Using Agronomic Tools to Improve Pineapple Quality and its Uniformity in Benin

Vodjo Nicodème Fassinou Hotegni

Thesis committee

Promotors

Prof. Dr P.C. Struik

Professor of Crop Physiology

Wageningen University

Prof. Dr J.G.A.J. van der Vorst

Professor of Operation, Research and Logistics

Wageningen University

Co-promotor

Dr W.J.M. Lommen

Assistant professor, Centre for Crop Systems Analysis

Wageningen University

Other members

Prof. Dr M.K. van Ittersum, Wageningen University

Prof. Dr D.J. Hounhouigan, University of Abomey Calavi, Cotonou, Benin

Dr W.J.J. Bijman, Wageningen University

Prof. Dr O. van Kooten, Wageningen University

This research was conducted under the auspices of the C.T. de Wit Graduate School for Production Ecology and Resource Conservation

Using Agronomic Tools to Improve Pineapple Quality and its Uniformity in Benin

Vodjo Nicodème Fassinou Hotegni

Thesis
submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. Dr M.J. Kropff,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public
on Tuesday 9 September 2014
at 4 p.m. in the Aula.

V.N. Fassinou Hotegni
Using Agronomic Tools to Improve Pineapple Quality and its Uniformity in Benin,

302 pages.

PhD thesis, Wageningen University, Wageningen, NL (2014)
With references, with summaries in English, French and Dutch

ISBN: 978-94-6257-038-2

Abstract

Fassinou Hotegni, V. N. (2014). Using agronomic tools to improve pineapple quality and its uniformity in Benin. PhD thesis, Wageningen University, The Netherlands, with summaries in English, Dutch and French. 302 pages.

Poor average quality and uniformity in quality have become major issues in agri-food chains. This is also the case in the pineapple sector in Benin where less than 2% of the fresh pineapple is exported to international markets. The average quality of pineapple delivered to other markets, local and regional, is poor. The present thesis studied the improvement options in the pineapple sector which will help pineapple producers to produce higher pineapple quality for different markets, including international ones. This thesis aimed at (1) understanding how fresh pineapple supply chains are organised in Benin and identifying the bottlenecks for delivering the right pineapple to the right market; (2) increasing our knowledge on the agronomic tools used by pineapple producers to produce pineapple fruits; (3) understanding how agronomic factors affect pineapple quality and harvesting time, and (4) proposing and discussing the trade-offs between cultural practices. Research included analysis of supply chains and cropping systems and field experimentation.

To understand how fresh pineapple supply chains are organised, 54 semi-structured interviews were held with key informants and 173 structured interviews with actor groups. Results indicated six main actor groups in the fresh pineapple chains: primary producers, exporters, wholesalers (those selling at local markets and those selling at regional markets), processors, retailers, and middlemen. Two pineapple cultivars were grown: Sugarloaf and Smooth Cayenne, with Sugarloaf being dominant in local and regional markets and Smooth Cayenne in European markets. The main constraints hampering the effectivity of the chains were: the non-controlled conditions under which the pineapple was transported from one actor group to another, the lack of appropriate storage facilities at wholesaler's and processor's levels, the unavailability of boxes for export and the non-concordance between actor groups in which quality attributes and criteria they valued most. In addition, most respondents interviewed affirmed that the pineapple quality was highly heterogeneous, emphasising the need to understand how pineapple is grown in Benin and what the constraints for producing high pineapple quality are.

To find out the agronomic tools in use by pineapple producers in Benin, interviews were held with 100 producers in the pineapple production areas. Pineapple production practices proved diverse for both cultivars in planting density, flowering induction practice and fertiliser application. The production systems of the two pineapple cultivars differed in planting material used (slips in cv. Sugarloaf; hapas plus suckers in cv. Smooth Cayenne); the use of K_2SO_4 (not commonly used in cv. Sugarloaf and commonly used in cv. Smooth Cayenne); the number of fertiliser applications (lower in cv. Sugarloaf than in cv. Smooth Cayenne) and in the maturity synchronisation practice by means of Ethephon (not commonly used in cv. Sugarloaf and commonly used in cv. Smooth Cayenne). Constraints for high quality production were the unavailability of planting material, unavailability and high costs of fertilisers and the heterogeneity in planting material weight.

To understand how agronomic factors affect pineapple quality and harvesting time, four on-farm experiments were conducted in commercial pineapple fields. Results first indicated that the heterogeneity in fruit weight was a consequence of the heterogeneity in plant vigour at artificial flowering induction time. The plant vigour at flowering induction was mainly related with the infructescence weight and less or not with crown weight. Second, results indicated that artificial flowering induction gave fruits with lower infructescence weight and heavier crown than natural flowering induction. Artificial maturity induction reduced the total soluble solids (TSS) concentration in the fruits. Finally, results showed that the reason why a high proportion of fruits in cv. Sugarloaf was not exportable to Europe was the high value in the ratio crown: infructescence height (above 1.5); in cv. Smooth Cayenne, reasons were a ratio crown: infructescence height as well as a TSS below 12 ºBrix.

To come up with improvement options for high pineapple quality production with low heterogeneity in quality, the possibility of pruning slips on selective plants as means to improve uniformity in fruit quality was evaluated through two on-farm experiments on commercial fields with cv. Sugarloaf. Results revealed that pruning of slips did not significantly improve average fruit quality attributes and was not successful in achieving more uniform fruit quality at harvesting time. Through one experiment per pineapple cultivar, we investigated how fruit quality and its variation were affected by weight (in both pineapple cultivars) and type (in cv. Smooth Cayenne only) of planting material. Results showed that fruits from heavy planting material had heavier infructescence and fruit weights, longer infructescence height, but shorter crown height and smaller ratio crown: infructescence height than those from light planting material. In cv. Sugarloaf fruits from heavy planting material

had higher variation in crown weight and lower variation in infructescence height than fruits from light and mixed (light plus heavy) planting materials. In cv. Smooth Cayenne, fruits from heavy planting material had a lower variation in fruit height than fruits from other classes of planting material. The type of planting material (in cv. Smooth Cayenne) had no effect on the average fruit quality attributes except on the crown height where fruits from hapas had shorter crowns than those from suckers. The type of planting material had in overall no significant effect on the variation in the fruit quality attributes.

The present study is a step towards the improvement of the whole pineapple sector in Benin. It identified constraints for high pineapple quality production but also tested and proposed improvement options for high pineapple quality production.

Keywords: *Ananas comosus*; Benin; cultural practices; fruit quality; hapas; heterogeneity; planting material; slips; suckers; supply chain; variation in quality; variation within crop; vigour.

Acknowledgements

I took my luggage for the PhD journey after receiving a call from Prof. Joseph Hounhouigan who advised me to apply for the PhD position. I first hesitated because I considered myself too young to go for that, but later I applied. Prof. Joseph Hounhouigan I am deeply indebted to you: ‘your call on that day has positively changed my life’ and here is the result. Once the application was submitted, it was the turn of Prof. M.A.J.S van Boekel, Dr Paul Ingenbleek and Dr A. van Tilburg to give me the chance to pursue that journey. The interview held in Benin in June 2008 in front of the three of you, was my first interview experience and here is where I landed. I am really grateful to all of you for believing in my capabilities to conduct the PhD studies.

The completion of this PhD project was possible because of two main funding organisations. I would like to thank the Interdisciplinary Research and Education Fund (INREF) of Wageningen University and Research Centre for its financial support through the Co-Innovation for Quality in African Foods Chains (CoQA) programme and the Netherlands Fellowship Program (NUFFIC) for funding this PhD project. I would also like to thank the LEB foundation for their financial support to my travel to Portugal (Lisboa) to attend the 28th International Horticultural Congress. Thanks also to the West Africa Research Association (WARA) for funding my travel to Ghana to explore the fresh Ghanaian pineapple chains.

During the PhD journey, I learnt a lot from so many people. I am especially grateful to my first promotor Prof. Paul Struik. Your modesty, prompt availability and fast reply to my emails and drafts always impressed me. Thanks for your encouragements, advices and assistance in experimental designs. Thanks also for your critical feedback on all the chapters which has greatly helped me to improve them. I would also like to thank your wife Prof. Dr Edith T. Lammerts van Bueren for her availability during the trip we had. I am also grateful to my second promotor Prof. Jack G.A.J van der Vorst for the energy you always brought to me during our meetings. Thanks for your inputs in the different papers and for your help in designing the supply chains studies. I have no words to thank my co-promotor Dr Willemien J.M. Lommen. In an early stage of my PhD, I remembered I cited a paper and you found, printed and commented on that paper, and advised me not to cite such paper because of its poor scientific quality. I was really impressed. From that day, I became very critical even on my own work. Dr Willemien J.M. Lommen, I have learnt a lot from you mainly on experimental design, data analysis, data presentation and paper writing. Thanks for your patience and for your great interest in my research. I would like to thank your husband Frans for his availability and approachableness during our visit to some sites in the Netherlands. I would like to thank my supervisor in Benin, Prof. Euloge K. Agbossou for always being there when needed. The discussions we had on my thesis helped me a lot to reshape some parts of the thesis.

During the PhD study, I have been part of a wonderful academic group: the Centre for Crop Systems Analysis (CSA). I gratefully acknowledge Nicole Wolffensperger, Sjanie van Roekel and Wampie van Schouwenburg for their assistance in immigration procedures for my stay at Wageningen and other administrative issues. Special thanks to Sjanie van Roekel for your encouragements. I would also like to thank Alex-Jan de Leeuw and Gijsbertje Berkhout for always being available to arrange matters related to financial issues. To my officemates, André Junqueira, Cesar Ospina Nieto Andres, Cong Wenfeng, Marcia de Melo Carvalho, I would like to thank you for the nice gestures. I am also thankful to Clara Pena Venegas, Giovani Theisen, Gisella Cruz Garcia and her husband Paul, Joyce Challe, Junqi Zhu, Marcelo Labra, Stella Kabiri, Uta Priegnitz and Yang Yu for their cheerful company. I would like to thank all the remaining Centre for Crop Systems Analysis staff for the nice moments during coffee, tea and cake sharing, especially Dr Aad van Aast for his support and great interest in my research activities and progress. The CSA and the Plant Production Systems (PPS) Group are part of the Plant Sciences group. I had the opportunity to meet some of the PPS members, mainly Bouba Traoré and Guillaume Ezui. I really enjoyed the time we spent together discussing about our progress and challenges.

I have also been part of great project team, the CoQA project team. I am grateful to all the members of the CoQA project in Wageningen, Benin, Ethiopia and South Africa. The different discussions we had during our annual workshops in Wageningen, Ethiopia and Benin were very helpful for me since they brought new ideas and new ways to face the challenges.

To my friends around the world that I met during my stay in Wageningen, I wish to thank you. I cannot list all of you, but I wish to thank especially Alexander Nuer, Caroline Kamenchu, Faith Katumbi, Farraka Sari Prasetiadi, Jose Cortez Arriola, Marlene Soriano Candia, Primrose Mukwasi, Somnuek Siriluk, Sulis Rini and Terrens Saaki for the nice time we had together. It was always good to forget (not completely) about all the work on our desk and relax for a while.

To my colleagues from Benin Abraham Adio Sauliou Mazu, Alphonse Singbo, Augustin Kouevi, Charles Tamou, Edmond Totin, Essègbèmon Akpo, Eugene Agbicodo, Euloge Togbé, Evans Agbossou, Fernande Honfo-Zannou, Fidèle Moutouana, Fidelia Bohissou Hounnou, Flora Chadare-Assogbadjo, Folachodé Akogou, Gérard Zoundji, Guirguissou Maboudou Alidou, Landry Fanou, Latifou Idrissou Aboubacary, Nadia Fanou-Fogny, Nathalie Kpera-Mam Sika, Ozias Hounkpatin, Rolland Yemadjè, Romaric Vihotogbé, Soulé Adekambi, Sylvain Dabadé, Yann Madode and Yessoufou Waliou, I would like to thank you for your assistance and the relaxing moments we had. A special thanks to Beninese colleagues in the CoQA project Djalalou-Dine Ademonla A. Arinloye and Harold Mênouwesso Hounhouigan for the nice collaboration and idea sharing. I had the opportunity to meet at Wageningen one of the course lecturers during my Engineer training in Crop Sciences in 2007; Dr Enoch Achigan-Dako, although you were in Wageningen for a different matter and for a short period, the discussion we had, helped me a lot at the earlier stage of my PhD studies. I would like to thank you for that. Thanks also to Dr Aliou Saidou for your encouragements.

To my others colleagues around the world, especially Armand Igor Yevide, Clément Sèwadé, Daye Loffa Joèl, Dossou Yovo Hubert, Felicienne Monsi Agboka, Fortuné Azihou, Jean Martial Johnson, Johanes Uriel Agbahey, Judicael Ahoueya, Léonie Koumassa, Maximilien Weke, Nadia Anoumou, Vivien Doto Chain, Vodouhè Gbèlidji, Wilfried Bonou and Yves Agnoun, I would like to thank you for your great support. I would also like to thank the pineapple producers, processors, wholesalers, retailers and exporters who participated in the studies; a special thanks to the members of the family Agossa at Tangbo-Djèvié (Zè) especially Valère Agossa for your great help in my experiments. Thanks to Annick Dansou, Berenger Dohounkpan, Charlotte Zoundji, Eugène Alissou, Franck Dako, Marcel Donou Hounsode, Michel Okan, Narcisse Mintole Quenum Ahouignan, Sylvanus Mensah and William Doko, for your untiring help in assisting me in data collection and impounding into excel. Thanks also to Anthony Botchway, Daniel Asherow, David Crentsil, Enoch Sarku, George Dzibolosu, Kwaku Amoafo-Yeboah, Rolland Botchway, Samuel Kofi Ackah, Solomon Benjamin and Stephen Mintah for your great help in providing me with data on pineapple fresh supply chains in Ghana.

I would like to thank my parents for their love, guidance and support. My sincere thanks to my father Janvier Fassinou and my mother Justine Minagnon Bonou for your attention and love. You have always supported me in all steps of my studies. Sincere thanks to my late uncle René Fassinou for his encouragements and to my two aunts: Félicienne

Fassinou and Thérèse Fassinou for their continuous encouragements. I also wish to thank my brothers Judicael Fassinou and Roger Fassinou, my sister Sévérine Fassinou and my cousins Aimee Fassinou, Aziz Damien, Clémence Fassinou, Diane Fassinou, Emilienne Fassinou, Firmine Fassinou, Gloria Damien, Simplicia Fassinou and Wilfried Fassinou and his wife Cecile Peltier for your moral support. I would like to thank my father-in-law Laurent Legouda and my late mother-in-law Victorine Goudjo for the confidence you have in me and your continuous support and help. Thanks also to Dinsou Linda Agbo, Guedenon Félicité, Ronald Legouda and Tayo Legouda for your support.

Last but not least, I would like to thank my wife Tinan Abachinou Prisca Legouda-Tobi and my son Tini Vianney Forlan Fassinou Hotegni for their love and continuous support.

Abbreviations

AFI	Artificial flowering induction
AMI	Artificial maturity induction
ANOVA	Analysis of variance
AP	Slips pruned on all plants
CARDER	Regional Action Centre for Rural Development
CeRPA	Regional Centre for Agriculture Promotion
CV	Coefficient of variation
DL	D-leaf length (cm)
Expt	Experiment
FH	Farmer’s harvest practice
FIP	Flowering induction practice
FP	Fraction of plants pruned
FS	Flowering synchronisation
HP	Harvesting practice
IH	Infructescence height (cm)
IW	Infructescence weight (kg)
MAF	Month after flowering induction
MAP	Month after planting
MFE	Month after flowering emergence
NFI	Natural flowering induction
NL	Number of functional leaves
NMI	Natural maturity induction
NP	No slips pruned on the plants
OH	Optimum harvest
P	Pruned
PT	Pruning time
Ra	Ratio crown: infructescence height
SN	Slip number
SW	Slip weight
TSS	Total soluble solids

Contents

CHAPTER 1

General introduction

1.1. Introduction

This thesis is part of the research programme "Co-Innovation for Quality in African Food Chains" (CoQA), which is a collaboration of Wageningen University with Hawassa University and Addis Ababa University in Ethiopia, University of Abomey-Calavi (Benin) and the University of Fort Hare (South Africa). The CoQA programme studies quality improvement options in three African food chains: pineapple in Benin, deciduous fruit in South Africa and potato in Ethiopia. The main objective is to analyse and design innovations for quality improvement in order to support smallholder producers in tailoring the quality of their products to the demands of their national and international supply chain customers, thus strengthening smallholder market access and competitiveness. In Benin, three PhDs were involved in improving the pineapple at three levels: the first PhD aimed at improving the pineapple quality at field level and related logistics processes, the second PhD aimed at improving the pineapple processing and marketing system, and the third PhD aimed at improving the governance structure in the pineapple supply chains in order to help small farmers to have better access to the markets. The present study is related to the improvement of pineapple quality and its uniformity in the field as well as related logistic processes.

This general introduction will provide (1) background information on Benin and pineapple production and distribution in this country; (2) a description of the morphological structures of a pineapple plant; (3) a problem statement and objectives; (5) a problem analysis and research questions, and (4) a section describing how the thesis is organised.

1.2. Background information on Benin and pineapple production and distribution

1.2.1. Benin: Geographical location, population, agro-ecological zones and main crops

Benin is a country located in West Africa between the latitudes 06°10' N and 12°25' N and the longitudes 0°45' E and 3°55' E. The country is bordered by Burkina Faso and Niger in the north, the Atlantic Ocean in the south, Togo in the west and Nigeria in the east (Figure 1.1). The population is about 9,983,884 inhabitants with an average population density of 87 inhabitants per km^2 (INSAE, 2014); the highest population density is observed in the southern part of the country.

Five agro-ecological zones (AEZ) are commonly identified in Benin, based on differences in climate and soil types: (1) the southern zone, (2) the transition zone, (3) the southern Borgou/southern Atacora zone, (4) the Atacora zone, and (5) the northern Borgou zone (INRAB 1995) (Figure 1.1). Details on the mean annual rainfall range, the type of climate, the soils types, and the main crops grown in each climatic zone are provided in Table 1.1.

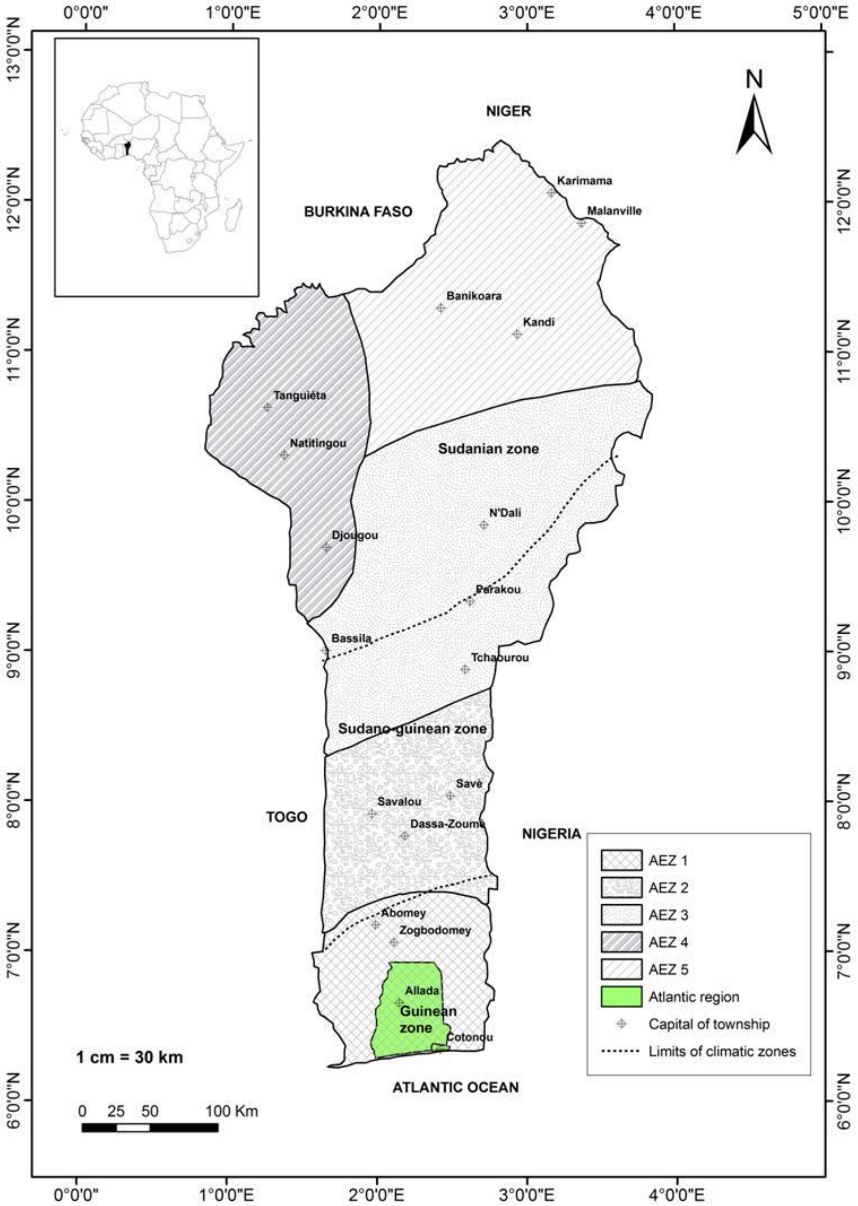


Figure 1.1. Map of Benin indicating the five agro-ecological zones (AEZ 1: Southern zone; AEZ 2: Transition zone; AEZ 3: Southern Borgou/Southern Atacora Zone; AEZ 4: Atacora Zone, and AEZ 5: Northern Borgou zone) and the three climatic zones (Guinean zone, Sudano-guinean zone and Sudanian zone) across the agro-ecological zones. The Atlantic department is highlighted in light-green colour

Table 1.1. Benin agro-ecological zones and their characteristics and main crops grown (adapted from INRAB 1995; Gnanglè et al. 2011)

Agro-ecological zones	Mean annual rainfall (mm)	Climate	Soils types	Main crops grown
Southern zone	1000-1400	Guinean: (subequatorial climate) with two rainy seasons and two dry seasons	Ferralitic	Maize, pineapple cassava, cowpea, palm
Transition zone	1000-1200	Sudano-guinean: no clear distinction between the two rainy seasons	Tropical ferruginous	Maize, cashew, groundnut, yam, cotton
Southern Borgou/Southern Atacora zone	900-1300	Sudanian: one rainy season and one dry season	Tropical ferruginous	Sorghum, cotton, maize, yam
Atacora zone	900-1200	Sudanian: one rainy season and one dry season	Tropical ferruginous	Sorghum, cowpea, maize, millet
Northern Borgou	600-800	Sudanian: one rainy season and one dry season	Tropical ferruginous	Cotton, maize, millet, sorghum

1.2.2. Pineapple in Benin: Importance, area, production, yield

Pineapple [*Ananas comosus* (L.) Merrill] is the eleventh important tropical fruit in terms of production volume in the world (FAO 2011). In West Africa, it is the second most important tropical fruit after banana (FAO 2009). In Benin, pineapple is viewed as a strategic crop, because, since 2006, pineapple is among the crops selected by the government to potentially alleviate poverty (Agbo et al. 2008). Pineapple is regarded a strategic crop for improving the livelihood of the actor groups involved in the pineapple sector (Tidjani-Serpos 2004).

In Benin, pineapple is produced in the southern part, mainly in the Atlantic department (region in light-green in Figure 1.1) where about 95% of the pineapple volume comes from (Arouna and Afomassè 2005). The Atlantic department is divided into eight municipalities: Abomey-Calavi, Zè, Allada, Torri-Bossito, Toffo, Kpomassè, Ouidah, So-Ava (INSAE 2004) (Figure 1.2); the first five municipalities (Abomey Calavi, Zè, Allada, Tori, and Toffo) contribute up to 99% of the total pineapple production in the Atlantic department (Gbenou et al. 2006). Pineapple harvested area, production and yield increased in Benin between 1990 and 2010 (Figure 1.3-A, B and C). From 2010 to 2011, the pineapple harvested area and production decreased (Figure 1.3-A and B) accompanied by a slight decrease in the yield (Figure 1.3-C). In 2011, Benin ranked 18th in terms of volume of pineapple produced in the world (FAO 2011). Data on pineapple yield in Benin from 1990 to 2011 revealed that Benin is the fourth country in the world delivering highest pineapple yield with an average yield of 43.7 Mg ha^{-1} after Costa Rica, Indonesia, and Panama (FAO 2012). Despite these performances in pineapple production and yield, less than 2% of the pineapple produced is exported to Europe (Figure 1.3-D).

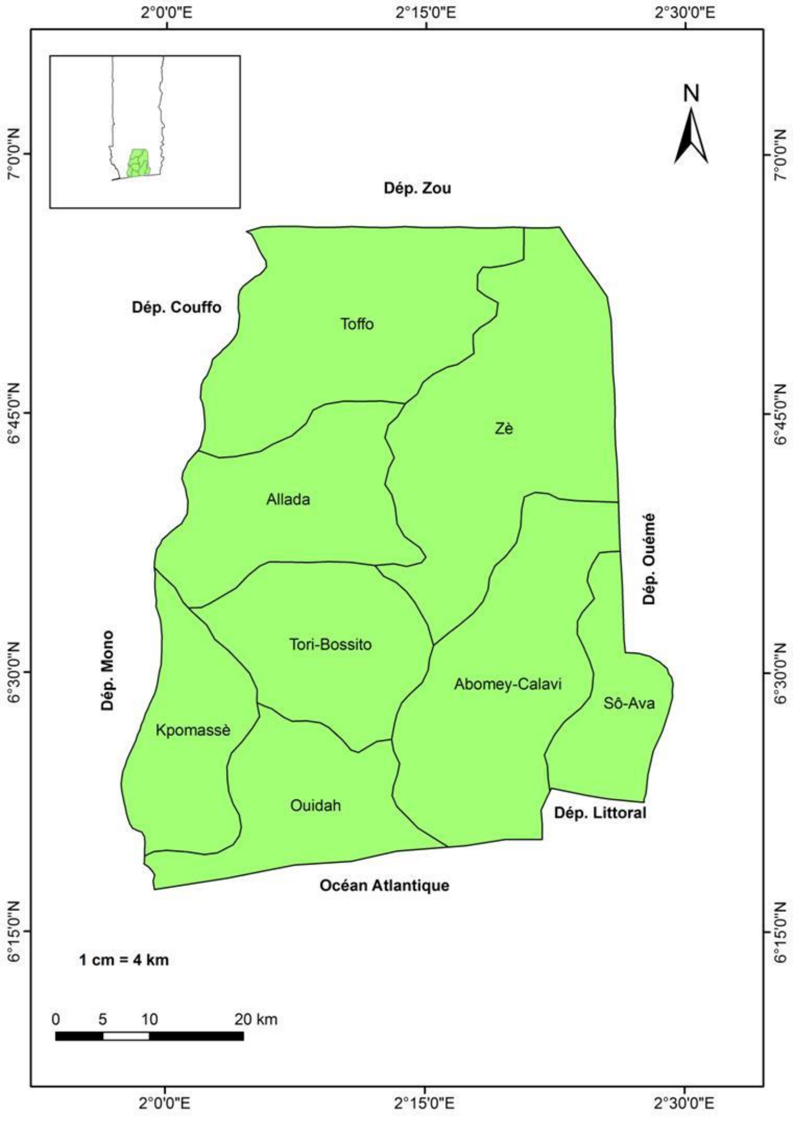


Figure 1.2. Map of Atlantic department with its eight municipalities; percentages show the contribution in pineapple production of the five main municipalities where pineapple is produced to the total pineapple production in the department [Percentages are taken from Gbenou et al. (2006)]

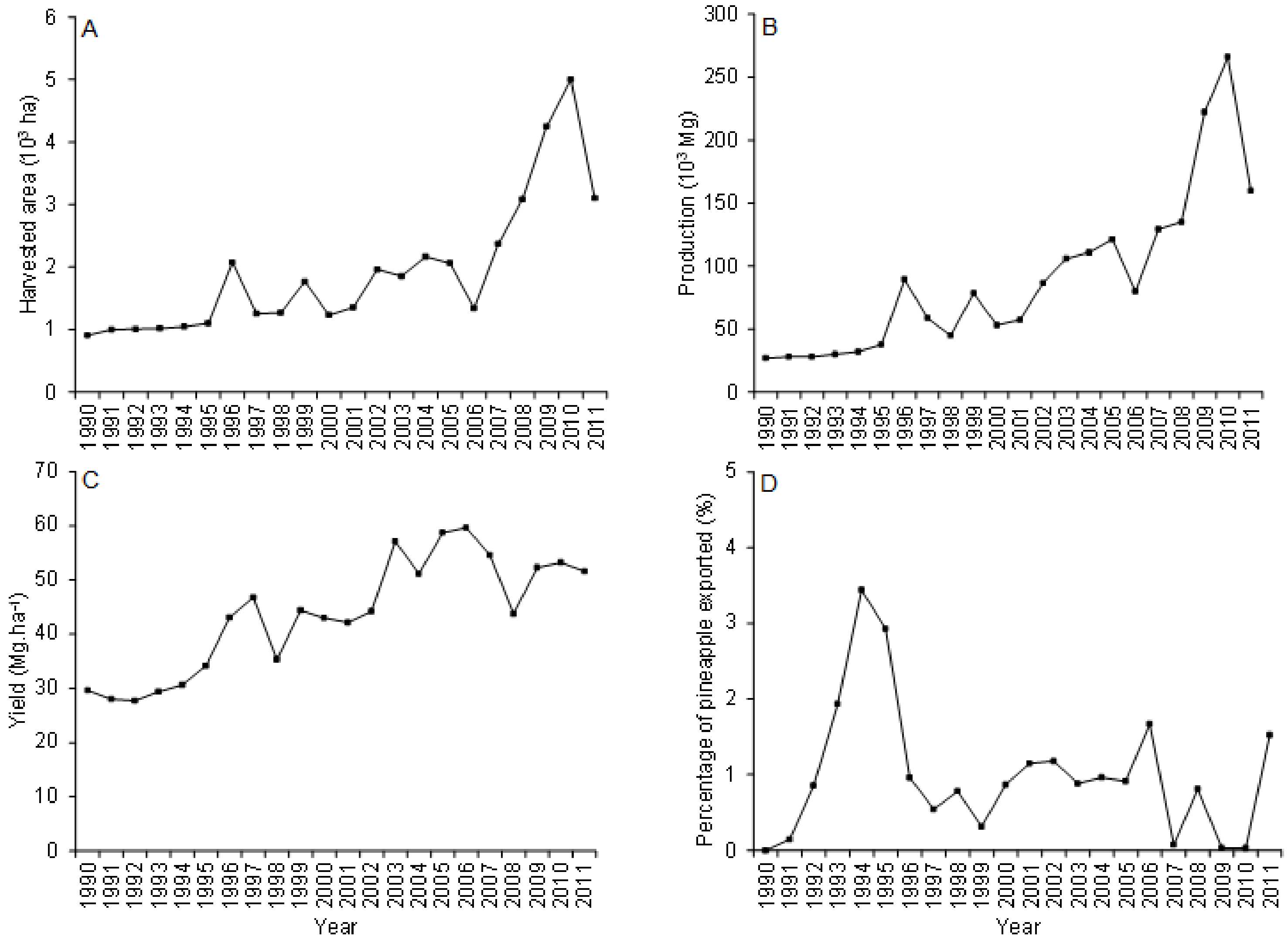


Figure 1.3. Trends in pineapple harvested area (A), production (B), yield (C) and percentage of fresh pineapple exported to Europe (D) in Benin from 1990 to 2011.
Source: FAO (2012)

1.3. Morphological structures of a pineapple plant

Pineapple is a perennial, herbaceous crop from the Bromeliaceae family. The adult plant is 1-2 m high and the main structures are the fruit, the peduncle, the stem, the leaves and the roots (Figure 1.4). The fruit is a multiple fruit (coenocarpium) formed from many individual flowers called florets. The fruit is composed of two main structures: the infructescence and the crown at the top of the infructescence (Figure 1.4). The peduncle which bears the fruit develops from the apex of the stem (Kerns et al. 1936). The stem has a distinct central cylinder, erect and club-shaped with the thickest diameter being 6.5-7.5 cm. The leaves are sword-shaped, tapered towards the tip and are directly attached to the stem. As most plants in the Bromeliaceae family, pineapple has the crassulacean acid metabolism (CAM) of photosynthesis (Malézieux et al. 2003). The roots are short, compact and located at the base of the stem (Coppens d'Eeckenbrugge and Leal 2003). In addition to these, other structures namely side shoots develop during pineapple development. These are: the slips (produced on the peduncle at the base of the fruit), the hapas (produced above ground on the main stem at the junction of the stem and the peduncle) and the suckers (originating below ground from the stem) (Hepton 2003) (Figure 1.4). These side shoots are the most frequently used planting materials.

In Benin, two main cultivars are grown: cv. Sugarloaf and cv. Smooth Cayenne. The main differences between the two cultivars are related to the shape and flesh of the fruit and the presence or absence of spines on the leaf margins. In cv. Smooth Cayenne the fruit is cylinder-shaped and has yellow flesh at maturity, while in cv. Sugarloaf the fruit is cone-shaped and has white flesh at maturity. In cv. Smooth Cayenne the leaf margins are smooth whereas in cv. Sugarloaf the leaf margins are spiny.

1.4. Problem statement and objectives

Pineapple is grown predominantly for its fruit that is either consumed fresh or processed. In Benin, three outlets exist: (1) the local market (Benin, located at Sèmè Kraké, Dantokpa, Zè, Sékou and Sèhouè places) for fresh pineapple and processing, (2) the regional market (Nigeria, Ghana, etc.) for fresh and processing, and (3) the European market (Belgium, the Netherlands, France, etc.) for fresh pineapple only. Different actor groups are operating in the markets: primary producers, traders, processors and exporters. For the local and regional markets, no formal quality standards are set; the quality standards are those of the actor groups in the

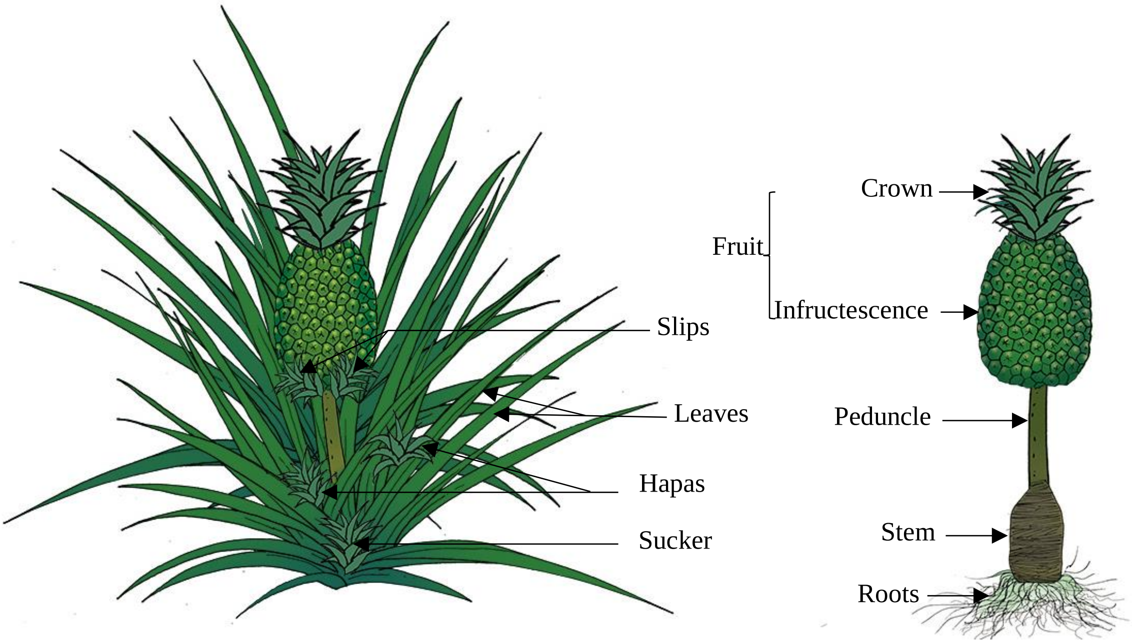


Figure 1.4. Pineapple morphological structure; on the right, the leaves are removed from an uprooted pineapple plant to clearly show the roots, stem and the peduncle

markets. For the European market, Codex Alimentarius (2005) has set a number of quality requirements for pineapple; these include criteria for average fruit quality as well as the associated heterogeneity in fruit weight, fruit height, the ratio crown height: infructescence height, the total soluble solids (TSS) and percentage of damage on the skin of the fruit.

The main problem of pineapple in Benin is the fact that the produce often does not meet the standards for any of the outlets and certainly not the European standards (Gbenou et al. 2006). Each time producers want to export fresh pineapple to European countries a huge quantity (more than 50% of what is delivered to be exported) is rejected because it does not meet the Codex Alimentarius criteria (Gbenou et al. 2006). For many years, attempts have been made to increase the percentage of fresh pineapple exported but still less than 2% of the fresh pineapple is exported to Europe during the last 10 years (Figure 1.3-D). The remaining pineapple is delivered to the local and regional markets with lower quality; nevertheless, the bulk of this pineapple loses its quality before being consumed (Gbenou et al. 2006).

These problems show that the existing pineapple supply chains are not effective in producing and delivering the right pineapple to the right market at the right time. At the onset of this research, it was unknown how different fresh pineapple supply chains were organised; also there was a lack of information on how pineapple was produced in Benin. Thus, increasing the knowledge on how the production and delivery systems work, and on the existing bottlenecks for improving quality is important to tackle the poor compliance with quality standards and to determine suitable agronomic tools to improve pineapple quality.

The general objectives of the thesis are:

(1) to understand how fresh pineapple supply chains are organised in Benin, especially with regards to fruit quality and quality requirements for traders, exporters and processors for local, regional and international markets, and identify the bottlenecks for delivering the right pineapple to the right market;

(2) to increase our knowledge on the agronomic tools in use by pineapple producers to produce pineapple fruits;

(3) to understand how agronomic factors affect pineapple quality and harvesting time; and

(4) to propose and discuss the trade-offs between cultural practices to improve pineapple quality and its uniformity.

The findings will contribute to the improvement of pineapple quality mainly at the producer's level. Combined with the findings of the two other PhDs' work in the CoQA project (see Section 1.1), it is expected that the whole pineapple supply chain network will be improved significantly since the chain will start with good pineapple quality.

1.5. Problem analysis and research questions

1.5.1. Reasons for poor pineapple quality

Reasons for the poor compliance with the pineapple quality standards can be found at two phases: post-harvest and pre-harvest. In this thesis emphasis is on the pre-harvest factor since the research of the two other PhD in the CoQA project (see Section 1.1.) is focused on post-harvest quality improvement. However, for a general understanding of the fresh pineapple supply chains and bottlenecks for delivering the right pineapple to the right market, the first research question is:

RQ1: What are the different fresh pineapple supply chains in Benin and why are the chains not effective in supplying the right pineapple quality?

The pre-harvest factor includes the pineapple cultivation in association with the fruit quality at harvesting time. In pineapple cultivation in general, three partly overlapping crop phases are distinguished: the vegetative phase (from planting to flowering induction time) characterized by an increase in number of leaves and diameter of the main stem; the generative phase (from flower initiation to fruit maturity) characterized by the flower initiation and fruit development and growth; and the propagative phase (begins at the generative phase and continues after the fruit is harvested) characterized by the production of side shoots. Cultivation starts in general with planting material, which can be the slips, hapas, suckers, or the crown (Hepton 2003), or plantlets from stem or crown sections (Heenkenda 1992). Slips, hapas and suckers are the dominant forms used in Benin. Natural flowering and maturity are variable and cause scheduling problems of the harvest because of non-synchronisation of the pineapple plants within a crop. Therefore crops are treated with growth regulators (e.g., ethylene, acetylene, calcium carbide and ethephon) to induce (and thus synchronise) flowering (Cunha 2005; Hepton 2003; Onaha et al. 1983) and to induce (and thus synchronise) the change of the skin colour during fruit ripening (Audinay 1970; Crochon et al. 1981; Saltveit 1999). These agronomic practices are referred to as “artificial flowering induction” or “forcing” and “artificial maturity induction”, respectively. It is important to stress that calcium carbide is poisonous and is only used to induce the flowering, not to induce the fruit maturity. At the onset of this research, it was unknown how pineapple was grown in Benin. So, the second research question *(RQ2*) is:

RQ2: What are the different ways of producing pineapple in Benin and what are the constraints that hamper the pineapple quality?

When flowering is induced in order to synchronize the time of flowering, the apical meristem which is differentiating into leaves undergoes transformation, initiating then reproductive development and flowering. When all flowers are initiated, the apical meristem resumes its vegetative activity, producing the crown of the fruit. It is known that the stage of development of a crop at flowering induction affects the fruit weight, with higher number of leaves leading to larger fruits (Malézieux 1993; Malézieux and Bartholomew 2003; Mitchell 1962). It is thus far unknown how individual fruit components i.e. the infructescence and crown weights and heights as well as ratio: crown: infructescence height, the TSS, the juice pH and flesh translucency are affected by the plant vigour at the flowering induction time. Flesh translucency is defined as flesh in a state of low porosity and a water soaked appearance owing to the intercellular free spaces being filled with liquid (Siderius and Krauss 1938); highly translucent flesh significantly lowers fruit quality (Bowden 1967). The gap in knowledge in the literature led to the third research question (*RQ3*) which is:

RQ3: How are differences in quality attributes between individual fruits within a crop associated with differences in vigour of the individual plants within the crop at the time of artificial flowering induction?

Artificial flowering induction will lead to plants flowering at an earlier developmental stage than natural flowering induction and might reduce fruit weight of especially the least advanced plants. In pineapple, natural flowering stimuli are shortening of the day length (Friend and Lydon 1979), dropping of the temperature (Bartholomew and Malézieux 1994) reduction of hours of radiation due to cloudiness (Bartholomew and Kadzimin 1977) and water deficit (Py et al. 1987). In bromeliad crops, smaller/lighter plants at the time of treatment produce fewer flowers (De Greef et al. 1982 working with Achmea), fewer fruitlets per spiral on pineapple fruits (Bartholomew et al. 2003) and lighter fruits (Malézieux et al. 2003). At the crop level, artificial flowering induction may thus increase the heterogeneity in fruit weight, because of the relative early induction of the least advanced plants. No findings on the effect of flowering synchronisation on pineapple quality attributes such as ratio crown height: infructescence height, fruit height, TSS, juice pH, translucency as well as the heterogeneity within each quality attribute have been reported in detail in the literature.

Natural maturation occurs when the fruit reaches its full size and skin colour changes from green to gold yellow, in line with changes in sugar concentrations, juice pH and flesh translucency. From 12 to 4 weeks before harvesting time, TSS is low. From 4 weeks before harvesting time, TSS increases until harvest time (Chen and Paull 2000). The pH starts to increase 2 weeks before the optimum harvest time until optimum harvest time (Singleton and Gortner 1965). When maturity is artificially induced, the increase in the TSS might be arrested or only hastened slightly due to the rapid change in skin colour from green to yellow and the sugar concentration could be lower than that of untreated fruit at a later (optimum) harvest moment. Similarly, the juice pH could also be lower thus reducing the average quality of the lot compared to fruits from natural maturity induction. At the crop level, artificial maturity induction could increase the heterogeneity in TSS and juice pH and probably in flesh translucency since the flesh translucency was found to be associated with sugar accumulation at harvest (Chen and Paull 2001).

In summary, artificial flowering and maturity inductions will reduce the heterogeneity among plants in time to flowering and time to maturity, but could increase heterogeneity in fruit quality, and could lower the average quality compared to natural flowering and maturity inductions. Not all pineapple plants are well developed at the moment of flowering synchronisation and not all fruits are at the same ripening stage at the moment of maturity synchronisation; this may decrease the potential quality of mainly the fruits from the least developed plants, especially when crop uniformity is poor. Thus, the fourth research question is:

RQ4: What are the trade-offs of synchronising flowering and maturity during the growth of pineapple crops on other quality characteristics of the harvested fruit lot, especially the heterogeneity within the lot, and why do flowering and maturity synchronisation lead to these trade-offs?

Due to the increase in heterogeneity in fruit quality created by flowering and maturity synchronization, agronomic practices that lead to crops with more uniformity among plants or fruits at the moments of flowering or maturity synchronization are needed since they may reduce the variability in quality of the fruits at harvest and will probably improve the average quality.

1.5.2. Improvement of the uniformity of pineapple fruit quality

The uniformity among plants and fruits at the moments of flowering and maturity synchronization can be controlled by agronomic practices that minimize variability and promote balanced vegetative or generative growth. This study concentrates on (1) planting material and (2) the pruning of the side shoots that may compete with fruit for assimilates.

The use of uniform planting material –side shoots– could minimise the initial variability within crops at an early stage of their development. In Benin, pineapple producers are used to mixing different types of side shoots to be used as planting material (when the cultivar cropped has different types of side shoots) and/or different weights within a type of planting material. It is known that within each type of planting material, a larger size or weight leads to a shorter duration from planting to natural flowering induction and bigger fruits, e.g., plants from large slips are larger, flowered earlier and produce larger fruits than plants from small slips (Linford et al. 1934). Scientists in the pineapple community claim the need to have uniform planting material at planting time (Hepton 2003; Reinhardt et al. 2000) but thus far, it is unknown to what extent reducing variation in the planting material weight for a single type or mixed types of planting material could increase the uniformity of the crop after planting and consequently reduce the variability in fruit quality while increasing the individual fruit quality. Therefore, the fifth research question is:

RQ5: How do uniformity in type and weight of planting material affect fruit quality and its variation at harvesting time?

