andere genoemde knelpunten waren de lange bewaarperiode, de hoge prijs van pootgoedknollen, de ‘‘slechte markt’’, de lange periode voordat het gewas rijp was, watergebrek en hoge temperaturen. De eerste drie hiervan zijn gerelateerd aan het gebrek aan pootgoed.

Uit de opgedane kennis werd een standaard teeltmethode ontwikkeld die is gebruikt in latere experimenten. Als pootgoed werd hierbij gekozen voor afgekiemde knolstukken, gemaakt door een middelgrote (12–15 cm) moederknol in drie stukken te breken; drie knolstukken werden gepoot per plantgat; een afstand van 75 × 90 cm werd gebruikt tussen plantgaten (14.815 plantgaten per ha); en de planten werden eenmaal getopt, wanneer het gewas een hoogte van 10–15 cm had bereikt. Deze methoden vallen binnen de ranges die door boeren toegepast worden. In de experimenten werd geen dierlijke mest toegediend omdat deze niet beschikbaar was.

Plantbouw en ontwikkeling van Plectranthus edulis

In Hoofdstuk 3 is de opbouw van de plant en de ontwikkeling van het gewas bestudeerd bij twee cultivars, Lofuwa en Chankua. Onderdelen van de plant waren: het moederknolstuk, kiemen, hoofdstengels, zijstengels, bladeren, bloeiwijzen, vruchten, zaden, wortels, stolonen en knollen. De bouw van de plant was vergelijkbaar met die van de gewone aardappel.

De planten bereikten een maximale hoogte van c. 1,50 m. De planten vormden hoofdstengels en primaire, secundaire en tertiaire zijstengels, waarbij de primaire en secundaire zijstengels en hun bladeren het belangrijkste deel van het loof vormden.

De eerste stolonen werden c. 70−84 dagen na poten (DNP) gevormd aan de ondergrondse knopen van de hoofdstengels en primaire zijstengels. Bovengrondse stolonen werden 12−16 weken later geïnitieerd dan ondergrondse stolonen en werden veel langer (tot 2,5 m). Knollen werden voor het eerst waargenomen op 126 DNP en werden meestal geproduceerd als een zwelling aan de top van een stolon, maar soms als een zwelling van een middengedeelte van de stolonen. Knollen bereikten maximaal een lengte van 20–25 cm, afhankelijk van de cultivar, en maximaal een diameter van c. 2 cm. De knollen in het middengedeelte van stolonen waren langer dan de knollen aan de top. De knollen waren stengelknollen met paren ‘‘ogen’’ die volgens hetzelfde patroon gerangschikt waren als de axillaire knoppen op de stolonen en stengels.

Nadat de knolinitiatie was begonnen, steeg het aantal knollen vrijwel lineair gedurende 12–14 weken, en maximale aantallen knollen (in deze proeven c. 150−160 per plantgat) werden bereikt rond 238 DNP, op het moment van rijpheid. Ook het aantal kleine knollen (< 10 of 20 g) steeg tot dat moment. Het gemiddeld gewicht per knol steeg in dezelfde periode tot 20–25 g per knol. De stijging in het knolversgewicht in de tijd werd daarom gerealiseerd via een toename in zowel het aantal knollen als het gewicht per knol. Knolversgewichten op 238 DNP waren 45−49 Mg ha^{-1} en het drogestofgehalte van de knollen was 19−21% (Hoofdstuk 4). Deze opbrengsten waren erg hoog vergeleken met die gerapporteerd werden door boeren.