The production of one type side shoots, the slips, starts early in the generative phase during which the fruit development and growth occur. These slips, commonly produced on cv. Sugarloaf (Norman 1976), will act as sinks competing with the fruit for available assimilates. Studies on the effects of removal of slips on the pineapple plant report contradictory findings. Wee and Ng (1970) removed all slips in excess to two slips that were kept on the plants and found no significant effect of slip pruning on fruit weight and fruit height. Norman (1976) removed the slips when the fruits started to develop and found that slip pruning increased fruit weight and had no effect on the TSS concentration in the fruit juice. Recent studies on the other hand revealed that slips could be important sources of assimilates for fruit growth and maintenance (Marler 2011). Since the production of the slips overlaps with fruit development and growth, slips may compete with fruit for assimilates available in the plants especially at the earlier stage of their development when they are not yet capable of producing their own assimilates. Thus, earlier slip pruning may have more positive effects on fruit quality than later pruning. Moreover, a higher uniformity in fruit weight and height might be achieved by pruning only the slips of the least developed plants that are likely to yield smaller fruits than well-developed plants. Thus far no literature has reported the effects of pruning slips selectively from plants with the smallest fruits in a crop on the final fruit quality and uniformity at harvest. Therefore, the sixth research question is:

RQ6: What is the effect of selective slip pruning on fruit quality and its variation at harvesting time?

1.6. Thesis outline

The part of the thesis following this introduction is organised according to the research questions, divided into eight main chapters (Figure 1.5):

Chapter 2 describes and analyses the existing fresh pineapple supply chains in the Atlantic department of Benin, the perception of quality within the chains and identifies the bottlenecks for delivering the right pineapple to the right market. First semi-structured interviews were conducted with key informants in the fresh pineapple supply chains. Then, in-depth questionnaires were administered to different actor groups in the pineapple chains: primary producers, exporters, wholesalers on different markets, retailers, middlemen and processors.

Chapter 3 deals with the current pineapple production systems in Benin and identifies the main constraints reducing the quality of the pineapple produced. The chapter is based on in-depth interviews with primary producers in Atlantic department. A finding from this chapter was that the heterogeneity in the quality of pineapple produced was high, which is elaborated in the next chapter.

The crop physiological mechanisms underlying the high fruit quality heterogeneity within a crop are studied in Chapters 4 and 5. Chapter 4 links the fruit quality of individual plants to the plant vigour at the time of flowering induction. Chapter 5 quantifies the trade-offs of flowering and maturity synchronisation on fruit quality. For these two chapters, field experiments were carried out on commercial pineapple fields.

In Chapters 6 and 7 possibilities are explored to reduce the fruit quality heterogeneity by using agronomic tools. Different types and sizes of planting material (Chapter 6) and pruning of slips of the least developed plants during fruit development (Chapter 7) were tested. For Chapter 6, field experiments were carried out on non-commercial fields; for Chapter 7, fields experiments were carried out on commercial fields.

This thesis concludes with Chapter 8, the general discussion, where results of different chapters are combined and discussed in depth in terms of their relevance for the pineapple sector in Benin as well as for the international scientific community. In Chapter 8, it is discussed how the fresh pineapple supply chains can be effective and how producers can tackle the constraints they encounter in producing high pineapple quality. Agronomic tools are suggested and the trade-offs between them are discussed.

Chapter 1: General introduction	- Background information on pineapple in Benin - Problem statement and analysis - Thesis objectives - Thesis outline
Chapter 2: Bottlenecks and opportunities for quality improvement in fresh pineapple supply chains in Benin	- Map and diagnose the fresh pineapple supply chains - Identify bottlenecks in pineapple quality improvement for different -markets **Approach**: *Interviews with actor groups using questionnaires*
Chapter 3: Analysis of pineapple production systems in Benin	- Describe and analyse pineapple production systems - Identify constraints reducing the quality of pineapple produced **Approach**: *Interviews with primary producers using questionnaires*
Chapter 4: Heterogeneity in pineapple fruit quality within crops results from plant heterogeneity at flowering induction	- Study association between plant vigour at flowering induction and fruit quality at harvesting time. - Study the role of the side-shoots in the fruit quality heterogeneity **Approach**: *Four experiments on commercial pineapple fields*
Chapter 5: Trade-offs of flowering and maturity synchronization for pineapple quality	- Quantify the trade-offs of flowering and maturity synchronization for pineapple quality, its heterogeneity and the proportion of exportable fruits. **Approach**: *Four experiments on commercial pineapple fields*
Chapter 6: Pineapple fruit quality and its variation as affected by weight and type of planting material	- Evaluate the effect of weight and type of planting material on pineapple fruit quality and its heterogeneity as well as the proportion of exportable fruits to Europe. **Approach**: *Two field experiments*
Chapter 7: Selective slip pruning in pineapple plants as means to reduce heterogeneity in fruit quality	- Study effect of selective slip pruning on fruit quality and whether the effect of selective slip pruning depends on the pruning time **Approach**: *Two experiments on commercial pineapple fields*
Chapter 8: General discussion	- How can the fresh pineapple supply chains be effective? - How can producers tackle the constraints they encounter? - Which agronomic tools can be used to improve the pineapple quality and its uniformity? - What further research needs to be done?

Figure 1.5. A schematic illustration of the different chapters in the thesis

References

Agbo, B., Agbola, G., Sissinto, E., & Akele, O. (2008). *Atelier de validation de la stratégie et d'élaboration de plan d'actions de la filière ananas au Benin*. Cotonou: MAEP and GTZ.

Arouna, A., & Afomassè, D. (2005). *Analyse de la compétitivité de la filière ananas au Benin*. Cotonou: Institut National de Recherches Agricoles au Benin (INRAB).

Audinay, A. (1970). Artificial control of pineapple ripening with Ethrel. *Fruits d'Outre Mer, 25*, 695-708.

Bartholomew, D. P., & Kadzimin, S. B. (1977). Pineapple. In P. Alvim & T. T. Kozlowski (Eds.), *Ecophysiology of tropical crops* (pp. 113-156). New York: Academic Press.

Bartholomew, D. P., & Malézieux, E. (1994). Pineapple. In B. Schaffer & P. C. Andersen (Eds.), *Handbook of environmental physiology of fruit crops Vol. II. Sub-tropical and Tropical Crops* (pp. 243-291). Boca Raton, Florida: CRC Press.

Bartholomew, D. P., Paull, R. E., & Rohrbach, K. G. (2003). *The pineapple: botany, production and uses*. Wallingford, UK: CABI Publishing.

Bowden, R. (1967). Translucency as an index of ripeness in pineapples. *Food Technology in Australia, 19*, 424-427.

Chen, C.-C., & Paull, R. E. (2000). Sugar metabolism and pineapple flesh translucency. *Journal of the American Society for Horticultural Science, 125*(5), 558-562.

Chen, C.-C., & Paull, R. E. (2001). Fruit temperature and crown removal on the occurrence of pineapple fruit translucency. *Scientia Horticulturae, 88*(2), 85-95.

Codex Alimentarius. (2005). Codex standard for pineapples. [Revision 1-1999, Amendment 1-2005]. Retrieved 10 January 2009, from www.codexalimentarius.net website: http://www.codexalimentarius.net/ web/more _info.jsp?id_sta=313

Coppens d'Eeckenbrugge, G., & Leal, F. (2003). Morphology, anatomy and taxonomy. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 13-32). Wallingford, UK: CABI Publishing.

Crochon, M., Teisson, C., & Huet, R. (1981). Effet d'une application d'ethrel avant la recolte sur la qualite gustative des ananas de Cote d'Ivoire. *Fruits, 36*, 409-415.

Cunha, G. A. P. (2005). Applied aspects of pineapple flowering. *Bragantia, 64*(4), 499-516.

De Greef, J., van Dijck, H., De Proft, M., & Mekers, O. (1982). Flowering maturity and ethylene production capacity of *Aechmea victoriana* through ACC application.

Growth Regulators, XXI IHC 137, 211-216.

FAO (Food and Agriculture Organization). (2009). *Statistical databases*. Retrieved 31 May 2012, from http://faostat.fao.org/site/342/default.aspx.

FAO (Food and Agriculture Organization). (2011). *Statistical databases*. Retrieved 10 October 2013, from http://193.43.36.221/site/339/default.aspx.

FAO (Food and Agriculture Organization). (2012). *Statistical databases*. Retrieved 28 November 2013, from FAO http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E.

Friend, D. J., & Lydon, J. (1979). Effects of daylength on flowering, growth, and CAM of pineapple (*Ananas comosus* [L.] Merrill). *Botanical Gazette, 140*(3), 280-283.

Gbenou, R. K., Traore, M., & Sissinto, E. (2006). *Etude accélérée de marché (EAM) sur les différents produits ananas au Benin*. Cotonou: Helvetas-Benin.

Gnanglè, C., Glèlè Kakaï, R., Assogbadjo, A., Vodounon, S., Yabi, J., & Sokpon, N. (2011). Tendances climatiques passées, modélisation, perceptions et adaptations locales au Bénin. *Climatologie, 8*, 27-40.

Heenkenda, H. (1992). Effect of plant size on sucker promotion in ‘Mauritius’ pineapple by mechanical decapitation. *Acta Horticulturae, 334*, 331-336.

Hepton, A. (2003). Cultural system. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 109-142). Wallingford, UK: CABI Publishing.

INRAB (Institut National de la Recherche Agronomique au Benin). (1995). *Plan directeur de la recherche agricole I. Politique nationale agricole*. Cotonou, Benin: INRAB.

INSAE (Institut National de la Statistique et de l'analyse economique). (2004). *Troisième recensement général de la population et de l’habitation (RGPH3)*. Cahier des villages et quartier du département de l’Atlantique. Cotonou: DED (Direction des Etudes Démographiques).

INSAE (Institut National de la Statistique et de l'analyse economique). (2014). *Quatrième recensement général de la population et de l’habitation* (RGPH4). Retrieved 8 May 2014, from INSAE http://www.insae-bj.org/

Kerns, K. R., Collins, J., & Kim, H. (1936). Developmental studies of the pineapple *Ananas comosus* (L.) Merr. *New Phytologist, 35*(4), 305-317.

Linford, M. B., King, N., & Magistad, O. C. (1934). Planting and fruit quality: comparison of large and small slips in pure and mixed stands. *Pineapple Quaterly, 4*, 176-190.

Malézieux, E. (1993). Dry matter accumulation and yield elaboration of pineapple in Cote D'Ivoire. *Acta Horticulturae, 334*, 149-158.

Malézieux, E., & Bartholomew, D. P. (2003). The pineapple: botany, production and uses. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *Plant nutrition* (pp. 143-165). Wallingford, UK: CABI Publishing.

Malézieux, E., Côte, F., & Bartholomew, D. P. (2003). Crop environment, plant growth and physiology. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 69-107). Wallingford, UK: CABI.

Marler, T. E. (2011). Leaf gas exchange of pineapple as influenced by fruit. *Acta Horticulturae, 902*, 239-243.

Mitchell, A. R. (1962). Plant development and yield in the pineapple as affected by size and type of planting material and times of planting and forcing. *Queensland Journal of Agricultural Science, Queensland, 22*, 409-417.

Norman, J. C. (1976). Influence of slip size, deslipping and decrowning on the 'Sugarloaf' pineapple. *Scientia Horticulturae, 5*(4), 321-329.

Onaha, A., Nakasone, F., & Ikemiya, H. (1983). Induction of flowering with oil-coated calcium carbide in pineapples. *Journal of the Japanese Society for Horticultural Science, 52*(3), 280-285.

Py, C., Lacoeuilhe, J. J., & Teisson, C. (1987). *The pineapple: cultivation and uses* (*Maisonneuve ed*.). Paris: Editions Quae.

Reinhardt, D., Souza, L. d. S., & Cabral, J. (2000). Abacaxi. Produção: aspectos técnicos. Cruz das Almas. *Embrapa Mandioca e Fruticultura, 7*, 41-44.

Saltveit, M. E. (1999). Effect of ethylene on quality of fresh fruits and vegetables. *Postharvest Biology and Technology, 15*(3), 279-292.

Siderius, C. P., & Krauss, B. H. (1938). Growth phenomena of pineapple fruits. *Growth, 1*, 181-196.

Singleton, V. L., & Gortner, W. A. (1965). Chemical and physical development of the pineapple fruit II. Carbohydrate and acid constituents. *Journal of Food Science, 30*(1), 19-23.

Tidjani-Serpos, A. (2004). *Contribution de la production d'ananas à l'amélioration des conditions de vie des producteurs: cas des Communes d'Abomey-Calavi et d'Allada dans le département de l'Atlantique (Sud-Bénin).* Thèse d'Ingénieur, Université d'Abomey-Calavi (UAC), Cotonou, Benin.

Wee, Y., & Ng, J. (1970). Decrowning and deslipping of the Singapore Spanish pineapple. *Tropical Agriculture, Trinidad and Tobago, 47*(1), 73-75.

CHAPTER 2

Bottlenecks and opportunities for quality improvement in fresh pineapple supply chains in Benin*

V.N. Fassinou Hotegni[1,2], W.J.M. Lommen[1], J.G.A.J. van der Vorst[3], E.K. Agbossou[2] and P.C. Struik[1]

[1] Centre for Crop Systems Analysis, Wageningen University, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands

[2] Faculté des Sciences Agronomiques, Université d'Abomey Calavi, 01 BP 526 Cotonou, Benin

[3] Operations Research and Logistics Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, the Netherlands

* Accepted for publication in the International Food and Agribusiness Management Review

Abstract

This study mapped and diagnosed the fresh pineapple supply chains in Benin to identify bottlenecks in pineapple quality improvement for different markets. A research framework was defined that comprised all relevant aspects to be researched. After 54 semi-structured interviews with key informants, 173 structured interviews were held with actor groups. The chain diagnosis showed there was no concordance between actor groups in which quality attribute they valued most. Moreover, pineapple quality was found to be highly heterogeneous. Key bottlenecks identified were lack of training of primary producers in production practices, unconditioned transport, and unavailability of boxes for export.

Keywords: *Ananas comosus*; pineapple; quality; outlets; supply chain.

2.1. Introduction

Pineapple [*Ananas comosus* (L.) Merrill] is a tropical fruit with a large production volume in the world (FAO 2009a). In West Africa, it is the second most important tropical fruit after banana (FAO 2009a). In Benin, it is one of the main crops in the Atlantic department in the south (Arouna and Afomassè 2005), where it is grown by 70% of the farmers for fresh consumption and processing into juice. Since 2006, pineapple is among the crops selected by the government in Benin to potentially alleviate poverty (Agbo et al. 2008) since Benin is the fourth country in the world delivering the highest pineapple yields (FAO 2012). Different market outlets exist: (1) the local outlet for fresh and processed pineapple, (2) the regional outlet for export to neighbouring countries (Nigeria, Ghana) for fresh and processed pineapple, and (3) the European outlet (export to Belgium, the Netherlands, France, etc.) for high-quality fresh pineapple.

The main problem of pineapple in Benin is the fact that the produce often does not meet the standards for any of the outlets and certainly not the European standards (Gbenou et al. 2006). Each time producers want to export fresh pineapple to European countries a huge quantity (more than 50% of what is delivered to be exported) is rejected because it does not meet the European import criteria (Gbenou et al. 2006). Despite frequent attempts, less than two percent of the total production of pineapple is exported to European countries (Agbo et al. 2008; FAO 2011). For example, in 2009, the pineapple production was about 222,223 Mg, but only 7 Mg (0.033 %) was exported (FAO 2009b). In 2010, from 220,800 Mg of pineapple produced, only 82 Mg (0.037%) was exported (FAO 2011). The remaining pineapples were delivered to the local and regional markets with lower quality demands and lower prices. Unfortunately, most of these pineapples lose their quality before being consumed (Gbenou et al. 2006) resulting in huge losses.

These problems show that the current pineapple supply chains are not effective in supplying the right quality of pineapple to meet the demands of the present markets. Such problems are also encountered in other countries, e.g. in Thailand (one of the biggest pineapple producers in the world) (Joomwong and Sornsrivichai 2005), and other crops in most Sub-Saharan African countries (Temu and Marwa 2007), e.g. mango in Ethiopia (Joosten 2007) and fresh fruits and vegetables in Kenya (Neven and Reardon 2004). Increased knowledge on how the different supply chains operate, and on existing bottlenecks for improving quality, is important to tackle these problems and establish effective chains. The primary objective of this paper is to describe and analyse the fresh pineapple supply chains in Benin and identify the main constraints for quality improvement to fulfil the requirements for different markets. The secondary objective of this paper is to identify the pineapple quality preferred in the different outlets and compare the quality preferred to the quality supplied. We based our analysis of the pineapple supply chains on a framework of Lambert and Cooper (2000) adapted by Van der Vorst et al. (2005). Preliminary results from semi-structured interviews helped us formulate the appropriate questions within the selected framework and develop a proper sampling strategy for the subsequent in-depth questionnaires with actor groups in the fresh pineapple supply chains. This study is an essential step towards improving the fresh pineapple supply chains in Benin. The approach used in this study can be applied by researchers working on other agri-foods chains, mainly in developing countries where there is a great need to understand why different chains are not effective in achieving their objectives.

The paper is organized as follows: first the research framework is described. Second, the methods used to gather and analyse information in the chains are described. Thereafter, we present results obtained through this framework and discuss how they contribute to meeting the objectives. Answers to the question "why the chains are not effective in supplying the right pineapple quality" are provided. Finally, the main findings are summarised followed by suggestions for quality improvements in the supply chains.

2.2. Research framework

A supply chain (SC) is generally defined as "a network of physical and decision-making activities connected by material and information flows that cross organizational boundaries" (Van der Vorst et al. 2009) and aims to deliver superior consumer value in a sustainable way at low cost. In the present study, a supply chain was regarded as viewed by Bijman (2002) i.e. as an orderly sequence of processes and flows of products and information from primary producers to consumers. This implies that in supply chains studies, actor groups, processes, flows of products and information management should be considered. In the last two decades much research has taken place analysing supply chains (foremost in the developed world) and identifying major improvement options (see Ebrahimi and Sadeghi 2013; Shukla and Jharkharia 2013 for recent reviews). A framework of Lambert and Cooper (2000), later adapted by Van der Vorst et al. (2005) is often used by scientists to evaluate and analyse logistic and information-management processes in food supply chains (Szymanowski 2007;

Van der Vorst et al. 2007; Verdouw et al. 2008).

In line with Van der Vorst et al. (2005) five elements are used to analyse the different fresh pineapple supply chains: (1) chain objectives and performance indicators, (2) the supply chain network structure, (3) supply chain business processes, (4) supply chain management components, and (5) chain resources (Figure 2.1). Preliminary results from semi-structured interviews (see Materials and Methods) helped us to phrase appropriate research questions within the framework, taking into account the characteristics of the pineapple chains studied. This resulted in 11 research questions that are projected within the elements of the framework described below (Figure 2.1).

2.2.1. Chain objective and performance indicators

The objective of the pineapple supply chain was assumed to be to deliver the right quality of pineapple to the different market outlets. To assess whether an objective is realized or not, specific performance indicators are required. In the present study, the main performance indicator was whether customer expectations regarding the quality of delivered product are met. In order to meet or exceed customer's expectations, it is important to know what quality of pineapple customers prefer (quality preferred) and to ensure that they are supplied with pineapples of that quality (Research questions 1 and 2 in Figure 2.1).

2.2.2. Supply chain network structure

The network structure is a description of (1) the different groups of actors in the chains, their roles and their experience in performing their activities, and (2) the interrelationships between actor groups in the network, thereby describing the different routes products take from primary producers to consumers (Lambert and Cooper 2000). The aim of describing the network structure was to sort out prevailing chains and to identify and characterise different groups of actors operating in these chains (Research questions 3 and 4 in Figure 2.1).

2.2.3. Supply chain business processes

Business processes include all activities designed to produce a specific output for a particular customer or market (Lambert and Cooper 2000; Van der Vorst 2006). In our case, business

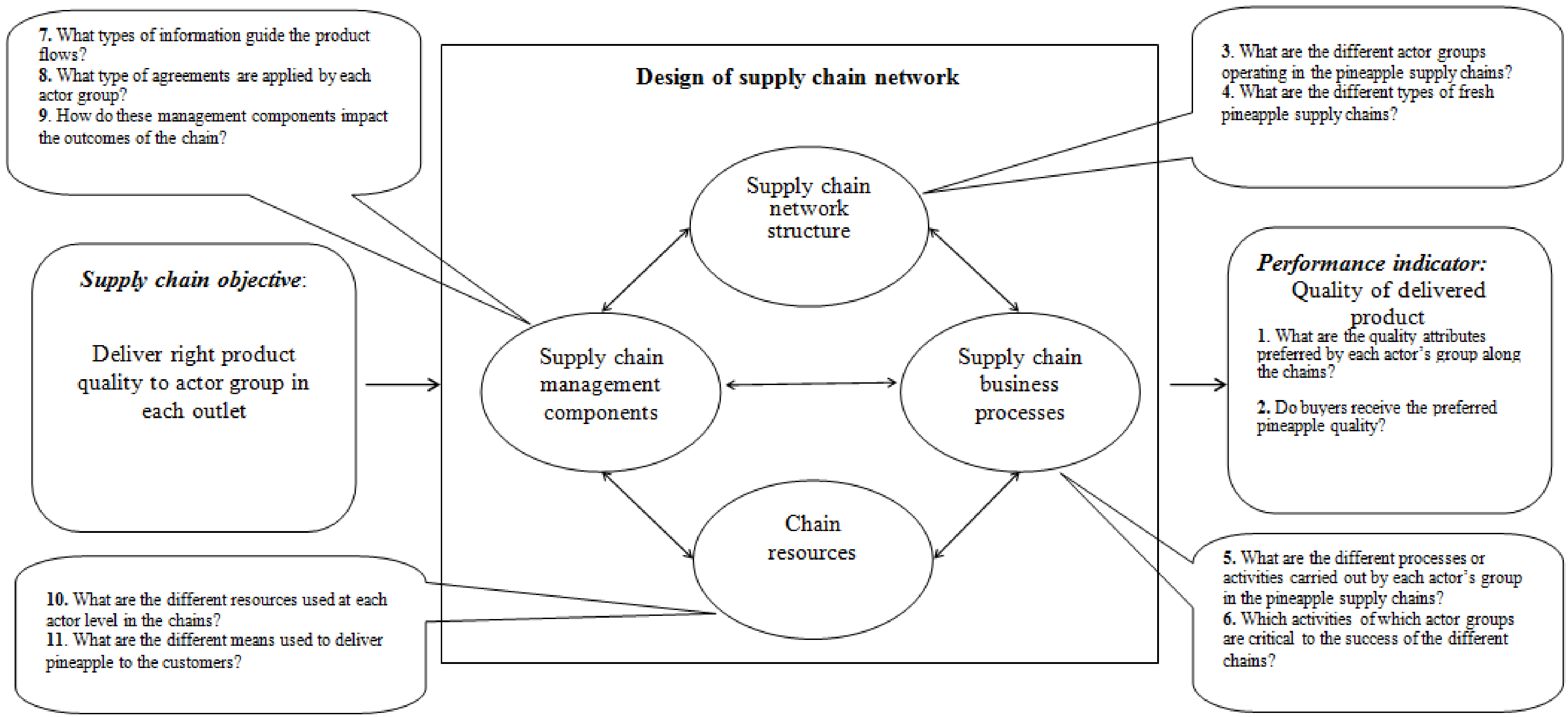


Figure 2.1. Research questions (1-11) within the research framework used in this study (adapted from Lambert and Cooper (2000) and Van der Vorst et al. (2005))

processes refer to all practices executed to meet the buyer's expectations in terms of pineapple quality. For example, how are pineapples grown and stored and what is done to reduce quality deterioration. The focus was on harvesting and storage practices because information on cultural practices was published by Fassinou Hotegni et al. (2012). The aims were to describe these practices in each actor group and to identify which practices influence product quality (Research questions 5 and 6 in Figure 2.1).

2.2.4. Supply chain management components

Lambert and Cooper (2000) defined nine management components in food supply chains needed for successful supply chain management: planning and control; work structure; organization structure; product flow facility structure; information flow facility structure; management methods; power and leadership structure; risk and reward structure; and culture and attitude. In our case of the fresh pineapple supply chain two management components were considered: the information flow facility (what kind of information is exchanged between actor groups and how) and the management methods (what are the different types of agreements between actor groups and when are agreements made). These management components were identified as relevant from the results of the semi-structured interviews (Research questions 7, 8 and 9 in Figure 2.1).

2.2.5. Chain resources

To ensure product and information flows, resources are needed. Chain resources include facilities, logistics means and information capabilities (Van der Vorst et al. 2005). The aim of integrating chain resources in the framework is to know the resources used by each actor group in the chains and to analyse how these resources could constitute a bottleneck to the success of the supply chains. In the present study, the focus was on the transport means because they were identified as the most used chain resources (Research questions 10 and 11 in Figure 2.1).

2.3. Methodology

A two-step method (Korneliussen and Grønhaug 2003) was used to collect data on the fresh pineapple supply chain network. First, 54 semi-structured interviews were held with key informants. Then, 173 structured interviews using in-depth questionnaires were held with different supply chain actors.

2.3.1. Semi-structured interviews

Semi-structured interviews (Leech 2002) were held with key informants in the fresh pineapple supply chains during September and October 2009 using a semi-structured questionnaire. Key informants comprised 13 primary producers, 1 exporter, 12 wholesalers plus retailers in different markets, 6 processors and 12 pineapple experts from 10 knowledge institutions. The aims of these semi-structured interviews were to obtain an overview of (1) actor groups in the chains (2) the activities carried out by the actor groups in the chains (3) information and product flows between actor groups in the chain and (4) the most important quality attributes for each actor group. This overview helped to select and elaborate proper research questions within the framemork. The main themes of the semi-structured interviews were (1) the actor groups in the chain and the pineapple cultivars grown and sold, (2) existing chains (3) product and information flows in the chains (4) activities by each actor group (5) main quality attributes for fresh pineapple, and (6) constraints hampering high quality.

2.3.2. Structured interviews using in-depth questionnaires

Actor groups sampling

Based on the preliminary results of the semi-structured interviews with key informants, in-depth questionnaires were designed and administered face-to-face during May and June 2010, to 100 primary producers, 3 exporters, 50 traders (35 wholesalers and 15 retailers), 10 middlemen and 10 processors. The primary producers were interviewed in the municipalities of the Atlantic department where pineapple was mainly produced (Table 2.1). These municipalities contributed 99% of the total pineapple production in the Atlantic department (Gbenou et al. 2006). The number of interviewed primary producers per municipality was proportional to its contribution to the total production in the Atlantic department. A stratified sampling method (Bailey 2008) based on the number of primary producers was used to determine the number of respondents per pineapple growing area within a municipality. Table

2.1 shows the number of primary producers surveyed per pineapple growing area. The wholesalers and retailers were selected proportionally to their number from the five main markets Sèmè Kraké, Dantokpa, Zè, Sékou and Sèhouè. Wholesalers on Zè, Sékou and Sèhouè sold to local customers only, whereas wholesalers on Sèmè Kraké and Dantokpa might focus on either local or regional customers. The processors and middlemen were randomly selected in the different municipalities. Local consumers, regional customers and importers were not part of this study.

Table 2.1. Number of primary producers surveyed per pineapple growing area

Municipality	Pineapple growing area	Number of primary producers
Abomey-Calavi	Fanto	11
	Glo-Centre	10
	Wawata	7
	Zinvié-Zoumè	6
	Kpé	4
	Kpaviédja	2
Zè	Agbondjedo	8
	Tangbo	7
	Anagbo	5
	Adjamè	4
	Houeta	3
	Gandaho	3
Allada	Adimalè	7
	Dodji Aliho	6
	Loto Dénou	4
	Lokoli	3
Tori	Sogbé Hétin	5
Toffo	Agbamè	3
	Ouègbo-Gare	2
TOTAL		100

Information collected

The questionnaires were designed to gather information on the network structure, the business processes at each actor group level, the management components, the resources used, the most important quality attributes and quality criteria per actor group, and constraints experienced by the actor groups operating in the chain for successfully delivering the right quality to the right market. Below the *network structure* respondents were first asked on their education level, experience in pineapple, the contribution of pineapple to their total income and the pineapple cultivars cropped/sold. Next, respondents were asked to name the actor groups from whom they received the pineapple and to whom they delivered the pineapple. Below the *business processes*, primary producers were asked how they cultivated their pineapples, on the their harvesting practices; on whether they had received any training on the pineapple production practices and on whether they belonged to a producer's organisation or not. The other actor groups were asked how and how long they stored their pineapples. Below *management components*, respondents were asked about the different types of agreements they had with other actor groups. Below *resources*, respondents were asked how the pineapple was transported from one actor to another.

Possible constraints on training and resources were identified based on the interviews with the key informants. Questions on these constraints during the in-depth interviews were pre-formulated. Respondents were asked to either agree or disagree using a five-point Likert scale (1 = completely disagree to 5 = completely agree) as suggested by Henson and Loader (2001) to find the barriers to agricultural exports from developing countries. Later the Likert points were regrouped into three points: agree (combining "completely agree" and "agree"), neither agree nor disagree and disagree (combining "completely disagree" and "disagree") (Allen and Seaman 2007).

2.3.3. Quality attributes and criteria determination along the chains

To determine which quality attributes each actor group valued most, the five attributes most frequently mentioned in the semi-structured interviews (weight of the pineapple, skin colour, skin damage, firmness and taste of the pineapple flesh) were presented to the respondents; they were asked to rank these five quality attributes for each of the pineapple cultivars grown and traded in Benin from the first to the fifth, with the first being what they valued most and the fifth being what they valued least.

To determine which criteria primary producers, wholesalers, retailers and processors applied to value different quality attributes, actor groups were asked to select the relevant criteria for weight of the pineapple, skin colour, skin damage, firmness, taste of the pineapple flesh, translucency of the pineapple flesh and internal browning. To determine the preferred weight of the pineapple, an at-line measurement technique was used (Callis et al. 1987), i.e.

three pineapples (fruit including crown) were selected by each respondent and weighted at their selling place. Skin colour criteria were determined using different maturity degrees: [0-25]%, [25-50]%, [50-75]% and more than 75%, concerning how many of the eyes of the pineapple were yellow. The criteria regarding skin damage were determined from four modalities: skin free of damage, damage on 1-4% of the area, damage on 4-8% of the skin area and more than 8% of the skin area damaged. The firmness criterion had two modalities: high or low. The taste of the pineapple was determined using sugar and lemon taste (well known by the respondents) as reference in modalities: always a taste like sugar, always a taste in between sugar and lemon, and always the lemon taste. The criteria used for translucency and internal browning were derived from Soler (1992). For translucency three modalities were used: [0-25]%, [25-50]%, and more than 50% of the flesh of the pineapple showing translucency. For internal browning four modalities based on the proportion of the blackheart symptoms were used: [0-25]%, [25-50]%, [50-75]%, and more than 75% of the flesh of the pineapple showing blackheart symptoms. Pictures were taken from Soler (1992) to help respondents indicate their choice. The European market quality attributes and criteria of importers were derived from the Codex standard for pineapple (Codex Alimentarius 2005). The heterogeneity in the pineapple quality supplied, important for exporting pineapple to Europe, was also assessed. Respondents were asked to agree or disagree using a five-point Likert scale (1 = completely disagree to 5 = completely agree) (Henson and Loader 2001) on whether the lot of the pineapple produced/supplied was highly heterogeneous.

2.3.4. Statistical analysis

Data were analysed using SPSS (Statistical Package for Social Science), version 16.0. To describe the supply chain network structure, descriptive statistics such as percentage were used to describe the (1) actor groups in the chain and (2) proportion of actors groups supplying the next actor group (s) with pineapples. To describe the business processes, the management components and the resources at each actor group level, descriptive statistics such as percentages were used. Practices below the business processes, management components, and resources elements were viewed to be critical for the chain objective when they were demonstrated in literature to negatively affect the quality of the product. To establish differences in the percentage of actors falling in the different Likert-scale classes for the different constraints, non-parametric Chi-square tests were performed (Clason and

Dormody 1994; Pallant 2010). For data on quality attributes, non-parametric Kendall coefficient of concordance (W) tests were first performed to test whether there was agreement within groups of actors in ranking different quality attributes from first to fifth (Kendall and Smith 1939; Legendre 2005). To test for differences in quality criteria (quality criteria produced/supplied by primary producers/sellers versus quality criteria preferred by customers), non-parametric Kruskal-Wallis tests were used. When differences between actor groups were significant, this test was followed by Mann-Whitney U tests (Field 2005) to compare a given actor group against all other groups. A Bonferroni's correction was applied (to control the type I errors), so all differences revealed by the Mann-Whitney U tests were reported at 0.05/10= 0.005 level of significance with 10 being the number of comparisons (Field 2005). To compare the differences in preferred weight among actor groups one way ANOVA was performed. For comparison of means, Gabriels pair-wise test procedure was applied at 0.05 significance level as the numbers of respondents in each actor group were not equal (Field 2005).

2.4. Results

In this section first the preliminary results of the semi-structured interviews will be presented, second the structure of the chain network will be described, third the business processes, thereafter the chain management components and the chain resources. Finally, the quality attributes and criteria preferred by the different actor's groups as well as a comparison between the pineapple quality supplied and the pineapple quality preferred will be presented.

2.4.1. Preliminary results of semi-structured interviews

The fresh pineapple supply chain was composed of primary producers, exporters (i.e. producers selling to the international market), wholesalers[1] (selling at local or regional markets), retailers, processors and so-called "middlemen". The middlemen's role was to seek for pineapple fields about to be harvested and to connect primary producers to customers. The numbers of pineapple primary producers, fresh pineapple exporters and formal processors in

[1]The difference between wholesalers in local market and wholesalers in regional market was based on the main clients they sold their pineapple to. So, wholesalers in local market comprised those selling their pineapple mainly to local customers while wholesalers in regional market comprised those selling mainly to regional customers.

the Atlantic department were estimated to be 3191, 3 and 25, respectively. Primary producers, exporters and middlemen were located in the pineapple growing areas in five municipalities, Abomey Calavi, Zè, Allada, Tori and Toffo, out of the eight municipalities that constitute the Atlantic Department. Wholesalers and retailers were based on five market places Sèmè Kraké (in Sèmè- Kpodji), Dantokpa (in Cotonou), Zè (in Zè), Sékou (in Allada) and Sèhouè (in Toffo). Their number fluctuated in these five markets places. Sèmè Kraké and Dantokpa were the main market places for the regional market since they were visited by both local and regional customers, i.e. customers from neighbouring countries, such as Nigeria, Ghana, Burkina Faso, Mali and Ivory Coast. Zè market, Sékou market and Sèhouè market were the main market places considered as local markets where pineapple was sold as the main commodity. Wholesalers and retailers had their base on the five market places considered in the study. Processors were located throughout the Atlantic department but most of them were not located in the pineapple growing areas, but in Littoral department (bordered by Atlantic department in West) close to the regional market places. Two pineapple cultivars were grown and sold: Smooth Cayenne and Sugarloaf.

Different activities took place at each actor group level. At primary producer's/exporter's level, the pineapple fruits were cultivated and harvested. At the wholesaler's/retailer's level, the pineapple fruits were just stored and sold. Wholesalers and retailers had their storage place on the five markets earlier mentioned. At processor's level, the pineapple was stored and processed into juice and dried pineappple. From one actor group to the next, trucks were used to transport the pineapple. Between primary producers and other actor groups in the chains, there were often some agreements made during the pineapple production which lasted 15-18 months. These agreements were often made by phone calls and were mainly based on the quantity, quality and the delivering time.

Wholesalers, retailers and processors affirmed not being supplied with their preferred pineapple quality. The most frequently mentioned quality attributes by actor groups, being the most valued ones, were the weight of the pineapple, skin colour, skin damage, firmness and taste of the pineapple flesh.

2.4.2. Structure of the pineapple chain network

Actor groups

Table 2.2 summarises the characteristics of the actor groups in the fresh pineapple chains. Most primary producers, exporters, processors and all middlemen were male; all wholesalers and retailers were female. Producers, and especially middlemen, wholesalers and retailers had less education than exporters and processors. 56% of the producers, all exporters and 63% of the wholesalers had 10 or more years of experience in pineapple cropping or selling, whereas all middlemen, 67% of the retailers and 60% of the processors had less than 10 years of experience in pineapple selling/processing. The contribution of pineapple to the total income was at least 40% for at least 90% of the respondents in each actor group, and at least 80% for the exporters and the majority of the wholesalers and retailers. Sugarloaf was the most cultivated and sold cultivar. Smooth Cayenne was the most exported cultivar.

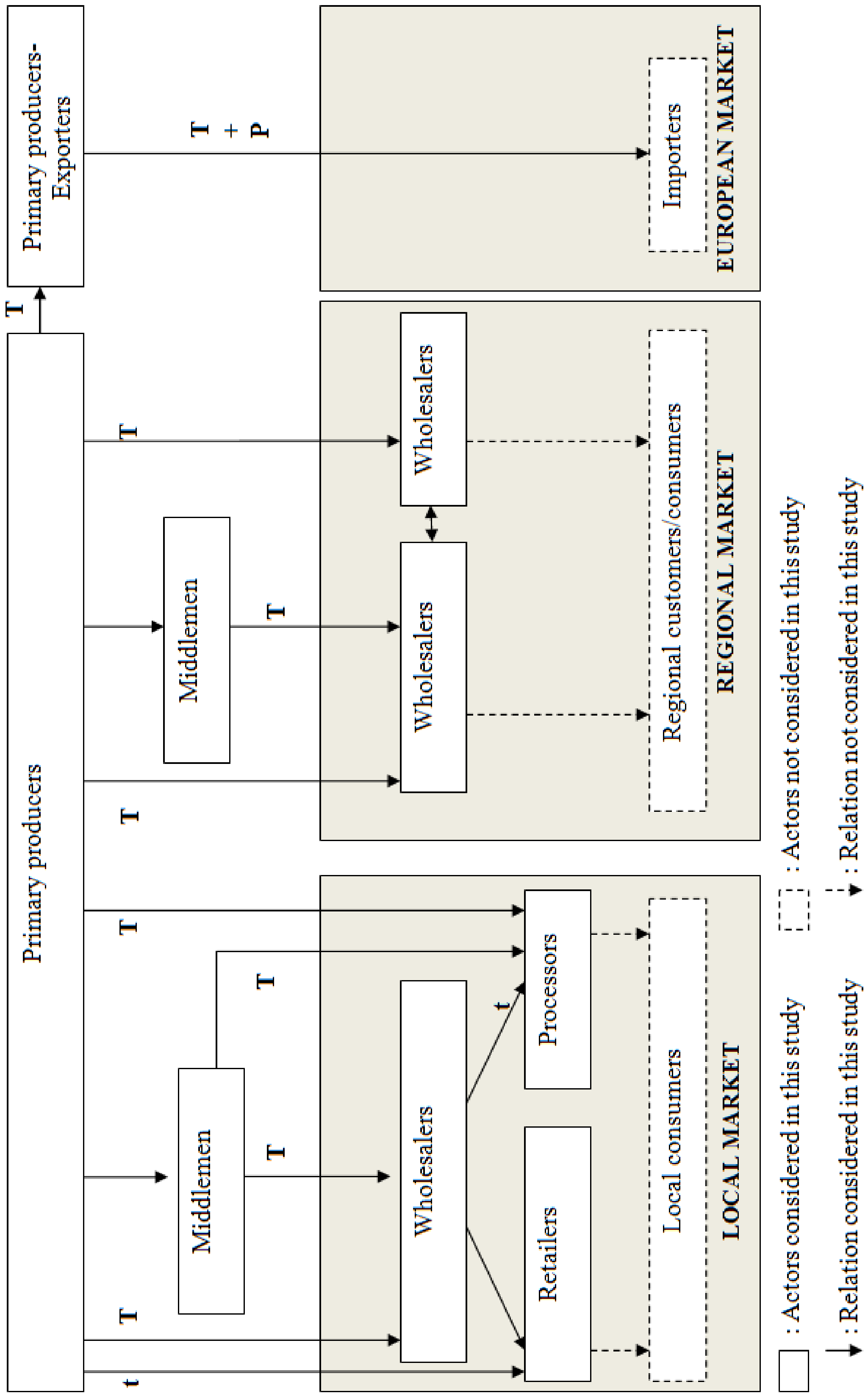
Chain structures

Figure 2.2 shows the different structures of the fresh pineapple chains. Two types of fresh pineapple supply chains prevailed to reach the local and regional markets: (1) chains where the customers (retailers, wholesalers and processors) reach the consumers after obtaining their pineapples directly from the primary producers, and (2) chains where customers reach the consumers after obtaining their pineapples through middlemen. In the local markets, seven fresh pineapple supply chains were prevailing: 1) primary producers-retailers-local consumers, 2) primary producers-wholesalers-retailers-local consumers, 3) primary producers-wholesalers-processors, 4) primary producers-middlemen-wholesalers-retailers-local consumers, 5) primary producers-middlemen-wholesalers-processors, 6) primary producers-middlemen-processors and 7) primary producers-processors. Three chains prevailed in the regional markets: 1) primary producers-wholesalers-regional customers, 2) primary producers-middlemen-wholesalers-regional customers, and 3) primary producers-middlemen-wholesalers-wholesalers-regional customers. For the European markets, the exporters sent their own pineapples to the importers, but incidentally bought pineapples from other primary producers (non-exporters) to meet the demand.

Table 2.2. Classification of the respondents based on different characteristics (%)

Characteristics	Modalities	Primary producers (n=100)	Exporters[a] (n=3)	Middlemen (n=10)	Wholesalers (n=35)	Retailers (n=15)	Processors (n=10)
Sex	Male	93	66	100	0	0	70
	Female	7	34	0	100	100	30
Education level	Non educated	42	0	60	74	86	0
	Literate	8	0	10	3	0	0
	Primary school	28	0	30	17	7	0
	Middle school	21	0	0	3	7	40
	University level	1	100	0	3	0	60
Experience (Exp) in pineapple	< 5 years	13	0	30	11	40	20
	5 ≤ Exp < 10 years	31	0	70	26	27	40
	10 ≤ Exp < 15 years	33	0	0	40	27	40
	≥ 15 years	23	100	0	23	6	0
Contribution of pineapple to total income (Inc)	< 20%	0	0	0	0	0	0
	20 ≤ Inc < 40%	7	0	0	0	0	10
	40 ≤ Inc < 60%	13	0	70	11	0	20
	60 ≤ Inc < 80%	51	0	30	20	33	30
	≥ 80%	29	100	0	69	67	40
Pineapple cultivars cropped/sold	Sugarloaf only	70	0	-[b]	69	87	30
	Smooth Cayenne only	3	0	-	0	0	0
	Both cultivars	27	100	-	31	13	70

[a] Primary producers who exported to European markets
[b] Did not crop/sell pineapple



T= Big truck "bachées"; t= Small truck "taxis"; P= Plane (Air transport)

Figure 2.2. Structure of the pineapple chains in Benin including means of transport of pineapple between actor groups

From primary producers to wholesalers, retailers, processors and exporters

Most of the Sugarloaf and 50% of the Smooth Cayenne wholesalers that obtained their pineapple directly from producers, bought from 6 or more producers (Table 2.3), while the limited number of retailers buying Sugarloaf directly from primary producers, bought only from 1-5 primary producers. Processors bought Sugarloaf directly from 6 or more primary producers. No retailers bought Smooth Cayenne from primary producers. All exporters obtained their additional pineapples directly from 11 or more primary producers. When middlemen were involved in obtaining pineapples from primary producers, the number of middlemen was no more than 4 for most wholesalers and 5 or more for most processors, for both cultivars (Table 2.3).

From wholesalers to wholesalers, retailers and processors

Wholesalers constituted another source of pineapple for the retailers and processors in the local market and for other wholesalers in the regional markets (Figure 2.2). The pineapple was delivered to retailers and processors on a first come first served basis by means of small trucks.

Most wholesalers obtaining pineapple from other wholesalers bought from 1-6 wholesalers (Table 2.3). This was observed at Dantokpa and especially Sèmè Kraké market places where 90% of the wholesalers sold their pineapples to regional customers. To meet those customers’ demands, wholesalers were often obliged to turn to other wholesalers at the same market. Most sales to regional customers took place during the evening and night at Sèmè Kraké market place.

Most retailers buying Sugarloaf from wholesalers obtained their pineapples from 4 or more wholesalers whereas retailers buying Smooth Cayenne got their pineapples from fewer than four wholesalers (Table 2.3). Most retailers bought and sold from the same market.

For both cultivars, most processors buying from wholesalers obtained their pineapples from 4 or more wholesalers.

Table 2.3. Percentage of different customers buying their pineapple from a given number of primary producers (directly or through middlemen) and wholesalers, for pineapple cultivars Sugarloaf and Smooth Cayenne

Pineapple source	Chain type	Number of people	Customers: Wholesalers (n=35)		Retailers (n=15)		Processors (n=10)		Exporters (n=3)	
			Sugarloaf (n=35)	Smooth Cayenne (n=11)	Sugarloaf (n=15)	Smooth Cayenne (n=2)	Sugarloaf (n=10)	Smooth Cayenne (n=7)	Sugarloaf (n=3)	Smooth Cayenne (n=3)
Primary producers	Directly[a] from primary producers	1-5	12	36	13	0	40	0	0	0
		6-10	34	9	0	0	20	0	0	0
		≥ 11	34	27	0	0	0	0	100	100
		Total	80	72	13	0	60	0	100	100
	Through middlemen	1-2	20	55	0	0	0	0	0	0
		3-4	20	9	0	0	30	29	0	0
		≥ 5	9	18	0	0	70	71	0	0
		Total	49	82	0	0	100	100	0	0
Wholesalers[b]	Directly from wholesalers	1-3	14	18	40	100	20	0	0	0
		4-6	14	27	47	0	10	14	0	0
		≥ 7	6	0	13	0	30	42	0	0
		Total	34	45	100	100	60	56	0	0

[a] Directly from primary producers means they contact primary producers themselves either by cell phone or face to face
[b] No customers obtained their pineapple from wholesalers through middlemen

2.4.3. Business processes

At primary producer's/exporter's level

The processes at primary producer's level consisted of cultivating and harvesting pineapple for different outlets. According to Fassinou Hotegni et al. (2012), the production system was either inspired from neighbour producers or inspired from those in use in neighbouring countries. Inputs used by producers included planting material (slips, hapas and suckers), fertilisers, and chemical products to induce flowering and to synchronise maturity. The planting materials were derived from plants kept in the field after harvest of the fruits for about 6 months. The primary producers obtained planting material either from their own previous field or from other producers' fields. Shops and CeRPA (Centre Régionale de la Production Agricole) were used to obtain the fertiliser; the chemical products to induce flowering and to synchronise maturity were obtained from shops and CeRPA.

After planting, fertilisers were applied, and carbide of calcium and ethephon were applied to induce flowering and synchronize maturity, respectively. Details on production practices are described by Fassinou Hotegni et al. (2012). Here attention is given to the harvesting practices and the producer's training.

At harvest time, pineapples were harvested by workers (generally women) hired by either the buyers or the primary producers. After harvest, 83% of the primary producers stated that they kept their pineapple fruits on the soil for a period proportional to the size of the field (generally this period ranged from 1 to 6 hours). The pineapple was loaded by two loaders hired by the drivers in unconditioned trucks. At the exporter's level, the pineapple once harvested were first sorted at the production site based on the quality attributes (mainly the external quality attributes, i.e. the skin colour, crown height, fruit height and fruit size) and then packed in boxes based on the uniformity in quality attributes before being sent to importers. The boxes were bought from neighbouring countries and were often not available leading to reduction or delay in the volume being exported.

There was a significant difference between the number of primary producers agreeing and disagreeing on not having received training to cultivate pineapple for (1) fertiliser application time and rate, (2) flowering synchronisation practices, time of application and rate, and on (3) pest and weed management ($P < 0.05$ in all cases) (Table 2.4).

Table 2.4. Percentage of primary producers that agree or disagree with having received training on pineapple production practices since they have started producing pineapple, based on the Likert-scale, n=100

Likert-scale[a]	No training on fertilisers application rate	No training on fertilisers application time	No training on flowering induction practices	No training on flowering induction time	No training on pest and weed management
Disagree	37	36	32	31	16
Neither agree nor disagree	4	4	4	4	5
Agree	59	60	64	65	79
$\chi 2$(Chi-square)[b]	5.042 *	6.000 *	10.667 *	12.042 *	41.779 *

[a] The five Likert-scale points were regrouped into three points: Agree (combining "completely agree'' and "agree''), neither agree nor disagree and disagree (combining "completely disagree'' and "disagree'').
[b] Chi square test was performed to compare the number of primary producers who disagree with those who agree. Therefore, the number of primary producers that "neither agree nor disagree'' with the statements were not considered.
*: Statistically significant at $0.05 > P \geq 0.01$

The number of primary producers agreeing that they never had received training since they had been cultivating pineapple was higher than the number disagreeing. Fifty eight per cent of the producers were not member of a producer's organisation.

At wholesalers and retailers and processors level

Pineapples delivered to wholesalers, retailers and processors were stored on the ground in a pile and kept in sunlight or shade, covered with bags or not covered. About 43% of the wholesalers stored their pineapples in the shade without covering, 32% in sunlight without covering, whereas 20% and 70% of the processors, respectively, stored their pineapple in these ways. Pineapple stayed in these conditions for 1-3 days. All retailers stored their pineapple in shade without covering them, for a period of 1-7 days.

2.4.4. Chain resources

From primary producers to wholesalers, retailers, processors and exporters

The pineapples were transported by independent drivers hired by the buyers, from primary producers to wholesalers, processors, retailers or exporters using either big trucks called "bachées'' or small trucks called "taxis" (Figure 2.2); "bachées", of which the capacity ranged from 1200 to 1400 pineapples for Smooth Cayenne and from 1440 to 2160 pineapples for Sugarloaf, were used when customers were wholesalers, processors or exporters; "taxis", of which the capacity ranged from 400 – 470 pineapples for Smooth Cayenne and from 480 – 720 pineapples for Sugarloaf, were used for transport to retailers (Figure 2.2). In both cases, environmental conditions were not controlled and pineapples were loaded individually next to each other by the loaders.

About 26% of the wholesalers deemed that they did not receive their pineapple on time and this was, next to lack of quality, one of the reasons why they rejected pineapple from the primary producers.

However, most of the wholesalers accepted the pineapple even if the quality was not what they expected; but in that case the price was reduced.

From exporters to importers

Exporters sent their pineapples to importers in European countries by plane (Figure 2.2). The pineapples were transported to the airport by means of either big trucks under uncontrolled conditions (when the volume of pineapple being exported was less than 5 tonnes) or very big trucks (when the volume of pineapple being exported was more than 5 tonnes) under controlled conditions. Once at the airport, the pineapples were unloaded from the trucks and loaded in the plane. However, it often occurred that the pineapple stayed for some hours or days under uncontrolled conditions at the airport before being loaded in the plane. Generally this situation was due to a lack of synchronisation between the pineapple harvest time and the plane (generally Air France) departure to Europe.

The importers transported the pineapples to the different European markets (Belgium, the Netherlands, France, etc.).

2.4.5. Management components

Three types of agreements existed between the primary producers and their customers (Table 2.5): (1) agreements made before planting time; in that case, producers had fixed customer(s) and the pineapple was delivered to them no matter the harvesting time; (2) agreements made between planting and before harvest; producers delivered all pineapple no matter the harvest time and quantity to a fixed customer(s) and (3) no agreements made before harvest time; primary producers falling in the third type of agreement had no contact with the buyer before the pineapple reached the closest stage to the harvest time.

Sometimes, primary producers making the third type of agreement could not find a buyer until they harvested their pineapple and brought them to the closest market. The proportion of producers making a certain type of agreement was not cultivar dependent (Table 2.5). The quantity of pineapple bought by wholesalers, retailers and processors depended on the quantity of pineapple in store and the period of the year. Most wholesalers (71%) bought one or two big trucks of pineapple from the producers when the quantity of pineapple in store was reaching a level of 60-90 pineapples. Retailers who obtained their pineapple from the wholesalers generally bought 40 pineapples (one forty) only when they had no pineapple left to sell. Retailers who obtained their pineapple directly from the primary producers generally bought 320-600 pineapples (8 to 15 forties) when the quantity of pineapple in store was reaching a level of 40-60 pineapples.

Processors bought a quantity of pineapple that ranged from one to four trucks for both cultivars when the quantity of pineapple in store was reaching one truck. The quantity of pineapple asked for by regional customers ranged from 120 pineapples to two big trucks loads.

Wholesalers, retailers obtaining their pineapple directly from primary producers, and processors affirmed that their buyer demand for pineapple was lower from mid-March to July and from mid-September to mid-October, while in the other months of the year (Mid-October to Mid-March and Mid-July to Mid-September) the demand was high. However, wholesalers, retailers and processors agreed that they bought their highest volume of pineapple from August to October coinciding with the Muslim fasting period of the study year.

Generally, exporters received orders from importers in European markets some months before the exporting date. The demand for pineapple by the importers varied between 20-40 tonnes (8-16 big trucks) per week. During the long dry season (January, February, March and early April), exporters faced problems to meet this quantity of fresh pineapple; they then collected additional pineapple from 20-40 well-known producers to whom they provided technical assistance in pineapple production. This collection was based on the external quality attributes and the uniformity in quality attributes required by the importers.

Table 2.5. Percentage of primary producers making selling agreements with wholesalers and processors at different pineapple developmental phases for two cultivars

Pineapple cultivar	Type of agreement			χ^{2a}
	Agreement made before planting	Agreement made between planting time and harvest	No agreement made before harvest	
Sugarloaf (n=97)	41	29	30	1.292 ns
Smooth Cayenne (n=30)	30	37	33	

[a] χ^2-analysis was carried out on numbers
ns: Not statistically significant, $P \geq 0.05$

2.4.6. Quality attributes and criteria along the chains

Most important quality attributes for different actor groups

Actor groups differed in their ranking of the quality attributes, weight of the pineapples, skin colour, skin damage, firmness and taste of the pineapple flesh from the most valued (first rank, first quality attribute) to the least valued (fifth rank, fifth quality attribute) (Figure 2.3).

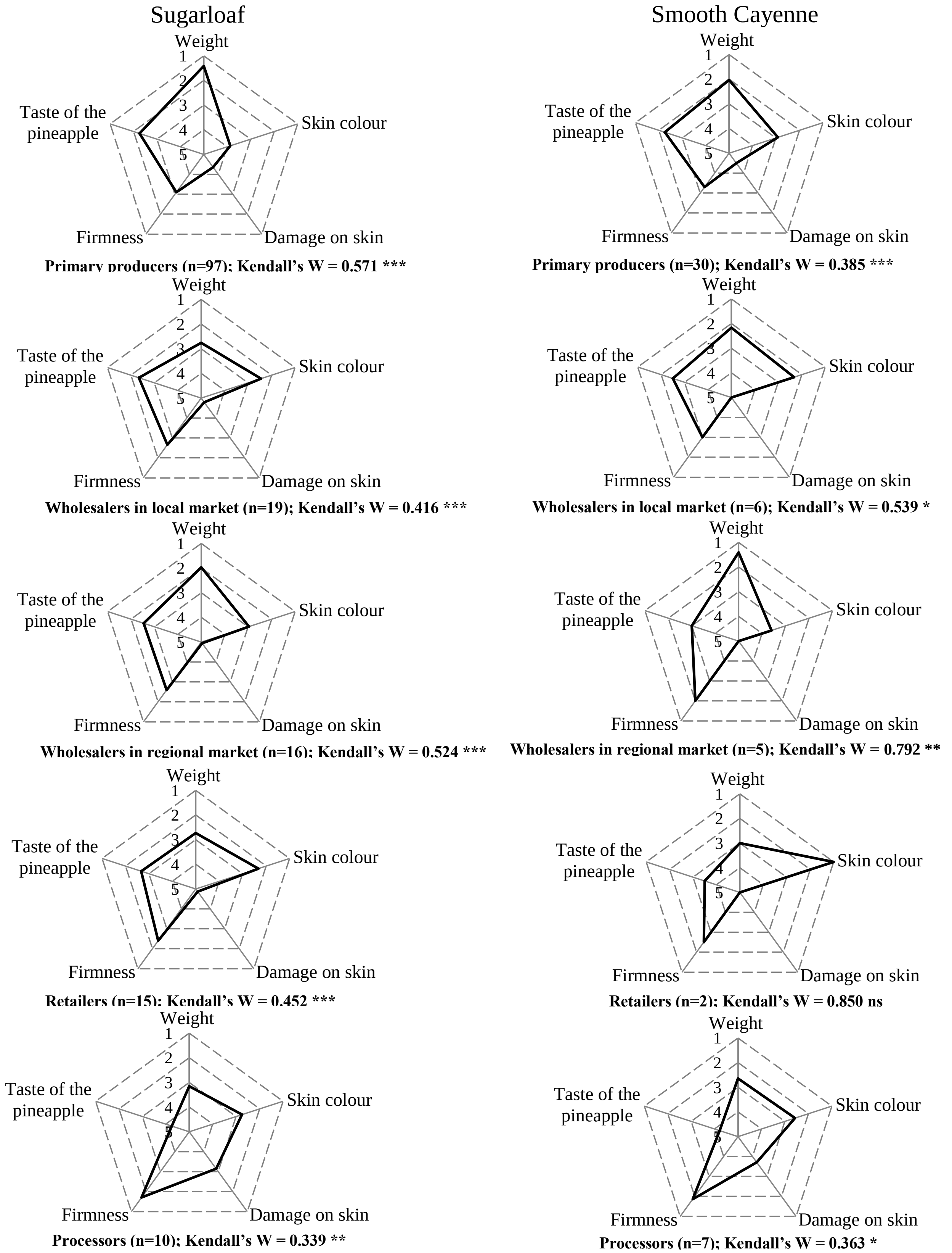
For Sugarloaf, there was agreement among primary producers in ranking the weight of the pineapple as first quality attribute followed by respectively the taste of the pineapple, the firmness, the skin colour and the skin damage (Kendall's W=0.571, P < 0.001) (Figure 2.3). The same observations were made for the Sugarloaf wholesalers selling at the regional market (Kendall's W=0.524, P < 0.001), whereas Sugarloaf wholesalers at the local market agreed on ranking the taste of the pineapple as first followed by skin colour (Kendall's W=0.416, P < 0.001). Contrary to the wholesalers, Sugarloaf retailers agreed on ranking the skin colour as first quality attribute followed by firmness and taste of the pineapple (Kendall's W=0.452, P < 0.001). The Sugarloaf processors differed from the other actor groups by agreeing on ranking firmness as first quality attribute followed by skin colour and weight of the pineapple (Kendall's W=0.339, P < 0.01).

For Smooth Cayenne, primary producers, wholesalers at the local and wholesalers at the regional market agreed on ranking the weight of the pineapple as first quality attribute (Figure 2.3). Differences among these actor groups were noticed in ranking the remaining quality attributes. For the primary producers, the second quality attribute was the taste of the pineapple, the skin colour being the third (Kendall's W=0.385, P < 0.001), whereas for the wholesalers selling Smooth Cayenne at the local market, skin colour and taste appeared to be the second and the third quality attributes respectively (Kendall's W=0.539, P < 0.05). Wholesalers selling Smooth Cayenne at the regional market agreed on ranking firmness and taste of the pineapple as second and third quality attributes (Kendall's W=0.792, P < 0.01). For the processors processing Smooth Cayenne, the five quality attributes were given more or less the same ranking when compared with their ranking for Sugarloaf.

Skin damage was the least valued quality attribute by all actor groups except processors (Figure 2.3).

Pineapple quality produced/supplied versus pineapple quality preferred

For both cultivars, the weight (fruit with crown) preferred by retailers was significantly lower than the weight preferred by wholesalers (Table 2.6); there was no significant difference in the desired weight between wholesalers at the local or the regional market.



***: Statistically significant at $P < 0.001$; **: Statistically significant at $0.01 > P \geq 0.001$; *: Statistically significant at $0.05 > P \geq 0.01$; ns: Not statistically significant, $P \geq 0.05$.

Figure 2.3. Mean rank assigned by different actors to the five most frequently mentioned quality attributes for the pineapple cultivars Sugarloaf (left) and Smooth Cayenne (right). A significant Kendall's coefficient of concordance (Kendall's W) indicates that there was agreement within actors' group on ranking the quality attributes from 1=first (most important) to 5 = fifth (least important)

Table 2.6. Pineapple fruit weight (kg per fruit) preferred by different actor groups for two cultivars

Cultivar	Actor group				*P*-value[a]
	Wholesalers		Retailers	Processors	
	Local market	Regional market			
Sugarloaf	1.47 ± 0.28 b	1.50 ± 0.27 b	1.08 ± 0.33 a	Every size	0.000
Smooth Cayenne	2.71 ± 0.35 b	2.85 ± 0.52 b	1.53 ± 0.18 a	Every size	0.011

[a] *P*-value from ANOVA test comparing the different groups of actors except processors; Values followed by the same letter within a row are not significantly different at 0.05 according to the Gabriel pair-wise test.

Preferred fruit weights were higher for Smooth Cayenne than for Sugarloaf. Processors were not exigent for fruit weight, so every pineapple size was convenient to them (Table 2.6). For the European markets, the average weight of the pineapple should be at least 0.80 kg with the crown and 0.664 kg without crown for the lowest weight class and no more than 2.75 kg with crown and 2.28 kg without crown for the highest weight class (Table 2.7).

Table 2.7. Average pineapple weight (kg ± 12%) with/without crown in different weight classes for pineapple export

Weight class	Weight with crown	Weight without the crown
A	2.75	2.28
B	2.30	1.91
C	1.90	1.58
D	1.60	1.33
E	1.40	1.16
F	1.20	1.00
G	1.00	0.83
H	0.80	0.66

Source: Codex Alimentarius (2005)

For Smooth Cayenne, the weights preferred by wholesalers were the top end of what would be the highest weight class suitable for export.

Kruskal-Wallis tests revealed that there were also significant differences between actor groups in taste (H=20.54, $P < 0.001$), firmness (H=29.66, $P < 0.001$), skin colour (H=13.33, $P < 0.01$) and translucency (H=27.84, $P < 0.001$) produced/preferred for Sugarloaf (Table 2.8) and in taste (H=14.22, $P < 0.01$) and skin colour (H=30.56, $P < 0.001$) produced/preferred for Smooth Cayenne (Table 2.9).

Differences in taste criteria preferred for Sugarloaf were observed between primary producers and processors (U=183.50, $P < 0.005$) and between wholesalers in regional markets and processors (U = 23.00, $P < 0.005$) (Table 2.10).

Most processors preferred Sugarloaf pineapples with always a taste in between sugar and lemon whereas most wholesalers at the regional market preferred pineapples having always a taste like sugar; most primary producers at the same time produced pineapple having a taste like sugar (Table 2.8). Differences in firmness and flesh translucency preferred for Sugarloaf existed between primary producers and other actors except processors (Table 2.10); all wholesalers at local and regional markets and all retailers preferred "always firm pineapple", while only 62% of the primary producers always aimed to produce firm pineapple (Table 2.8); similarly 70% of the primary producers produced Sugarloaf having 25-50% of the flesh translucent while most wholesalers in local and regional markets as well as retailers preferred pineapple having 0-25% of the flesh translucent (Table 2.8). For skin colour, a difference in quality criteria preferred for Sugarloaf was only observed between primary producers and wholesalers in the local market (U = 589.00; $P < 0.005$) (Table 2.10). Sixtyfive percent of primary producers produced Sugarloaf pineapple with 25-50% yellow skin, while 68% of the wholesalers at the local market preferred pineapple with 0-25% yellow skin (Table 2.8).

Difference in taste preferred for Smooth Cayenne was observed between primary producers and processors (U = 32.50; $P < 0.005$) (Table 2.11).

Most Smooth Cayenne primary producers produced pineapple with a taste like sugar whereas most processors preferred pineapple with a taste between sugar and lemon (Table 2.9). As to the skin colour, difference in quality criteria was observed between primary producers and all other actor groups except retailers (Table 2.11). Eighty percent of the primary producers produced pineapple with less than 50% of skin yellow, while all wholesalers in local and regional markets as well as most of the processors preferred pineapple with more than 50% of the skin yellow (Table 2.9).

Wholesalers at both markets as well as retailers and processors preferred pineapple presenting less than 25% of blackheart symptoms and free of skin damage, independent of the cultivar; primary producers responded well to these quality criteria requirements since all of them affirmed producing pineapple fulfilling these criteria (Table 2.8 and Table 2.9).

Another aspect of the pineapple quality preferred by other actor groups including the importers (affirmed by exporters) along the chain was a very low heterogeneity in the different quality attributes. It was noticed that more than 50% of wholesalers in local and regional markets as well as well as retailers and processors agreed that there was

Table 2.8. Percentage of actor groups producing/supplying Sugarloaf pineapple and valuing the different quality criteria within each quality attribute

Quality attributes	Quality criteria	Primary producers (n=97)	Wholesalers		Retailers (n=15)	Processors (n=10)	Kruskal-Wallis test (H)
			Local market (n=19)	Regional market (n=16)			
Taste	Always a taste like sugar	72	47	81	53	10	20.54 ***
	Always a taste in between sugar and lemon	28	53	19	40	90	
	Always the lemon taste	0	0	0	7	0	
Firmness	Always firm pineapple	62	100	100	100	40	29.66 ***
	Always pineapple with low firmness	38	0	0	0	60	
Skin colour	0-25% of the eyes has yellow colour	33	68	56	53	70	13.33 ***
	25-50% of the eyes has yellow colour	65	32	44	40	30	
	50-75% of the eyes has yellow colour	2	0	0	7	0	
	>75% of the eyes has yellow colour	0	0	0	0	0	
Translucent flesh	0-25% of the flesh translucent	15	69	56	53	30	27.84 ***
	25-50% of the flesh translucent	70	26	38	40	70	
	>50% of the flesh translucent	15	5	6	7	0	
Internal browning	0-25% of the blackheart symptoms	100	100	100	100	100	-[a]
	25-50% of the blackheart symptoms	0	0	0	0	0	
	50-75% of the blackheart symptoms	0	0	0	0	0	
	>75% of the blackheart symptoms	0	0	0	0	0	
Skin damage	Free of damage	100	100	100	100	100	-[a]
	Damage on 1-4% of the skin area	0	0	0	0	0	
	Damage on 4-8% of the skin area	0	0	0	0	0	
	Damage on more than 8% of the skin area	0	0	0	0	0	

***: Statistically significant at $P < 0.001$

[a] Kruskal-Wallis test was not performed because actor groups answers felt in the same quality criteria

Table 2.9. Percentage of actor groups producing/supplying Smooth Cayenne pineapple and valuing the different quality criteria within each quality attribute

Quality attributes	Quality criteria	Primary producers (n=30)	Wholesalers		Retailers (n=2)	Processors (n=7)	Kruskal-Wallis test (H)
			Local market (n=6)	Regional market (n=5)			
Taste	Always a taste like sugar	83	50	60	100	15	14.22 **
	Always a taste in between sugar and lemon	17	50	40	0	85	
	Always the lemon taste	0	0	0	0	0	
Firmness	Always firm pineapple	60	100	100	100	43	8.85 ns
	Always pineapple with low firmness	40	0	0	0	57	
Skin colour	0-25% of the eyes has yellow colour	10	0	0	0	0	30.56 ***
	25-50% of the eyes has yellow colour	80	0	0	50	29	
	50-75% of the eyes has yellow colour	10	50	80	50	71	
	>75% of the eyes has yellow colour	0	50	20	0	0	
Translucent flesh	0-25% of the flesh translucent	57	83	20	50	71	5.03 ns
	25-50% of the flesh translucent	43	17	80	50	29	
	>50% of the flesh translucent	0	0	0	0	0	
Internal browning	0-25% of the blackheart symptoms	100	100	100	100	100	-[a]
	25-50% of the blackheart symptoms	0	0	0	0	0	
	50-75% of the blackheart symptoms	0	0	0	0	0	
	>75% of the blackheart symptoms	0	0	0	0	0	
Skin damage	Free of damage	100	100	100	100	100	-[a]
	Damage on 1-4% of the skin area	0	0	0	0	0	
	Damage on 4-8% of the skin area	0	0	0	0	0	
	Damage on more than 8% of the skin area	0	0	0	0	0	

: Statistically significant at $0.01 > P \geq 0.001$; *: Statistically significant at $P < 0.001$.

[a] Kruskal-Wallis test was not performed because actor groups answers felt in the same quality criteria

Table 2.10. Mann-Whitney U test values comparing actor groups producing/supplying Sugarloaf pineapple for the different quality criteria within each quality attributes

Quality attributes	Quality criteria	Actor group	Primary producers	Wholesalers local market	Wholesalers regional market	Retailers	Processors
Taste	Always a taste like sugar	Primary producers	-	693.0 ns	705.0 ns	577.0 ns	**183.5 ***
	Always a taste in between sugar	Wholesalers local market	693.0 ns	-	100.5 ns	139.0 ns	59.5 ns
	and lemon	Wholesalers regional market	705.5 ns	100.5 ns	-	85.0 ns	**23.0 ***
	Always the lemon taste	Retailers	577.0 ns	139.0 ns	85.0 ns	-	47.0 ns
		Processors	**183.5 ***	59.5 ns	**23.0 ***	47.0 ns	-
Firmness	Always firm pineapple	Primary producers	-	**570.0 ***	**480.0 ***	**450.0 ***	379.0 ns
	Always pineapple with low firmness	Wholesalers local market	**570.0 ***	-	152.0 ns	142.0 ns	**38.0 ***
		Wholesalers regional market	**480.0 ***	152.0 ns	-	120.0 ns	**32.0 ***
		Retailers	**450.0 ***	142.5 ns	120.0 ns	-	**30.0 ***
		Processors	379.0 ns	**38.0 ***	**32.0 ***	**30.0 ***	-
Skin colour	0-25% of the eyes has yellow colour	Primary producers	-	**589.0 ***	588.0 ns	605.5 ns	302.5 ns
	25-50% of the eyes has yellow colour	Wholesalers local market	**589.0 ***	-	133.0 ns	118.0 ns	93.5 ns
	50-75% of the eyes has yellow colour	Wholesalers regional market	588.5 ns	133.5 ns	-	113.0 ns	69.0 ns
	>75% of the eyes has yellow colour	Retailers	605.0 ns	118.0 ns	113.0 ns	-	61.0 ns
		Processors	302.5 ns	93.5 ns	69.0 ns	61.0 ns	-
Translucent flesh	0-25% of the flesh translucent	Primary producers	-	**492.5 ***	**446.0 ***	**440.5 ***	362.0 ns
	25-50% of the flesh translucent	Wholesalers local market	**492.5 ***	-	134.0 ns	121.0 ns	62.0 ns
	>50% of the flesh translucent	Wholesalers regional market	**448.0 ***	134.0 ns		116.0 ns	62.5 ns
		Retailers	**440.5 ***	121.5 ns	116.0 ns	-	61.0 ns
		Processors	362.0 ns	62.0 ns	62.0 ns	61.0 ns	-

Values in bold indicate significant Mann-Whitney U test

ns: Not statistically significant, $P \geq 0.005$; *: Statistically significant at $P < 0.005$ (0.005 was selected based on Bonferroni's correction) a large heterogeneity in pineapple size[2] delivered to them no matter the cultivar (Figure 2.4). Likewise, most primary producers also admitted that there was a large heterogeneity in pineapple size at harvest (Figure 2.4). Concerning heterogeneity in the taste of the pineapple, most Sugarloaf wholesalers at the local market and most Smooth Cayenne retailers agreed that there was a large heterogeneity in taste; a large heterogeneity in fruit firmness was confirmed to exist by most Sugarloaf wholesalers in regional markets and most Smooth Cayenne retailers. Most Sugarloaf and Smooth Cayenne wholesalers at the regional market agreed on a large heterogeneity existing in the pineapples they received for skin colour (Figure 2.4). Most Sugarloaf and Smooth Cayenne processors agreed there was a large heterogeneity in pineapple flesh translucency. For the European market, heterogeneity in quality attributes is very important since fruits in the same boxes should be uniform in skin colour, weight, etc. (Codex Alimentarius 2005); exporters faced difficulties meeting this quality demand since they often collected pineapple from many primary producers.

2.5. Discussion

2.5.1. Fresh pineapple supply chains structure

The fresh pineapple supply chain network in Benin was composed of six main groups of actors: primary producers, exporters, middlemen, wholesalers, retailers and processors. For all these actor groups, but especially for the exporters, pineapple was very important due to its high contribution to the total income constitution (Table 2.2). Actor groups were integrated in differently structured chains leading to four outlets: (1) the local outlet for fresh pineapple, (2) the local outlet for processing pineapple, (3) the regional outlet for export to neighbouring countries for either fresh or processing pineapple, and (4) the export outlet for import in Europe (Figure 2.2). The chains to the local outlets differed in the involvement of wholesalers versus direct delivery by primary producers to retailers and processors and in the involvement of middlemen to search for fields and contact primary producers versus direct contact by wholesalers and processors. Chains to the regional market operated always through wholesalers, who might use middlemen or have direct contact with primary producers.

[2] Here the size was comparable to the weight since actor groups were able to see the lot of the pineapple delivered to them/harvested and gave their point of view on it.

Table 2.11. Mann-Whitney U test values comparing actor groups producing/selling Smooth Cayenne pineapple for the different quality criteria within each quality attributes

Quality attributes	Quality criteria	Actor group	Primary producers	Wholesalers local market	Wholesalers regional market	Retailers	Processors
Taste	Always a taste like sugar	Primary producers	-	60.0 ns	57.5 ns	25.0 ns	**32.5** *
	Always a taste in between sugar	Wholesalers local market	60.0 ns	-	13.5 ns	3.0 ns	13.5 ns
	and lemon	Wholesalers regional market	57.0 ns	13.5 ns	-	3.0 ns	9.5 ns
	Always the lemon taste	Retailers	25.0 ns	3.0 ns	3.0 ns	-	1.0 ns
		Processors	**32.5** *	13.5 ns	9.5 ns	1.0 ns	-
Skin colour	0-25% of the eyes has yellow colour	Primary producers	-	**4.5** *	**6.0** *	16.5 ns	**37.5** *
	25-50% of the eyes has yellow colour	Wholesalers local market	**4.5** *	-	10.5 ns	1.5 ns	7.5 ns
	50-75% of the eyes has yellow colour	Wholesalers regional market	**6.0** *	10.5 ns	-	2.0 ns	10.0 ns
	>75% of the eyes has yellow colour	Retailers	16.5 ns	1.5 ns	2.0 ns	-	5.5 ns
		Processors	**37.5** *	7.5 ns	10.0 ns	5.5 ns	-

ns: Not statistically significant, $P \geq 0.005$; *: Statistically significant at $P < 0.005$ (0.005 was selected based on Bonferroni's correction)

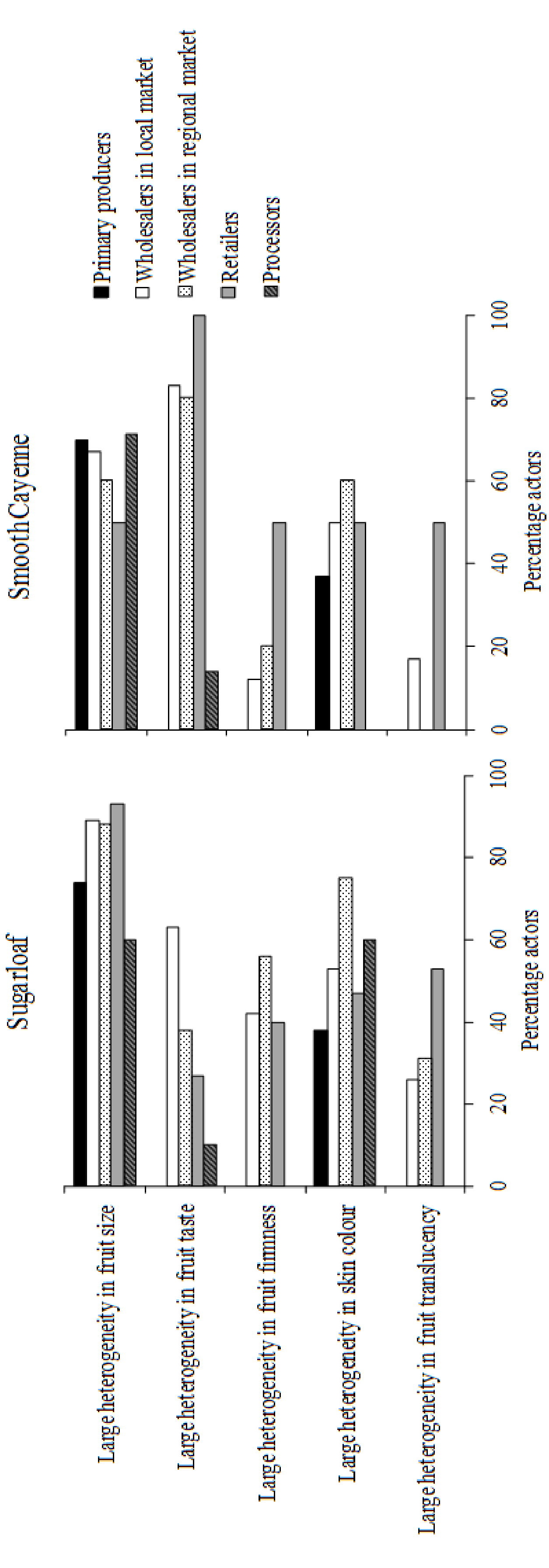


Figure 2.4. Percentage of actors in different groups, agreeing (combining the responses "agree" and "completely agree") with statements on the heterogeneity in quality of pineapple cultivars Sugarloaf (left) and Smooth Cayenne (right) that they produced or received

Chains to the European outlet were direct, with exporting farmers contacting neighbouring primary producers (Figure 2.2). The same situation defined as partial integration between exporting farmers and primary producers was observed in Ghanaian pineapple chains where exporters used purchases from primary producers as buffers to respond to the European Union demand in pineapple (Suzuki et al. 2011). In these conditions, primary producers obtaining advice on cultural practices and assistance in getting inputs to grow their crop from exporters, would tend to produce high-quality pineapple and so meet the demands of exporters for quality as well (Suzuki et al. 2011).

2.5.2. Business processes and constraints for the succes of the chains

Business processes at each actor group level can impact the quality of the pineapple delivered to customers/consumers and affect the success of the pineapple chain. In analysing the pineapple production systems, Fassinou Hotegni et al. (2012) found that constraints in the pineapple cultivation in Benin were the diverse production systems and a lack of planting material and some fertilisers. In our study, most primary producers agreed on not having received any training on pineapple production practices such as fertiliser application time and rate, flowering synchronisation time and rate and pest and weed management since they had started producing pineapple (Table 2.4). This will also be a bottleneck to high-quality pineapple production since Subramanian and Matthijs (2007) reported the lack of training as one of the critical factors in high-quality production. The lack of training of primary producers can be viewed as a threat to the success of the pineapple chain since Cetinkaya (2011) argued that training actor groups in their activities constituted a key element in implementing successful supply chains.

It was also noticed that the pineapple was left for hours in sunlight on the soil after harvest before being loaded. This exposure of the fruit to high temperature was reported as one of the causes associated with translucency (Chen et al. 2009). Then, the fruits may become translucent, i.e. the flesh of the fruit will show water soaking, and therefore becomes fragile (Py et al. 1987) and more susceptible to diseases (Gortner 1963).

Results also showed that most primary producers were not a member of a producer's organisation. The same findings were reported in Brazil by de Sá Sobrinho et al. (2009) and this was argued to be a negative factor contributing to the lack of organisation of the chains and therefore to non-successful chains. Belonging to producer's organisations facilitates the organisation of the production and the access to credit and other support services (Coulter et al. 2009) and promotes good practices in the chains (UNEP 2012).

Results also indicated the unavailability of boxes for export.The government should either make the boxes needed by exporters available in the country or stimulate the private sector to take this up. This would create opportunities for off-farm employment and incite exporters to continue producing pineapple for European countries.

At wholesaler and processor's level, the storage of pineapples in the sun could also increase fruit translucency as previously stated for the primary producer's level.

2.5.3. Chain resources and constraints for the succes of the chains

From one actor group to another, the pineapple was delivered under non-controlled conditions in "taxis'' or "bachées'' by independent drivers hired by the buyers (Figure 2.2). When combining the ways the fruits are treated after harvest, i.e. the exposure of the fruits in sunlight for some hours, the loading in trucks next to each other and the unconditionned transport conditions, the quality of the fruit, especially the firmness, could be reduced (Crisosto et al. 1995) and thus will limit the possibilities to reach higher-valued markets and increase losses. In Benin, there are no cold facilities for pineapple. It is well known that temperature conditions affect the fruit shelf life (Nunes and Edmond 2002). According to Hardenburg et al. (1990) and Cantwell (2002) the optimum storage temperature for a long shelf life for pineapple is 10 °C. In Cotonou, Zè, Allada and Toffo where the Dantokpa, Zè, Sékou and Sehouè markets are located, the mean monthly temperatures range from 27-31 °C; they range from 25-30 °C in Sèmè-Kpodji where the Sèmè Kraké market is located (INSAE 2004). In these conditions of high temperature, the pineapple shelf life will be reduced leading to high degree of rotting when not quickly sold. These high temperature conditions may also play a positive role, since they may be the cause of the absence of blackheart problems (cf. Tables 2.8 and 2.9); blackheart symptoms develop when fruits are exposed to temperatures below 10-12 °C (Akamine et al. 1975; Keetch and Balldorf 1979).

In the current situation, the chain resources used do not help in keeping the quality of produced pineapple. The establishment of a cold chain especially in the export chain as is the case in Ghana (Fassinou Hotegni 2013) is needed for keeping the quality. Cold storage facilities at exporter level and at the airport will reduce rejection of pineapples by importers since the fruits will still be fresh and well-looking. Therefore, actions need to be taken by the government to implement the storage facilities or to stimulate the private sector to take this up.

2.5.4. Management components and constraints for the success of the chains

Our results indicated that 30% of the primary producers producing Sugarloaf and 33% of the primary producers producing Smooth Cayenne had no selling agreement with their customers at the time of harvest (Table 2.5). This could be considered as a factor preventing primary producers to meet their customers' quality criteria. In pineapple it takes 15-18 months before the fruit is harvested (Fassinou Hotegni et al. 2012). Having an order before harvesting time would allow primary producers to know the type of pineapple quality they have to produce. This means that information sharing between actor groups in the chains should be more intensive to facilitate the supply of preferred pineapple quality. Cooperation between actor groups within a chain is essential to access high quality export markets as highlighted by Garcia Martinez and Poole (2004) for the Morrocan citrus chain.

2.5.5. Mismatch between pineapple quality supplied and pineapple quality preferred

Primary producers producing Sugarloaf pineapple and wholesalers in the regional market selling Sugarloaf pineapple shared the weight as the "most valued" quality attribute; this was not the case for wholesalers at the local market selling Sugarloaf pineapple, retailers selling Sugarloaf pineapple and processors (Figure 2.3). As to the Smooth Cayenne cultivar, actor groups sharing the weight as the "most valued" quality attribute were primary producers, wholesalers in the local market as well as wholesalers in the regional market (Figure 2.3). However, retailers desired a lower weight than wholesalers; processors were not exigent in pineapple weight (Table 2.6). Considering the fact that wholesalers constituted a major source of pineapple for all retailers (Table 2.3), the observed mismatch in pineapple weight criteria between wholesalers and retailers could be viewed as a constraint for not meeting retailer's quality criteria in pineapple weight. Wholesalers will have the tendency to buy big pineapple from primary producers and will most likely present that big pineapple to the retailers who will be obliged to buy them although their quality criteria are not met. So for the chains where retailers bought their pineapple from wholesalers, wholesalers appeared to be the critical actor group to the success of the chains.

For the other quality attributes criteria, results revealed that there was a mismatch between (1) primary producers and processors for the taste criteria for both cultivars (Tables 2.10 and 2.11), (2) primary producers and wholesalers in the local market, primary producers and wholesalers in the regional market and primary producers and retailers for the firmness and translucency criteria for cultivar Sugarloaf, (3) primary producers and wholesalers in local market for the skin colour criteria for both cultivars, primary producers and wholesalers in regional market and primary producers and processors for skin colour criteria for Smooth Cayenne pineapple (Tables 2.10 and 2.11). These mismatches between the quality of pineapple supplied and the quality of pineapple preferred could be considered as a bottleneck to the success of the chains as stated by Fisher (1997), stressing once more the importance of information exchange between actor groups in the chains.

The fact that primary producers were the main pineapple source of wholesalers and processors (processing Sugarloaf) and an additional source for some retailers (Table 2.4), and the fact that there was a mismatch between the quality of pineapple supplied by primary producers and the quality preferred by processors, wholesalers and retailers show that primary producers are the actors critical to the success of the chains where wholesalers, processors (Sugarloaf processors) and retailers obtained their pineapple from them.

The results also revealed that another problem encountered in the chains was the heterogeneity in pineapple quality, mainly in size (comparable to weight) and skin colour (Figure 2.4). This was an important point especially for the exporters since they should fit uniform fruits with specific quality criteria in the boxes. So, in addition to the quality criteria that should be met (Codex Alimentarius 2005), a higher uniformity in fruit quality is needed to improve the volume of exported pineapple. According to Luning and Marcelis (2006), the heterogeneity in quality is linked to production practices. Therefore, it is important to fully understand and analyse the pineapple production system so as to implement good production practices yielding more uniform and acceptable pineapple quality. On the other hand, the heterogeneity of the pineapple (mainly the size) could create opportunities for hawker salers and pineapple processors.

2.6. Conclusions and implications

Many actor groups operate in the fresh pineapple supply chains of Benin. The chains were not successful in delivering the right product quality to the markets. First, the research identified a large mismatch in perception of quality between different actor groups. There was a mismatch between wholesalers and retailers for the weight demands of the pineapple fruit; a mismatch for taste, firmness and translucency criteria was identified between primary producers and wholesalers, retailers and processors. These observations make wholesalers and primary producers critical actor groups in the chains. Second, all buyers concluded there was a large heterogeneity in quality delivered by the producers. This could be due to the way the pineapple is produced. Bottlenecks for achieving and keeping a high quality level of the fruits were lack of training of primary producers in production practices, limited organisation of farmers, the poor transportation system and the poor storage conditions at wholesaler and processor levels, and also at the airport when the pineapple was intended to be exported. In addition, the lack of transport boxes constituted another constraint for export.

For the establishment of successful fresh pineapple supply chains in Benin, it is important to first tackle the main bottlenecks. Emphasis should be given to solve the problems at primary producers' level so that the chain starts with high-quality produce with low heterogeneity in pineapple quality. This requires not only training of primary producers in best production practices but also research on tools to reduce the heterogeneity in pineapple quality. In addition, the performance of the chains could increase by aligning the quality criteria of actor groups in the chain.

Acknowledgements

Authors are grateful to pineapple primary producers (including exporters), wholesalers, retailers, processors and middlemen for kindly providing us with required information and to the Interdisciplinary Research and Education Fund (INREF) of Wageningen University and Research Centre for its financial support through the Co-Innovation for Quality in African Foods Chains (CoQA) programme.

References

Agbo, B., Agbola, G., Sissinto, E., & Akele, O. (2008). *Atelier de validation de la stratégie et d'élaboration de plan d'actions de la filière ananas au Benin*. Cotonou: MAEP and GTZ.

Akamine, E. K., Goo, T., Steepy, T., Greidanus, T., & Iwaoka, N. (1975). Control of endogenous brown spot of fresh pineapple in postharvest handling [Physiological disease]. *Journal American Society for Horticultural Science, 100*, 60-65.

Allen, I. E., & Seaman, C. A. (2007). Likert scales and data analyses. *Quality Progress, 40*(7), 64-65.

Arouna, A., & Afomassè, D. (2005). *Analyse de la compétitivité de la filière ananas au Benin*. Cotonou: Institut National de Recherches Agricoles au Benin (INRAB).

Bailey, K. (2008). *Methods of social research* (*Fourth ed.*). New York: Free Press.

Bijman, W. J. J. (2002). *Essays on agricultural co-operatives; governance structure in fruit and vegetable chains*. Rotterdam: PhD Thesis Erasmus University

Callis, J. B., Illman, D. L., & Kowalski, B. R. (1987). Process analytical chemistry. *Analytical Chemistry, 59*(9), 104-116.

Cantwell, M. (2002). Optimal handling conditions for fresh produce. In A. A. Kader (Ed.), *Postharvest Technology of Horticultural Crops* (pp. 511-518). USA: University of California: Division of Agricultural and Natural Resources

Cetinkaya, B. (2011). Developing a sustainable supply chain strategy. In B. Cetinkaya, R. Cuthbertson, G. Ewer, T. Klaas-Wissing, W. Piotrowicz & C. Tyssen (Eds.), *Sustainable supply chain management: practical ideas for moving toward best practice* (pp. 17-55). Berlin, Heidelberg: Springer-Verlag.

Chen, N., Paull, R., Chen, C., & Saradhuldhat, P. (2009). Pineapple production for quality and postharvest handling. *Acta Horticulturae, 822*, 253-260.

Clason, D. L., & Dormody, T. J. (1994). Analyzing data measured by individual Likert-type items. *Journal of Agricultural Education, 35,* 4.

Codex Alimentarius. (2005). Codex standard for pineapples. [Revision 1-1999, Amendment 1-2005]. Retrieved 10 January 2009, from www.codexalimentarius.net website: http://www.codexalimentarius.net/ web/more _info.jsp?id_sta=313 .

Coulter, J., Goodland, A., Tallontire, A., & Stringfellow, R. (2009). Marrying farmer cooperation and contract farming for service provision in a liberalising sub-Saharan Africa. *Natural Resource perspectives*, *48,* 1-4

Crisosto, C. H., Mitchell, F. G., & Johnson, S. (1995). Factors in fresh market stone fruit quality. *Postharvest News and Information, 6*(2), 17-21.

de Sá Sobrinho, R., Barbosa, J., de S. Costa, D., Lacerda, J., dos Santos, D., de O. Vieira, D., et al. (2009). Commercialization forms and organization of pineapple producers in the state of Paraíba, Brazil. *Acta Horticulturae, 822*, 313-316.

Ebrahimi, M., & Sadeghi, M. (2013). Quality management and performance: An annotated review. *International Journal of Production Research, 51*(18), 5625-5643.