Lichtonderschepping, stralingsconversie-efficiëntie, groei en knolproductie

Ondanks de hoge knolopbrengsten in vergelijking met die van boeren, was de gemiddelde drogestofproductie van het gewas over het gehele groeiseizoen slechts 4,2−4,6 g m^{-2} dag^{-1}. De experimenten die zijn beschreven in Hoofdstuk 4 tonen aan dat twee processen deze drogestofproductie beperkten: de lichtonderschepping door het gewas en de efficiëntie waarmee de opgevangen straling werd omgezet in drogestof, de stralingsconversie-efficiëntie (RUE, *radiation use efficiency*). Slechts ongeveer een derde van alle invallende straling werd onderschept door het bladerdek. Dit werd veroorzaakt door een late opkomst (c. 4 weken), een trage ontwikkeling van het bladerdek na opkomst tot volledige grondbedekking was bereikt (c. 20 weken), een zeer korte periode waarin de grondbedekking 100% was (c. 2 weken) en een scherpe daling daarna (6−8 weken). De gemiddelde RUE was slechts 1,59 g MJ^{-1}

fotosynthetisch actieve straling (PAR), zoals werd vastgesteld voor het gewas in Wondogenet. De RUE steeg na opkomst geleidelijk tot c. 2,7 g MJ^{-1} PAR vroeg in de knolvormingsfase, maar daalde daarna door een stagnatie (cultivar Chankua in Awassa) of daling (overige cultivar × locatie combinaties) van het totaal drooggewicht, die enkele weken duurde. De totale drogestofproductie daalde door een sterke daling in drogestofgewicht van het loof – vooral de stengels – die nog niet werd gecompenseerd door de stijging in het drooggewicht van de knollen. Later veranderde dit en stegen het totaal drooggewicht en de RUE weer. De oogstindex was 81–99% op het moment dat de knolopbrengst maximaal was.

Bewaring in situ

Boeren zijn gewend de knollen *in situ* in de grond te bewaren, nadat het gewas is afgerijpt. In Hoofdstukken 3 en 4 is aangetoond dat dit gebruik het aantal knollen en het gewicht aan knollen dramatisch doet dalen. Wanneer knollen gedurende 6 weken *in situ* werden bewaard, daalde het versgewicht aan knollen met 36–59% en het aantal knollen met 18–48%. Zowel respiratie als verlies aan water leverden daar een bijdrage aan.

Effecten van toppen

De effecten van het toppen van het loof werden bestudeerd in Hoofdstuk 5. Het aantal maal toppen werd gevarieerd tussen nul en drie, waarbij de eerste keer getopt werd op het moment dat de meeste stengels c. 15 cm hoog waren, en de latere keren telkens na 44–46 dagen. In het algemeen werd er een positief effect gevonden van toppen op de loofontwikkeling en een positief – hoewel niet altijd significant – effect op de knolopbrengst. Toppen verhoogde het aantal hoofdstengels, zijstengels en bladeren significant. Toppen bevorderde ook vroege vorming van stolonen, maar had geen significante invloed meer op het aantal stolonen later in het seizoen. Het aantal knollen per stolon, het aantal knollen per plantgat en het gemiddelde versgewicht per knol werden niet significant beïnvloed door toppen. In Awassa steeg de grondbedekking door het loof met een stijging in de frequentie waarmee getopt werd door de effecten van het toppen op het aantal zijstengels en bladeren. De stijging in knolversgewicht door toppen (+7%) en in knoldrooggewicht (+9%) vergeleken met de controle (niet toppen) waren echter niet significant in Awassa. In Wondogenet bevorderde toppen de grondbedekking door het loof, maar profiteerde het gewas niet meer extra van een derde maal toppen. Gemiddeld verhoogde toppen in Wondogenet het knolversgewicht (+17%) en knoldrooggewicht (+22%) bij de eindoogst wel vergeleken met de niet-getopte controle. Typische opbrengsten behaald in deze experimenten waren c. 21 Mg ha^{-1} verse knolopbrengst bij de eindoogst (208 DNP). Omdat de veroudering enigszins werd vertraagd door het toppen en omdat de grondbedekking van de getopte planten bij de eindoogst nog hoger was dan die van niet-getopte planten, zou het opbrengstverhogende effect van toppen waarschijnlijk sterker zijn geweest wanneer het gewas wat later zou zijn geoogst. Omdat de opbrengstverschillen tussen de frequenties van toppen niet groot waren, is het waarschijnlijk dat het beperken van de frequentie van toppen tot eenmaal, tijd, arbeid en geld zal besparen.