FAO (Food and Agriculture Organization). (2009a). *Statistical databases*. Retrieved 31 December 2010, from http://faostat.fao.org/DesktopDefault.aspx.

FAO (Food and Agriculture Organization). (2009b). *Statistical databases*. Retrieved 31 May 2012, from http://faostat.fao.org/site/342/default.aspx.

FAO (Food and Agriculture Organization). (2011). *Statistical databases*. Retrieved 10 October 2013, from http://193.43.36.221/site/339/default.aspx.

FAO (Food and Agriculture Organization). (2012). *Statistical databases*. Retrieved 28 November 2013, from FAO http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E.

Fassinou Hotegni, V. N., Lommen, W. J. M., van der Vorst, J. G. A. J., Agbossou, E. K., & Struik, P. C. (2012). Analysis of pineapple production systems in Benin. *Acta Horticulturae, 928*, 47-58.

Fassinou Hotegni, V. N. (2013). Exploring the fresh pineapple export chains in Ghana. *Spring Newsletter 2013. West African Research Association*,13-14.

Field, A. (2005). *Discovering statistics using SPSS*. Sage Publications: London.

Fisher, M. L. (1997). What is the right supply chain for your product? *Harvard Business review, 75*, 105-117.

Garcia Martinez, M., & Poole, N. (2004). The development of private fresh produce safety standards: implications for developing Mediterranean exporting countries. *Food Policy*, *29*(3), 229-255.

Gbenou, R. K., Taore, M., & Sissinto, E. (2006). *Etude accélérée de marché (EAM) sur les différents produits ananas au Benin*. Cotonou: Helvetas-Benin.

Gortner, W. A. (1963). Field-fresh pineapple for export. *Research Report 99*. Hawaii: Pineapple Research Institute.

Hardenburg, R. E., Watada, A. E., & Yang, C. (1990). *The commercial storage of fruits, vegetables, and florist and nursery stoc*ks (Vol. 66). Davis, Washington.

Henson, S., & Loader, R. (2001). Barriers to agricultural exports from developing countries: the role of sanitary and phytosanitary requirements. *World Development, 29*(1), 85-102.

INSAE (Institut National de la Statistique et de l'analyse economique). (2004). *Troisième recensement général de la population et de l'habitation (RGPH3)*. Cahier des villages et quartier du département de l'Atlantique. Cotonou: DED (Direction des Etudes Démographiques).

Joomwong, A., & Sornsrivichai, J. (2005). Impact of cropping season in northern Thailand on the quality of Smooth Cayenne pineapple. II. Influence on physico-chemical attributes. *International Journal of Agriculture and Biology, 8*(3), 482-490.

Joosten, F. (2007). Development strategy for the export-oriented horticulture in Ethiopia. Retrieved 25 January 2014, from Ethiopian Horticultural Producers and Exporters Assocition (EHPEA) http://library.wur.nl/way/bestanden/clc/1891396.pdf

Keetch, D., & Balldorf, D. (1979). The incidence of certain pineapple fruit blemishes in the Eastern Cape and Border. *Citrus and Subtropical Fruit Journal, 551*, 12-15.

Kendall, M. G., & Smith, B. B. (1939). The problem of m rankings. *The Annals of Mathematical Statistics, 10*(3), 275-287.

Korneliussen, T., & Grønhaug, K. (2003). Quality perceptions in international distribution: an empirical investigation in a complete distribution chain. *Supply Chain Management: An International Journal, 8*(5), 467-475.

Lambert, D. M., & Cooper, M. C. (2000). Issues in supply chain management. *Industrial Marketing Management, 29*(1), 65-83.

Leech, B. L. (2002). Asking questions: techniques for semistructured interviews. *American Political Science Association, 35*(4), 665-668.

Legendre, P. (2005). Species associations: the Kendall coefficient of concordance revisited. *Journal of Agricultural, Biological, and Environmental Statistics, 10*(2), 226-245.

Luning, P. A., & Marcelis, W. J. (2006). A techno-managerial approach in food quality management research. *Trends in Food Science & Technology, 17*(7), 378-385.

Neven, D., & Reardon, T. (2004). The rise of Kenyan supermarkets and the evolution of their horticulture product procurement systems. *Development Policy Review, 22*(6), 669-699.

Nunes, M. C. N., & Edmond, J. P. (2002). Storage temperature. In J. A. Bartz & J. K. Brecht (Eds.), *Postharvest Physiology and Pathology of Vegetables* (pp. 209-228). New York: Marcel Dekker Inc.

Pallant, J. (2010). *SPSS survival manual: A step by step guide to data analysis using SPSS*: McGraw-Hill International.

Py, C., Lacoeuilhe, J. J., & Teisson, C. (1987). *The pineapple: cultivation and uses* (*Maisonneuve ed.*). Paris: Editions Quae.

Shukla, M., & Jharkharia, S. (2013). Agri-fresh produce supply chain management: a state-of-the-art literature review. *International Journal of Operations & Production Management, 33*(2), 114-158.

Soler, A. (1992). *Pineapple: quality criteria*. Paris: Centre de coopération internationale en recherche agronomique pour le développement CIRAD-IRFA.

Subramanian, U., & Matthijs, M. (2007). *Can sub-Saharan Africa leap into global network trade*? Policy Research Working Paper No. 4112. Washington, D.C: The World Bank.

Suzuki, A., Jarvis, L. S., & Sexton, R. J. (2011). Partial vertical integration, risk shifting, and product rejection in the high-value export supply chain: The Ghana pineapple sector. *World Development, 39*(9), 1611-1623.

Szymanowski, W. (2007). Application of information technologies in food supply chain and networks management in the environment of food market globalization–Traceability concept. *Olsztyn Economic Journal, 2*, 88-100.

Temu, A., & Marwa, N. W. (2007). Changes in the governance of global value chains of fresh fruits and vegetables: opportunities and challenges for producers in Sub-Saharan Africa. Retrieved 25 January 2014, from Citeseer http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.193.8858&rep=rep1&type=pdf.

UNEP (United Nations Environment programmes). (2012). *Avoiding future famines: Strengthening the ecological foundation of food security through sustainable food systems*. Nairobi, Kenya: United Nations Environment Programme (UNEP).

Van der Vorst, J., Beulens, A., & van Beek, P. (2005). Innovations in logistics and ICT in food supply chain networks. In W. M. Jongen & M. T. G. Meulenberg (Eds.), *Innovation in agri-food systems: Product quality and consumer acceptance* (pp. 245-292). Wageningen: Wageningen Academic Publishers.

Van der Vorst, J., Duineveld, M. P., Scheer, F.-P., & Beulens, A. J. (2007). *Towards logistics orchestration in the pot plant supply chain network.* Paper presented at the 14th International Annual Euroma Conference, 17-20 June, Ankara, Turkey.

Van der Vorst, J. G. (2006). Performance measurement in agri-food supply-chain networks, an overview. In C. Ondersteijn, R. Wijnands, R. Huirne & O. van Kooten (Eds.), *Quantifying the agri-food supply chain* (pp. 15-26). Wageningen: Springer Science.

Van der Vorst, J. G., Tromp, S.-O., & van der Zee, D-J. (2009). Simulation modelling for food supply chain redesign; integrated decision making on product quality, sustainability and logistics. *International Journal of Production Research*, *47*(23), 6611-6631.

Verdouw, C., Beulens, A. J., Bouwmeester, D., & Trienekens, J. (2008). Modelling demand-driven chain networks using multiple CODPs *Lean business systems and beyond* (pp. 433-442). Boston: Springer.

CHAPTER 3

Analysis of pineapple production systems in Benin*

V.N. Fassinou Hotegni[1,2], W.J.M. Lommen[1], J.G.A.J. van der Vorst[3], E.K. Agbossou[2] and P.C. Struik[1]

[1] Centre for Crop Systems Analysis, Wageningen University, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands

[2] Faculté des Sciences Agronomiques, Université d'Abomey Calavi, 01 BP 526 Cotonou, Benin

[3] Operations Research and Logistics Group, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, the Netherlands

* Published as: Fassinou Hotegni, V. N., Lommen, W. J. M., van der Vorst, J. G. A. J., Agbossou, E. K., & Struik, P. C. (2012). Analysis of pineapple production systems in Benin. *Acta Horticulturae, 928*, 47-58.

Abstract

In Benin, pineapple is an important fruit crop, mainly grown in the Atlantic department. The overall quality of the two cultivars grown, cvs Sugarloaf and Smooth Cayenne, does not meet the requirements for some outlets and the heterogeneity in fruit quality within and between lots is high. This paper (1) describes and analyses the pineapple production systems of cvs Sugarloaf and Smooth Cayenne and (2) identifies the main constraints reducing the quality of pineapple produced. First, semi-structured interviews were carried out with key informants including producers' organisations, input supplier and extension agents. Next, an in-depth questionnaire was carried out with 100 producers in the Atlantic department. Additionally, pedological and meteorological information was collected. Results indicated that pedo-climatic conditions in the Atlantic department were favourable for pineapple cultivation. The production practices were very diverse for both cultivars, especially regarding planting material used (slips, hapas and suckers), planting density, flowering induction time, and fertiliser application. The production systems of the two cultivars differed in type of planting material used, planting density, use of K_2SO_4, number of fertiliser applications and ethephon application. In cv. Smooth Cayenne cultivation, only hapas and suckers were used, planting density was lower, the number of fertiliser applications was higher, K_2SO_4 was generally used and maturity was more often synchronised than in cv. Sugarloaf cultivation. The main constraints were availability of appropriate planting material, heterogeneity in weight, age and leaf number of planting material, and availability and high costs of fertilisers. Tackling all these constraints would help producers improve the quality of produced pineapple in Benin.

Keywords: *Ananas comosus*; cultural practices; fertiliser; heterogeneity; fruit quality; planting material.

3.1. Introduction

In Benin, the rural sector occupies 70% of the work force, contributes 39% to the Gross Domestic Product (GDP) and provides 90% of the export earnings (MAEP, 2005). In order to reduce poverty, the Benin government has decided to promote new export crops including pineapple [*Ananas comosus* (L.) Merrill]. Pineapple is the second most important tropical fruit in terms of production volume in West Africa, after banana (FAO, 2009). In Benin, it is the main crop in the southern part, mainly in the Atlantic department, where it is cultivated by about 70% of the producers. The Atlantic department realizes about 95% of the total Benin pineapple production (Helvetas-Bénin 2008). Two varieties are cultivated: cv. Smooth Cayenne and cv. Sugarloaf, with cv. Sugarloaf being the most cultivated one (Authors' own observations). The main problem of pineapple in Benin is the poor quality for local, regional and international outlets (Gbenou et al. 2006).

An analysis of the whole pineapple supply chain showed that the major constraints encountered by producers, wholesalers (when it comes to exporting the pineapple) and processors are the heterogeneity in pineapple quality produced or delivered, poor compliance with quality criteria such as size and sugar concentration, and late delivery (Authors' own observations). These constraints may be linked to the way the pineapple is cultivated in the field, since the quality of agri-food is affected by cultural practices (e.g., Brown, 1986). Consequently, it is important to describe and analyse the pineapple production system(s) in Benin in order to identify the main factors that could reduce the quality of delivered pineapple and especially could increase the heterogeneity in quality. To date, no studies have been carried out on pineapple cultivation in Benin, despite its importance. Therefore, the objectives of this research are to describe and analyse cvs Sugarloaf and Smooth Cayenne production systems in Benin and to identify the constraints that reduce the quality of pineapple produced. This was a baseline study useful for improving the production system and the quality of produced pineapple.

The research questions are:

What are the different ways of producing cv. Smooth Cayenne and cv. Sugarloaf in Benin?

What are the differences between the production systems of the two cultivars?

What are the different constraints that hamper the pineapple quality in Benin?

3.2. Materials and methods

After a literature review on pineapple cultural practices across the world, first a semi-structured interview was carried out with key informants from two producers' organisations: RePAB (Réseau des Producteurs d'Ananas du Benin) and ARPA (Association Régionale des Producteurs d'Allada), one input supplier: PADFA (Projet d'Appui à la Filière Ananas au Benin) and the extension agents at the CeRPA (Centre Régionale de la Production Agricole) in the Atlantic department to increase our knowledge on existing cultural practices and constraints. Next, an in-depth pre-tested questionnaire was used to interview 100 producers in the Atlantic department. Five municipalities (Abomey-Calavi, Allada, Zè, Toffo and Tori) out of the 8 municipalities that constituted that department (INSAE 2004) were selected based on their contribution to the total volume of pineapple produced in Benin. The number of producer respondents per municipality was proportional to the contribution of each municipality to the total volume of pineapple produced in Benin. A stratified sampling method based on the number of producers was used to determine the number of producer respondents per pineapple growing area within a municipality. These growing areas were: Glo Centre, Fanto, Wawata, Zinvié Zoumè, Kpaviédja, Kpé (in Abomey Calavi municipality); Agbondjédo, Tangbo, Houéta, Anagbo, Adjamè, Gandaho (in Zè municipality); Adimale, Dodji-Aliho, Loto-Denou, Lokoli (in Allada municipality); Agbame, Houegbo-Gare (in Toffo municipality); and Sogbe Hetin (in Tori municipality). The questionnaire was developed to gather information on production practices and constraints. To determine the constraints, a five-point Likert scale with the ratings "strongly disagree (1)'', "disagree (2)'', "neither agree nor disagree (3)'', "agree (4)'' and "strongly agree (5)''was used.

Data were analysed by SPSS, version 16.0. A chi-square test on numbers of producers was used to assess whether the constraints experienced by producers concerning planting material and fertilisers depended on the sources they were obtained from. Data are presented in percentages for clarity of presentation.

Cluster analysis was used to identify different production systems (Bernhardt et al. 1996). First, relevant production practices variables were submitted to hierarchical cluster analysis to select the number of different clusters from the distances coefficients in the scree diagram (elbow rule). Ward's method was used to calculate the distances. Next, the K-means algorithm (Hartigan 1985) was used to partition the producers' production systems into the pre-determined cluster number, with the Euclidean distance being used as similarity measure

(Bernhardt et al. 1996). The final cluster centres per variable, i.e. the averages, were used to describe the clusters. To identify the production practices variables that separated the production systems of the two cultivars, discriminant analysis was performed. All data were standardised before analysis.

3.3. Results

3.3.1. Description of the Atlantic department

The Atlantic department has a subequatorial climate with two rainy seasons (the first from March to July and the second from September to October) alternating with two dry seasons (the first from November to March and the second in August). The mean monthly temperatures range from 27 °C to 31 °C and the mean annual rainfall is about 1200 mm from which 700-800 mm is recorded in the first rainy season and 400-500 mm in the second (INSAE 2004). The main crops grown are pineapple, maize, cassava, groundnut, tomato and pepper (INSAE, 2004). The pedological map of Benin revealed that the Atlantic department is covered by one major group of soils which is the ferrallitic soil (Willaime and Volkoff 1967). This type of soil is characterised by good physical conditions (very deep soil and good drainage, i.e. permeable soil and high water-holding capacity) and relatively good chemical conditions (good cation exchange capacity). The pH ranges from 5.5 to 6.0 (Agossou 1983).

3.3.2. Description of pineapple cultural practices

The cultural practices of cvs. Sugarloaf and Smooth Cayenne are shown in Table 3.1. Planting starts with land preparation and producers preferred the start of the first rainy season as planting time. Planting materials used included all traditional propagule types: slips (produced on the peduncle at the base of the fruit), hapas or side shoots (produced above ground from the stem at the junction of the stem and the peduncle) and suckers (side shoots originating below ground from the stem). Crowns (produced at the top of the fruit) were not used. Slips, hapas and suckers were used by Sugarloaf producers whereas only hapas and suckers were used by Smooth Cayenne producers. These planting materials were obtained from plants kept in the field after the previous harvest, or other producers or both (Table 3.1).

No producers obtained their planting material from PADFA, an institution aiming at

Table 3.1. Pineapple production system practices in Benin.

Production practices	Cultivar	Description	Remarks
Area under pineapple	Sugarloaf	Area ranged from 0.08-15 ha	On average Sugarloaf producers had 1.92 ha
	Smooth Cayenne	Area ranged from 0.08-4 ha	On average Smooth Cayenne producers had 1.33 ha
Land preparation			
Preparation tool	Both cultivars	Hoe	
Type of labour	Both cultivars	Family, labour sharing and hire labour	All producers hired labour
Planting			
Type of planting material	Sugarloaf	Slips, suckers and hapas	64% of Sugarloaf producers used slips, hapas and suckers
			28% of Sugarloaf producers used only slips
			8% of Sugarloaf producers used only slips and hapas
	Smooth Cayenne	Hapas plus suckers	All Smooth Cayenne producers used hapas and suckers
Source of planting material	Sugarloaf	Producers obtained their planting material from either previous harvested field, other producers or both previous harvested field and other producers	38% of Sugarloaf producers obtained their planting material from previous harvested field only 4% of Sugarloaf producers obtained their planting material from other producers 58% of Sugarloaf producers obtained their planting material from both previous harvested field and other producers
	Smooth Cayenne	Producers obtained their planting material from either previous harvested field, or other producers or both previous harvested field and other producers	20% of Smooth Cayenne producers obtained their planting material from previous harvested field 3% of Smooth Cayenne producers obtained their planting material from other producers 77% of Smooth Cayenne producers obtained their planting from both sources
Preferred planting time	Both cultivars	March-April-May-June	Rainfall season

Table 3.1. Continued (1)

Production practices	Cultivar	Description	Remarks
Treatment before planting	Both cultivars	No treatment	
Plant arrangement	Sugarloaf	Plants arranged in beds of two alternating rows: Row width: 35.9 ± 1.95 cm (range 20- 50 cm); between plants: 27.4 ± 1.71 cm (range 20-40 cm); between double rows: 57.3 ± 3.58 cm (range 30-80 cm)	Used by 65% of Sugarloaf producers
		Plants arranged in single rows: Row width: 71.3 ± 3.87 cm (range 50-80 cm); between plants: 32.2 ± 1.23 cm (range 30-40 cm)	Used by 28% of Sugarloaf producers
		Plants arranged in quincunxes: Row width: 29.7 ± 0.51 cm (range 28-30 cm); between plants: 44.3 ± 1.42 cm (range 40-45 cm)	Used by 7% of Sugarloaf producers
	Smooth Cayenne	Plants arranged in beds of two alternating rows: Row width: 45.5 ± 4.45 cm (range 30-75 cm) ; between plants: 34.2 ± 3.17 cm (range 20-50 cm); between double rows: 75.0 ± 5.01 cm (range 50-100 cm)	Used by 63% of Smooth Cayenne producers
		Plants arranged in single rows: Row width: 62.5 ± 5.97 cm (range 50-75 cm); between plants: 31.9 ± 2.63 cm (range 30-40 cm)	Used by 27% of Smooth Cayenne producers
		Plants arranged in quincunxes: Row width: 32.7 ± 5.33 cm (range 30-38 cm); between plants: 50.0 ± 10 cm (range 45-60 cm)	Used by 10% of Smooth Cayenne producers
Planting density	Sugarloaf	8.6 ± 0.35 plants/m² for those arranging the plants in beds of two alternating rows	The number of plants ranged from 4-17 plants/m²
		4.6 ± 0.14 plants/m² for those arranging the plants in single rows	The number of plants ranged from 4-6 plants/m²
		7.3 ± 0.28 plants/m² for those arranging the plants in quincunxes	The number of plants ranged from 7-9 plants/m²

Table 3.1. Continued (2)

Production practices	Cultivar	Description	Remarks
	Smooth Cayenne	5.2 ± 0.40 plants/m^2 for those arranging the plants in beds of two alternating rows	The number of plants ranged from 4-11 plants/m^2
		5.3 ± 0.36 plants/m^2 for those arranging the plants in single rows	The number of plants ranged from 4-7 plants/m^2
		7.3 ± 0.33 plants/m^2 for those arranging the plants in quincunxes	The number of plants ranged from 7-8 plants/m^2
Fertilisation practices			
Type of fertilisers used	Both cultivars	NPK 15-20-15; NPK 16-16-16; NPK 10-20-20; Urea 46%N; K_2SO_4 50% K_2O and 18% S	
Number of applications	Sugarloaf	1-4 applications	98% of Sugarloaf producers fertilised at least 2 times. Of those (24%) who fertilised 2 times, most applied Urea + NPK 3.2 ± 0.21 and 7.7 ± 0.59 months after planting Of those (34%) who fertilised 3 times, most applied Urea 2.3 ± 0.22 or NPK 2.0 months after planting the first time; NPK 2.5 ± 0.34 or NPK + Urea 5.1 ± 0.46 or Urea 4.3 ± 0.25 months after planting the second time and K_2SO_4 9.7 ± 0.66 or NPK 7.1 ± 0.54 months after planting the third time Of those (4%) who fertilised 4 times, most applied Urea at 2 months after planting, NPK + Urea two times at 4 and 6 months after planting and NPK at 8-9 months after planting
	Smooth Cayenne	2-4 applications	All Smooth Cayenne producers fertilised at least 2 times Of those (40%) who fertilised 2 times, most applied Urea + NPK at 3.1 ± 0.28 and 7.4 ± 0.60 months after planting Of those (54%) who fertilised 3 times most applied Urea at 2.6 ± 1.01 months after planting, NPK at 5.2 ± 1.32 months after planting and K_2SO_4 at 8.4 ± 0.48 months after planting Those (6%) who fertilised four times applied Urea at 2, 4 and 6 months after planting and K_2SO_4 or K_2SO_4+NPK at 9 or 14 months after planting.

Table 3.1. Continued (3)

Production practices	Cultivar	Description	Remarks
Source of the fertilisers	Both cultivars	Producers obtained the fertilisers from CeRPA, shops or both	57% and 59% of Sugarloaf producers and 67% and 53% of Smooth Cayenne producers obtained the fertilisers from CeRPA and shops respectively.
Flowering synchronisation (FS)			
Chemical product used	Both cultivars	Carbide of Calcium (CaC_2)	
Application time and number	Sugarloaf	One application at 9-13 months after planting	42% of the Sugarloaf producers applied CaC_2 at 12 months after planting, 28% at 10 months after planting
	Smooth Cayenne	One application at 9-13 months after planting	34% of the Smooth Cayenne producers applied CaC_2 at 10 months after planting
Criterion used	Both cultivars	Number of months after planting	
Maturity synchronisation			
Chemical product used	Both cultivars	Ethephon	
Application time and number	Sugarloaf	No or one application at 16-17 months after planting	Only 10% of Sugarloaf producers applied Ethephon.
	Smooth Cayenne	No or one application at 14-19 months after planting	60% of Smooth Cayenne producers applied Ethephon.
Criteria used	Both cultivars	Number of months after flowering synchronisation (4-5 months after FS)	Generally 5 months after FS for growers using this criterion
		Fruit size	When the fruit size was optimum (based on their experience)
		Delivering time to consumers	Generally 2 weeks before the delivering time
Crown gouging	Both cultivars	No or gouged crown at 1.5-2 weeks before harvest	10% of Sugarloaf producers and 20% of Smooth Cayenne producers gouged the crown. Gouging was done at 1.5-2 weeks before harvest time

Table 3.1. Continued (4)

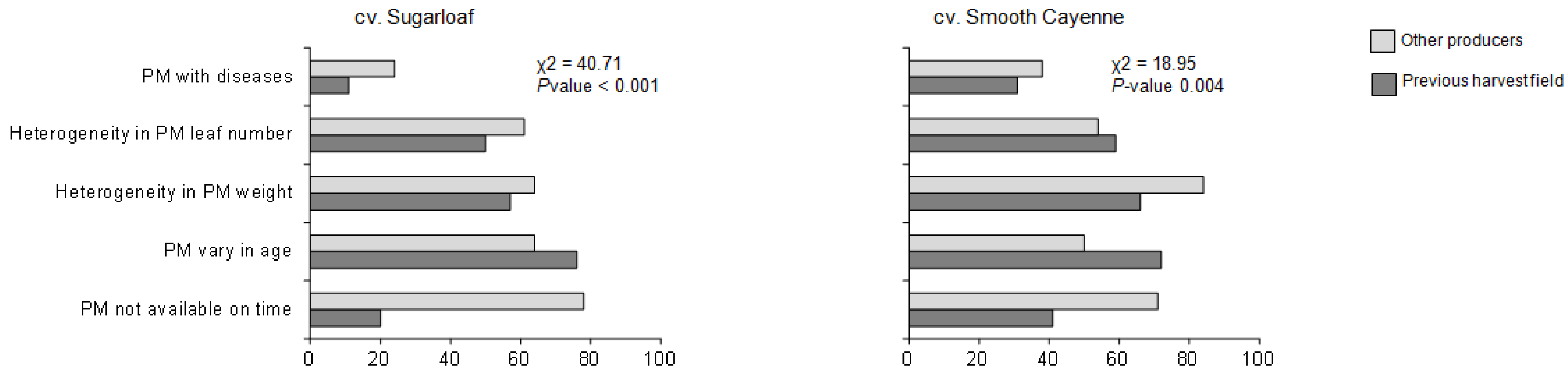
Production practices	Cultivar	Description	Remarks
Side shoot pruning	Both cultivars	No pruning	Producers did not even know such technique exists
Fruit protection on field against sunburn	Both cultivars	No protection or use of palm leaves, maize leaves or dry weeds loosely distributed on top of the crop	24% and 20% of respectively Sugarloaf and Smooth Cayenne producers protected their fruit against sunburn
Weeding practice	Both cultivars	Hand weeding (10-15 per crop cycle) or herbicides.	Only few producers used herbicides
Disease and insect control	Both cultivars	None	The occurrence of diseases and pest was very low. The only case we noticed was the Wilt disease affecting the planting material.
Intercropping system	Both cultivars	Pineapple associated with maize, cassava, tomato and chili pepper, or no intercropping	89% of the producers used intercropping system. From that 89% associated pineapple with maize
Harvest			
Harvesting number	Both cultivars	One harvest	The ratoon crop was only used for planting material production
Harvesting time	Sugarloaf	16.2 ± 0.25 months (range 14-19 months) after planting	
	Smooth Cayenne	15.8 ± 0.52 months (range 14-19 months) after planting	
Yield	Sugarloaf	Evaluated in terms of number of trucks, the number of trucks was: 17.0 ± 0.52 trucks/ha	The truck capacity is 1440-2160 pineapples for 'Sugarloaf'
	Smooth Cayenne	Evaluated in terms of number of trucks; the number of trucks was 19.0 ± 1.02 trucks/ha	The truck capacity is 1200-1400 pineapples for 'Smooth Cayenne'

providing producers with planting material. The main reason stated by producers was they did not know that such an institution existed. Figure 3.1 shows the percentage of producers using each of these sources that agreed with pre-formulated constraints for each source. The results of the Chi-square test show that the constraints depended significantly on the source for both pineapple cultivars. The main constraints were the non availability of planting material from other producers when needed, the heterogeneity of the planting material (mainly when sourced from other producers), and the variation in planting material age (mainly when the planting material was derived from plants kept after the previous harvest).

Most producers arranged the plants in beds of two rows at planting (Table 3.1) in association with maize. The planting densities were highly variable, ranging from 4-17 plants/m^2 in cv. Sugarloaf and from 4-11 plants/m^2 in cv. Smooth Cayenne. Also the fertilisation practices were diverse in number of applications and type of fertiliser used (Table 3.1). Fertilisers were collected from CeRPA or shops where sellers are pineapple producers or other people. Figure 3.2 summarises the percentage of producers using each of these sources that agreed with pre-formulated constraints for each source. The results of the Chi-square test show that the constraints related to fertilisers were not source-dependent. The main constraints were the non availability and the high costs of the fertilisers.

During crop development, producers induced flowering 9-13 months after planting by means of CaC_2, using the months after planting as the main criterion. Forty-two percent of the Sugarloaf producers induced flowering 12 months after planting and 34% of Smooth Cayenne producers induced flowering 10 months after planting (Table 3.1). Before harvest, some producers applied 2-chloroethyl phosphonic acid ($ClCH_2CH_2PO(OH)_2$; Ethephon), which enhances the skin colour change from green to yellow (Audinay 1970; Crochon et al. 1981). The criteria used by producers to apply Ethephon were the number of months after flowering induction (4-5, generally 5 months), the fruit size (when the fruit reached the optimum size), or the delivering/selling time (2 weeks before delivering/selling). Few producers practiced crown gouging, i.e. mechanical removal of the shoot apex of the crown. After harvest of the fruits, the ratoon-crop was kept only for planting material production.

Cluster analysis on the production practices variables revealed four clusters, but from the cluster centres per variable, these clusters could not be realistically distinguished into different pineapple production systems.



PM: Planting material

Figure 3.1. Percentage of producers growing cvs Sugarloaf and Smooth Cayenne and obtaining the planting material from other producers and previous harvest field that agreed (combining the responses "agree" and "strongly agree") with constraints linked to those sources

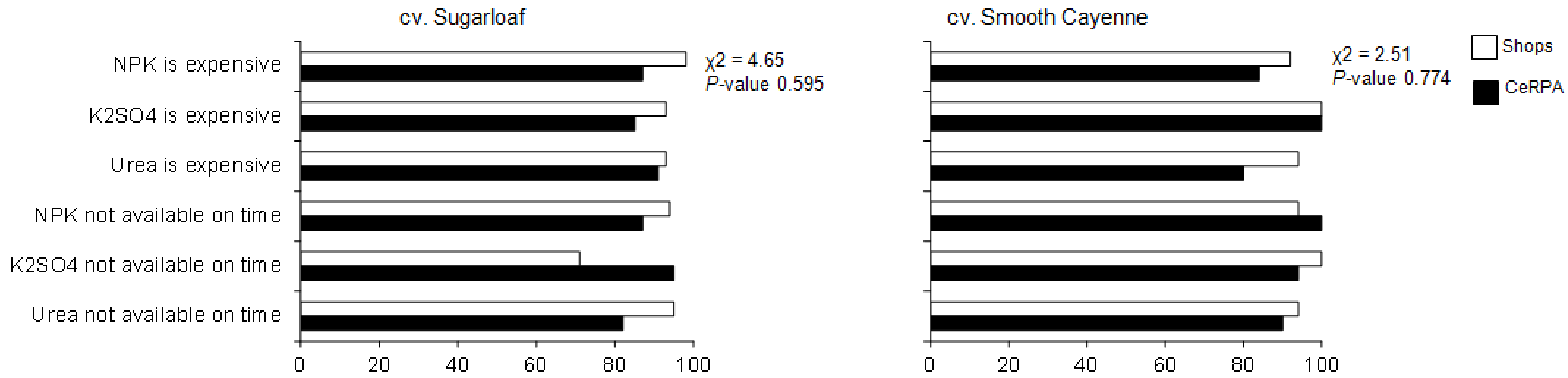


Figure 3.2. Percentage of producers growing cvs Sugarloaf and Smooth Cayenne using the indicated fertilisers and obtaining them from CeRPA and shops, that agreed (combining the responses "agree" and "strongly agree") with constraints linked to those sources

3.3.3. Differences in production system between cvs Sugarloaf and Smooth Cayenne

Table 3.2 shows which practices differentiated the ways in which the two cultivars were produced. There was a significant difference between the cultivars' production systems in type of planting material used, planting density, use of K_2SO_4, number of fertiliser applications and ethephon application. For cv. Smooth Cayenne, all producers used hapas and suckers as planting material whereas for cv. Sugarloaf all producers used slips and most additionally hapas and suckers. Planting density was higher in Sugarloaf cultivation (4-17 plants/m^2) than in cv. Smooth Cayenne cultivation (4-11 plants/m^2). For cv. Smooth Cayenne, the number of fertiliser applications was higher than for cv. Sugarloaf, K_2SO_4 was generally used and Ethephon was more often applied.

3.4. Discussion

Temperature is one the most important factors that determine pineapple growth. In the Atlantic department, the temperature range (between 27 °C and 31 °C) is favourable for pineapple growth since it has been found that pineapple growth decreases rapidly at mean temperatures below 15 °C and above 32 °C (Neild and Boshell 1976) or below 10 °C and above 35 °C (Bartholomew and Criley 1983; Malézieux et al. 1994; Py et al. 1987). Also the mean annual rainfall of 1200 mm is favourable for pineapple growth and development because optimum rainfall for good commercial pineapple cultivation ranges from 1000 mm to 1500 mm (Bartholomew et al. 2003a). Also the soil characteristics (good drainage and pH ranging from 5.5-6.0) are favourable because the best soils for pineapple culture have a neutral to acid pH (Hepton 2003; Morton 1987) with good drainage (Collins 1960; Hepton 2003) in order to prevent water logging and root diseases. This means that the pedo-climatic conditions for pineapple production are satisfied and that the main constraints that reduce the production of high quality pineapples for different outlets have to be linked to the production system. The possibility of PADFA supplying producers with planting material was unknown and producers obtained planting material only from other sources and own production (Table 3.1). The planting material was heterogeneous in weight, age and number of leaves (Figure 3.1) and this could contribute to the heterogeneity in pineapple quality observed since there is a relation between the size and type of planting material and fruit size (e.g. Linford et al. 1934; Malézieux 1993). Singh (2002) argued that the availability of best planting material is

Table 3.2. *P*-values for the differences in production practices of cvs Sugarloaf and Smooth Cayenne pineapple in Benin

Production practices	*P*-value[a]
Field size (ha)	ns
Planting material from previous harvest field	ns
Planting material from other producers	ns
Planting material from both previous sources	ns
Use of slips at planting	_[b]
Use of hapas at planting	0.001 ***
Use of suckers	0.000 ***
Plants arranged in beds of two alternating rows	ns
Plants arranged in single rows	ns
Plants arranged in quincunxes	ns
Planting density (plants/m^2)	0.000 ***
Use of NPK	ns
Use of Urea	ns
Use of K_2SO_4	0.000 ***
Number of fertiliser applications	0.032 *
Fertilisers from CeRPA	ns
Fertilisers from shops	ns
Fertilisers from both CeRPA and shops	ns
Time between planting and flowering induction (months)	ns
Use of ethephon for maturity synchronisation	0.000 ***
Crown gouging practice	ns
Fruit protection against sunburn	ns
Use of herbicide	ns
Inter-cropping	ns
Time between flowering induction and harvest (months)	ns

[a] Probability of obtaining the Fisher test statistic for determining production practices that discriminate cvs Sugarloaf and Smooth Cayenne.
[b] No *P*-value was computed since this variable did not vary within a cultivar. Slips were only used for Sugarloaf.
ns: Not statistically significant ; *: Statistically significant at $0.05 > P \geq 0.01$; ***: Statistically significant at $P < 0.001$.

important to assure successful crop production. In addition, it is important for producers to get their planting material on time so as to meet the delivering time set by their customers. The great diversity in planting density observed could also contribute to the quality and heterogeneity in quality of pineapple. High planting densities reduce growth (Zhang and

Bartholomew 1992) and consequently average plant weight, decrease fruit diameter (Treto et al. 1974; Zhang and Bartholomew 1992) and fruit length (Norman 1978), increase the total acids concentration and reduce the total soluble solids (Bartholomew et al. 2003b; Chadha et al. 1974; Mustaffa 1988). Another source of heterogeneity in quality could be the different fertilisation practices since the nutritional status of the pineapple influences its growth and consequently its yield and quality (Malézieux and Bartholomew 2003). It is important to note that there was no specific fertiliser formulation for pineapple in Benin; and due to the fertilisers' availability and cost problem some producers may apply what they have at hand or not apply at all. This is one of the critical points of high quality pineapple production since the moment of fertiliser application greatly influences the quality. For instance, N application after flowering synchronisation decreases total soluble solids and total acidity (Spironello et al. 2004) and increases fruit size (de Paula et al. 1991).

Another plausible cause of the heterogeneity in pineapple quality will be linked to flowering induction. Firstly, because pineapple plants with their initial variability at planting time in terms of size and type of planting material will not all have reached the same developmental stage when flowering is induced by the grower. In addition, there was a large variation in the number of months after planting at which flowering was induced.

The number of hand weeding over the crop cycle was high (Table 3.1) and constitutes another constraint because hand weeding is a time consuming activity. Weeds are a serious constraint in crop production in Benin (Vissoh et al. 2004). In pineapple cultivation, they reduce the mean fruit length, diameter and weight (Eshetu et al. 2007).

Some practices like pruning of developing slips and side shoots before harvest time were not applied by producers. As slip formation overlaps with the period of fruit development and maturation, slips may act as sinks competing directly with the fruit for assimilates. Therefore, removing slips could be an option to increase pineapple fruit size and perhaps also its quality.

3.5. Conclusions

Although the Atlantic department is favourable for pineapple cultivation there were some constraints in the production system that reduced the quality of pineapple. These constraints included availability of appropriate planting material, heterogeneity in planting material weight and age, availability of fertilisers, and cost of the fertilisers. All these constraints made it difficult to control the heterogeneity in quality in the field. The production practices were very diverse for both cultivars grown. Tackling the constraints would help producers improve the quality of produced pineapple in Benin.

Acknowledgements

Authors are grateful to the Interdisciplinary Research and Education Fund (INREF) of Wageningen University for its financial support through the Co-Innovation for Quality in African Foods Chains (CoQA) programme.

References

Agossou, V. (1983). *Les sols Béninois et leurs potentialités agricoles*. Cotonou: Centre National d'Agropédologie.

Audinay, A. (1970). Artificial control of pineapple ripening with Ethrel. *Fruits d'Outre Mer, 25*, 695-708.

Bartholomew, D. P., & Criley, R. A. (1983). Tropical fruits and beverage crops. In L. G. Nickell (Ed.), *Plant growth regulating chemicals*. Boca Raton: CRC Press.

Bartholomew, D. P., Malézieux, E., Sanewski, G. M., & Sinclair, E. (2003b). Inflorescence and fruit development and yield. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 167-202). Wallingford, UK: CABI publishing.

Bartholomew, D. P., Paull, R. E., & Rohrbach, K. G. (2003a). *The pineapple: botany, production and uses*. Wallingford, UK: CABI Publishing.

Bernhardt, K. J., Allen, J. C., & Helmers, G. A. (1996). Using cluster analysis to classify farms for conventional/alternative systems research. *Review of Agricultural Economics, 18*(4), 599-611.

Brown, B. I. (1985). Temperature management and chilling injury of tropical and subtropical fruit. *Acta Horticulturae, 175*, 339-342.

Chadha, K. L., Melanta, K. R., & Shikhamany, S. D. (1974). High density planting increases pineapple yields. *Indian Agriculture, 18*, 3-5.

Collins, J. L. (1960). *The pineapple: botany, cultivation and utilization*. New York: Interscience Publishers.

Crochon, M., Teisson, C., & Huet, R. (1981). Effet d'une application d'ethrel avant la recolte sur la qualite gustative des ananas de Cote d'Ivoire. *Fruits, 36*, 409-415.

de Paula, M. B., de Carvalho, V. D., Nogueira, F. D., & da Silva Souza, L. F. (1991). Efeito da calagem, potássio e nitrogênio na produção e qualidade do fruto do abacaxizeiro. *Pesquisa Agropecuária Brasileira, 26*(9), 1337-1343.

Eshetu, T., Tefera, W., & Kebede, T. (2007). Effect of weed management on pineapple growth and yield. *Ethiopian Journal of Weed Management, 1*, 29-40.

FAO (Food and Agriculture Organization). (2009). Statistical databases. Retrieved from 31 December 2010, from http://faostat.fao.org/DesktopDefault.aspx.

Gbenou, R. K., Taore, M., & Sissinto, E. (2006). *Etude accélérée de marché (EAM) sur les différents produits ananas au Benin*. Cotonou: Helvetas-Benin.

Hartigan, J. A. (1985). Statistical theory in clustering. *Journal of classification, 2*(1), 63-76.

Helvetas-Bénin. (2008). Appui à la filière ananas biologique et equitable: document du projet. Cotonou, Benin: Helvetas-Bénin.

Hepton, A. (2003). Cultural system. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 109-142). Wallingford, UK: CABI Publishing.

INSAE (Institut National de la Statistique et de l'analyse economique). (2004). *Troisième recensement général de la population et de l'habitation (RGPH3)*. Cahier des villages et quartier du département de l'Atlantique. Cotonou: DED (Direction des Etudes Démographiques).

Linford, M. B., King, N., & Magistad, O. C. (1934). Planting and fruit quality: comparison of large and small slips in pure and mixed stands. *Pineapple Quaterly, 4*, 176-190.

Malézieux, E. (1993). Dry matter accumulation and yield elaboration of pineapple in Cote D'Ivoire. *Acta Horticulturae, 334*, 149-158.

Malézieux, E., & Bartholomew, D. P. (2003). Plant nutrition. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 143-165). Wallingford, UK: CABI Publishing.

Malézieux, E., Zhang, J., Sinclair, E. R., & Bartholomew, D. P. (1994). Predicting pineapple harvest date in different environments, using a computer simulation model. *Agronomy Journal, 86*(4), 609-617.

MAEP (Ministère de l'Agriculture de l'Elevage et de la Pêche). (2005). *Rapport sur l'Ananas au Bénin*, Cotonou, Benin : MAEP.

Morton, J. F. (1987). Fruits of warm climates. In J. F. Morton (Ed.), *Flora neotropica*. Miami, Florida: NYBG.

Mustaffa, M. M. (1988). Influence of plant population and nitrogen on fruit yield and quality and leaf nutrient content of 'Kew' pineapple. *Fruits, 43*(7), 455-458.

Neild, R. E., & Boshell, F. (1976). An agroclimatic procedure and survey of the pineapple production potential of Colombia. *Agricultural Meteorology, 17*(2), 81-92.

Norman, J. C. (1978). Responses of Sugarloaf pineapple, *Ananas comosus* (L.) Merr., to plant population densities. *Gartenbauwissenschaft*, *43*, 237-240.

Py, C., Lacoeuilhe, J. J., & Teisson, C. (1987). *The pineapple: cultivation and uses* (*Maisonneuve ed.*). Paris: Editions Quae.

Singh, B. P. (2002). Nontraditional crop production in Africa for export. In J. W. Janick (Ed.), *Trends in new crops and new uses.* (pp. 86-92). Alexandria: ASHS Press.

Spironello, A., Quaggio, J. A., Teixeira, L. A. J., Furlani, P. R., & Sigrist, J. M. M. (2004). Pineapple yield and fruit quality affected by NPK fertilization in a tropical soil. *Revista Brasileira de Fruticultura, 26*(1), 155-159.

Treto, E., Gonzales, A., & Gomez, J. M. (1974). Etude de différentes densités de plantation chez la variété d'ananas Espanola Roja. *Fruits*, *29*, 279-284.

Vissoh, P. V., Gbèhounou, G., Ahanchédé, A., Kuyper, T. W., & Röling, N. G. (2004). Weeds as agricultural constraint to farmers in Benin: results of a diagnostic study. *NJAS-Wageningen Journal of Life Sciences, 52*(3), 305-329.

Willaime, P., & Volkoff, B. (1967). *Carte pédologique du Dahomey: à l'échelle de 1: 1 000 000*. Paris: ORSTOM.

Zhang, J., & Bartholomew, D. P. (1992). Simulation of pineapple growth, development and yield. *Acta Horticulturae, 334*, 205-220.

CHAPTER 4

Heterogeneity in pineapple fruit quality within crops results from plant heterogeneity at flower induction*

V.N. Fassinou Hotegni[1,2], W.J.M. Lommen[1], E.K. Agbossou[2] and P.C. Struik[1]

[1] Centre for Crop Systems Analysis, Wageningen University, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands

[2] Faculté des Sciences Agronomiques, Université d'Abomey Calavi, 01 BP 526 Cotonou, Benin

* Submitted

Abstract

Heterogeneity in fruit quality constitutes a major constraint in agri-food chains. In this paper the sources of the heterogeneity in pineapple in the field were studied in four experiments in commercial pineapple fields. The aims were to determine (a) whether differences in pineapple fruit quality among individual fruits are associated with differences in vigour of the individual plants within the crop at the time of artificial flowering induction; and (b) whether the side shoots produced by the plant during the generative phase account for the fruit quality heterogeneity. Two pineapple cultivars were considered: cv. Sugarloaf and cv. Smooth Cayenne. Plant vigour at the time of artificial flowering induction was measured by three variates: the number of functional leaves, the D-leaf length and their cross product. Fruit quality attributes measured at harvest time included external attributes (weight and height of fruit, infructescence and crown) and internal quality attributes (total soluble solids, juice pH, translucent flesh). Results showed that the heterogeneity in fruit weight was a consequence of the heterogeneity in vigour of the plants at the moment of flowering induction; that effect was mainly on the infructescence weight and less or not on the crown weight. The association between plant vigour variates at flowering induction and the internal quality attributes of the fruit were poor and/or not consistent across experiments. The weight of the slips (side shoots), explained part of the heterogeneity in fruit weight, infructescence weight and fruit height in cv. Sugarloaf. Possibilities for reducing the variation in fruit quality by precise cultural practices are discussed.

Keywords: *Ananas comosus*; D-leaf; fruit size; variation in quality; variation within crop; vigour.

4.1. Introduction

In the last decades, costumers have become more demanding on uniformity of agricultural products, in addition to quantity, quality and delivering time (Beamon 1999). In pineapple production, a large heterogeneity in pineapple quality (size and taste) is an important constraint for successfully meeting market requirements (Fassinou Hotegni et al. unpublished; Takane 2004; Vagneron et al. 2009). For export of agricultural products, the Codex Alimentarius (2005) has set a number of quality criteria; for pineapple these include the degree of acceptable fruit quality as well as the associated heterogeneity in fruit weight, fruit height, the ratio crown height: infructescence height, the total soluble solids (TSS) and percentage of damage. The heterogeneity in quality of a product is caused by many factors, including the cultural practices underlying its production (Luning and Marcelis 2006; Ritter et al. 2008). Finding the source of product heterogeneity in the field is therefore fundamental for designing methodologies to obtain a more uniform product quality at harvest.

In pineapple, the high heterogeneity in quality at harvest may originate from a large heterogeneity in the vigour of the individual plants within a crop, especially at the time of flowering induction. Pineapple is a vegetatively propagated, perennial crop, showing three partly overlapping phases: the vegetative phase, characterized by an increase in number of leaves and diameter of the main stem (from planting to flowering induction); the generative phase (from flowering initiation to fruit maturity); and the propagative phase when different types of side shoots are produced (starting during the generative phase and continuing after the fruit harvest). Different types of vegetative organs are used as planting material: slips (shoots produced on the peduncle at the base of the fruit), hapas or side shoots (shoots produced above ground on the stem at the junction of the stem and the peduncle), suckers (side shoots originating below ground from the stem) and crowns (produced at the top of the fruit) (Hepton 2003) with slips, hapas and suckers being the most frequently used planting material. Plants are single-stemmed in the first year of production. To proceed from the vegetative to the reproductive phase, growth regulators are applied that release ethylene or acetylene which induce and synchronize flowering of the main stem (Collins 1960). This artificial flowering induction takes place 6 to 16 months after planting depending on the environment (Malézieux et al. 2003) and the desired delivery time of the fruits (generally five to six months after flowering induction) (Bartholomew et al. 2003; Kerns et al. 1936). After flowering induction, the formation of vegetative leaves on the main stem ceases

(Bartholomew and Malézieux 1994) as the result of the transition of the apex to the generative stage (Bartholomew et al. 2003) and multiple florets are initiated at the apex. Vegetative leaf production is resumed later when the production of florets ceases and the crown leaves are initiated (Bartholomew et al. 2003). The stage of development of a crop at flowering induction affects the later fruit weight, with a high number of leaves leading to larger fruits (Malézieux 1993; Malézieux et al. 2003; Mitchell 1962; Py and Lossois 1962; Py and Pelegrin 1958; Van Overbeek 1946). Consequently, also the heterogeneity in fruit weight of the plants within a field may be related to the heterogeneity among plants at the time of flowering induction. In some cultivars (e.g. Smooth Cayenne), fruit maturity is synchronized by applying the compound Ethephon (Smith 1991).

A pineapple fruit consists of the infructescence and the crown. It is thus far unknown if and how their individual weights and height, and the ratio between crown and infructescence height are affected by the plant status at the time of artificial flowering induction.

Defoliation of pineapple plants three weeks before harvest was shown to reduce the TSS concentration in the fruit and the fruit flesh translucency; the lowest values were obtained when all leaves were removed (Chen and Paull 2000). This shows that the plant status can affect also internal fruit characteristics. It is thus far unknown if fruits from more vigorous plants at the time of flowering induction, will show a different internal quality, e.g., a higher concentration of TSS, different juice pH, more translucent flesh, or different internal browning, when compared to fruits from less vigorous plants.

Also production of slips or other side shoots by the plant during fruit development may account for fruit quality heterogeneity. The initiation of slips occurs before the end of flowering initiation (Kerns et al. 1936). Studies on the relation between slip pruning and the fruit size show contradictory results. Norman (1976) found that removing slips increased fruit weight; recent studies on the other hand revealed that slips were important sources of assimilates for fruit growth and maintenance (Marler 2011a). Because the production of the slips overlaps with fruit development and growth, they may compete for input of assimilates from the leaves on the main stem. Therefore, the number and/or the weight of the additional vegetative organs produced might contribute - in addition to the plant vigour at flowering induction - to the differences in fruit quality at harvest.

The objectives of this study were to analyse (a) if and how differences in quality attributes between individual fruits within a crop are associated with differences in vigour of the individual plants within the crop at the time of artificial flowering induction; and (b) if and how the number and the weight of side shoots formed during the generative phase also account for fruit quality heterogeneity at harvest time in addition to the initial plant vigour at flowering induction. Results will help to understand why fruit quality is variable and will allow development of precise cultural practices that will reduce the fruit quality heterogeneity at harvest.

4.2. Materials and methods

4.2.1. Experimental site and design

Four on-farm experiments were carried out on commercial pineapple fields in the Atlantic department in the south of Benin (West Africa) between February 2010 and August 2012 with two pineapple cultivars: Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4). Two different producers were selected per cultivar based on (a) the age of their pineapple crop being close to the common artificial flowering induction time and (b) whether they applied the common practices for these cultivars, as described by Fassinou Hotegni et al. (2012). Information on the fields and cultural practices until artificial flowering induction time is provided in Table 4.1.

Four experimental plots were installed per experiment, which were part of a larger experiment not reported on here. Each net plot consisted of six rows of 10 plants each. The net experimental plots were surrounded by two rows with border plants.

4.2.2. Artificial flowering induction and maturity synchronization

Crops were artificially induced between 10 and 13 months after planting (Table 4.1) using carbide of calcium (CaC_2), a compound producing acetylene when it reacts with water. Following farmer's practices, 50 ml of a solution containing 10 g/l and 15 g/l of CaC_2 for Sugarloaf and Smooth Cayenne respectively, was applied into the centre of the leaf rosette of each plant. This application was carried out once in cv. Sugarloaf and three times, with an interval of three days, in cv. Smooth Cayenne. Following farmer's practices, maturity of the fruits was synchronized only in cv. Smooth Cayenne, 143 days after artificial flowering induction, by spraying 3.5 ml of a solution of 14 ml/l Ethephon (2-chloroethylphosphonic

Table 4.1. Field information and cultural practices in the four experiments with cvs Sugarloaf or Smooth Cayenne

Field information and cultural practices	Cv. Sugarloaf		Cv. Smooth Cayenne	
	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Location	06°36'09.2"N and 02°16'31.6"E	06°37'26.4"N and 02°16'13.1"E	06°36'43.7"N and 02°19'55.1"E	06°36'44"N and 02°19'54.3"E
Municipality (district)	Zè (Tangbo Djevie)	Zè (Tangbo Djevie)	Abomey-Calavi (Zinvié)	Abomey-Calavi (Zinvié)
Soil type (U.S. equivalent)	Ferralitic soil (Ultisols)	Ferralitic soil (Ultisols)	Ferralitic soil (Ultisols)	Ferralitic soil (Ultisols)
Climate	Subequatorial	Subequatorial	Subequatorial	Subequatorial
Planting time[a]	February 2010	July 2010	April 2011	May 2011
Type of planting material used[a]	Slips	Slips	Hapas and suckers	Hapas and suckers
Planting material treatment before planting[a]	No treatment	No treatment	No treatment	No treatment
Planting arrangement	Flat beds of two alternating rows	Flat beds of two alternating rows	Flat beds of two alternating rows	Flat beds of two alternating rows
Plant spacing: BP[b] × BR[c]/BDR[d] (cm)	40 ×50/80	35 × 45/65	47 × 55/75	47 × 55/75
Plant density (plants/m^2)	3.85	5.19	3.27	3.27
First Urea (46N) + NPK (10-20-20)	7 MAP[e] (18 Sept2mber 2010)	2 MAP (15 September 2010)	3 MAP (20 July 2011)	2 MAP (17 July 2011)
Application form	Solid at the base of the plants	Solid at the base of the plants	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g Urea + g NPK)	6 + 3	6 + 3	5 + 4	5 + 4
Second Urea (46N) + NPK (10-20-20)	Not applied	Not applied	6 MAP (15 October 2011)	5 MAP (24 October 2011)
Application form	Not applied	Not applied	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g Urea + g NPK)	Not applied	Not applied	4 + 5	4 + 5
NPK (10-20-20) application	12 MAP (22 Febr. 2011)	9 MAP (16 April 2011)	Not applied	Not applied
Application form	Solid	Solid	Not applied	Not applied
Dose per plant (g NPK)	7	7	Not applied	Not applied
K_2SO_4 (50-18) application	Not applied	Not applied	10 MAP (8 February 2012)	9 MAP (17 February 2012)
Application form	Not applied	Not applied	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g K_2SO_4)	Not applied	Not applied	7	7
Artificial flower induction time	13 MAP (6 March 2011)	10 MAP (4 May 2011)	10 MAP (22 February 2012)	10 MAP (3 March 2012)
Weed control	Hand weeding	Hand weeding	Hand weeding	Hand weeding
Harvest time	18 MAP (3-4 Aug. 2011)	15 MAP (2, 3 and 5 Oct. 2011)	15 MAP (24-25 July 2012)	15 MAP (3-4 Aug. 2012)

[a] Information gathered from pineapple producer (field owner)
[b] BP, spacing between plants within a row
[c] BR, spacing between rows
[d] BDR, spacing between double rows
[e] MAP, months after planting

acid), a compound producing ethylene, on the skin of each fruit. This application was carried out twice with an interval of four days.

Pineapple fruits were harvested between 150 and 154 days after flowering induction. The pineapple fruits were harvested following farmer's practice which was at the moment when the skin colour of at least 25% of the plants (i.e. 15 out of 60 plants in a net plot) had started to change from green to yellow. All fruits per plot were harvested on that day and were individually processed.

4.2.3. Observations and measurements

Three variates representing the vigour of the individual plants within a crop at the moment of artificial flowering induction were assessed: (1) the number of functional leaves per plant (NL) (green leaves excluding those withered over more than 10 cm of their length), (2) the length of the D-leaf (DL) (the longest leaf in a pineapple plant according to Malézieux et al. (2003) and (3) their cross product (NL× DL). The number of functional leaves indicates the developmental status of the plant at flowering induction time. The D-Leaf is used to assess the growth and the nutritional status of the plant (Malézieux et al. 2003). The cross product NL× DL is a proxy for the total leaf area of the plant. The number of functional leaves and DL were assessed on all individual plants one day before flowering induction. The D-leaf was identified by bunching all leaves together and selecting the longest. Next, the length was measured with a twig combined with a ruler.

External and internal fruit quality attributes were assessed at harvest on the fruits from all individual plants. External fruit quality attributes included the weight and height of the (total) fruit and of the infructescence and the crown separately, the ratio crown height: infructescence height and the number of fruitlets per infructescence. The number of fruitlets or "eyes" on the infructescence was determined by multiplying the number of spirals counted counter-clockwise and the average number of fruitlets on the first and last spiral. Internal fruit quality attributes included TSS, juice pH, the percentage of flesh being translucent, and internal browning. To determine these, the pineapple was cut longitudinally into two halves. A portion of the juice obtained from squeezing one half was used to determine the TSS by a hand refractometer; another portion of that juice was used to determine the juice pH by a hand-held pH meter. The percentage of fruit flesh that was translucent and internal browning were visually estimated on the second half following the methods of Paull and Reyes (1996).

The type, number and total weight of side shoots (slips, hapas and suckers) per plant were also recorded at harvest time.

4.2.4. Statistical analysis

Data were analysed using R version 2.15.2 (R Development Core Team, 2012). Fruits with more than one crown at harvest (13 and 6 fruits in Experiments 3 and 4 respectively) were excluded in the analysis. Heterogeneity in plant vigour variates and in fruit quality attributes was described by the coefficient of variation (CV) which is a measure of the variability in a population relative to the mean (cf. Field 2009; Illipronti et al. 2000; Ott and Longnecker 2010; Schouten et al. 1997). CVs were calculated per plot and differences in CV between cultivars for each plant vigour variate and each quality attribute were assessed using a t-test. Differences in CV between plant vigour variates as well as differences in CV between quality attributes within an experiment were assessed using an ANOVA. When the F value from the ANOVA was significant, LSDs ($\alpha = 0.05$) were used to separate means.

To determine if and how the plant vigour variates at flowering induction were associated with fruit quality attributes at harvest, simple linear regressions were performed on the combined data from all plots per experiment, using NL, DL and NL×DL as explanatory variates and each fruit quality attribute as response variate. Percentage flesh translucency was transformed using square root transformation ($\sqrt{x+0.5}$) before analysis (Bartlett 1936; Gonzalez 2009). Which plant vigour variable was best associated with a fruit quality attribute was determined using the adjusted R^2. The higher the adjusted R^2, the higher is the percentage of the variance in the response variate accounted for.

To determine whether the number and the weight of the additional side shoots produced (slips) accounted for fruit quality heterogeneity in addition to the plant vigour variates at flowering induction, a multiple regression was performed by using the plant vigour variates (explaining the highest percentage of the variance in the fruit quality attributes variates) as well as the number or weight of the slips as explanatory variates and the different fruit quality attributes as response variates. A hierarchical method was used in which the plant vigour variates were entered first and the weight or number of slips was entered next, to analyse the contribution of slip weight/number to fruit quality heterogeneity. Existence of colinearity between the explanatory variates was checked using Pearson coefficient of correlation (*r*). A value of *r* greater than 0.80 reveals multiple colinearity between the explanatory variates (Field 2009); in that case the explanatory variables were not used in the multiple regression model. The significance of the F change (significance of the improvement of the adjusted coefficient of multiple regression R^2) derived from the multiple regression model was used to evaluate the effect of slip weight/number.

4.3. Results

4.3.1. Initial heterogeneity in plant vigour at flowering induction

The initial heterogeneity in plant vigour (NL, DL and NL×DL) within a field was quantified using the CV. For all vigour variates, the initial heterogeneity was not different between experiments with cv. Sugarloaf and experiments with cv. Smooth Cayenne (Table 4.2). In all four experiments, variation in NL×DL was higher than variation in NL and DL, and variation in DL was lowest (Table 4.2).

4.3.2. Heterogeneity in fruit quality attributes at harvest

When comparing the CV in different external fruit quality attributes at harvest across experiments with different cultivars (Table 4.2), the variation in crown weight, crown height and ratio crown: infructescence height was higher in the experiments with cv. Smooth Cayenne than in those with cv. Sugarloaf, whereas the variation in all other attributes was similar across cultivars.

In all experiments, variation in infructescence weight was higher than variation in other external quality attributes. Variation in fruit weight, infructescence weight and the crown weight was higher than in the respective heights of these organs in all experiments (Table 4.2). Variation in infructescence weight was higher than variation in fruit and crown weight. The crown weight was the least variable weight attribute except in Experiment 3, where it was comparable to fruit weight (Table 4.2). Variation in infructescence height was higher than variation in fruit height in all experiments (Table 4.2), whereas variation in crown height was comparably low as variation in fruit height in the Sugarloaf experiments and comparably high as variation in infructescence weight in the Smooth Cayenne experiments. Variation in the ratio crown: infructescence height was higher than that in the underlying attributes, except in Experiment 2 where the difference with the variation in infructescence

Table 4.2. Differences in plant vigour and fruit quality variation (CV) within experiments and between experiments with different cultivars

Variates	Cv. Sugarloaf		Cv. Smooth Cayenne		Difference between cultivars
	Experiment 1	Experiment 2	Experiment 3	Experiment 4	*P*-value[a]
Plant vigour variates at the time of flower induction					
Number of functional leaves (NL)	0.21 b[b]	0.24 b	0.22 b	0.26 b	0.308
D-leaf length (DL)	0.12 a	0.08 a	0.09 a	0.09 a	0.225
NL×DL	**0.28 c**	**0.29 c**	**0.26 c**	**0.33 c**	0.630
Difference within experiments: *P*-value[c]	0.000 ***	0.000 ***	0.000 ***	0.000 ***	
External fruit quality attributes at harvest					
Fruit weight	0.33 c	0.28 d	0.30 c	0.34 e	0.535
Infructescence weight	**0.39 d**	**0.33 e**	**0.38 d**	**0.42 f**	0.087
Crown weight	0.24 b	0.18 b	0.31 c	0.27 d	0.007 **
Fruit height	0.11 a	0.09 a	0.13 a	0.11 a	0.167
Infructescence height	0.23 b	0.18 bc	0.20 b	0.21 bc	0.934
Crown height	0.13 a	0.11 a	0.20 b	0.17 b	0.000 ***
Ratio crown: infructescence height	0.31 c	0.22 c	0.32 c	0.32 e	0.039 *
Number of fruitlets	0.25 b	0.18 b	0.20 b	0.23 cd	0.913
Difference within experiments: P-value	0.000 ***	0.000 ***	0.000 ***	0.000 ***	
Internal fruit quality attributes at harvest					
Total soluble solids	0.06 a	0.06 a	0.10 a	0.10 a	0.000 ***
Juice pH	0.05 a	0.05 a	0.03 a	0.03 a	0.001 ***
Translucent flesh[d]	**0.81 b**	**0.70 b**	**2.39 b**	**1.16 b**	0.020 *
Difference within experiments: *P*-value	0.000 ***	0.000 ***	0.007 **	0.000 ***	

[a] Assessed by a t-test
[b] Within columns and groups of variates, values followed by the same letter are not significantly different according to the $LSD_{0.05}$
[c] Assessed by ANOVA
[d] Untransformed data used
*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$.
Values in bold indicated where the variation was the highest for each group of variates : plant vigor; external fruit quality attributes and internal fruit quality attributes

height was not significant. The CV in number of fruitlets was similar to the CV in infructescence height.

For all internal quality attributes, variation in TSS and flesh translucency was higher in the experiments with cv. Smooth Cayenne than in the experiments with cv. Sugarloaf. Variation in juice pH was higher in experiments with cv. Sugarloaf than in experiments with cv. Smooth Cayenne. In all experiments, the most variable internal quality attribute was flesh translucency. Variation in TSS and variation in juice pH were very low and not significantly different from each other in all experiments (Table 4.2).

4.3.3. Associations between plant vigour at the time of artificial flowering induction and external fruit quality at harvest

In all crops there were strong associations between the initial vigour of a plant at flowering induction and the total fruit weight of that plant at harvest; higher NL, DL and NL×DL all were associated with heavier fruits at harvest (Table 4.3). Based on adjusted R^2 values (0.463 – 0.686), NL×DL was the vigour variate showing the strongest association with fruit weight (Table 4.3; Figure 4.1-A1-4). The R^2 values for the relations between plant vigour variates and infructescence weights were comparable to those for total fruit weights and also highest for NL×DL (Table 4.3; Figure 4.1-B1-4). However, R^2 values for the relations between vigour variates and crown weight were much lower and not significant for NL×DL in two out of four experiments (Table 4.3; Figure 4.1-C1-4), suggesting that the positive associations between NL×DL and fruit weight were mainly caused by the positive effect of high vigour on the infructescence weight, and less or not on crown weight. Variation in crown weight was better explained by DL than by NL×DL, but with low R^2 values varying between 0.024 and 0.142. The cross product NL×DL was also significantly positively associated with the fruit height and the association was very clear for cv. Sugarloaf (Table 4.3; Figure 4.1-D1 and D2); for cv. Smooth Cayenne, this association was poorer although significant in both experiments (Table 4.3; Figure 4.1-D3 and D4). Of the attributes underlying fruit height, the infructescence height also increased with an increase in NL×DL in all experiments, but the crown height was differently related to NL×DL in the two cultivars; for cv. Sugarloaf a weak positive association was found to be significant only in one of the two experiments whereas a negative association was found in both Smooth Cayenne experiments (Table 4.3). As for crown weight, crown height showed a better association with DL than with NL×DL, but for

Table 4.3. Linear regression models of the association between plant vigour variates (number of functional leaves (NL), D-leaf length (DL), number of functional leaves × D-leaf length (NL×DL)) at artificial flower induction (explanatory variates) and fruit quality attributes at harvest (response variates) across individual plants in the four experiments, cvs Sugarloaf and Smooth Cayenne

Fruit quality attribute at harvest	Plant vigour at flower induction	Cv. Sugarloaf				Cv. Smooth Cayenne			
		Experiment 1 (n=240)		Experiment 2 (n=240)		Experiment 3 (n=227)		Experiment 4 (n=234)	
		R^2 adj.	Equation	R^2 adj.	Equation	R^2 adj.	Equation	R^2 adj.	Equation
External quality attributes									
Fruit weight	NL[a]	0.472	Y= -0.064 + 0.046***NL	0.618	Y= 0.144 + 0.040***NL	0.411	Y= 0.293 + 0.025***NL	0.415	Y= 0.253 + 0.028***NL
	DL[b]	0.500	Y= -0.839 + 0.022***DL	0.282	Y= -0.685 + 0.021***DL	0.196	Y= -0.496 + 0.020***DL	0.297	Y= -0.913 + 0.025***DL
	NL×DL	0.645	Y= 0.085 + 4.6.10^{-4}***NL×DL	0.686	Y= 0.280 + 3.9.10^{-4}***NL×DL	0.467	Y= 0.339 + 3.0.10^{-4}***NL×DL	0.463	Y= 0.370 + 2.9.10^{-4}***NL×DL
Infructescence weight	NL	0.474	Y= -0.194 + 0.043***NL	0.617	Y= -0.033 + 0.040***NL	0.410	Y= 0.062 + 0.023***NL	0.464	Y= -0.041 + 0.028***NL
	DL	0.482	Y= -0.890 + 0.020***DL	0.266	Y= -0.806 + 0.020***DL	0.173	Y= -0.587 + 0.018***DL	0.280	Y= -1.031 + 0.023***DL
	NL×DL	0.638	Y= -0.048 + 4.3.10^{-4}***NL×DL	0.679	Y= 0.106 + 3.8.10^{-4}***NL×DL	0.458	Y= 0.110 + 2.7.10^{-4}***NL×DL	0.501	Y= 0.087 + 2.9.10^{-4}***NL×DL
Crown weight	NL	0.078	Y= 0.131 + 0.003***NL	0.000	Y= 0.178 + 2.5.10^{-4} ^{NS}NL	0.023	Y= 0.233 + 0.002*NL	0.000	Y= 0.294 + 0.0002^{NS}NL
	DL	0.142	Y= 0.051 + 0.002***DL	0.024	Y= 0.125 + 0.001**DL	0.037	Y= 0.092 + 0.002**DL	0.052	Y= 0.118 + 0.002***DL
	NL×DL	0.133	Y= 0.135 + 3.0.10^{-5}***NL×DL	0.003	Y= 0.176 + 4.0.10^{-6NS}NL×DL	0.034	Y= 0.230 + 2.3.10^{-5}**NL×DL	0.002	Y= 0.283 + 6.8.10^{-6NS}NL×DL
Fruit height	NL	0.252	Y= 26.886 + 0.424***NL	0.276	Y= 31.605 + 0.340***NL	0.044	Y= 28.095 + 0.104**NL	0.007	Y= 31.644 + 0.043^{NS}NL
	DL	0.402	Y= 15.800 + 0.249***DL	0.377	Y= 13.080 + 0.310***DL	0.035	Y= 22.912 + 0.107**DL	0.093	Y= 21.990 + 0.136***DL
	NL×DL	0.402	Y= 27.599 + 0.005***NL×DL	0.390	Y= 31.789 + 0.004***NL×DL	0.060	Y= 28.020 + 0.001***NL×DL	0.024	Y= 31.193 + 0.001*NL×DL
Infructescence height	NL	0.336	Y= 5.201 + 0.351***NL	0.510	Y= 7.604 + 0.318***NL	0.340	Y= 7.001 + 0.175***NL	0.484	Y= 5.982 + 0.208***NL
	DL	0.423	Y= -2.050 + 1.183***DL	0.278	Y= -0.374 + 0.184***DL	0.177	Y= 1.023 + 0.145***DL	0.351	Y= -2.744 + 0.188***DL
	NL×DL	0.476	Y= 6.218 + 0.004*** NL×DL	0.584	Y= 8.570 + 0.003*** NL×DL	0.401	Y= 7.218 + 0.002***NL×DL	0.540	Y= 6.843 + 0.002***NL×DL
Crown height	NL	0.010	Y= 21.685 + 0.074^{NS}NL	0.000	Y= 24.001 + 0.022^{NS}NL	0.021	Y= 21.094 - 0.070*NL	0.171	Y= 25.662 - 0.164***NL
	DL	0.047	Y= 17.850 + 0.066***DL	0.095	Y= 13.454 + 0.126***DL	0.001	Y= 21.889 - 0.039^{NS}DL	0.011	Y= 24.657 - 0.052^{NS}DL
	NL×DL	0.031	Y= 21.381 + 0.001**NL×DL	0.011	Y= 23.219 + 0.001 ^{NS}NL×DL	0.021	Y= 20.803 - 0.001*NL×DL	0.141	Y= 24.350 - 0.001***NL×DL
Ratio crown height:	NL	0.189	Y= 3.053 - 0.051***NL	0.246	Y= 2.318 - 0.027***NL	0.236	Y= 2.488 - 0.029***NL	0.504	Y= 3.059 - 0.042***NL
Infructescence height	DL	0.194	Y= 3.894 - 0.024***DL	0.046	Y= 2.456 - 0.010***DL	0.125	Y= 3.484 - 0.024***DL	0.270	Y= 4.390 - 0.033***DL
	NL×DL	0.236	Y= 2.839 - 4.9.10^{-4}***NL×DL	0.234	Y= 2.179 - 2.5.10^{-4}***NL×DL	0.273	Y= 2.440 - 2.4.10^{-4}***NL×DL	0.515	Y= 2.836 - 4.2.10^{-4}***NL×DL
Number of fruitlets	NL	0.284	Y= 30.063 + 2.182***NL	0.374	Y= 53.249 + 1.607***NL	0.363	Y= 48.722 + 1.380***NL	0.446	Y= 45.637 + 1.604***NL
	DL	0.365	Y= -15.813 + 1.147***DL	0.273	Y= -0.065 + 1.077***DL	0.165	Y= 7.625 + 1.069***DL	0.354	Y= -27.156 + 1.519***DL
	NL×DL	0.406	Y= 36.252 + 0.022***NL×DL	0.445	Y= 57.431 + 0.016***NL×DL	0.412	Y= 51.271 + 0.016***NL×DL	0.507	Y= 51.874 + 0.017***NL×DL

Table 4.3. Continued

Fruit quality attributes at harvest	Plant vigour at flower induction	Cv. Sugarloaf				Cv. Smooth Cayenne			
		Experiment 1 (n=240)		Experiment 2 (n=240)		Experiment 3 (n=227)		Experiment 4 (n=234)	
		R^2 adj.	Equation	R^2 adj.	Equation	R^2 adj.	Equation	R^2 adj.	Equation
Internal quality									
Total soluble solids	NL	0.004	$Y= 14.270 + 0.017^{NS}NL$	0.017	$Y= 15.236 - 0.020{*}NL$	0.016	$Y= 10.772 + 0.022{*}NL$	0.016	$Y= 10.750 + 0.019{*}NL$
	DL	0.045	$Y= 13.016 + 0.019{**}DL$	0.000	$Y= 14.577 + 0.002^{NS}DL$	0.136	$Y= 6.459 + 0.062{***}DL$	0.000	$Y= 10.928 + 0.005^{NS}DL$
	NL×DL	0.018	$Y= 14.174 + 2.4.10^{-4}{*}NL \times DL$	0.013	$Y= 15.106 - 1.6.10^{-4}{*}NL \times DL$	0.052	$Y= 10.465 + 3.8.10^{-4}{***}NL \times DL$	0.012	$Y= 10.911 + 1.7.10^{-4NS}NL \times DL$
Juice pH	NL	0.107	$Y= 3.349 + 0.012{***}NL$	0.002	$Y= 3.752 - 0.002^{NS}NL$	0.200	$Y= 3.274 + 0.006{***}NL$	0.067	$Y= 3.309 + 0.004{***}NL$
	DL	0.110	$Y= 3.154 + 0.006{***}DL$	0.005	$Y= 3.873 - 0.002^{NS}DL$	0.083	$Y= 3.102 + 0.005{***}DL$	0.037	$Y= 3.188 + 0.003{**}DL$
	NL×DL	0.139	$Y= -3.395 + 1.2.10^{-4}{***}NL \times DL$	0.006	$Y= 3.754 - 2.5.10^{-5NS}NL \times DL$	0.224	$Y= 3.280 + 7.2.10^{-5}{***}NL \times DL$	0.068	$Y= 3.328 + 3.5.10^{-5}{***}NL \times DL$
Translucent flesh[c]	NL	0.039	$Y= 2.249 + 0.081{**}NL$	0.199	$Y= 1.704 + 0.119{***}NL$	0.000	$Y= 1.759 + 0.024^{NS}NL$	0.041	$Y= 1.494 + 0.046{**}NL$
	DL	0.007	$Y= 2.521 + 0.019^{NS}DL$	0.042	$Y= 0.901 + 0.044{**}DL$	0.051	$Y= -4.982 + 0.094{***}DL$	0.048	$Y= -1.295 + 0.052{***}DL$
	NL×DL	0.032	$Y= 2.871 + 0.001{**}NL \times DL$	0.197	$Y= 2.260 + 0.001{***}NL \times DL$	0.011	$Y= 1.298 + 4.7.10^{-4NS}NL \times DL$	0.051	$Y= 1.634 + 0.001{***}NL \times DL$

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; *** Significant at the 0.001 probability level; [a]: NL, number of functional leaves at flower induction; [b]: DL, D-leaf length at flower induction; [c]: Regression was based on square root transformed data.

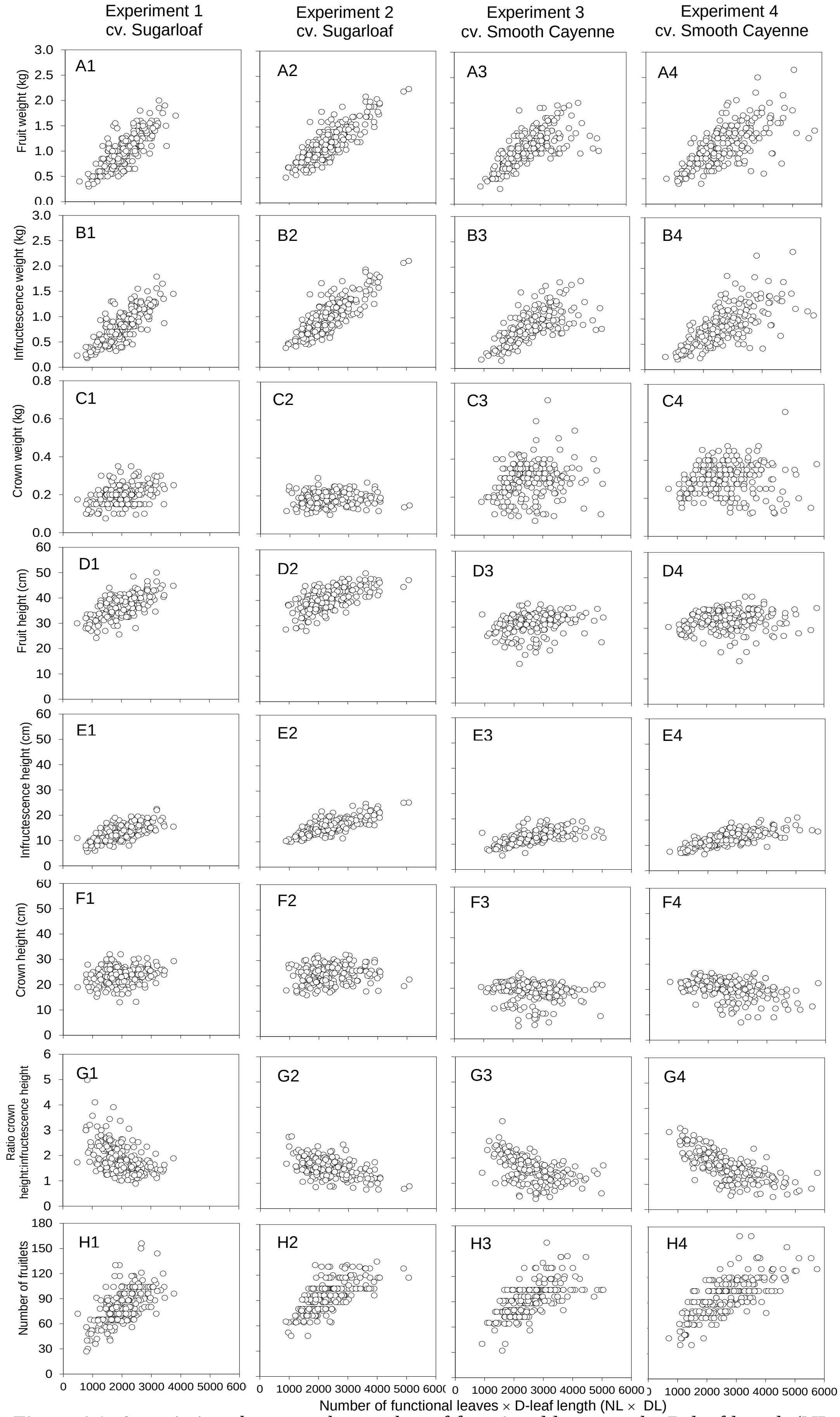


Figure 4.1. Associations between the number of functional leaves × the D-leaf length (NL×DL) at flowering induction time and the external fruit quality attributes in Experiments 1 and 2 (cv. Sugarloaf) and Experiments 3 and 4 (cv. Smooth Cayenne)

cv. Sugarloaf only. For cv. Smooth Cayenne, the negative association between the initial plant vigour and crown height was even clearer for NL than for NL×DL in one experiment (Table 4.3).

The cross product NL×DL was significantly negatively associated with the ratio crown height: infructescence height (Table 4.3; Figure 4.1-F1-4) in all experiments.

Figures showing the associations of the external quality attributes with NL and DL can be found in the supplementary materials (Figures S4.1 and S4.2).

4.3.4. Associations between plant vigour at the time of artificial flowering induction and internal fruit quality attributes at harvest

The plant vigour variates at the time of artificial flowering induction were not or only weakly associated with the TSS, juice pH and translucency of the fruits at harvest (Table 4.3; Figure 4.2 for associations with NL×DL). Figures showing the associations with NL and DL can be found in the supplementary materials (Figures S4.3 and S4.4).

Weak but significant associations between at least one of the vigour variates and TSS were found in all experiments, but these associations were positive in three experiments and negative in one experiment, and consequently not consistent across experiments (Table 4.3).
For cv. Smooth Cayenne, the cross product NL×DL was the strongest vigour variate to be weakly, but consistently positively associated with juice pH (Table 4.3; Figure 4.2-B3 and B4). For cv. Sugarloaf the same results were found in Experiment 1 (Table 4.3; Figure 4.2-B1); whereas in Experiment 2 no significant associations were found between any of the vigour variates and juice pH (Table 4.3; Figure 4.2-B2; Figures S4.3-B2 and S4.4-B2).

No consistent associations were found between the vigour variates and flesh translucency for cv. Smooth Cayenne (Table 4.3). For cv. Sugarloaf, NL was the strongest vigour variate to be weakly but consistently associated with flesh translucency (Table 4.3; Figure S4.3-C1 and C2).

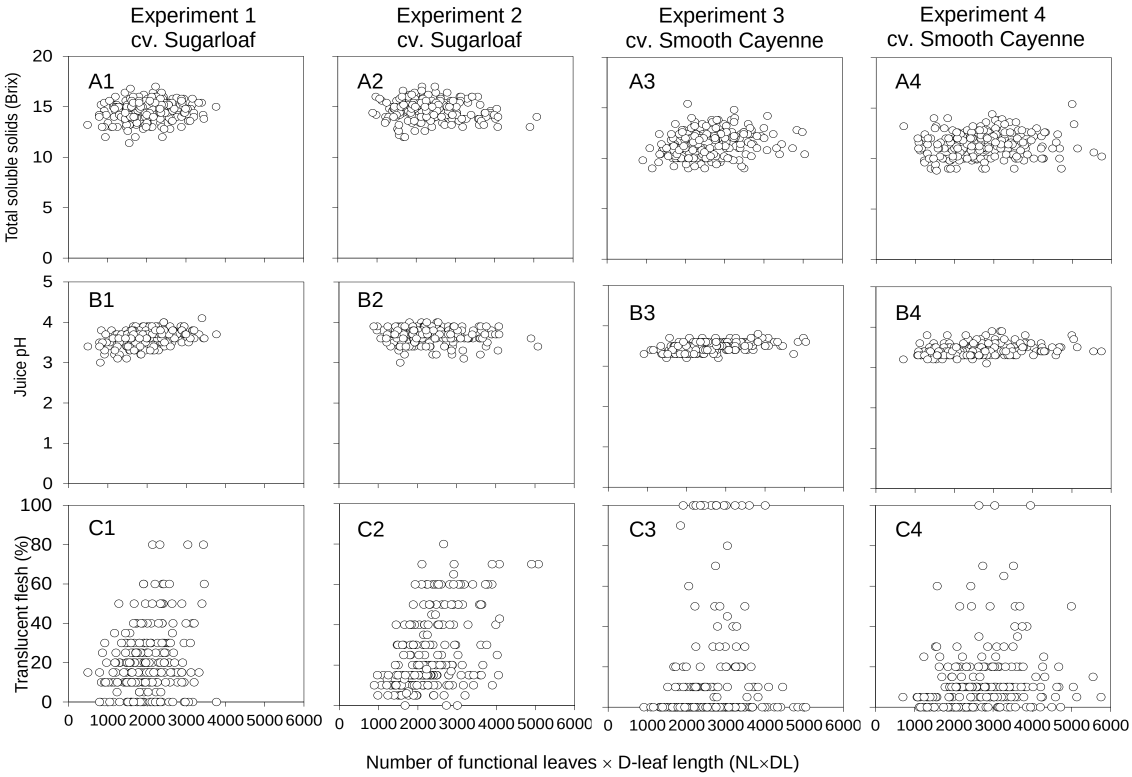


Figure 4.2. Associations between the number of functional leaves × the D-leaf length (NL×DL) at flowering induction time and the internal fruit quality attributes in Experiments 1 and 2 (cv. Sugarloaf) and Experiments 3 and 4 (cv. Smooth Cayenne)

4.3.5. Influence of side shoot production on the association between initial plant vigour and fruit quality at harvest

Production of side shoots

The type of side shoots (slips, hapas and suckers) produced at harvest time was not the same for the two pineapple cultivars and differed across the two experiments per cultivar. Sugarloaf produced mainly slips; the number of plants producing slips was higher in Experiment 2 than in Experiment 1 (Table 4.4). No slips were observed in cv. Smooth Cayenne. Only very few plants produced hapas in both cultivars (Table 4.4) and none had produced suckers at harvest time (Table 4.4). Based on these results, only Experiment 2 was used to test whether the number and/or the weight of the slips produced accounted additionally for fruit quality heterogeneity.

Number or weight of slips accounting for the fruit quality heterogeneity

Pearson's correlation coefficient revealed that there was a strong and positive correlation between the different plant vigour variates and the number and weight of slips at harvest (Table 4.5). However, since the correlation coefficients were not above 0.80, we concluded that there was no multiple colinearity. Therefore, the number or weight of the slips was added as additional explanatory variate to the linear regression models in Table 4.3.

The addition of the number of slips to the regression models did not significantly increase the explanation of the variability (adjusted R^2) in the external and internal quality attributes (Table 4.6). The weight of the slips significantly increased the explained variability in fruit weight, infructescence weight and the fruit height. Higher slip weight was associated with higher fruit weight, infructescence weight and fruit height (Table 4.6).

Table 4.4. Number of plants that produced a certain type of side shoot in the four experiments, cvs Sugarloaf and Smooth Cayenne

Type of side shoot	Cv. Sugarloaf		Cv. Smooth Cayenne	
	Experiment 1 (n=240)	Experiment 2 (n=240)	Experiment 3 (n=227)	Experiment 4 (n=234)
Slips	13	182	0	0
Hapas	1	5	2	5
Suckers	0	0	0	0

Table 4.5. Pearson correlation coefficient (*r*) between plant vigour variates at the time of artificial flower induction and the number and weight of slips at harvest across individual plants in Experiment 2, cv. Sugarloaf (n=240)

Plant vigour variate	Slip number	Slip weight
Number of functional leaves (NL)	0.571***	0.576***
D-leaf length (DL)	0.542***	0.570***
Cross product (NL×DL)	0.650***	0.671***

***: Statistically significant at $P < 0.001$

Table 4.6. Multiple regression models showing the association between the strongest plant vigour variate at the time of flower induction plus slip weight or number (explanatory variates) and external fruit quality attributes at harvest (response variates) in Experiment 2, cv. Sugarloaf (n=240)

Fruit quality attribute at harvest	Explanatory variates	Experiment 2		
		R^2 adj.	*P*-value for significance in F change[a]	Equation
External quality attributes				
Fruit weight	NL[b]×DL[c] + SN[d]	0.688	0.085	$Y = 0.307 + 3.62.10^{-4***} NL \times DL + 0.011^{ns} SN$
	NL×DL + SW[e]	0.690	0.035 *	$Y = 0.324 + 3.55.10^{-4***} NL \times DL + 1.43.10^{-4*} SW$
Infructescence weight	NL×DL + SN	0.682	0.064	$Y = 0.135 + 3.56.10^{-4***} NL \times DL + 0.012^{ns} SN$
	NL×DL + SW	0.683	0.038 *	$Y = 0.150 + 3.51.10^{-4***} NL \times DL + 1.42.10^{-4*} SW$
Crown weight	DL + SN	0.028	0.166	$Y = 0.109 + 0.001^{**} DL - 0.001^{ns} SN$
	DL + SW	0.022	0.476	$Y = 0.116 + 0.001^{*} DL - 7.92.10^{-6\,ns} SW$
Fruit height	NL×DL + SN	0.397	0.062	$Y = 32.312 + 0.003^{***} NL \times DL + 0.206^{ns} SN$
	NL×DL + SW	0.402	0.019 *	$Y = 32.666 + 0.003^{***} NL \times DL + 0.003^{*} SW$
Infructescence height	NL×DL + SN	0.587	0.091	$Y = 8.841 + 0.003^{***} NL \times DL + 0.107^{ns} SN$
	NL×DL + SW	0.588	0.078	$Y = 8.946 + 0.003^{***} NL \times DL + 0.001^{ns} SW$
Crown height	DL + SN	0.095	0.367	$Y = 12.441 + 0.140^{***} DL - 0.087^{ns} SN$
	DL + SW	0.093	0.510	$Y = 12.609 + 0.137^{***} DL - 0.001^{ns} SW$
Ratio crown height:	NL×DL + SN	0.229	0.776	$Y = 2.171 - 2.40.10^{-4***} NL \times DL - 0.003^{ns} SN$
infructescence height	NL×DL + SW	0.229	0.953	$Y = 2.182 - 2.50.10^{-4***} NL \times DL + 9.22.10^{-6\,ns} SW$
Number of fruitlets	NL×DL + SN	0.448	0.087	$Y = 59.048 + 0.015^{***} NL \times DL + 0.638^{ns} SN$
	NL×DL + SW	0.450	0.138	$Y = 59.921 + 0.014^{***} NL \times DL + 0.008^{ns} SW$
Internal quality attributes				
Total soluble solids	NL + SN	0.022	0.145	$Y = 15.350 - 0.028^{**} NL + 0.040^{ns} SN$
	NL + SW	0.013	0.958	$Y = 15.241 - 0.020\ NS\ NL + 1.52.10^{-5\,ns} SW$
Translucent flesh	NL + SN	0.200	0.250	$Y = 1.865 + 0.107^{***} NS\ NL + 0.056^{ns} SN$
	NL + SW	0.203	0.131	$Y = 1.963 + 0.103^{***} NS\ NL + 0.001^{ns} SW$

[a] Significance of the F change after adding SN or SW to the regression model
[b] NL, number of functional leaves at flower induction
[c] DL, D-leaf length at flower induction
[d] SN, slip number
[e] SW, slip weight

4.4. Discussion

4.4.1. Plant vigour at the time of artificial flowering induction and external fruit quality at harvest

Our data show that in the pineapple crops, most of the external quality attributes of the fruit at harvest were significantly and positively associated with the initial vigour of the plant at the moment of artificial flowering induction (Table 4.3). This suggests there is a good chance of decreasing the heterogeneity in fruit quality within a lot by increasing the uniformity of the crop at the moment of flowering induction.

Differences in initial plant vigour accounted for a high proportion of the variation in fruit weight. Comparing the three vigour variates, the highest proportion of the heterogeneity in fruit weight was explained by NL×DL (Table 4.3, Figure 4.1-A1-4). The association between the NL×DL and the fruitlets number and the fruit weight at harvest was positive. Reasons explaining this are likely that out of the three vigour variates, NL×DL would be best related to leaf area, and that higher values of the NL × DL at the time of artificial flowering induction thus would indicate a higher leaf area and consequently a higher photosynthetic capacity and amount of assimilates available in a plant at the time of artificial flowering induction i.e. at the end of the vegetative phase. Since the production of new normal leaves ceases once flowering is induced (Bartholomew and Malézieux 1994), the available assimilates at the flowering induction time that were allocated to the roots and leaves, now additionally are partitioned to the new sinks, i.e. the infructescence, crown and peduncle. Earlier studies showed that a large proportion of assimilates is allocated to the infructescence and the crown (Marler 2011b). This means that the more assimilates are available at flowering induction, the higher would be the fruit weight. The association of fruit weight with plant vigour at flowering initiation shows the importance of the development stage and morphology of the plants at flowering induction for final fruit quality, and is consistent with experiments in which later flowering induction increased fruit weight in whole crops (Bartholomew et al. 2003; Mitchell 1962) and in individual plants (Van Overbeek 1946).