Effecten van de grootte van het gepote knolstuk, het aantal knolstukken en het plantpatroon

De effecten van het aantal en de grootte van de knolstukken gebruikt voor poten, en van het patroon waarin de knolstukken werden gepoot op de gewasontwikkeling, opbrengstcomponenten en gewichtsverdeling van de geoogste knollen, zijn onderzocht in Hoofdstuk 6. Het breken van een moederknol van 12–15 cm in 2–4 stukken voor poten vergrootte het aantal knoppen op de knol dat succesvol uitgroeide tot hoofdstengels. Het breken van de moederknol in meer dan twee knolstukken, verlaagde echter de succeskans van een individueel knolstuk om een overlevende hoofdstengel te produceren tot < 1, waarschijnlijk omdat de knolstukken te klein werden en onvoldoende reserves bezaten om competitieve hoofdstengels te vormen. Het breken van de moederknol verhoogde ook het aantal dochterknollen, verlaagde de gemiddelde grootte van de individuele dochterknollen en verhoogde het totaal gewicht aan dochterknollen in een van de twee uitgevoerde experimenten. Wanneer er slechts één knolstuk per plantgat werd gepoot, resulteerden grotere knolstukken in meer stengels, meer stolonen, meer knollen per m^2, grotere knollen en hogere knolopbrengsten. Het poten van meer knolstukken van eenzelfde grootte per plantgat resulteerde in meer stengels, meer stolonen en meer knollen per m^2 en verhoogde zo het versgewicht aan knollen. Het poten van de individuele knolstukken in een rij in plaats van het combineren van meerdere knolstukken in één plantgat had weinig effect op de opbrengstcomponenten, maar verhoogde de knolopbrengst in Wondogenet.

Over alle experimenten steeg de verse knolopbrengst met een stijging van het aantal hoofdstengels tot 2,5–3 hoofdstengels per m^2. Onder de gegeven productiecondities, zou het optimaal zijn voor de boeren om te steven naar dit aantal stengels voor een maximale opbrengst. Dit aantal stengels is te bereiken door voldoende pootgoed te gebruiken (gelijk aan minimaal een middelgrote moederknol per plantgat) en deze in twee of drie stukken te breken. Dit komt overeen met de boerenpraktijk. Een extra verhoging van de opbrengst kan bereikt worden door de individuele knolstukken verder van elkaar te poten in een rij, in plaats van geclusterd in één plantgat. Meer dan c. 2,5–3 stengels per m^2 zal niet leiden tot een hogere opbrengst, maar zal het aantal (kleinere) knollen vergroten en het gemiddeld knolgewicht verlagen.

Typische opbrengsten behaald in deze experimenten waren c. 30 Mg ha^{-1} vers knolgewicht op 243 DNP. In deze set proeven werd een verhoging van het vers knolgewicht nooit bereikt via uitsluitend een verhoging van het gemiddeld gewicht per knol, maar ofwel via een verhoging van het aantal knollen plus het gemiddeld gewicht per knol ofwel uitsluitend via verhoging van het aantal knollen.

Het verband tussen de ontogenese van het gewas en de teeltmethodieken

Het eerste gedeelte van de algemene discussie (Hoofdstuk 7) legt verband tussen het huidige inzicht in de ontogenese van het gewas en de teelttechnieken.

De lange periode die nodig was om volledige grondbedekking door het gewas te bereiken (c. 5 maanden), zou het gevolg kunnen zijn van het gebruik van kleine knolstukken als pootgoed, het afkiemen van de knolstukken en de wijde pootafstand. Grotere knolstukken kunnen resulteren in een snellere opkomst en een sneller begingroei van het loof, en zullen ook een hogere kans op succes geven. Ook het gebruik van knolstukken met kiemen – òf kiemen die tijdens de bewaring zijn gegroeid òf kiemen die zijn geproduceerd na afkiemen – kan de opkomst en de begingroei versnellen. Ook het verhogen van de plantdichtheid zal de grondbedekking tijdens het eerste gedeelte van de groeiperiode verhogen. Vanwege de zeer trage stijging van de grondbedekking in de tijd bij de gebruikte plantdichtheid, zou verdubbeling van de plantdichtheid kunnen leiden tot het 4 weken eerder bereiken van volledige grondbedekking dan in de huidige experimenten. Sommige teeltmaatregelen die door de boeren worden uitgevoerd, verhogen de grondbedekking. Hiertoe horen de bemesting, het toppen en de onkruidbestrijding. Stikstof, bijvoorbeeld, kan in de gewone aardappel de bladoppervlakte verhogen, vertakking van de stengels bevorderen en de bebladeringsduur verlengen. Toppen verhoogde het aantal hoofdstengels, zijstengels en bladeren, de grondbedekking en het vertraagde de afrijping van het gewas.