Our data show that the positive association between the initial plant vigour and later fruit weight was mainly due to an effect on the infructescence weight whereas the effect on the crown was much smaller and only consistently significant for one vigour variate (Table 4.3; Figure 4.1-C1-4; Figure S4.1-C1-4 and Figure S4.2-C1-4). Such differences in the effect on the infructescence and crown could probably be explained by the differences in timing of their development. The initiation of the florets may have continued longer in infructescences bearing more florets, which may have delayed the onset of crown formation.

Each floret differentiates into one fruitlet. Our results revealed that in all experiments, all plant vigour variates are positively associated with the number of fruitlets at harvest indicating that in vigorous plants more florets were able to develop into fruitlets. As with fruit weight, NL × DL was the plant vigour explaining the largest proportion of variation in number of fruitlets. After flowering induction, pineapple plants show an increase of the width of the apex (Wee and Rao 1979) which bears the florets. Thus, more assimilates available - plants with high NL × DL - would lead to high volume increase of the apex and consequently high number of florets that will differentiate into fruitlets.

Considering the fruit height, it was found that the association between NL × DL and the fruit height was strong in the experiments with cv. Sugarloaf (R^2 =0.402 and 0.390 in Experiments 1 and 2 respectively) and significant but much weaker in the experiment with cv. Smooth Cayenne (R^2 =0.060 and 0.024 in Experiments 3 and 4, respectively) (Table 4.3; Figure 4.1-D1-4). These differences were due to the differences between cultivars in the associations between NL × DL and fruit height components: infructescence height and crown height. The former was positive for both cultivars, but the association between NL × DL and crown height was positive for cv. Sugarloaf (Table 4.3; Figure 4.1-F1 and F2) and negative for cv. Smooth Cayenne (Table 4.3; Figure 4.1-F3 and F4). This means that for cv. Smooth Cayenne, more vigorous plants produce fruits with a shorter crown (Figure 4.1-F3 and F4) lowering then the total fruit height, hence the poor association observed between the NL × DL and the fruit height at harvest for cv. Smooth Cayenne. This is also in line with the significantly negative correlations between the infructescence height and the crown height for cv. Smooth Cayenne (Tables S4.3 and S4.4).

The negative associations between NL × DL and the ratio crown height: infructescence height (Table 4.3; Tables S4.1, S4.2, S4.3 and S4.4; Figure 4.1-G1-4) follow logically from the clear increase in infructescence height with increase in NL × DL combined with the poor and negative association between the initial plant vigour and the crown height. Reasons for such differences are described above.

4.4.2. Plant vigour at the time of artificial flowering induction and internal fruit quality at harvest

Heterogeneity in pineapple taste is also a problem in the pineapple supply chain (Fassinou Hotegni et al., unpublished). In the present paper, TSS and juice pH were assessed to represent taste. Our findings indicated that the variation in TTS and especially in pH were very small compared to those in fruit and infructescence weight. There were no clear associations between the initial plant vigour and TSS, juice pH or flesh translucency since the results were not consistent across experiments. Such results are in line with idea that fruit ripening and maturation - affecting TSS and juice pH- occur autonomous in proportion to the fruit size established, and in relation to time and external conditions. However, for the flesh translucency, results showed a consistent positive correlation between translucency and TSS in the experiments with Smooth Cayenne (Tables S4.3 and S4.4). These results on flesh translucency in cv. Smooth Cayenne confirm the findings of Chen and Paull (2001), that translucency is affected by sugar concentration at harvest time.

4.4.3. Cultivar differences in heterogeneity in external and internal quality at harvest

In this study, the experiments with cv. Smooth Cayenne showed a higher variation than the experiments with cv. Sugarloaf in some external quality attributes and internal quality attributes (Table 4.2). We attribute most of these differences to genotypic differences and differences in the cultivation practices of these cultivars, although the differences between experiments also might be affected by the location and season. The high variation in the crown weight and height in cv. Smooth Cayenne compared to cv. Sugarloaf (Table 4.2) might originate in part from the diverse planting material; mixtures of hapas and suckers were used in cv. Smooth Cayenne planting while only slips were used in cv. Sugarloaf planting. It is well known that plants grown from suckers initiate fruits earlier than plants grown from hapas (Bartholomew et al. 2003); so variation would exist in the growth of the two types of planting material. In our study, variation in plant vigour variates at flowering induction was similar for both cultivars. Therefore, variation in growth of the hapas and suckers expresses itself later during the generative phase increasing variation in crown weight and height in cv. Smooth Cayenne and suggesting a relationship between the type of planting material used and the morphology of the fruit produced. The higher variation in the ratio crown: infructescence height in cv. Smooth Cayenne than in cv. Sugarloaf was certainly the consequence of a higher variation in crown height and opposite associations between plant vigour and crown height, and plant vigour and infructescence height (Tables S4.2 and S4.3).

When considering the internal quality attributes, variation in TSS and translucency was higher in cv. Smooth Cayenne than in cv. Sugarloaf while for the variation in juice pH the opposite was observed. Differences in variation in TSS between the two cultivars might be due to maturity synchronization practices in cv. Smooth Cayenne which might increase variation in TSS. In pineapple fruits, at two weeks before the ripening of the fruit, the TSS increases until the harvest (Singleton and Gortner 1965); when maturity is synchronised by applying Ethrel on the skin of the fruits - at different stages of natural ripening process (different TSS) - degreening of the shell is accelerated artificially (Smith 1991). Then, the variation in TSS will be higher in cv. Smooth Cayenne when compared to cv. Sugarloaf where no maturity was synchronised. Higher variation in flesh translucency in cv. Smooth Cayenne might be due to the high variation in TSS; TSS and translucency are positively associated in cv. Smooth Cayenne as shown in Tables S4.3 and S4.4.

4.4.4. Slip weight effect on fruit quality heterogeneity at harvest

The weight of slips but not the number of slips accounted for an extra part of the variation in fruit weight, infructescence weight and fruit height in addition to the effect related to the initial plant vigour (Table 4.6). This effect of the slip weight was positive (Table 4.6). Differences in fruit weight, infructescence weight and the height of the fruit thus may not originate only from differences in initial plant vigour but also to a small extent from differences in the weight of slips produced. This might be the result of transfer of assimilates from the slips to the fruit (Marler 2011a). Slips are composed of leaves and the slip weight will give a better idea of the photosynthetic capacity of the slips than the slip number. A better understanding of the role of the slips would help to improve fruit weight, infructescence weight and fruit height.

4.5. Conclusions and implications

The heterogeneity in fruit weight, infructescence weight and height, the number of fruitlets, and ratio crown height: infructescence height in pineapple crops is a direct consequence of the heterogeneity in plant vigour at the time of artificial flowering induction of these crops. Among the plant vigour variates the cross product NL × DL was the vigour variate explaining the highest proportion (up to 68.7%) of the variance in fruit weight; that effect was mainly on the infructescence weight and less or not on the crown weight. In addition to the plant vigour variates, slip weight also accounted for variation in fruit weight, infructescence weight and fruit height. Plant vigour at flowering induction was weakly and not consistently associated with TSS, juice pH and the flesh translucency. Differences existed between experiments with different cultivars; a higher variation in crown weight, crown height and ration crown: infructescence height, TSS and translucency but a lower variation in pH were observed in cv. Smooth Cayenne than in cv. Sugarloaf.

Results from this study are important to design agronomic tools to get a more uniform fruit weight quality at harvest. Achieving a more uniform crop with regards to plant vigour - especially NL × DL - at flowering induction would reduce the fruit quality heterogeneity, especially the external fruit quality, at harvest. This could probably be achieved by reducing heterogeneity in planting material at planting through the use of uniform planting material in terms of type (hapas or suckers in cv. Smooth Cayenne) and weight. In cv. Sugarloaf which produces numerous slips during the generative phase, uniformity in the fruit quality probably also could be improved by pruning slips on the least vigorous plants.

Acknowledgements

The authors are thankful to the North-South Interdisciplinary Research and Education Fund (INREF) of Wageningen University and Research Centre and the Netherlands Organisation for International Cooperation in Higher Education (NUFFIC) for their financial support through the Co-Innovation for Quality in African Foods Chains (CoQA) programme and the Netherlands Fellowship Programs (NFP), respectively.

References

Bartholomew, D. P., & Malézieux, E. (1994). Pineapple. In B. Schaffer & P. C. Andersen (Eds.), *Handbook of environmental physiology of fruit crops Vol. II. Sub-tropical and Tropical Crops* (pp. 243-291). Boca Raton, Florida: CRC Press.

Bartholomew, D. P., Malézieux, E., Sanewski, G. M., & Sinclair, E. (2003). Inflorescence and fruit development and yield. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 167-202). Wallingford, UK: CABI Publishing.

Bartlett, M. (1936). The square root transformation in analysis of variance. *Supplement to the Journal of the Royal Statistical Society, 3*(1), 68-78.

Beamon, B. M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management, 19*(3), 275-292.

Chen, C.-C., & Paull, R. E. (2000). Sugar metabolism and pineapple flesh translucency. *Journal of the American Society for Horticultural Science, 125*(5), 558-562.

Chen, C.-C., & Paull, R. E. (2001). Fruit temperature and crown removal on the occurrence of pineapple fruit translucency. *Scientia Horticulturae, 88*(2), 85-95.

Codex Alimentarius. (2005). Codex standard for pineapples. [Revision 1-1999, Amendment 1-2005]. Retrieved 10 January 2009, from www.codexalimentarius.net website: http://www.codexalimentarius.net/ web/more _info.jsp?id_sta=313.

Collins, J. L. (1960). *The pineapple: botany, cultivation and utilization*. New York:

Interscience Publishers.

Fassinou Hotegni, V. N., Lommen, W. J. M., van der Vorst, J. G. A. J., Agbossou, E. K., & Struik, P. C. (2012). Analysis of pineapple production systems in Benin. *Acta Horticulturae, 928*, 47-58.

Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). London: Sage publications.

Gonzalez, R. (2009). *Data analysis for experimental design*. New York: Guilford Press.

Hepton, A. (2003). Cultural system. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 109-142). Wallingford, UK: CABI Publishing.

Illipronti, R. A., Langerak, C. J., Lommen, W. J. M., & Struik, P. C. (2000). Uniformity, performance and seed quality of soybean (*Glycine max* (L.) Merrill) seed crops grown from sub-samples of one seed lot obtained after selection for physical seed attributes. *Journal of Agronomy and Crop Science, 184*(2), 81-88.

Kerns, K. R., Collins, J., & Kim, H. (1936). Developmental studies of the pineapple *Ananas comosus* (L) Merr. *New Phytologist*, *35*(4), 305-317.

Luning, P. A., & Marcelis, W. J. (2006). A techno-managerial approach in food quality management research. *Trends in Food Science & Technology, 17*(7), 378-385.

Malézieux, E. (1993). Dry matter accumulation and yield elaboration of pineapple in Cote D'Ivoire. *Acta Horticulturae, 334*, 149-158.

Malézieux, E., Côte, F., & Bartholomew, D. P. (2003). Crop environment, plant growth and physiology. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 69-107). Wallingford, UK: CABI Publishing.

Marler, T. E. (2011a). Leaf gas exchange of pineapple as influenced by fruit. *Acta Horticulturae, 902*, 239-243.

Marler, T. E. (2011b). Partitioning of dry matter in fruiting and vegetative pineapple plants of homogeneous age. *Acta Horticulturae, 902*, 253-256.

Mitchell, A. R. (1962). Plant development and yield in the pineapple as affected by size and type of planting material and times of planting and forcing. *Queensland Journal of Agricultural Science, Queensland, 22*, 409-417.

Norman, J. C. (1976). Influence of slip size, deslipping and decrowning on the 'Sugarloaf' pineapple. *Scientia Horticulturae, 5*(4), 321-329.

Ott, L. R., & Longnecker, M. (2010). *An introduction to statistical methods and data analysis*

(6th ed.). Brooks/Cole, Belmont, CA: Cengage Learning.

Paull, R. E., & Reyes, M. E. (1996). Preharvest weather conditions and pineapple fruit translucency. *Scientia Horticulturae*, *66*(1), 59-67.

Py, C., & Lossois, P. (1962). Prévisions de récolte en culture d'ananas (II): étude de corrélations. *Fruits*, *17*(2), 75-87.

Py, C., & Pelegrin, P. (1958). Prévisions de récolte en culture d’ananas. *Fruits, 13,* 243-251.

R Development Core Team. (2012). R: A language and environment for statistical computing. Vienna, Austria: ISBN 3-900051-07-0, UR.

Ritter, C., Dicke, D., Weis, M., Oebel, H., Piepho, H., Büchse, A., et al. (2008). An on-farm approach to quantify yield variation and to derive decision rules for site-specific weed management. *Precision Agriculture, 9*(3), 133-146.

Schouten, R. E., Otma, E. C., van Kooten, O., & Tijskens, L. (1997). Keeping quality of cucumber fruits predicted by biological age. *Postharvest Biology and Technology, 12*(2), 175-181.

Singleton, V. L., & Gortner, W. A. (1965). Chemical and physical development of the pineapple fruit II. Carbohydrate and acid constituents. *Journal of Food Science*, *30*(1), 19-23.

Smith, L. G. (1991). Effects of ethephon on ripening and quality of freshmarket pineapples. *Australian Journal of Experimental Agriculture, 31*, 123-127.

Takane, T. (2004). Smallholders and nontraditional exports under economic liberalization: The case of pineapples in Ghana. *African Study Monographs*, *25*(1), 29-43.

Vagneron, I., Faure, G., & Loeillet, D. (2009). Is there a pilot in the chain? Identifying the key drivers of change in the fresh pineapple sector. *Food Policy, 34*(5), 437-446.

Van Overbeek, J. (1946). Control of flower formation and fruit size in the pineapple. *Botanical Gazette, 108*, 64-73.

Wee, Y. C., & Rao, A. N. (1979). Development of the inflorescence and "crown" of *Ananas comosus* after treatment with acetylene, NAA, and ethephon. *American Journal of Botany, 66*, 351-360.

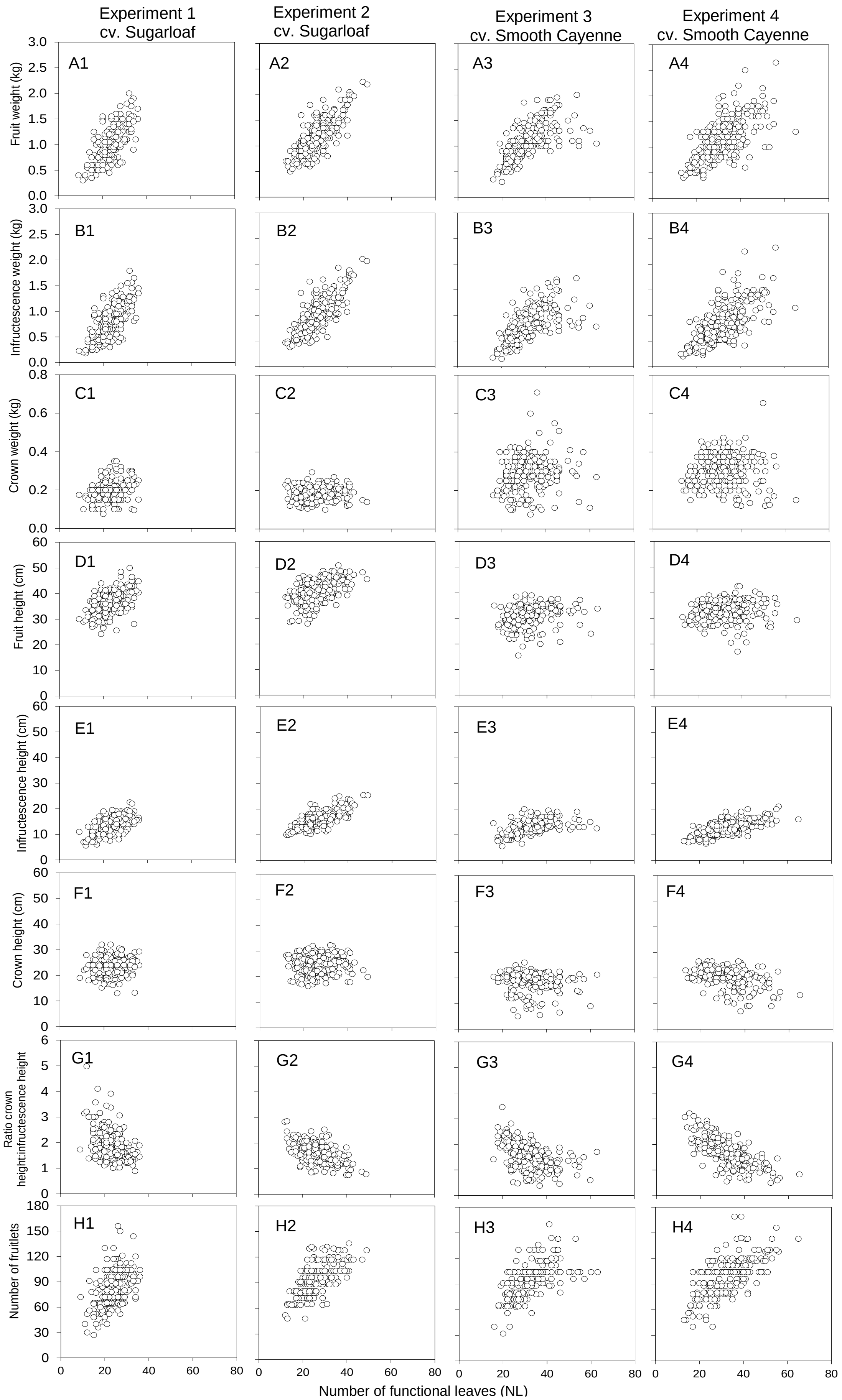


Figure S4.1. Association between the number of functional leaves (NL) at flowering induction time and the external fruit quality attributes in Experiments 1 and 2 (cv. Sugarloaf) and Experiments 3 and 4 (cv. Smooth Cayenne)

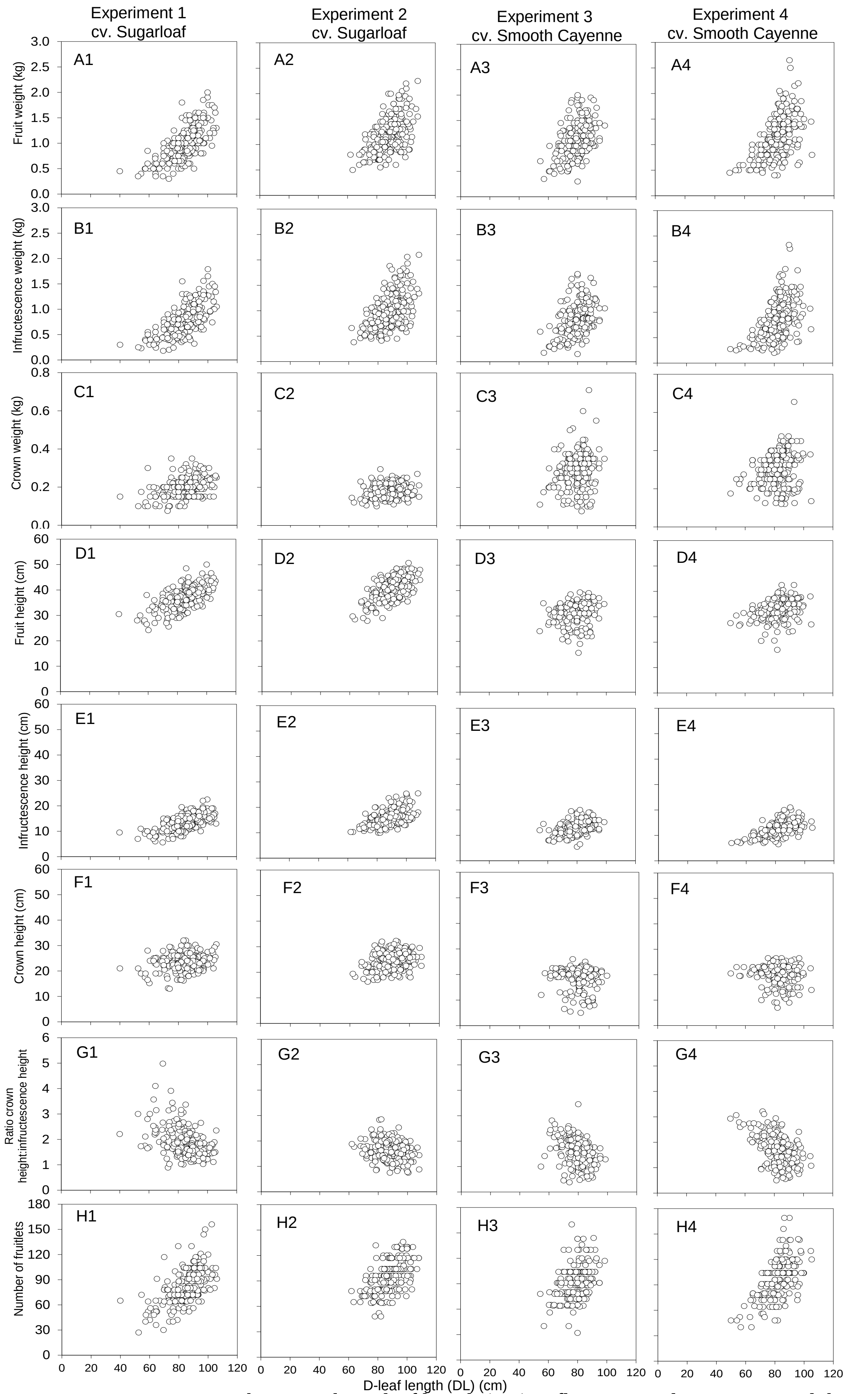


Figure S4.2. Association between the D-leaf length (DL) at flowering induction time and the external fruit quality attributes in Experiments 1 and 2 (cv. Sugarloaf) and Experiments 3 and 4 (cv. Smooth Cayenne)

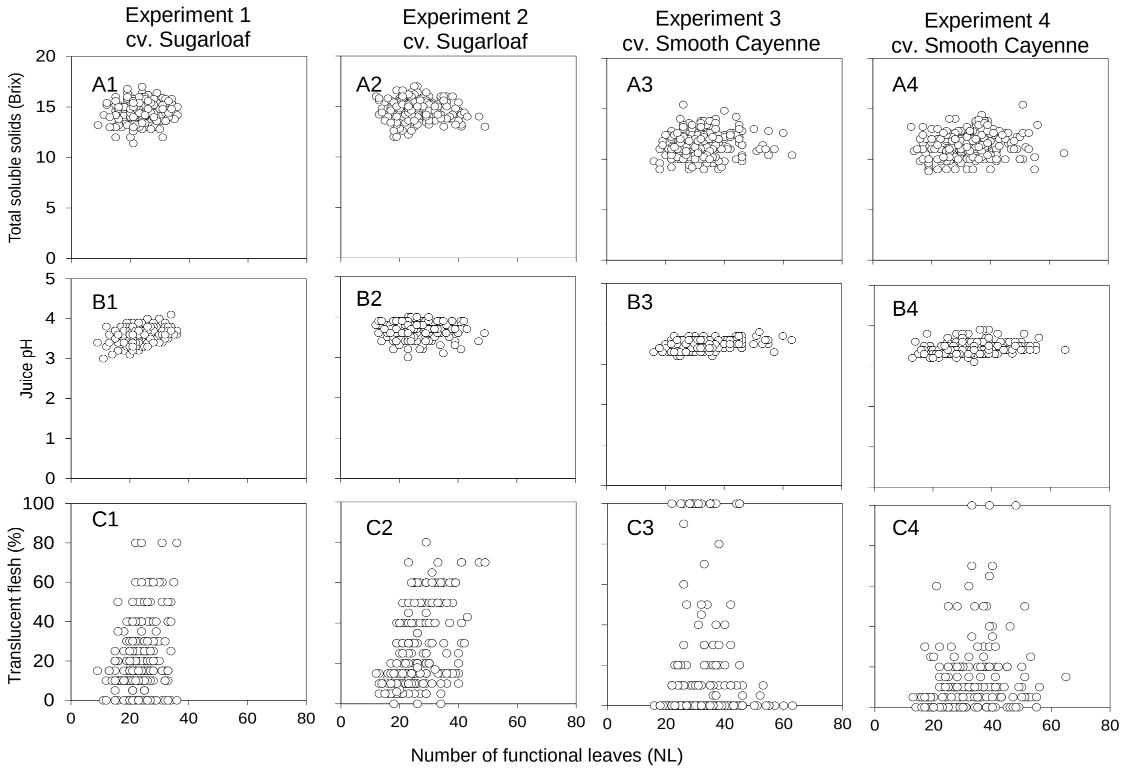


Figure S4.3. Association between the number of functional leaves (NL) at flowering induction time and the internal fruit quality attributes in Experiments 1 and 2 (cv. Sugarloaf) and Experiments 3 and 4 (cv. Smooth Cayenne)

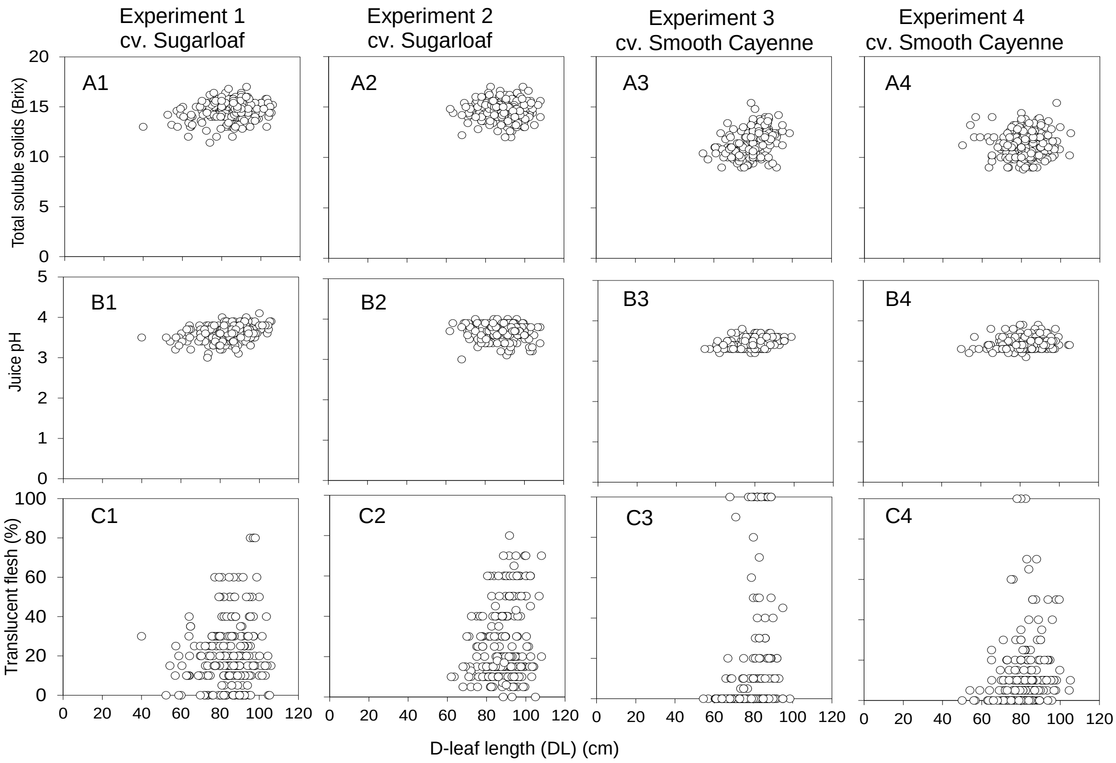


Figure S4.4. Association between the D-leaf length (DL) at flowering induction time and the internal fruit quality attributes in Experiments 1 and 2 (cv. Sugarloaf) and Experiments 3 and 4 (cv. Smooth Cayenne)

Table S4.1. Correlation matrix showing Pearson correlation coefficient (*r*) between the plant vigor variates at the time of artificial flowering induction and the different quality attributes at harvest for Experiment 1, cv. Sugarloaf (n=240)

	NL	DL	NL×DL	Fruit Weight	IW	Crown weight	Fruit height	IH	Crown height	Ra	Number of fruitlets	TSS	Juice pH	Translucent flesh
NL[a]	1	0.483***	0.928***	0.689***	0.690***	0.287***	0.505***	0.582***	0.118	-0.438***	0.536***	0.088	0.333***	0.207***
DL[b]		1	0.761***	0.709***	0.696***	0.381***	0.636***	0.652***	0.226***	-0.444***	0.606***	0.222***	0.337***	0.105
NL×DL			1	0.804***	0.799***	0.369***	0.636***	0.692***	0.188**	-0.489***	0.639***	0.149*	0.377***	0.189**
Fruit weight				1	0.991***	0.487***	0.751***	0.856***	0.184**	-0.594***	0.720***	0.098	0.289***	0.176**
IW[c]					1	0.363***	0.700***	0.871***	0.101	-0.640***	0.743***	0.077	0.278***	0.184**
Crown weight						1	0.646***	0.270***	0.608***	0.039	0.157*	0.175**	0.191**	0.024
Fruit height							1	0.669***	0.698***	-0.214***	0.481***	0.079	0.236***	0.132*
IH[d]								1	-0.065	-0.830***	0.778***	0.030	0.217**	0.132*
Crown height									1	0.512***	-0.103	0.077	0.108	0.051
Ra[e]										1	-0.665***	-0.023	-0.131*	-0.099
Number of fruitlets											1	-0.050	0.181**	0.209**
TSS[f]												1	0.392***	-0.126
Juice pH													1	0.005
Translucent flesh														1

[a] NL, number of functional leaves at flowering induction
[b] DL, D-leaf length at flowering induction
[c] IW, infructescence weight
[d] IH, infructescence height
[e] Ra, ratio crown height: infructescence height
[f] TSS, total soluble solids
*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

Table S4.2. Correlation matrix showing Pearson correlation coefficient (*r*) between the plant vigor variates at the time of artificial flower induction and the different quality attributes for Experiment 2, cv. Sugarloaf (n=240)

	NL	DL	NL×DL	Fruit Weight	IW	Crown weight	Fruit height	IH	Crown height	Ra	Number of fruitlets	TSS	Juice pH	Translucent flesh
NL[a]	1	0.386***	0.960***	0.787***	0.787***	0.049	0.529***	0.716***	0.044	-0.499***	0.614***	-0.146*	-0.080	0.450***
DL[b]		1	0.619***	0.534***	0.519***	0.167**	0.616***	0.530***	0.315***	-0.224***	0.526***	0.016	-0.095	0.213***
NL×DL			1	0.829***	0.825***	0.085	0.627***	0.765***	0.124	-0.487***	0.669***	-0.132*	-0.100	0.447***
Fruit weight				1	0.995***	0.104	0.679***	0.883***	0.088	-0.592***	0.743***	-0.190**	-0.099	0.541***
IW[c]					1	0.002	0.630***	0.900***	0.011	-0.649***	0.760***	-0.204***	-0.101	0.527***
Crown weight						1	0.515***	-0.123	0.756***	0.518***	- 0.125	0.138*	0.020	0.171**
Fruit height							1	0.613***	0.727***	-0.037	0.557***	-0.031	-0.152*	0.424***
IH[d]								1	-0.097	-0.789***	0.821***	-0.202**	-0.148*	0.371***
Crown height									1	0.640***	- 0.012	0.136*	-0.063	0.212**
Ra[e]										1	- 0.644***	0.199**	0.049	-0.158*
Number of fruitlets											1	-0.146*	-0.085	0.318***
TSS[f]												1	0.467***	0.029
Juice pH													1	0.134*
Translucent flesh														1

[a] NL, number of functional leaves at flowering induction
[b] DL, D-leaf length at flowering induction
[c] IW, infructescence weight
[d] IH, infructescence height
[e] Ra, ratio crown height: infructescence height
[f] TSS, total soluble solids
*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

Table S4.3. Correlation matrix showing Pearson correlation coefficient (r) between the plant vigor variates at the time of artificial flower induction and the different quality attributes for Experiment 3, cv. Smooth Cayenne (n=227)

	NL	DL	NL×DL	Fruit Weight	IW	Crown weight	Fruit height	IH	Crown height	Ra	Number of fruitlets	TSS	Juice pH	Translucent flesh
NL[a]	1	0.283***	0.959***	0.643***	0.642***	0.164*	0.220***	0.585***	-0.160*	-0.489***	0.605***	0.144*	0.451***	0.068
DL[b]		1	0.533***	0.447***	0.421***	0.202**	0.197**	0.425**	-0.076	-0.359***	0.410***	0.373***	0.295***	0.236***
NL×DL			1	0.685***	0.678***	0.195**	0.253***	0.635***	-0.158*	-0.525***	0.644***	0.236***	0.477***	0.124
Fruit weight				1	0.962***	0.380***	0.403***	0.831***	-0.130*	-0.619***	0.820***	0.294***	0.345***	0.348***
IW[c]					1	0.114	0.242***	0.838***	-0.307***	-0.719***	0.826***	0.267***	0.414***	0.380***
Crown weight						1	0.653***	0.184**	0.569***	-0.185**	0.186**	0.165*	-0.149*	-0.021
Fruit height							1	0.402***	0.789***	0.205**	0.289***	0.030	-0.091	0.005
IH[d]								1	-0.245***	-0.786***	0.754***	0.231***	0.347***	0.257***
Crown height									1	0.744***	-0.200**	-0.123	-0.331***	-0.161*
Ra[e]										1	-0.622***	-0.242***	-0.418***	-0.270***
Number of fruitlets											1	0.246***	0.392***	0.260***
TSS[f]												1	0.171**	0.308***
Juice pH													1	0.297***
Translucent flesh														1

[a] NL, number of functional leaves at flowering induction
[b] DL, D-leaf length at flowering induction
[c] IW, infructescence weight
[d] IH, infructescence height
[e] Ra, ratio crown height: infructescence height
[f] TSS, total soluble solids
*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

Table S4.4. Correlation matrix showing Pearson correlation coefficient (r) between the plant vigor variates at the time of artificial flower induction and the different quality attributes for Experiment 4, cv. Smooth Cayenne (n=234)

	NL	DL	NL×DL	Fruit Weight	IW	Crown weight	Fruit height	IH	Crown height	Ra	Number of fruitlets	TSS	Juice pH	Translucent flesh
NL[a]	1	0.491***	0.966***	0.646***	0.684***	0.025	0.106	0.697***	-0.417***	-0.712***	0.670***	0.143*	0.266***	0.213***
DL[b]		1	0.684***	0.547***	0.532***	0.236***	0.312***	0.595***	-0.125	-0.523***	0.597***	0.038	0.203**	0.227***
NL×DL			1	0.682***	0.710***	0.078	0.169**	0.736***	-0.381***	-0.719***	0.713***	0.128	0.269***	0.234***
Fruit weight				1	0.980***	0.391***	0.512***	0.924***	0.166*	-0.716***	0.828***	0.155*	0.411***	0.324***
IW[c]					1	0.199**	0.399***	0.942***	-0.298***	-0.781***	0.830***	0.159*	0.424***	0.310***
Crown weight						1	0.671***	0.193**	0.552***	0.082	0.236***	0.031	0.063	0.162*
Fruit height							1	0.416***	0.726***	0.056	0.388***	-0.076	0.085	0.189**
IH[d]								1	-0.324***	-0.852***	0.848***	0.131*	0.392***	0.304***
Crown height									1	0.703***	-0.238***	-0.178**	-0.208***	-0.033
Ra[e]										1	-0.737***	-0.195**	-0.364***	-0.259***
Number of fruitlets											1	0.153*	0.278***	0.316***
TSS[f]												1	0.033	0.152*
Juice pH													1	-0.146*
Translucent flesh														1

[a] NL, number of functional leaves at flowering induction
[b] DL, D-leaf length at flowering induction
[c] IW, infructescence weight
[d] IH, infructescence height
[e] Ra, ratio crown height: infructescence height
[f] TSS, total soluble solids
*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

CHAPTER 5

Trade-offs of flowering and maturity synchronisation for pineapple quality*

V.N. Fassinou Hotegni[1,2], W.J.M. Lommen[1], E.K. Agbossou[2] and P.C. Struik[1]

[1] Centre for Crop Systems Analysis, Wageningen University, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands

[2] Faculté des Sciences Agronomiques, Université d'Abomey Calavi, 01 BP 526 Cotonou, Benin

* Submitted

Abstract

In the pineapple sector of Benin, poor fruit quality prevents pineapple producers to enter the European market. We investigated effects of common cultural practices, flowering and maturity synchronisation, (1) to quantify the trade-offs of flowering and maturity synchronisation for pineapple quality, its heterogeneity and the proportion of fruits exportable to European markets, and (2) to determine the effect of harvesting practice on quality attributes and their uniformity. Four on-farm experiments were conducted during three years using cultivars Sugarloaf and Smooth Cayenne. A split-split plot design was used in each experiment, with flowering induction practice as main factor (artificial or natural flowering induction), maturity induction practice as split factor (artificial or natural maturity induction) and harvesting practice as the split-split factor (farmers' harvest practice or individual fruit harvesting at optimum maturity). Natural flowering induction gave fruits with higher infructescence weight and height, lighter and shorter crown, lower ratio crown: infructescence height, and a higher proportion of fruits exportable to Europeans markets than artificial flowering induction. Natural flowering induction also reduced the variation in infructescence and fruit weights, and in infructescence height in cv. Sugarloaf. The costs of these improvements by natural flowering induction were the longer durations from planting to flowering induction and harvesting, the higher number of harvestings of the fruits and the lower proportion of plants producing fruits compared to crops from artificially flowering-induced plants. Natural maturity induction increased the total soluble solids concentration in the fruits compared to artificial maturity induction thus increasing the proportion of fruits exportable to Europeans markets, at the cost of only a slightly longer time from flowering induction to harvesting. Harvesting at optimum maturity gave fruits with higher total soluble solids and lower variation in total soluble solids in naturally maturity induced fruits compared to the farmers' harvest practice.

Keywords: *Ananas comosus*; cultural practices; flowering and maturity induction; exportable fruits; uniformity.

5.1. Introduction

In most developing countries, primary producers often face difficulties to export their product to European countries due to poor quality (Hatab and Hess 2013; Neven et al. 2009; Reardon et al. 2001; Royer and Bijman 2012; Trienekens and Zuurbier 2008; Vorley and Fox 2004). This is certainly the case in the fresh pineapple chains in Benin where less than 2% of the pineapple is exported to Europe (FAO 2012). In Benin, primary producers fail to significantly increase the proportion of fresh pineapple exported to Europe due to the lack of compliance with demands for quality of fruits set by the Codex Alimentarius (2005). Quality attributes considered in the Codex Alimentarius are fruit weight, ratio crown height: infructescence height, total soluble solids (TSS), internal browning and flesh translucency. Fruit quality attributes can be affected by cultural practices and post-harvest practices (Aggelopoulou et al. 2010; Shewfelt 1990; Zúñiga-Arias et al. 2009). Since pineapple fruit quality can hardly be improved by post harvest practices (Royer and Bijman 2012), this study concentrated on fruit quality issues in the field. Understanding the trade-offs of some common cultural practices (determining the fruit quality) for fruit quality would help to improve it.

In pineapple, the transition from the vegetative to the generative phase can take place in two ways. The first is by natural flowering induction (**NFI**), in which environmental stimuli are inducing flowering. These environmental stimuli can be: shortening of the day length (Friend and Lydon 1979), temperature dropping (Bartholomew and Malézieux 1994), reduction of hours of radiation due to cloudiness (Bartholomew and Kadzimin 1977) and water deficit (Py et al. 1987). Natural flowering induction occurs in the presence of at least one of these factors (Cunha 2005) and when the plant has attained an appropriate size to capture and respond to enviromental stimuli (Py et al. 1987). The second and common way in pineapple cultivation is by artificial flowering induction (**AFI**) or "forcing", which consists of applying growth regulators releasing acetylene or ethylene (Cunha 2005; Hepton 2003; Onaha et al. 1983; Reid and Wu 1991). Artificial flowering induction (a) advances flowering, (b) improves uniformity of flowering, (c) makes the harvest moment predictable, and (d) makes harvesting more uniform (Adikaram and Abayasekara 2012; Cunha 2005; Fassinou Hotegni et al. 2012). However, AFI could probably constitute a source of poor fruit quality at harvest time when compared to NFI as all plants are induced to flower, no matter their size. Studies by Malézieux et al. (2003) showed that plants within a crop that are small at the moment of AFI produce small fruits. To date, no research has reported the trade-offs of flowering induction practices for quality of pineapple fruits. We hypothesize that artificial flowering induction will lead to poorer and less uniform fruit quality than NFI.

Not only flowering induction may account for poor quality at harvesting; maturity induction could be an additional source of poor quality. Fruit maturity can be induced in two ways: naturally or artificially. Natural maturity induction (**NMI**) is characterized by natural and gradual changes in the skin colour and in internal quality attributes such as TSS (an indicator of the sweetness of the pineapple juice) and juice pH (Moneruzzaman et al. 2008). From 12 to 4 weeks before harvesting time, TSS is low. From 4 weeks before harvesting time, TSS increases until harvest time (Chen and Paull 2000). The pH starts to increase 2 weeks before harvesting time until harvesting time (Singleton and Gortner 1965). Artificial maturity induction (**AMI**) is achieved by applying an ethylene-releasing compound on the skin of the fruit. Such practice (a) hastens the change in the skin colour from green to yellow resulting in a uniformly yellow skin colour (Bartholomew et al. 2003; Chuenboonngarm et al. 2007; Crochon et al. 1981) and (b) concentrates the fruit harvesting. However, Hepton (2003) argued that earlier AMI slows down both sugar accumulation and full cell expansion. Since the rate of the pineapple inflorescence development and growth varies among plants within a crop (Bartholomew et al. 2003; Kerns et al. 1936), we hypothesize that AMI to all fruits at the same moment will lead to overall poorer internal fruit quality attributes than NMI; the variation in internal quality attributes might also be affected.

Harvesting time plays an important role in determining the final fruit quality (Wijesinghe and Sarananda 2002). Generally, fruits from artificially induced pineapple crops are harvested when 25% of the pineapple fruits in the field reach harvesting maturity. That way of harvesting (**FH**, farmers' harvesting practice) leads to harvesting fruits from the least and most advanced plants simultaneously and may reduce the average quality. We assume, as suggested by Muasya et al. (2006) for crops grown from seed, that harvesting of individual pineapple fruits at their optimum harvesting time (**OH** practice) would allow fruits to develop their full potential before harvesting, which may yield a higher average quality compared to FH.

An additional quality attribute nowadays of concern by some importers is the degree of uniformity in the quality of supplied product (Barrena Ruiz et al. 2013; Cetinkaya 2011; Léchaudel and Joas 2007; Luning and Marcelis 2006; Zúñiga-Arias et al. 2009). Artificial flowering induction and artificial maturity induction may increase the heterogeneity in quality attributes compared to NFI and NMI since within a crop, the plants at the time of AFI and the fruits at the time of AMI would not be all in the same development stage. We hypothesise that harvesting fruits individually at OH although labour demanding, will reduce the heterogeneity in fruits quality compared to FH.

The objectives of this study were (1) to quantify the trade-offs of flowering and maturity synchronisation for pineapple quality, heterogeneity in pineapple quality and the proportion of fruits exportable to European markets and (2) to determine the effect of harvesting practice on quality attributes and their uniformity. Four on-farm experiments were conducted during three years; plants were induced to flower naturally or artificially; fruit maturity was induced naturally or artificially and fruits were harvested according to the farmers harvest practice or the optimum harvest (for individual fruits) practice. Quality attributes and percentage of exportable fruits to Europe were assessed.

5.2. Materials and methods

5.2.1. Experimental sites

Four on-farm experiments were carried out on commercial pineapple fields in the Atlantic department in the south of Benin between February 2010 and July 2013. The pineapple cultivars used were Sugarloaf in Experiments 1 and 2, and Smooth Cayenne in Experiments 3 and 4. The experimental sites were selected on fields of different producers based on (a) the age of their pineapple crop being close to the common artificial flowering induction time and (b) whether they cropped their pineapple following the common practices described by Fassinou Hotegni et al. (2012). Information on the fields and cultural practices until artificial flowering induction time is provided in Table 5.1.