De loofgroei stopte na c. 5,5−6 maanden, waarschijnlijk omdat de inductie van eindstandige bloeiwijzen verdere uitbreiding van het loof en uiteindelijk ook het handhaven van een groene bladoppervlakte verhinderde. Wanneer eindstandige bloeiwijzen worden gevormd, beperkt dit verdere loofgroei en moeten planten hun assimilatenstroom anders verdelen.

Opties om de opkomst en begingroei te versnellen zullen dan ook alleen met succes de uiteindelijke knolopbrengst verhogen wanneer ook de knolvorming vervroegd wordt: de ondergrondse delen van het gewas moeten de geproduceerde assimilaten gebruiken. In de huidige experimenten, werden de eerste knollen pas iets later dan 4 maanden na poten aangelegd, 6−8 weken nadat de eerste stolonen geïnitieerd waren. Ter vergelijking: de volledige productiecyclus van de gewone aardappel duurt in Ethiopië slechts ongeveer 4 maanden. Bij *P. edulis* leek de knolvorming in een vroeg stadium beperkt door een lage capaciteit van de knollen om assimilaten op te nemen. Dit kon veroorzaakt worden door het nog lage aantal knollen, hun beperkte *sink*-activiteit of door een snelheidsbeperkende stap in de omzetting van assimilaten tot opslagverbindingen. Aanwijzingen hiervoor zijn (1) de tijdelijke stagnatie of daling in totale drogestofproductie in de periode dat de daling in drogestof van het loof nog niet werd gecompenseerd door een verhoging in drogestof van de knollen, (2) de onafgebroken initiatie van nieuwe knollen tot het einde van de groeiperiode (3) de initiatie en groei van bovengrondse stolonen – en daardoor extra knolvormingsplaatsen – in deze periode. Het is op dit moment niet bekend of en hoe de knolinitiatie kan worden vervroegd. Teeltmethoden die gericht zijn op het bevorderen van vroege vorming van stolonen (zoals toppen) en vertakking van stolonen kunnen de basis leggen voor productie van zoveel mogelijk knollen in een vroeg stadium, en zo de capaciteit verhogen om assimilaten te gebruiken. Nader onderzoek is nodig naar de omstandigheden en manieren waarmee de capaciteit van individuele knollen om assimilaten op te nemen kan worden verhoogd.

Knelpunten en een onderzoeksagenda

Het tweede gedeelte van de algemene discussie behandelt de knelpunten die het gewas bedreigen ondanks zijn aantrekkelijkheid, en wat gedaan moet worden om het gewas succesvoller te maken. Elke poging om het gewas succesvoller te maken moet beginnen met het oplossen van de twee belangrijkste knelpunten: *het gebrek aan pootgoedknollen* en *de slechte bewaarbaarheid van de geproduceerde knollen*.

Het gebrek aan pootgoedknollen is een gevolg van de extreem lage vermeerderingssnelheid (25% van de beteelde oppervlakte moest voor pootgoed gereserveerd worden) in combinatie met of mede als gevolg van de slechte bewaarbaarheid van de knollen. Verbetering lijkt mogelijk via de ontwikkeling van alternatieve vermeerderingsmethoden en pootgoedproductiesystemen. Alternatieve vermeerderingsmethoden zijn bijvoorbeeld stengelstekken en kiemstekken. Het gebruik van snelle vermeerdering *in vitro* kan worden overwogen, maar is nu wellicht nog te kostbaar.