Experiment 1 was carried out from February 2010 to June 2013. During this period, the mean monthly temperature ranged between 24.9 (August 2012) and 30.0 °C (February 2010); the monthly rainfall ranged between 0 (March and December 2011) and 624 mm (June 2010) (Figure 5.1). Experiment 2 was carried out from July 2010 to June 2013; the mean monthly temperature during that period ranged between 24.9 (August 2012) and 29.3 ºC (March 2013); the total monthly rainfall amount ranged between 0 (March and December 2011) and 426 mm (June 2012). Experiments 3 and 4 were carried out from April 2011 to July 2013 and May 2011 to June 2013 respectively; the ranges in the mean monthly temperatures and rainfall amount were the same in the two experiments, and varied between

Table 5.1. Field information and cultural practices in the four experiments with cvs Sugarloaf or Smooth Cayenne

Field information and cultural practices	Cv. Sugarloaf		Cv. Smooth Cayenne	
	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Location	06°36'09.2"N and 02°16'31.6"E	06°37'26.4"N and 02°16'13.1"E	06°36'43.7"N and 02°19'55.1"E	06°36'44"N and 02°19'54.3"E
Municipality (district)	Zè (Tangbo Djevie)	Zè (Tangbo Djevie)	Abomey-Calavi (Zinvié)	Abomey-Calavi (Zinvié)
Soil type (U.S. equivalent)	Ferralitic soil (Ultisols)	Ferralitic soil (Ultisols)	Ferralitic soil (Ultisols)	Ferralitic soil (Ultisols)
Climate	Subequatorial	Subequatorial	Subequatorial	Subequatorial
Planting time[a]	February 2010	July 2010	April 2011	May 2011
Type of planting material used[a]	Slips	Slips	Hapas and suckers	Hapas and suckers
Planting material treatment before planting[a]	No treatment	No treatment	No treatment	No treatment
Planting arrangement	Flat beds of two alternating rows	Flat beds of two alternating rows	Flat beds of two alternating rows	Flat beds of two alternating rows
Plant spacing: BP[b] × BR[c]/BDR[d] (cm)	40 ×50/80	35 × 45/65	47 × 55/75	47 × 55/75
Plant density (plants/m^2)	3.85	5.19	3.27	3.27
First Urea (46N) + NPK (10-20-20)	7 MAP[e] (18 Sept2mber 2010)	2 MAP (15 September 2010)	3 MAP (20 July 2011)	2 MAP (17 July 2011)
Application form	Solid at the base of the plants	Solid at the base of the plants	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g Urea + g NPK)	6 + 3	6 + 3	5 + 4	5 + 4
Second Urea (46N) + NPK (10-20-20)	Not applied	Not applied	6 MAP (15 October 2011)	5 MAP (24 October 2011)
Application form	Not applied	Not applied	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g Urea + g NPK)	Not applied	Not applied	4 + 5	4 + 5
NPK (10-20-20) application	12 MAP (22 Febr. 2011)	9 MAP (16 April 2011)	Not applied	Not applied
Application form	Solid	Solid	Not applied	Not applied
Dose per plant (g NPK)	7	7	Not applied	Not applied
K_2SO_4 (50-18) application	Not applied	Not applied	10 MAP (8 February 2012)	9 MAP (17 February 2012)
Application form	Not applied	Not applied	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g K_2SO_4)	Not applied	Not applied	7	7
Artificial flower induction time	13 MAP (6 March 2011)	10 MAP (4 May 2011)	10 MAP (22 February 2012)	10 MAP (3 March 2012)
Weed control	Hand weeding	Hand weeding	Hand weeding	Hand weeding

[a] Information gathered from pineapple producer (field owner)
[b] BP, spacing between plants within a row
[c] BR, spacing between rows;
[d] BDR, spacing between double rows
[e] MAP, months after planting

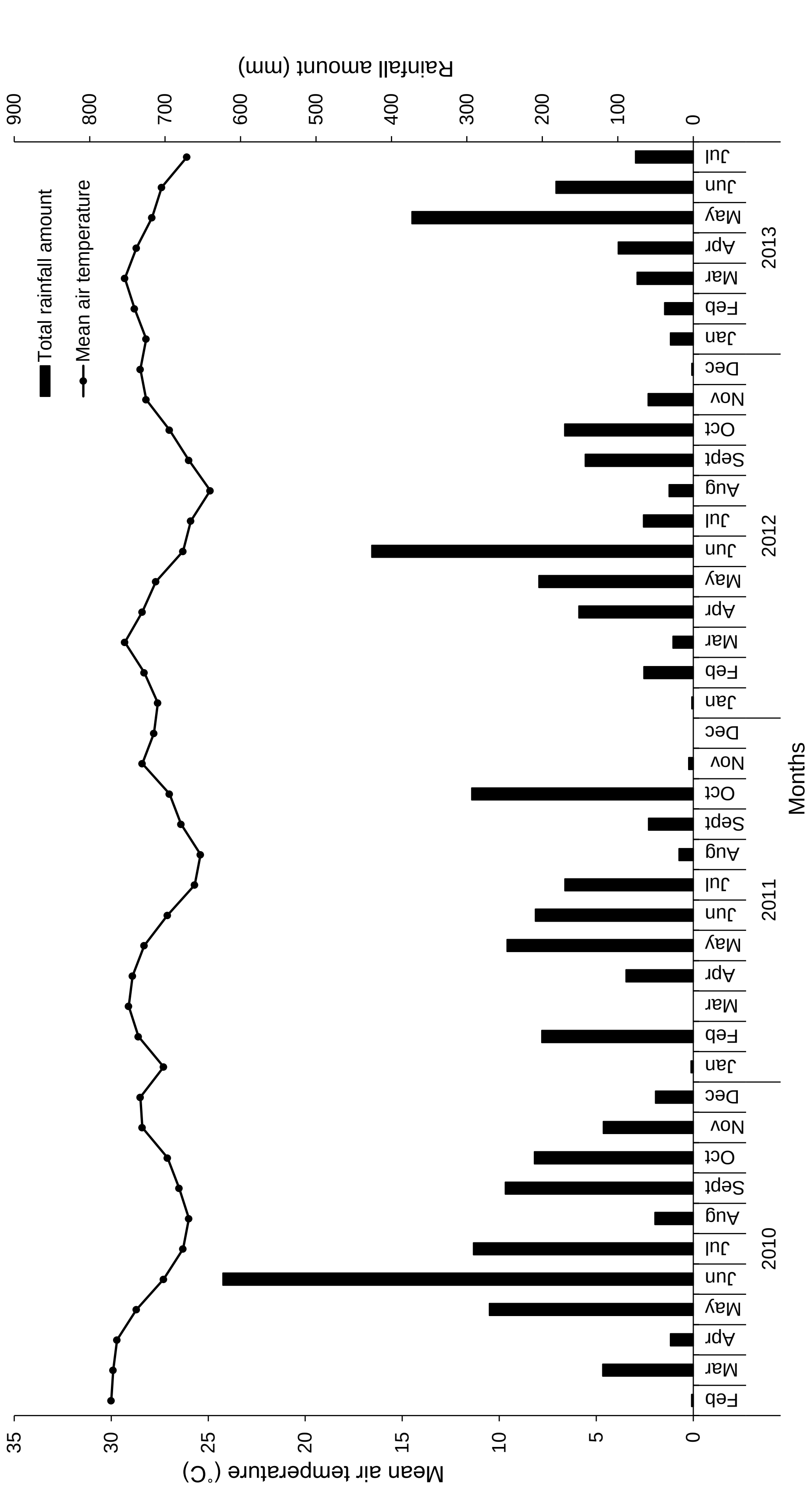


Figure 5.1. Variation in mean air temperature and monthly rainfall during the experimentation period (February 2010 to July 2013)

24.9 (August 2012) and 29.3 ºC (March 2012, 2013) and 0 (December 2011) and 426 mm (June 2012) respectively (Figure 5.1).

5.2.2. Design, treatments, induction and harvesting practices

Design and treatments

In each experiment a split-split-plot design was used with four replicated blocks and three factors; the *flowering induction practice* was the main factor and had two levels: AFI and NFI; the *fruit maturity practice* was the split factor and had two levels: AMI and NMI; the *harvesting practice* was the split-split factor and had two levels: FH and OH. The net plot consisted of 60 plants arranged in 6 rows of 10 plants each. The net plots were surrounded by two guard rows and two guard plants within rows.

Flowering induction practice

In the AFI plots, plants were artificially induced between 10 and 13 months after planting (Table 5.1) using carbide of calcium[1] (CaC_2), a compound producing acetylene when it reacts with water. Following farmers' practices for artificial flower induction, 50 ml of a solution containing 10 g/l and 15 g/l of CaC_2 for Sugarloaf and Smooth Cayenne respectively, was applied into the centre of the leaf rosette of each plant. This application was carried out once in cv. Sugarloaf and three times, with an interval of three days, in cv. Smooth Cayenne.

In the NFI plots, environmental factors were the stimuli for the plants. These plants were weekly checked for inflorescence emergence[2]. The date of inflorescence emergence was recorded and from that, the induction date was computed by subtracting 34 days; it is well known in Benin that the period between flowering induction and inflorescence emergence lasts 34 days. In February 2013, i.e. three years and two and a half years after the planting of Experiments 1 and 2 respectively and two years after the planting of the Smooth Cayenne experiments, there were still some plants in the NFI plots which had not flowered. Decision was made to discontinue checking the naturally induced plants for inflorescence emergence

[1] It is important to stress here that calcium carbide was only used to induce flowering, not to induce fruit maturity.

[2] Inflorescence emergence, also called red heart stage, refers to the stage at which the inflorescence is visible, i.e., can be seen at the centre of the leaf rosette. At the red heart stage the inflorescence is surrounded by reddish short leaves at the base of the inflorescence.

occurrence. Therefore, plants in the naturally flowering-induced plots which flowered after February 2013 were excluded from the experiments.

Maturity induction practice

Following farmers’ practices, maturity of cv. Smooth Cayenne fruits was induced on individual fruits 143 days after flowering induction, by spraying 3.5 ml of a solution of 14 ml/l Ethephon (2-chloroethylphosphonic acid), a compound producing ethylene, on the skin of each fruit. This application was carried out twice with an interval of four days. In Benin, the practice of inducing maturity artificially is commonly applied in cv. Smooth Cayenne but not in cv. Sugarloaf (Fassinou Hotegni et al. 2012). On the artificially flowering-induced plants in Experiment 1, cv. Sugarloaf, since farmers’ criteria in determining the appropriate application time for Ethephon was not well known, Ethephon was applied once at 153 days after flower induction. This was found to be late because of occurrence of natural changes in skin colour before that moment. Through discussions with pineapple farmers and explorations of the pineapple fields in the experimental zone, we concluded that one application at 143 days after flower induction was appropriate for maturity induction in cv. Sugarloaf. Therefore, maturity induction was carried out on the naturally flowering-induced plants in Experiment 1 and on all AMI plots in Experiment 2, 143 days after flowering induction. This application was carried out once. In order to avoid carry-over effects of the Ethephon, a waterproof tarpaulin was used to cover the non-treated plots before AMI. The tarpaulins were removed immediately after treatment.

Harvesting practice

Pineapple fruits were hand-harvested. In the NMI plots, the FH practice was the moment when the skin colour had started to change from green to gold yellow in at least 25% of the fruits in a net plot for the naturally maturity induced fruits; the OH practice was the moment when 25% of the skin of an individual fruit had changed from green to gold yellow for the naturally maturity-induced fruits. In the AMI plots, 7 days after the application (second application in cv. Smooth Cayenne) of the Ethephon, all fruits changed to a fully yellow orange colour at the same time. The FH and OH dates were therefore similar.

5.2.3. Data collection

Three types of data were collected: data on the duration of the plant development phases on the individual plants within all plots; data on the number of harvestings of the fruits per plot; and data on fruit quality at harvest on the individual plants within all plots. Data on the plant development phases included the duration of the vegetative and generative phases and of the full period from planting to harvesting. The duration of the vegetative phase was defined as the time from planting to flowering induction. The duration of the generative phase was defined as the time from flowering induction to harvesting. Data on the number of harvestings of the fruits were collected per plot; it was defined as the number of harvestings of the fruits until the harvesting of all fruits (present) in a plot. Data on the following quality attributes were collected on the fruits at harvest time: fruit (infructescence + crown) weight, infructescence weight, crown weight, fruit height, infructescence height, crown height, the ratio crown height: infructescence height, the TSS in the pineapple juice, the juice pH, the percentage of translucent flesh and the percentage flesh showing blackheart symptoms (characteristic of internal browning). For the weight attributes, a scale was used. For the height attributes a ruler was used. To determine TSS, juice pH, percentage of translucent flesh and percentage of flesh showing blackheart symptoms, pineapples were cut longitudinally into two halves. A portion of the juice obtained from squeezing one half was used to determine TSS by a hand refractometer; another portion of that juice was used to determine the juice pH by a hand-held pH meter. The second fruit half was used to estimate visually the percentage of fruit with translucent flesh and internal browning following the methods of Paull and Reyes (1996).

Following the Codex Alimentarius (2005), minimum quality criteria to export fresh pineapple to Europe are that the fruit weight should range between 0.7 and 2.75 kg, the ratio crown: infructescence height between 0.5 and 1.5 and TSS should be at least 12º Brix. These criteria were used to compute the percentage of exportable pineapple fruits per treatment.

5.2.4. Data analysis

Data were analysed using GenStat for Windows 16th Edition (VSN International 2013). Percentage of naturally flowering-induced plants was calculated per month and the cumulative percentage was used to have an overview of the total percentage of naturally flowering-induced plants per plot under NFI.

A three-way ANOVA for a split-split-plot design was used to test the effects of the flowering induction, maturity induction and harvesting practice, and their interactions, on (a) average duration of the plant development phases, (b) number of harvestings of the fruits, (c) average fruit quality and heterogeneity in fruit quality attributes, and (d) proportion of fruits meeting the minimum European markets criteria for pineapple fruit. Translucent flesh data were transformed using square root transformation ($\sqrt{x+0.5}$) before analysis (Bartlett 1936; Gonzalez 2009). The heterogeneity in fruit quality attributes was computed per plot using the coefficient of variation, i.e. the measure of the variability in the value in a population relative to the mean. Data on proportion of fruits meeting the minimum European markets criteria for pineapple were transformed using arcsine transformation of the square root of the proportion before analysis (Fernandez 1992). Proportions equal to 0 or 1 were replaced by (1/4n) and [1-(1/4n)] respectively, where n is the total number of fruits per net plot (Fernandez 1992). In case of interactions, means or coefficients of variation were separated using LSD. To determine which quality criteria did not meet the minimum European market criteria, different combinations of quality criteria were set and the percentage of non-exportable fruits for each combination of quality criteria was computed.

5.3. Results

5.3.1. Occurring of flowering and percentage of plants producing fruits at the end of the experiments

In all experiments, the artificially flowering-induced plants flowered uniformly after the carbide application. In the naturally flowering-induced plants, flowering occurred over a longer period with slight differences between the cultivars (Figures S5.1 and S5.2). In cv. Sugarloaf, plants were naturally induced mainly from July to January whereas in Experiment 2 some plants also were induced from March to May (Figure S5.1). The highest percentages of plants becoming naturally induced were recorded in August and December (Figure S5.1) in cv. Sugarloaf. In cv. Smooth Cayenne, plants were mainly induced naturally from May to November and in February, whereas some plants were induced in December (Figure S5.2). The highest percentages of plants becoming naturally induced were recorded in June and October in Experiment 3 and in June and November in Experiment 4 (Figure S5.2).

In all experiments, all artificially flowering-induced plants produced fruits. In the NFI treatments, the percentage of plants that had produced fruits at the end of the experiments ranged from 45 (108 out of 240 plants) to 81% (195 out of the 240 plants) (Figures S5.1 and S5.2).

5.3.2. Duration of the plant development phases and number of harvestings of the fruits

Duration of the vegetative phase

The effect of flowering induction practice on the average duration from planting to flowering induction was consistent in all experiments (Figure 5.2-A1-4) despite the presence of significant interactions between the flowering induction practice and the maturity induction practice in Experiments 1, 3 and 4 (Table S5.1). Naturally flowering-induced plants had a longer duration of the vegetative phase than AFI plants. In NFI plants, the average duration from planting to flowering induction was at least 200 and 150 days longer than in AFI plants in cvs Sugarloaf and Smooth Cayenne, respectively. In the AFI treatments, all plants became induced to flower on the same date whereas in the NFI treatments, the time between the first and last induced plants varied from 164 to 535 days in cv. Sugarloaf and from 150 to 197 days in cv. Smooth Cayenne (Figure 5.2).

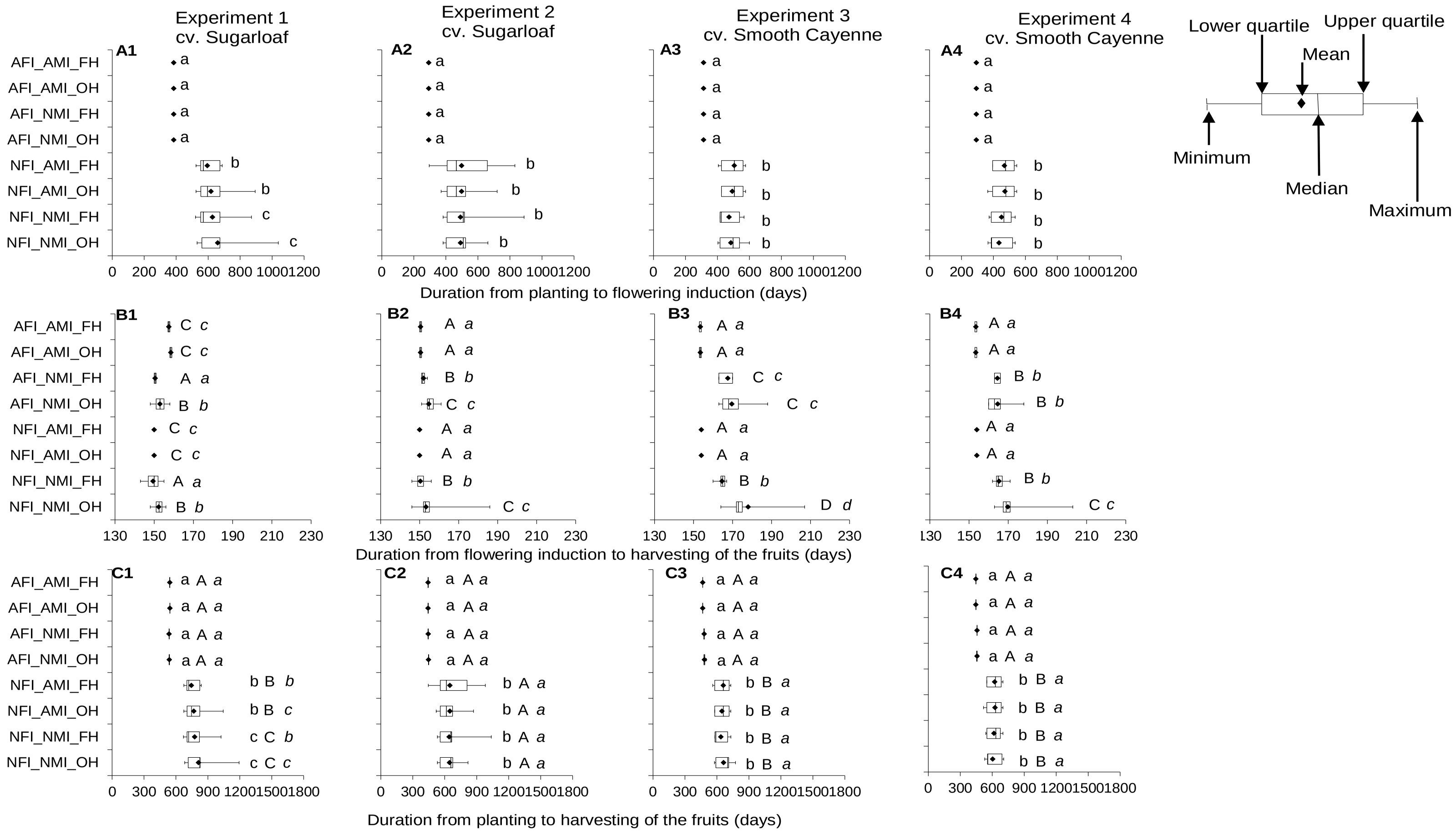
Duration of the generative phase

Natural maturity induction led to a longer duration of the generative phase than AMI except in Experiment 1 where the opposite was observed (Figure 5.2-B1) because maturity was artificially induced late as explained in the Materials and Methods section.

In NMI treatments, the average duration of the generative phase was at least 1[3] day longer in cv. Sugarloaf and 11 days longer in cv. Smooth Cayenne than in AMI treatments. In the AMI treatments, the difference between plants was 0 or 1 day whereas in the NMI treatments the difference between plants varied between 1 to 40 days in cv. Sugarloaf and 3 to 43 days in cv. Smooth Cayenne (Figure 5.2-B1-4).

In all experiments, harvesting practice did not affect the duration of the generative phase when AMI was applied (Figure 5.2-B1-4). When maturity was naturally induced,

[3] Value derived from Experiment 2 only, cv. Sugarloaf.



AFI: Artificially flowering-induced plants; AMI: Artificially maturity-induced fruits; NFI: Naturally flowering-induced plants; NMI: Naturally maturity-induced fruits; FH: Farmers' harvest practice; OH: Optimum harvest

Next to the boxplots

Similar *small* letters within a diagram indicate that differences in the duration between flowering induction practices are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.1). All means are compared on $LSD_{0.05}$ in case of interactions.

Similar *capital* letters within a diagram indicate that differences in the duration between maturity induction practices are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.1). All means are compared on $LSD_{0.05}$ in case of interactions.

Similar letters in *italic* within a diagram indicate that differences in the duration between harvesting practices are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.1). All means are compared on $LSD_{0.05}$ in case of interactions.

Figure 5.2. Boxplots with whiskers showing the effects of flowering and maturity induction practices and harvesting practice on the average duration from planting to flowering induction, from flowering induction to harvesting and from planting to harvesting in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4) and the distribution (maximum, minimum, quartiles, median) of each characteristic

fruits harvested at OH showed a longer generative phase than those harvested at FH after all flowering induction treatments in cv. Sugarloaf and the NFI treatments in cv. Smooth Cayenne (Figure 5.2-B1-4). The generative phase of the fruits harvested at OH was 2 and 1 day(s) longer than that of fruits harvested at FH in cvs Sugarloaf and Smooth Cayenne, respectively.

Duration from planting to harvestings of the fruits

The effect of flowering induction practice on the duration from planting to harvesting of the fruits was consistent across experiments: NFI led to a longer duration than AFI (Figure 5.2-C1-4). Under NFI, the duration from planting to harvesting was between 196 and 274 days longer than that in AFI in the Sugarloaf experiments and between 146 and 192 days longer than that in AFI in the Smooth Cayenne experiments.

In Experiments 2 to 4, no significant effects of maturity induction practice on the duration from planting to harvesting were observed (Table S5.1). An effect was found only in Experiment 1 in the NFI plants where AMI led to shorter duration from planting to harvesting than NMI (Figure 5.2-C1).

Effects of harvesting practice on the duration from planting to harvesting were found in Experiment 1 only and depended on the flowering induction practice (Table S5.1); under NFI treatment, the OH practice showed longer duration from planting to harvesting than the FH practice (Figure 5.2-C1). In Experiments 2, 3 and 4, and the AFI treatments in Experiment 1, no significant effects of harvesting practice on the duration from planting to harvesting were observed (Table S5.1).

Number of harvestings of the fruits

The effects of flowering induction practice on the number of harvestings of the fruits were consistent across experiments. The number of harvestings of the fruits in the NFI plots was higher than that in the AFI plots (Figure 5.3). The number of harvestings in the NFI plots was 3 to 12 times and 2 to 6 times higher than that in the AFI plots in cvs Sugarloaf and Smooth Cayenne, respectively.

Effects of maturity induction practice on the number of harvestings of the fruits were also consistent across experiments. In all experiments, the maturity induction practice did not affect the number of harvestings in the treatments under AFI harvested at FH (Figure 5.3), but NMI increased the number of harvestings in the treatments under AFI harvested at OH as compared to AMI. When considering the treatments under NFI, NMI resulted in a comparable (Experiments 1, 3 and 4) or lower (Experiment 2) number of harvestings than AMI under FH, but, more harvestings under OH (Figure 5.3).

Effects of harvesting practice on the number of harvestings of the fruits were also consistent across experiments. Harvesting practice did not significantly affect the number of harvestings when the fruits were artificially maturity-induced. When maturity was naturally induced, the number of harvestings was higher in the plots harvested at OH than that in the plots harvested at FH (Figure 5.3); in that case, harvesting at OH increased the number of harvestings by 3-8 and 2-6 times compared to the FH practice in cvs Sugarloaf and Smooth Cayenne respectively (Figure 5.3).

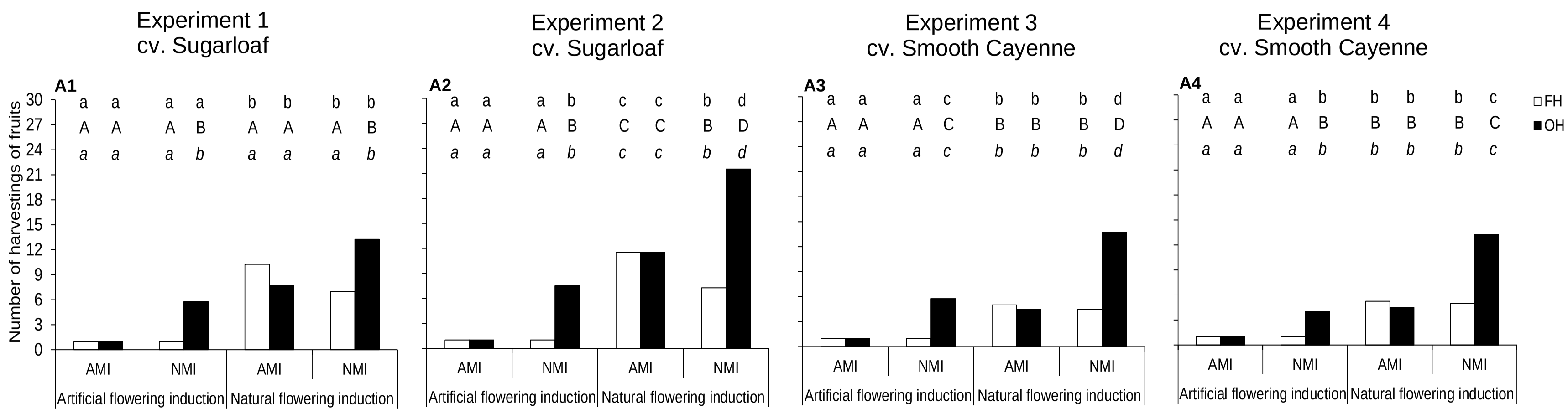
5.3.3. Effects of flowering induction practice, maturity induction practice and harvesting practice on average pineapple quality

Effects of flowering induction practice on average fruit quality attributes

The effects of flowering induction practice on the infructescence and crown weights were consistent across experiments, but the effect on total fruit weight was cultivar dependent (Figure 5.4). Natural flowering induction resulted in fruits with higher infructescence weights but lighter crown weights than AFI (Figure 5.4). Under NFI, there was an increase in the infructescence weights ranging from 9 to 33% and 50 to 84% compared to AFI in cvs Sugarloaf and Smooth Cayenne, respectively.

Under NFI, there was a reduction in crown weights ranging from 44 to 57% and 18 to 43% compared to AFI in cvs Sugarloaf and Smooth Cayenne, respectively. In cv. Sugarloaf, NFI did not change the total fruit weight compared to AFI (Figure 5.4-C1 and C2), whereas in cv. Smooth Cayenne, NFI resulted in heavier fruits than AFI (Figure 5.4-C3 and C4). In cv. Smooth Cayenne, the increase in fruit weight ranged from 28 to 59%.

Natural flowering induction also yielded fruits with longer infructescences (Figure 5.5-A1-4) and generally with shorter crowns (Figure 5.5-B1, B2 and B4) than AFI. Consequently, in all experiments, the ratio crown: infructescence height was significantly



AMI: Artificially maturity-induced fruits
NMI: Naturally maturity-induced fruits
FH: Farmers' harvest practice
OH: Optimum harvest
Similar *small* letters at the top of each bar indicate that differences between means in the flowering induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.1). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *capital* letters at the top of each bar indicate that differences between means in the maturity induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.1). In case of interactions all means are compared at $LSD_{0.05}$.
Similar small letters in *italic* (when present) at the top of each bar indicate that differences between means in the harvesting practice treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.1). In case of interactions all means are compared at $LSD_{0.05}$.

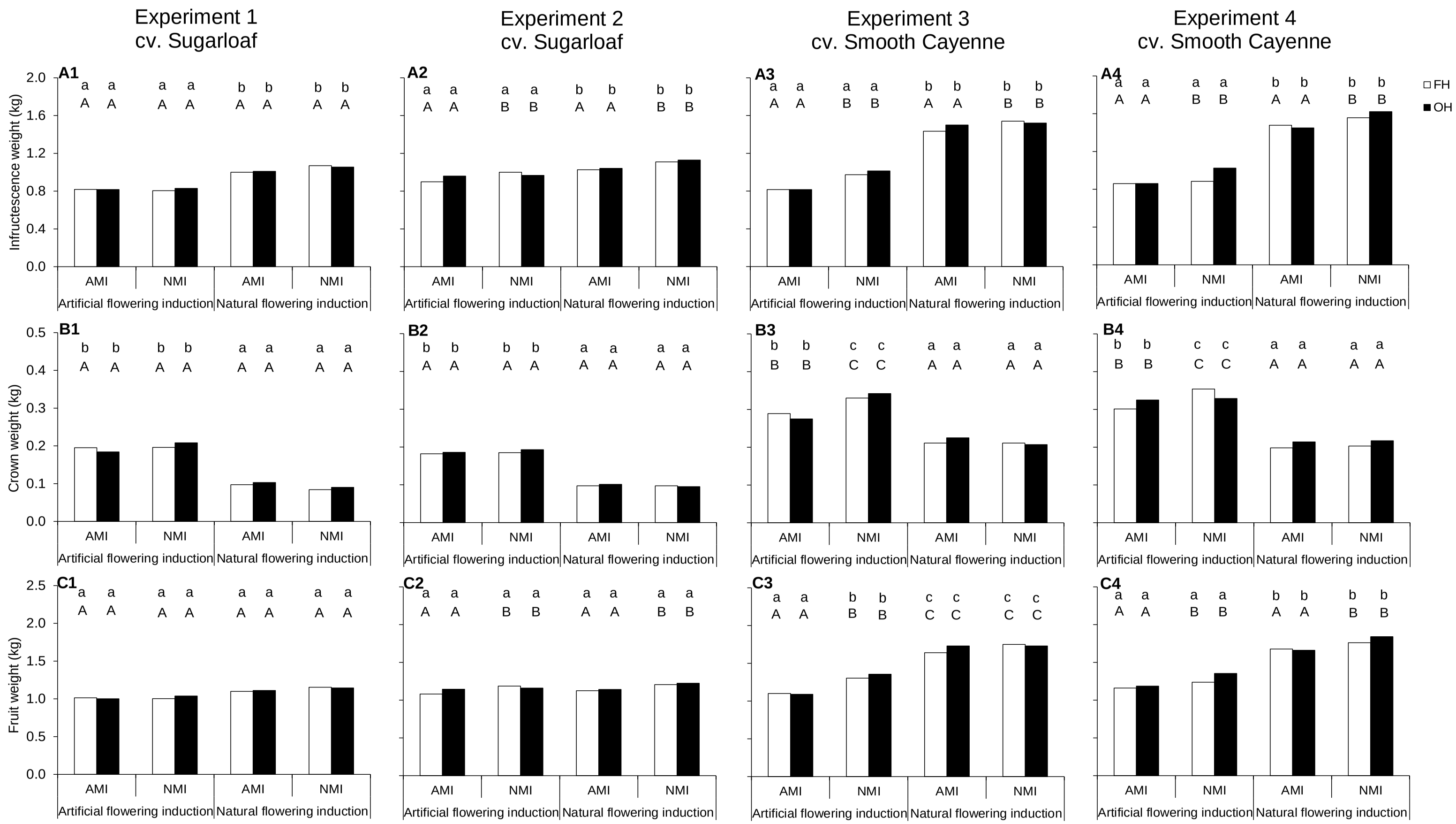
Figure 5.3. Effects of flowering and maturity induction practice and harvesting practice on the number of harvestings of the fruits in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)

lower in the fruits from NFI plants than in the fruits from AFI plants (Figure 5.5-C1-4). Under NFI, there was an increase in the infructescence heights ranging from 21 to 51% and 18 to 29% compared to AFI in cvs Sugarloaf and Smooth Cayenne, respectively. There was also a diminution in the crown heights ranging from 33 to 44% and 16 to 24% compared to AFI in Sugarloaf experiments and Smooth Cayenne, Experiment 4, respectively. The diminution in the ratio crown: infructescence heights under NFI, ranged from 46 to 61% (cv. Sugarloaf) and 22 to 40% (cv. Smooth Cayenne). The effect of flowering induction practice on the total fruit height varied across experiments (Figure 5.5-D1-4).

The effects of flowering induction practice on the percentage translucent flesh, TSS and juice pH were cultivar dependent (Figure 5.6). In cv. Sugarloaf, the effect of flowering induction practice on translucent flesh was variable across experiments. Flowering induction practice had no significant effect on TSS (Table S5.2; Figure 5.6). Naturally flowering-induced plants produced fruits with higher juice pH than AFI plants (Figure 5.6-C1 and C2). Under NFI, the increase in juice pH ranged from 4 to 14% compared to AFI. In cv. Smooth Cayenne, NFI plants produced fruits with higher translucency than AFI plants (Figure 5.6-A3 and A4). Under NFI, the percentage translucent flesh increased by more than 100% compared to AFI. The effects of flowering induction practice on TSS were consistent across Smooth Cayenne experiments under AMI treatments, where NFI plants gave fruits with higher TSS than AFI plants (Figure 5.6-B3 and B4). Under the NMI treatments, the effects of flowering induction practice on the TSS were not consistent. The effects of flowering induction practice on the juice pH were consistent across Smooth Cayenne experiments. Flowering induction practices did not affect the juice pH under AMI treatments. In the NMI treatments, NFI increased the juice pH (Figure 5.6-C3 and C4). Internal browning was not observed in any fruit.

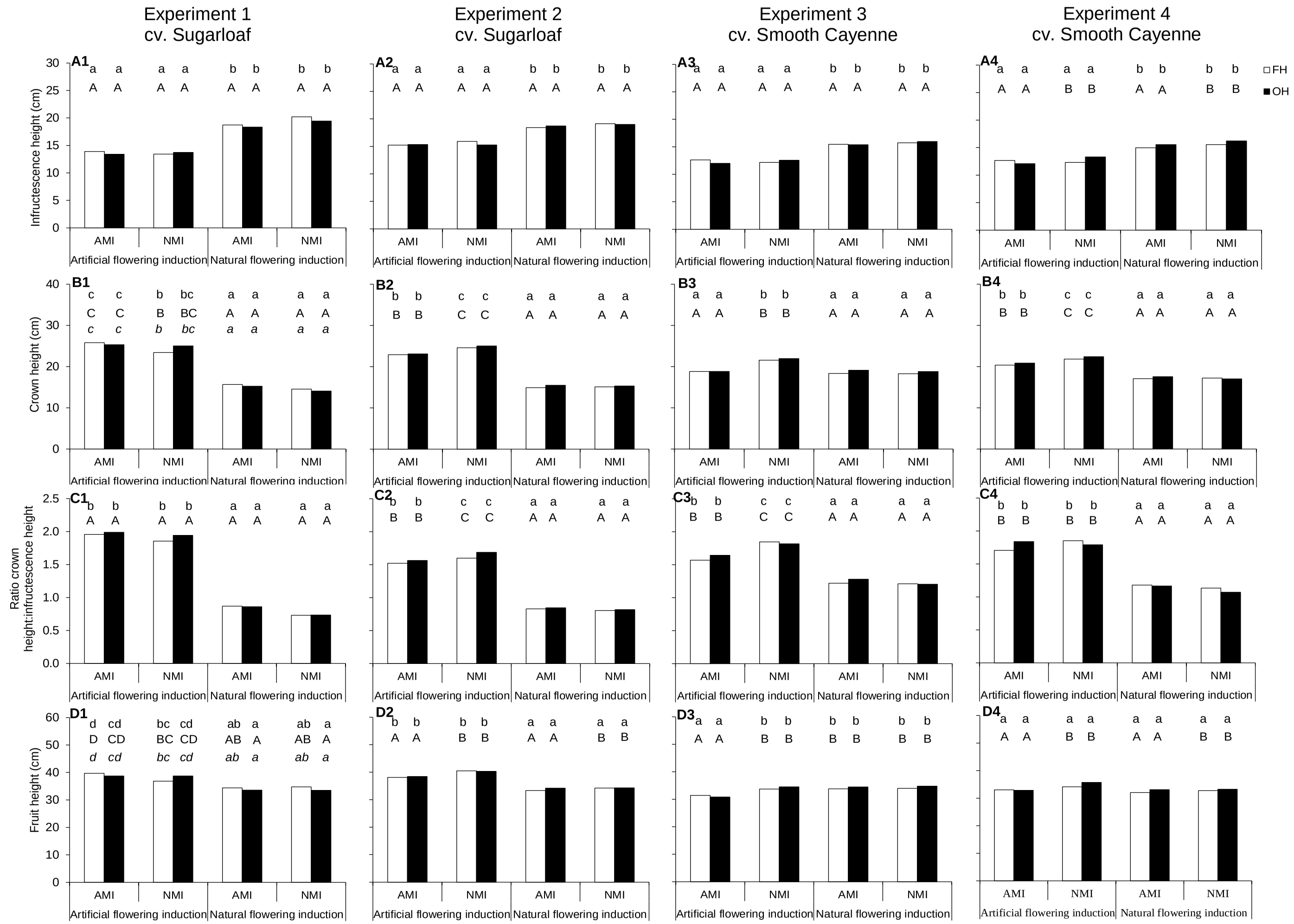
Effects of maturity induction practice on average fruit quality attributes

Significant effects of maturity induction practice on weight attributes were found in Experiments 1, 3 and 4 (Table S5.2). NMI gave fruits with higher infructescence weights than AMI fruits (Figure 5.4-A2-4), except in Experiment 1. When NMI occurred, there was an increase in the infructescence weights ranging from 8 to 11% and 1 to 24% compared to AMI in cvs Sugarloaf and Smooth Cayenne, respectively. Maturity induction practice had no significant effect on the crowns weight in cv. Sugarloaf. In cv. Smooth Cayenne, the effect of



AMI: Artificially maturity-induced fruits; NMI: Naturally maturity-induced fruits
FH: Farmers' harvest practice; OH: Optimum harvest
Similar small letters at the top of each bar indicate that differences between means in the flowering induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.2). In case of interactions all means are compared at $LSD_{0.05}$.

Figure 5.4. Effects of flowering and maturity induction practice and harvesting practice on the infructescence, crown and fruit weights in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)



AMI: Artificially maturity-induced fruits; NMI: Naturally maturity-induced fruits; FH: Farmers' harvest practice; OH: Optimum harvest.
Similar *small* letters at the top of each bar indicate that differences between means in the flowering induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.3). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *capital* letters at the top of each bar indicate that differences between means in the maturity induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.3). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *small* letters in *italic* (when present) at the top of each bar indicate that differences between means in the harvesting practice treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.3). In case of interactions all means are compared at $LSD_{0.05}$.

Figure 5.5. Effects of flowering and maturity induction practice and harvesting practice on the infructescence and crown heights, ratio crown height:infructescence height and fruit height in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)

maturity induction practice depended on the flowering induction practice (Table S5.2). Maturity induction practice did not affect the crowns weights when the plants were naturally flowering-induced; when the plants were artificially flowering-induced, NMI fruits had heavier crowns than AMI fruits (Figure 5.4-B3 and B4). Naturally maturity induced fruits had higher total fruit weight than AMI fruits in AFI plants in Experiments 2, 3 and 4 and in NFI plants in Experiments 2 and 4 (Figure 5.4-C2-4). In Experiment 1 and NFI plants in Experiment 3 there was no significant effect of maturity induction practice.

Significant effects of maturity induction practices on the heights attributes were found in all experiments (Table S5.3). In one out of the four experiments (Experiment 4), NMI fruits showed slightly longer infructescence heights than AMI fruits (Figure 5.5-A4). In the other experiments maturity induction practice had no effect on the infructescence height (Table S5.3). In all experiments except Experiment 1, the effects of maturity induction practice on crown height and the ratio crown: infructescence height depended on the flowering induction practice (Table S5.3). Maturity induction practice did not affect the crown height as well as the ratio crown: infructescence height when the plants were naturally flowering-induced (Figure 5.5-B1-4 and C1-4). When the plants were artificially flowering-induced, NMI fruits gave fruits with higher crowns heights than AMI fruits (Figure 5.5-B2-4), except in Experiment 1 where this effect was not clear-cut. Concerning the ratio crown: infructescence height, Experiments 2 and 3 indicated that NMI fruits from AFI plants had a higher ratio crown: infructescence height than AMI fruits (Figure 5.5-C2 and C3); in Experiments 1 and 4 maturity induction practice did not significantly affect the ratio crown: infructescence heights of the fruits originating from AFI plants (Figure 5.5-C1 and C4). The effect of maturity induction practice on the total fruit height was in general consistent across experiments in the fruits from AFI plants. In these plants, NMI fruits were taller than AMI fruits in three experiments (Figure 5.5-D2-4). In the fruits from NFI plants, this was found in Experiments 2 and 4 only (Figure 5.5-D2 and D4); in Experiments 1 and 4, the maturity induction practice did not affect the heights of the fruits originating from NFI plants (Figure 5.5-D1 and D3).

The effects of maturity induction practice on flesh translucency were not clear-cut in cv. Sugarloaf experiments; in cv. Smooth Cayenne experiments, maturity induction practice did not affect the flesh translucency of the fruits from the NFI plants (Figure 5.6-A3 and A4). In all experiments, NMI fruits had generally a higher TSS than AMI fruits (Figure 5.6-B1-4). When the fruits were naturally maturity-induced, there was an increase in TSS ranging from 2 to 10% and 3 to 37% compared to AMI fruits in cvs Sugarloaf and Smooth Cayenne, respectively. Maturity induction practice in general did not affect the juice pH of the fruits from AFI plants. In NFI plants, NMI fruits had generally a higher juice pH than AMI fruits (Figure 5.6-C1-4).

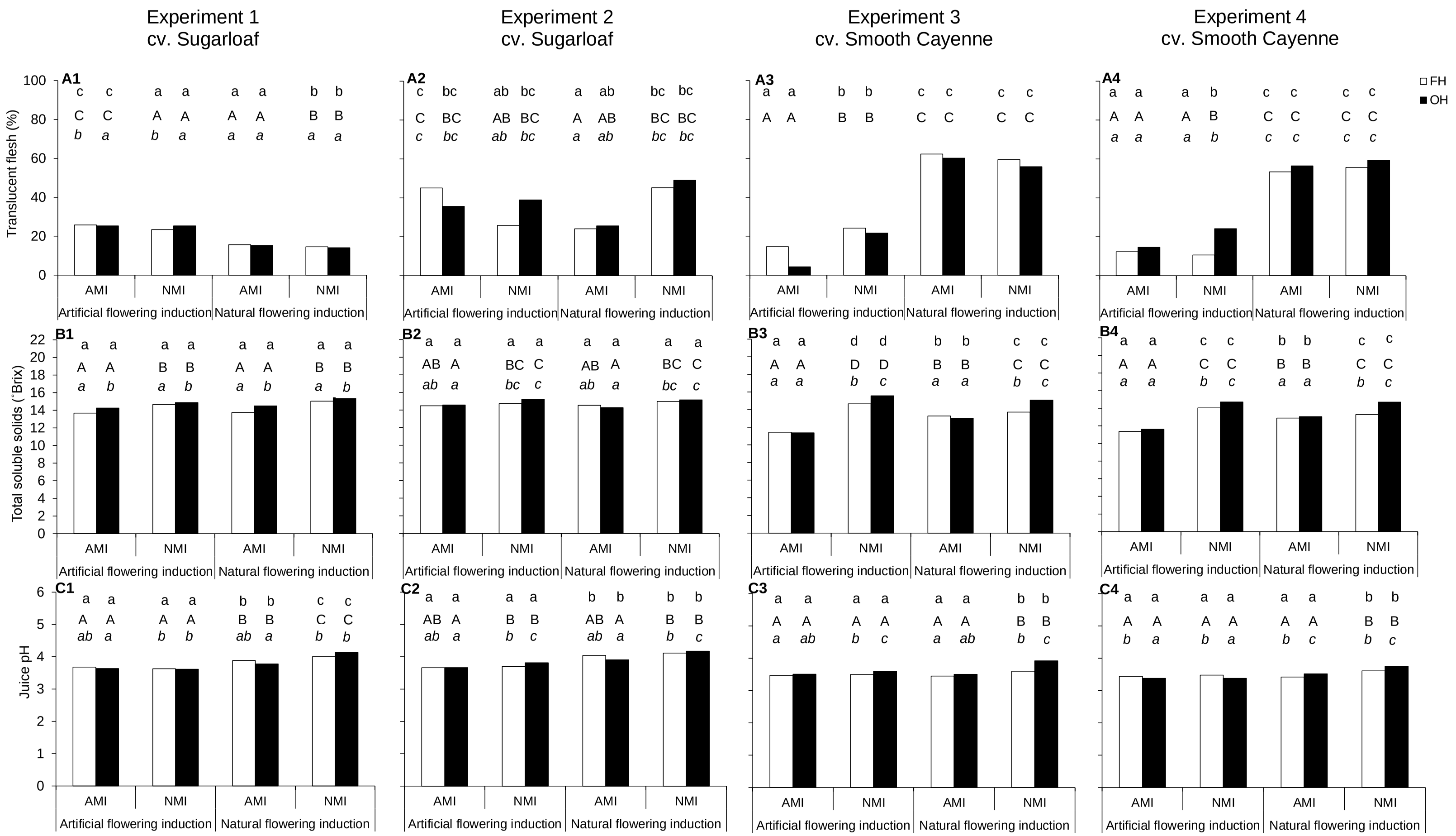
Effects of harvesting practice on average fruit quality attributes

In all experiments, harvesting practice had no significant effects on weight attributes (Table S5.2) and height attributes (Figure 5.5). Harvesting practice also did not affect the flesh translucency of the fruits from NFI plants (Figure 5.5-A1-4). On the fruits from AFI plants, the same observations were made (Figure 5.5-A2-4) except in Experiment 1 where harvesting of the fruits at OH gave fruits with a lower percentage translucent flesh than the FH practice (Figure 5.5-A1). In all experiments except Experiment 1, the effect of harvesting practice on the TSS depended on the maturity induction practice (Table S5.4). In general, results were consistent and showed that NMI fruits harvested at OH had higher TSS than under the FH practice (Figure 5.6-D1-4). For the AMI fruits, harvesting practice did not affect the TSS except in Experiment 1 where AMI fruits harvested at OH showed higher TSS than fruits under the FH practice. In all experiments except Experiment 4, the effect of harvesting practice on the juice pH depended on the maturity induction practice. Harvesting practice did not affect significantly the juice pH of the AMI fruits in Experiments 1, 2 and 3; in the NMI fruits, the effect of harvesting practice on the juice pH was not clear-cut (Figure 5.6-C1-4).