De vermeerderingsfactor zou kunnen worden verhoogd tot meer dan 1:4 door de bewaarbaarheid van de knollen te verbeteren of door de ontwikkeling van speciale manieren om kwalitatief hoogwaardig pootgoed te verbouwen. Er zijn nog aanzienlijke verbeteringen mogelijk in het optimaliseren van de hoeveelheid pootgoed die nodig is. Pootgoed kan ook geproduceerd worden door gespecialiseerde producenten binnen een regio, in de koelere productieregio's, of zelfs buiten de traditionele teeltgebieden van *P. edulis*. Het verdient sterke aanbeveling een onderzoeksprogramma te initiëren naar pootgoedproductie van *P. edulis* en de effecten van de pootgoedkwaliteit op de prestatie van het gewas uit dat pootgoed.

De bewaarbaarheid was een ernstig probleem voor zowel knollen voor consumptie als knollen die als pootgoed werden gereserveerd. De *in situ* bewaarmethode die gebruikt werd voor consumptieknollen leidde tot verliezen in versgewicht van 36–59% binnen 6 weken. Ook pootgoedknollen werden normaliter *in situ* in de grond bewaard, al werden ze bedekt met enset- of bananenblad, mest of afval om ze te beschermen tegen sterke instraling door de zon. Soms werden ze later verplaatst naar beschaduwde plekken in een speciaal gegraven greppel of gat en opnieuw afgedekt.

Verbetering van de bewaarbaarheid is het beste te bereiken via het voorkomen van evaporatie door het tegengaan van een te lage relatieve vochtigheid, het beperken van de ademhaling van de knollen door de temperatuur zo laag mogelijk te houden en door het voorkomen van vroegtijdig kiemen van de knollen. Het verdient aanbeveling een onderzoeksprogramma te initiëren naar het gedrag van consumptie- en pootgoedknollen van *P. edulis* tijdens de bewaring en geschikte technologieën om deze knollen te bewaren.

In aanvulling op deze belangrijkste knelpunten, zal onderzoek naar ziekten en plagen en hun management en onderzoek naar de afstemming van de verschillende agronomische methoden op de fysiologie van het gewas helpen om de economische opbrengst voor de boeren en de betrouwbaarheid waarmee het gewas geteeld kan worden te vergroten. Een goede beschrijving van de fysiologische eigenschappen van de huidige cultivars en hun reactie op weersomstandigheden zou moeten plaatsvinden om als basis te dienen voor selectie en veredeling van verbeterde genotypen. Ten slotte moeten ook de samenstelling en voedingswaarde van *P. edulis* beter gedocumenteerd worden.

Curriculum vitae

Mulugeta Taye was born in Addis Ababa, Ethiopia, on 27 November, 1960. After he completed his high school education, he joined the Awassa College of Agriculture and graduated with a Diploma in Horticulture in 1978. He joined the Alemaya College of Agriculture and obtained his BSc degree in Plant Sciences in 1984. After he served for about 4 years in Awassa College he joined the Alemaya University of Agriculture and obtained his MSc degree in Plant Sciences with specialization in Horticulture in 1992. Since his MSc graduation he works for the Awassa College. Meanwhile he started to pursue a PhD with the Crop and Weed Ecology Group of Wageningen University in 2001. Mulugeta also attended several training programmes including a course on potato production and processing organized by the International Agricultural Centre in the Netherlands in 1993, and a course in Development in potato technology for rural development in Sub-Saharan Africa, organized by the ARC-Roodeplaat Vegetable and Ornamental Plant Institute, South Africa, and the International Agricultural Centre of Wageningen University and Research Centre, the Netherlands, held in South Africa in 2003. He also attended a participatory rural appraisal training organized by the Southern Region Bureau of Agriculture of Ethiopia and FARMAFRICA, a UK based non-governmental organization, in 2003. He published several papers on cassava and produced teaching material on coffee and tea production.

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