5.3.4. Effects of flowering induction practice, maturity induction practice and harvesting practice on heterogeneity in pineapple quality

Effects of flowering induction practice on heterogeneity in pineapple quality

The effects of flowering induction practice on the variation in weight attributes were cultivar dependent for the infructescence and fruits weights. In cv. Sugarloaf, NFI plants gave fruits with lower variability in infructescence and fruit weights than AFI plants (Figure 5.7-A1, A2 and C1, C2); the diminution in the variation ranged from 33 to 53% and 28 to 53% respectively. In cv. Smooth Cayenne, the flowering induction practice did not affect the variation in infructescence weights in the NMI fruits (Figure 5.7-A3 and A4); in the AMI fruits, the effect of flowering induction practice on the variation in infructescence weights was



AMI: Artificially maturity-induced fruits; NMI: Naturally maturity-induced fruits; FH: Farmers' harvest practice; OH: Optimum harvest.
Similar *small* letters at the top of each bar indicate that differences between means in the flowering induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.4). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *capital* letters at the top of each bar indicate that differences between means in the maturity induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.4). In case of interactions all means are compared at $LSD_{0.05}$.
Similar small letters in *italic* (when present) at the top of each bar indicate that differences between means in the harvesting practice treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.4). In case of interactions all means are compared at $LSD_{0.05}$.

Figure 5.6. Effects of flowering induction practice, maturity induction practice and harvesting practice on percentage translucent flesh, total soluble solids and juice pH in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)

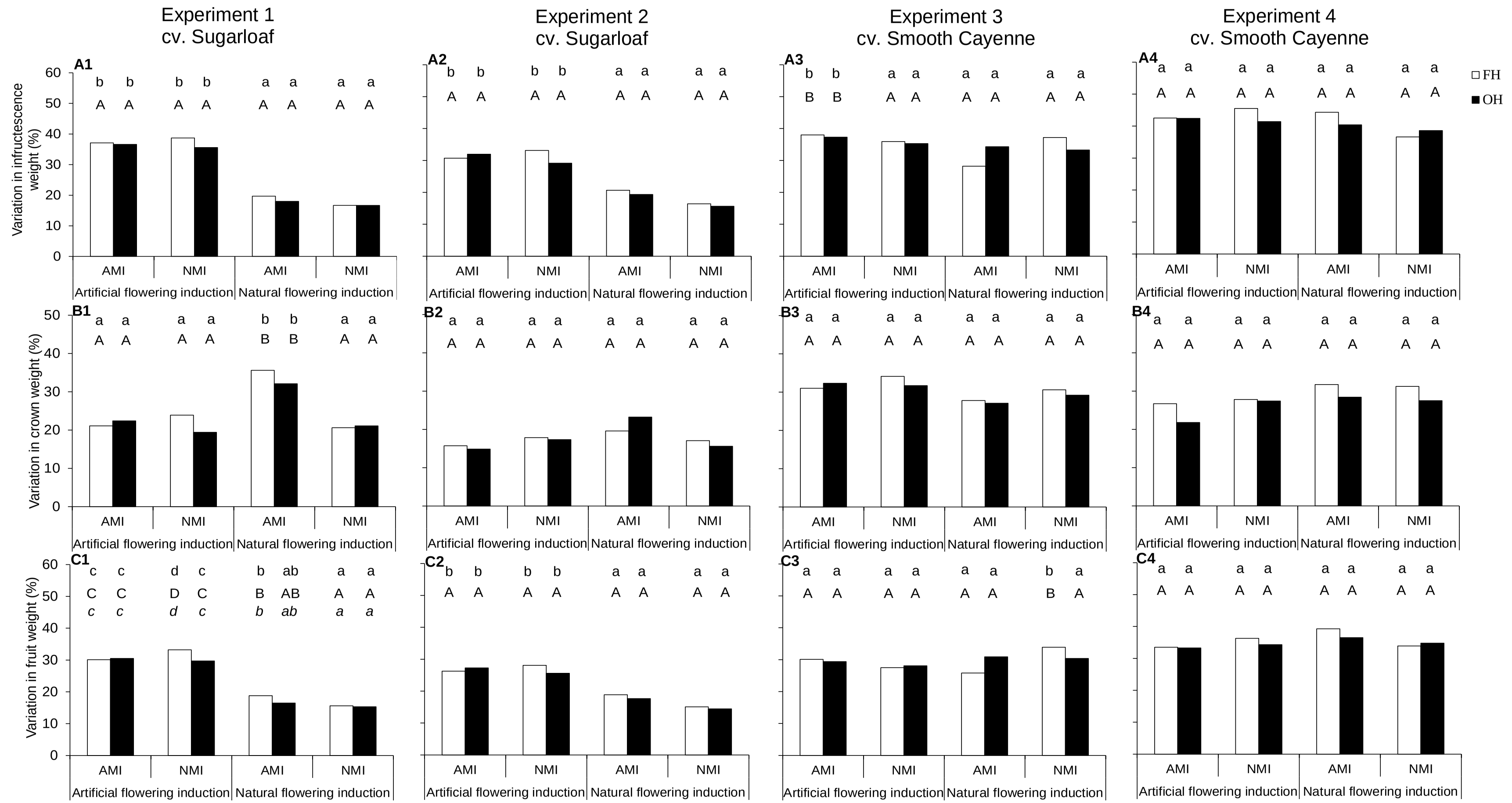
not consistent (Figure 5.7-A3 and A4). In Smooth Cayenne experiments, flowering induction practice had no effect on the variation in fruit weights (Table S5.2).

The effect of flowering induction practice on the variation in crown weights was consistent in three out of four experiments, showing no effect on the variation in crown weights (Figure 5.7-A2-4). Flowering induction practice affected the variation in crown weights in Experiment 1 only (Table S5.2): under AMI treatments, NFI plants gave fruits with higher variation in crown weights than AFI plants (Figure 5.7-B1).

Effects of flowering induction practice on the variation in height attributes were cultivar dependent for the infructescence and fruit heights. In cv. Sugarloaf, NFI gave fruits with lower variation in infructescence heights than AFI (Figure 5.8-A1 and A2); the diminution ranged from 31 to 56%. In Sugarloaf experiments, under AMI treatments, flowering induction practice did not affect the variation in fruit heights; under NMI treatments, the effect was not clear-cut (Figure 5.8-D1 and D2). In cv. Smooth Cayenne, the effects of flowering induction practice on the variation in infructescence heights were not consistent across experiments (Figure 5.8-A3 and A4). In Smooth Cayenne, NFI plants gave fruits with higher variation in fruit heights than AFI plants (Figure 5.8-D3 and D4); the increase in the variation ranged from 27 to 115%. Flowering induction practice did not affect the variation in ratio crown: infructescence heights except in Experiment 1 (Table S5.3) where under NMI treatments, NFI plants gave fruits with lower variation than AFI plants (Figure 5.8-C1-4). The NFI plants gave fruits with higher variation in crown heights than AFI plants except in Experiment 1 where there was no effect on the variation in crown heights (Figure 5.8-B1-4).

The effects of flowering induction practice on the variation in the percentage translucent flesh depended on the cultivar. In cv. Sugarloaf, under AMI treatments, NFI plants gave fruits with 17 to more than 100% higher variation in percentage translucent flesh than AFI plants (Figure 5.9-A1 and A2). In cv. Smooth Cayenne, NFI plants gave fruits with 55 to 81% lower variation in percentage translucent flesh than AFI plants (Figure 5.9-A3 and A4). The effect of flowering induction practice on the variation in TSS was not consistent across experiments (Figure 5.9-B1-4).

The effects of flowering induction practice on the variation in juice pH were largely consistent. Under AMI treatments, NFI plants gave fruits with higher variation in juice pH than AFI plants (Figure 5.9-C1-4). The same observations were made in the treatments under NMI except in Experiment 3 where under NMI the NFI plants gave fruits with lower variation



FH: Farmers' harvest practice; OH: Optimum harvest; AMI: Artificially maturity-induced fruits; NMI: Naturally maturity-induced fruits.
Similar *small* letters at the top of each bar indicate that differences between means in the flowering induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.2). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *capital* letters at the top of each bar indicate that differences between means in the maturity induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.2). In case of interactions all means are compared at $LSD_{0.05}$.
Similar small letters in *italic* (when present) at the top of each bar indicate that differences between means in the harvesting practice treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.2). In case of interactions all means are compared at $LSD_{0.05}$.

Figure 5.7. Effects of flowering induction practice, maturity induction practice and harvesting practice on the variation in infructescence, crown and fruit weights in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)

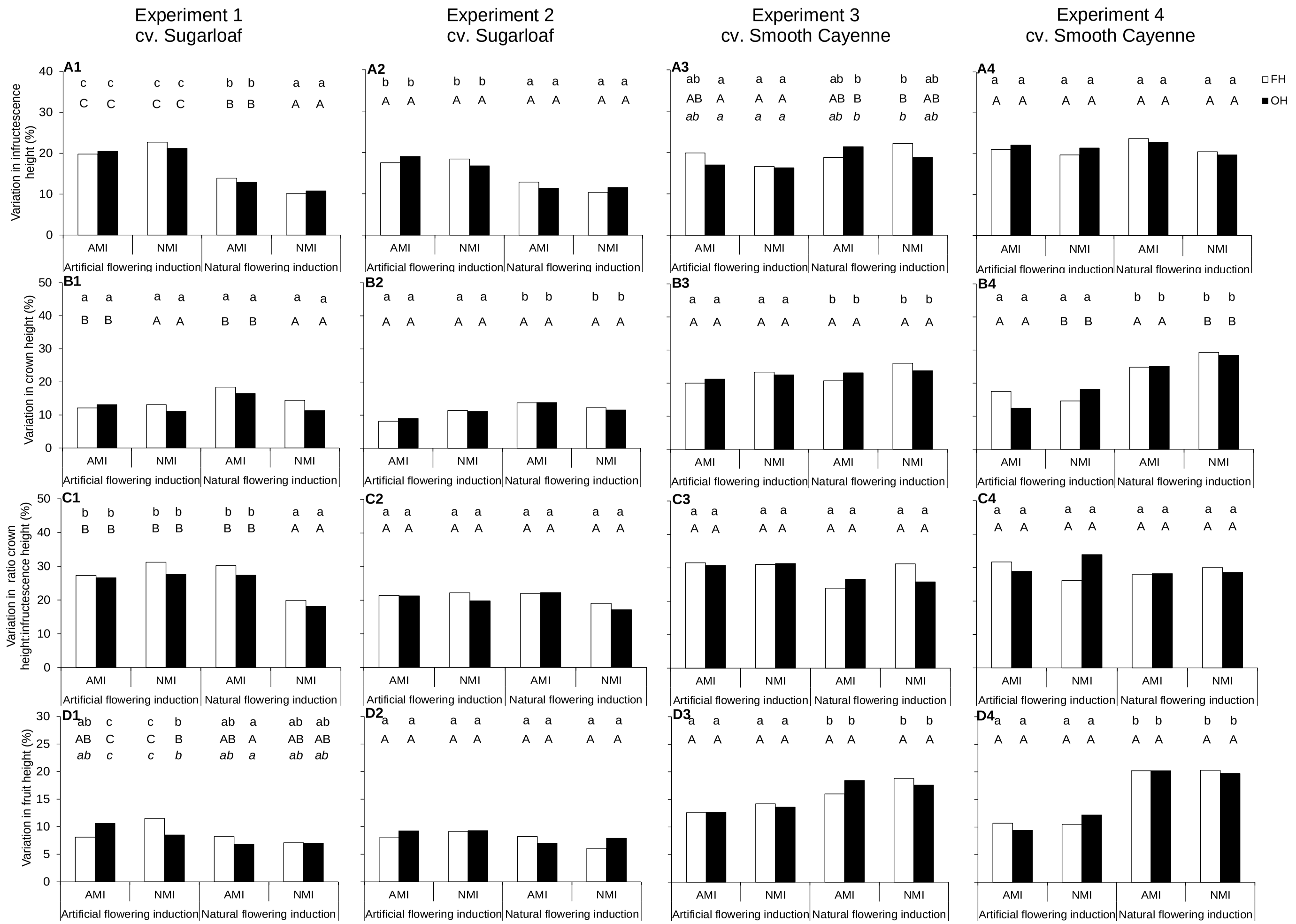
in juice pH than AFI plants.

Effects of maturity induction practice on heterogeneity in pineapple quality

The effects of maturity induction practice on the variation in infructescence, crown or fruit weights were not significant in three out of the four experiments (Table S5.2). Maturity induction practice affected the variation in infructescence weights in Experiment 3 only: under AFI treatments, NMI fruits showed lower variation in infructescence weights than AMI fruits (Figure 5.7-A3). Maturity induction practice affected the variation in crown weights in Experiment 1 only: under NFI treatments, NMI fruits showed lower variation in crown weights than AMI fruits (Figure 5.7-B1). Maturity induction practice affected the variation in fruit weights in Experiment 1 only, but the effect was not clear-cut (Figure 5.7-C1).

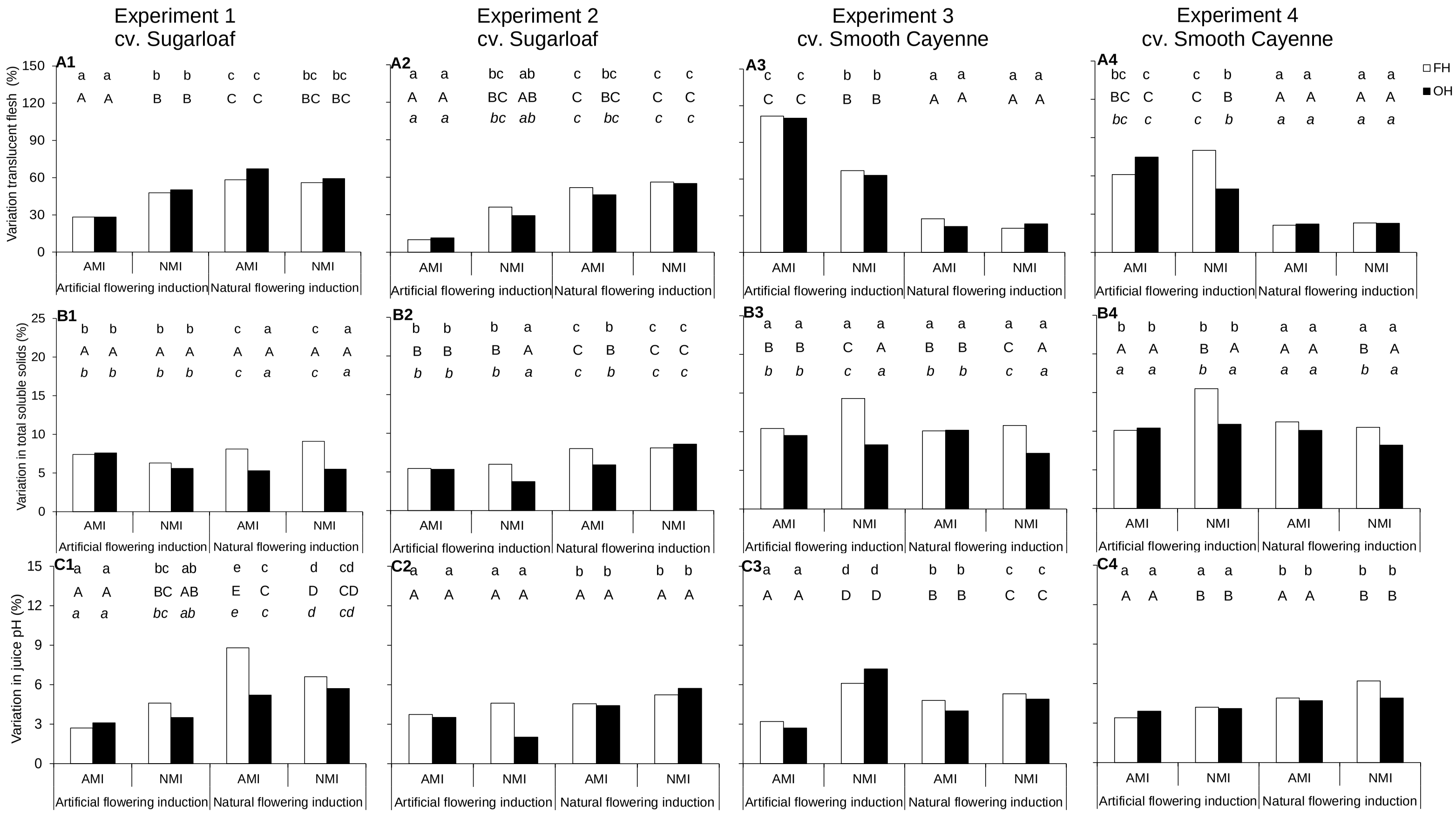
Similarly to the weight attributes, in three out of the four experiments, maturity induction practice did not significantly affect the variation in infructescence height, ratio crown: infructescence height, and fruit height. Effects were only observed in Experiment 1 where under NFI treatments, NMI fruits showed lower variation in infructescence height and ratio crown: infructescence height than AMI fruits (Figure 5.8-A1 and C1) whereas the variation in fruit height was not affected (Figure 5.8-D1). In Experiment 1, under AFI treatments, maturity induction practice had no effect on infructescence height and ratio crown: infructescence height (Figure 5.8-A1 and C1) whereas the effect of on fruit height was not clear-cut (Figure 5.8-D1). Concerning the crown height, maturity induction practice had no effect on its variation in Experiments 2 and 3 whereas in Experiments 1 and 4 opposite effects were found; AMI fruits showed lower variation in crown height than NMI fruits in Experiment 1 and higher variation in Experiment 4 (Figure 5.8-B1 and B4).

In all experiments, maturity induction practice had no effect on the variation in percentage translucent flesh in fruits from NFI plants (Figure 5.9-A1 to A4). The effect on the variation in TSS was not consistent across experiments. The effect of maturity induction practice on the variation in juice pH was clear cut in cv. Smooth Cayenne experiments where NMI fruits consistently showed a slightly higher variation in juice pH than AMI fruits (Figure 5.9-C3 and C4).



AMI: Artificially maturity-induced fruits; NMI: Naturally maturity-induced fruits; FH: Farmers' harvest practice; OH: Optimum harvest.
Similar *small* letters at the top of each bar indicate that differences between means in the flowering induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.3). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *capital* letters at the top of each bar indicate that differences between means in the maturity induction treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.3). In case of interactions all means are compared at $LSD_{0.05}$.
Similar small letters in *italic* (when present) at the top of each bar indicate that differences between means in the harvesting practice treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.3). In case of interactions all means are compared at $LSD_{0.05}$.

Figure 5.8. Effects of flowering induction practice, maturity induction practice and harvesting practice on the variation in infructescence and crown heights, ratio crown height: infructescence height and fruit height in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)



AMI: Artificially maturity-induced fruits; NMI: Naturally maturity-induced fruits; FH: Farmers' harvest practice; OH: Optimum harvest.
Similar *small* letters at the top of each bar indicate that differences between means in the flowering induction treatments are not significant based on the ANOVA results (consider *P*- values in bold in Table S5.4). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *capital* letters at the top of each bar indicate that differences between means in the maturity induction treatments are not significant based on the ANOVA results (consider *P*- values in bold in Table S5.4). In case of interactions all means are compared at $LSD_{0.05}$.
Similar small letters in *italic* (when present) at the top of each bar indicate that differences between means in the harvesting practice treatments are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.4). In case of interactions all means are compared at $LSD_{0.05}$.

Figure 5.9. Effects of flowering induction practice, maturity induction practice and harvesting practice on variation in percentage translucent flesh, total soluble solids and juice pH in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)

Effects of harvesting practice on heterogeneity in pineapple quality

Harvesting practice did not significantly affect the variation in any of the weights attributes, except in fruit weight in Experiment 1 (Table S5.2), where harvesting of NMI fruits originating from AFI plants at OH showed lower variation in fruit weights than when using the FH practice (Figure 5.7-C1).

Harvesting practice also did not affect the variation in heights attributes except for fruit heights in Experiment 1 where harvesting of the NMI fruits originating from AFI at OH showed lower variation in fruit heights than those harvested at FH; harvesting of the fruits from AMI fruits originating from AFI plants at OH showed higher variation in fruits heights than the FH practice (Figure 5.8-D1).

Harvesting practice did not significantly affect the variation in percentage translucent flesh except in Experiment 4 where harvestings of the NMI fruits originating from AFI at OH showed lower variation in percentage translucent flesh than harvesting at FH (Figure 5.9-A4). The effect of harvesting practice on the TSS depended on the cultivar. In cv. Sugarloaf, harvesting practice did not affect the variation in TSS for AMI fruits originating from AFI plants (Figure 5.9-B1 and B2). Harvestings of the AMI fruits originating from NFI, at OH showed lower variation than the FH practice (Figure 5.9-B1 and B2). In cv. Smooth Cayenne harvesting practice did not affect the variation in TSS in the AMI fruits (Figure 5.9-B3 and B4). Harvestings of the NMI fruits at OH showed lower variation in TSS than the FH practice (Figure 5.9-B3 and B4). Harvesting practice did not significantly affect the variation in juice pH except in Experiment 1 where harvesting of the AMI fruits originating from NFI plants at OH showed lower variation in juice pH than the FH practice (Figure 5.9-C1).

5.3.5. Effects of flowering induction practice, maturity induction practice and harvesting practice on percentage of fruits exportable to Europeans markets

In all experiments, flowering induction practice had significant (Table S5.5) and consistent effects on the percentage of fruits exportable to Europe (Figure 5.10). Naturally flowering-induced plants yielded a higher percentage exportable fruits than AFI plants (Figure 5.10-A1-4). Under NFI, there was an increase in the percentage of exportable fruits compared to AFI between 74 and 453% in cv. Sugarloaf and between 112 and 186% in cv. Smooth Cayenne.

The effect of maturity induction on the percentage of fruits exportable to Europe was not clear-cut in Experiments 2 and 3; in Experiments 1 and 4 NMI treatments gave more exportable fruits than AMI treatments (Figure 5.10-A1 and A4). The effect of harvesting practice on the percentage of fruits exportable to Europe depended on the cultivar. In cv. Sugarloaf, harvesting practice did not affect the percentage of fruits exportable to Europe in fruits originating from NFI plants (Figure 5.10-A1 and A2). In fruits originating from AFI plants, the effect of harvesting practice on the percentage of fruits exportable to Europe was not clear-cut (Figure 5.10-A1 and A2). In the Smooth Cayenne experiments, the effect of harvesting practice on the percentage of fruits exportable to Europe was consistent.

Harvestings of the NMI fruits at OH gave more exportable fruits than the FH practice (Figure 5.10-A3 and A4); the increase in the fruits exportable to Europe ranged between 14-30% for NMI fruits harvested at OH compared to the FH practice.

When analysing the reasons why a higher proportion of fruits from AFI plants compared to NFI plants was not exportable (Figure 5.10), our results revealed that in cv. Sugarloaf, the ratio crown: infructescence height was the most limiting quality criterion because it had too high values (above 1.5) for a high percentage of fruits in the AFI plots (Table 5.2). In addition, small fruit weight also limited the percentage of exportable fruits. In cv. Smooth Cayenne, there were two quality criteria limiting the proportion of exportable fruits: the ratio crown: infructescence height which was higher than 1.5 and the TSS which was less than 12 °Brix (Table 5.3).

5.4. Discussion

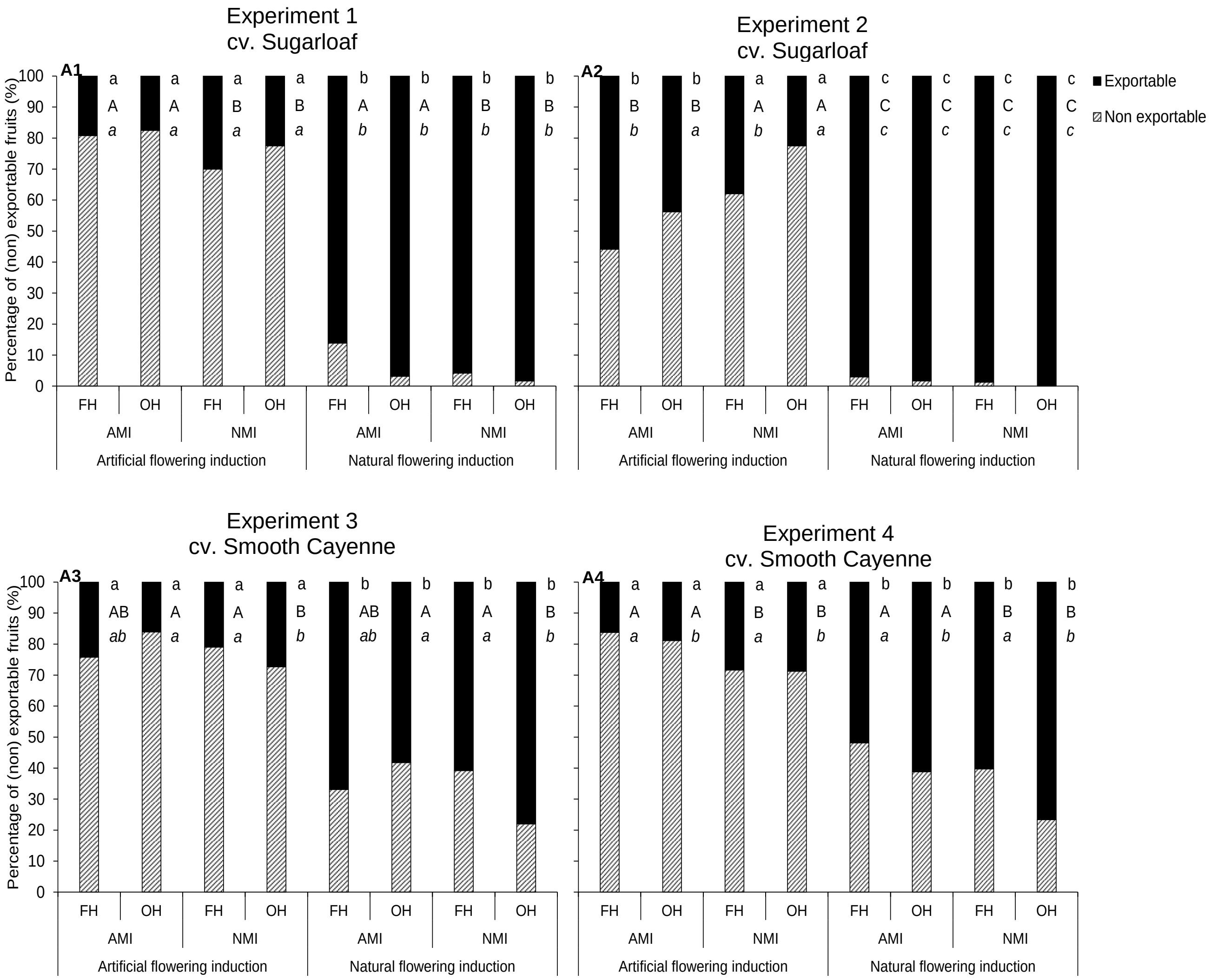
5.4.1. Trade-offs of flowering induction practice, maturity induction practice and harvesting practice pineapple quality and proportion of fruits exportable to Europe

Trade-offs of flowering synchronisation for pineapple quality and proportion of fruits exportable to Europe

One of the objectives of this study was to quantify the trade-offs of flowering synchronisation for pineapple quality and proportion of exportable fruits. Our results clearly indicated that NFI improved the fruit quality compared to AFI (Figure 5.11). Naturally flowering-induced plants gave fruits with higher infructescence weight and height (Figures 5.4-A1-4 and 5.5-A1-4), lighter and shorter crown (Figures 5.4-B1-4 and 5.5-B1-4) and consequently a lower ratio crown: infructescence height when compared to AFI plants (Figure 5.5-C1-4). Natural flowering induction did not change the total fruit weight in cv. Sugarloaf (Figure 5.4-C1 and C2); in cv. Smooth Cayenne, NFI gave higher fruit weight than AFI (Figure 5.4-C3 and C4). These improvements in fruit quality attributes allowed NFI to increase the percentage of fruits exportable to European markets by more than 100% in the two cultivars (Figure 5.10). Another advantage of NFI was that there were no costs for farmers for flowering induction.

The costs of achieving these improvements in fruit quality attributes by NFI were (Figure 5.11): first, in NFI, the time from planting to flowering induction was on average 200 and 150 days longer than that in the AFI plants in cvs Sugarloaf and Smooth Cayenne respectively. In addition, NFI plants were induced to flower over a long period of time and not at the same date as was the case in the AFI (Figures S5.1 and S5.2); there was a large time lag between the first NFI plants and the last NFI plants: 164-535 days and 150-197 days in cvs Sugarloaf and Smooth Cayenne, respectively (Figure 5.2). The time from planting to harvesting of the NFI plants was 196-274 days longer than that of the AFI plants in cv. Sugarloaf and 146-192 days in cv. Smooth Cayenne (Figure 5.2). As a result, not all fruits produced by the NFI plants were harvested on a single day as was the case for AFI plants; there were many harvestings in NFI plants (Figure 5.3). The number of harvesting of the fruits from NFI plots was 3 to 12 times and 2 to 6 times higher than that in the AFI plots in cvs Sugarloaf and Smooth Cayenne, respectively (Figure 5.3). In addition, the proportion of plants from which fruits were harvested ranged from 45-81% in the NFI treatments and was 100% in the AFI treatments (Figures S5.1 and S5.2). The increase in the number of days from planting to flowering induction, the number of days from planting to harvesting of the fruits and the number of harvestings of the fruits, and the decrease in the percentage plants that actually produced fruits are reasons that could jeopardize the acceptance of natural flowering induction practice by pineapple producers. Allowing pineapple plants to flower naturally will oblige pineapple producers to keep their field under pineapple crop for a long period. The extra days under which the field will be kept under pineapple could alternatively be used to grow other crops that have a crop cycle of 120-130 days (about 4 months), such as maize (*Zea mays*). Later artificial flowering induction based on the developmental status of the plants may help producers to achieve a higher fruit quality, closer to that obtained with natural flowering induction.

There are two possible reasons why NFI plants produced better fruits than AFI plants. The first might be linked to the longer time from planting to flowering induction (Figure 5.2)



AMI: Artificially maturity-induced fruits;
NMI: Naturally maturity-induced fruits;
FH: Farmers' harvest practice;
OH: Optimum harvest.

Similar *small* letters aligned close to the bars filled in black indicate that differences between the percentages of exportable fruits following the flowering induction practice are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.5). In case of interactions all means are compared at $LSD_{0.05}$.
Similar *capital* letters aligned close to the bars filled in black indicate that differences between the percentages of exportable fruits following the maturity induction practice are not significant based on the ANOVA results (consider *P*- values in bold in Table S5.5). In case of interactions all means are compared at $LSD_{0.05}$.
Similar small letters in *italic* aligned close to the bars filled in black indicate that differences between the percentages of exportable fruits following the harvesting practice are not significant based on the ANOVA results (consider *P*-values in bold in Table S5.5). In case of interactions all means are compared at $LSD_{0.05}$.

Figure 5.10. Effects of flowering induction practice, maturity induction practice and harvesting practice on the percentages of fruits that are exportable and non-exportable to European markets in cvs Sugarloaf (Experiments 1 and 2) and Smooth Cayenne (Experiments 3 and 4)

Table 5.2. Percentage of total fruits per treatment being non-exportable to European markets and falling within different set of quality criteria combinations in cv. Sugarloaf

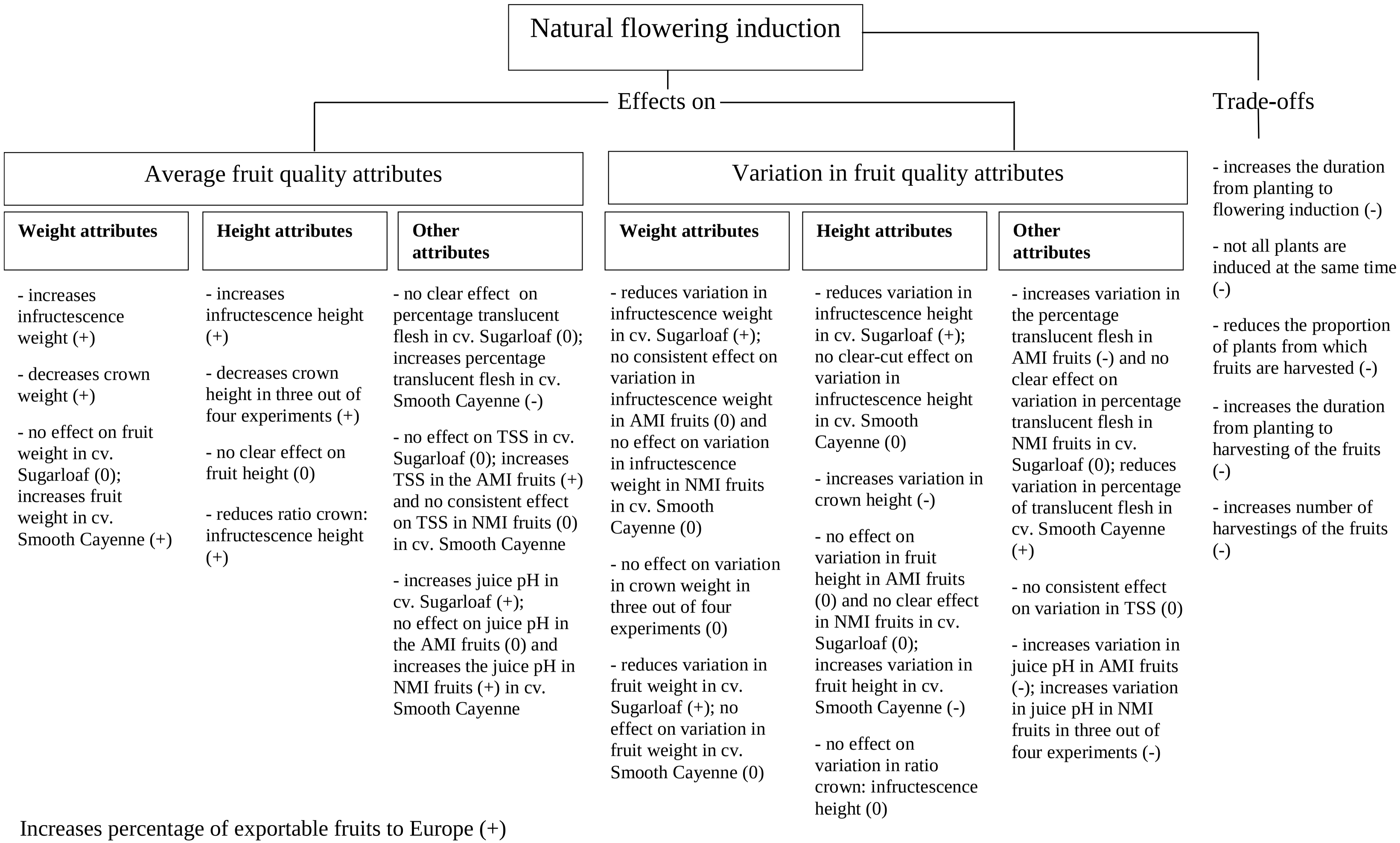
Fruit weight (kg)	Ratio crown: infructescence height	TSS (°Brix)	Experiment 1								Experiment 2							
			Artificial flowering induction				Natural flowering induction				Artificial flowering induction				Natural flowering induction			
			AMI[a]		NMI[b]		AMI		NMI		AMI		NMI		AMI		NMI	
			FH[c]	OH[d]	FH	OH	FH	OH	FH	OH	FH	OH	FH	OH	FH	OH	FH	OH
< **0.7**[e]	[0.5-1.5]	≥ 12	0.0	0.8	0.8	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.4	0.0	2.3	0.0	0.0	0.0
< **0.7**	**> 1.5**	**< 12**	0.4	1.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
< **0.7**	**> 1.5**	≥ 12	13.7	12.9	17.5	11.6	0.6	0.0	0.0	0.0	5.8	3.7	3.3	3.7	0.6	1.1	0.0	0.0
[0.7-2.75]	**< 0.5**	≥ 12	0.0	0.0	0.0	0.0	1.3	0.6	2.8	1.7	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
[0.7-2.75]	[0.5-1.5]	**< 12**	2.9	0.4	0.0	0.0	6.6	0.0	1.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
[0.7-2.75]	**> 1.5**	**< 12**	2.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0
[0.7-2.75]	**> 1.5**	≥ 12	**61.2**[f]	**66.2**	**51.3**	**65.8**	5.3	1.9	0.0	0.0	**37.0**	**50.8**	**58.3**	**68.3**	0.0	0.5	0.0	0.0
> 2.75	[0.5-1.5]	≥ 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.0	0.0	0.0	0.0
> 2.75	**> 1.5**	≥ 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0

[a] Artificially maturity-induced fruits
[b] Naturally maturity-induced fruits
[c] FH, Farmers' harvest practice
[d] OH, Optimum harvest
[e] Quality criteria in bold refer to the quality criteria that do not respond to the quality requirement in the European markets
[f] Numbers in bold refer to where a huge number of pineapple fruits are not exportable to Europe

Table 5.3. Percentage of total fruits per treatment being non-exportable to European markets and falling within different set of quality criteria combinations in cv. Smooth Cayenne

Fruit weight (kg)	Ratio crown: infructescence height	TSS (°Brix)	Experiment 3								Experiment 4							
			Artificial flowering induction				Natural flowering induction				Artificial flowering induction				Natural flowering induction			
			AMI[a]		NMI[b]		AMI		NMI		AMI		NMI		AMI		NMI	
			FH[c]	OH[d]	FH	OH	FH	OH	FH	OH	FH	OH	FH	OH	FH	OH	FH	OH
< 0.7[e]	**< 0.5**	≥ 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
< 0.7	[0.5-1.5]	**< 12**	0.4	1.3	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
< 0.7	[0.5-1.5]	≥ 12	0.0	0.0	0.9	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.6	1.4	0.7	0.0	0.0
< 0.7	**> 1.5**	**< 12**	7.0	8.7	0.9	0.0	0.0	0.0	0.0	0.0	8.9	8.3	6.5	0.0	0.0	0.0	0.0	0.0
< 0.7	**> 1.5**	≥ 12	1.7	0.0	1.4	1.9	0.0	0.6	3.0	0.0	3.4	1.7	3.7	4.5	0.7	0.0	0.0	0.0
[0.7-2.75]	**< 0.5**	≥ 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	2.8
[0.7-2.75]	**< 0.5**	**< 12**	1.3	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
[0.7-2.75]	**< 0.5**	≥ 12	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
[0.7-2.75]	[0.5-1.5]	**< 12**	17.6	19.5	4.6	0.9	15.1	12.6	6.5	0.0	19.6	9.6	0.4	0.0	21.1	15.8	14.8	0.0
[0.7-2.75]	**> 1.5**	**< 12**	**32.1**[f]	**38.7**	6.9	0.4	1.4	4.4	1.7	0.0	**34.2**	**43.4**	7.9	2.6	2.9	1.4	0.0	0.9
[0.7-2.75]	**> 1.5**	≥ 12	15.4	15.6	**64.2**	**69.3**	15.1	18.9	26.6	23.6	17.5	18.0	**53.0**	**62.7**	13.8	15.1	12.9	6.5
> 2.75	**< 0.5**	≥ 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9
> 2.75	[0.5-1.5]	**< 12**	0.0	0.0	0.0	0.0	0.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.7	0.0	0.0
> 2.75	[0.5-1.5]	≥ 12	0.0	0.0	0.0	0.0	0.7	3.1	4.3	4.8	0.0	0.0	0.0	0.0	5.8	5.0	7.4	0.0
> 2.75	**> 1.5**	≥ 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0.0	12.1

[a] Artificially maturity-induced fruits
[b] Naturally maturity-induced fruits
[c] FH, Farmers' harvest practice
[d] OH, Optimum harvest
[e] Quality criteria in bold refer to the quality criteria that do not respond to the quality requirement in the European markets
[f] Numbers in bold refer to where a huge number of pineapple fruits are not exportable to Europe



AMI: Artificially maturity-induced; NMI: Naturally maturity-induced
TSS: total soluble solids

(+) Positive effect (compared to what is desirable)
(-) Negative effect (compared to what is desirable)
(0) No effect

Figure 5.11. Effects and trade-offs of natural flowing induction vs. artificial flowering induction in a pineapple crop

in relation to the vigour of the plants at the flowering induction time. The longer time from planting to flowering induction in the NFI plants might allow them to reach a larger size and become more vigorous than the AFI plants where all the plants, no matter their size, were induced to flower. Recent works by Fassinou Hotegni et al. (unpublished data) disclosed the existence of strong, positive associations between the vigour of individual plants within a crop at (artificial) flowering induction and the later infructescence and fruit weights and heights. Plants that were more developed at flowering induction were likely to produce heavier infructescences and fruits as well as taller infructescences and fruits (Fassinou Hotegni et al. unpublished data). In the present study, NFI plants must be more developed at flower induction than AFI plants, because of their longer time to flowering induction, and more assimilates may have been available at flowering induction time in NFI plants. Consequently, NFI plants were likely to produce fruits with heavier and taller infructescences. However, crown weight and height were reduced in NFI plants. Such observations are in agreement with the view that when more assimilates are available at the flowering induction time, relatively more dry matter might be allocated to infructescence growth than crown growth. This also could explain the low ratio crown: infructescence height in the fruits from NFI plants.

Another reason why NFI plants may produce better fruits could be a longer exposure to inducing stimuli. Most natural flowering inductions occurred during the coldest months (August and December) in cv. Sugarloaf and the wettest (reduction of the hours of solar radiation) month (June) in cv. Smooth Cayenne (Figures 5.1, S5.1 and 5.2). During these natural flowering induction periods in the NFI treatments, plants were induced continuously by external stimuli. Such continuous flowering induction of NFI plants might have played a role in achieving fruits with higher infructescence weights and height compared to AFI plants (Figure 5.4-A1-4; Figure 5.5-A1-4). This view is supported by the observations that NFI plants produced infructescences with higher number of fruitlets called “eyes” than AFI plants (not shown). In the case of the tomato (*Solanum lycopersicum*) crop Adams et al. (2001) found tomato plants exposed to low temperatures produced higher number of flowers per truss than those exposed to relatively higher temperatures. In the case of citrus (*Citrus sinensis*), Moss (1976) found that citrus plants exposed to low temperatures produced a higher number of flowers per inflorescence than those exposed to high temperatures.

However, very late flowering induction may lead to an increase in competition for resources among and within plants. In this situation, NFI plants may produce lower average fruit quality than AFI plants that were induced to flower at an earlier stage.

Trade-offs of maturity synchronisation for pineapple quality and proportion of exportable fruits

A second objective of this study was to quantify the trade-offs of maturity synchronisation for pineapple quality and proportion of fruits exportable to Europe. In all experiments except Experiment 1, NMI fruits presented higher infructescence weights than AMI fruits (Figure 5.4-A2-4). In the fruits from AFI plants, NMI fruits were taller than AMI fruits (Figure 5.5-D2-4). In all experiments, NMI fruits were sweeter than AMI fruits (Figure 5.6-B1-4). These improvements caused by NMI led to a small increase in the proportion of exportable fruits, mainly in Experiments 1 and 4 (Figure 5.10-A1 and A4). Another advantage of NMI is that there are no costs for farmers for Ethephon application.

Extra costs of obtaining fruits with these quality attributes were due to the length of the generative period and the number of harvestings (Figure 5.12). The period between flowering induction and harvest was 1 to 11 days longer in NMI than in AMI fruits. The number of harvestings of the fruits was higher in the NMI treatments than AMI treatments when fruits were harvested at OH (Figure 5.3).

The positive effect of natural maturity induction on fruit weight (Figure 5.12) through the infructescence weight was not expected but can be explained. The infructescence growth follows a sigmoid curve with a slight increase during the last weeks before the harvesting time (Siderius and Krauss 1938). The increase of the infructescence weight during the last weeks is accompanied by flattening of the fruitlets on the skin of the fruits (Siderius and Krauss 1938). When AMI was carried out, the degree of flattening in the shell slowed down (personal observation), suggesting a limited capacity of the infructescence to further increase in size. Such conclusion is in line with that reached by Hepton (2003) who argued that fruit weight increased less when AMI was carried out earlier. Reasons why the NMI gave sweeter fruits than AMI can be found in the increase in TSS, and especially the sucrose accumulation occurring during the last two weeks before harvesting (Chen and Paull 2000). Similar effects of NMI on TSS compared to AMI have thus far only been reported by Crochon et al. (1981) who based themselves, however, on a set of only 10 fruits.

The higher proportion of exportable fruits occurring when NMI was carried out compared to AFI (Figure 12) was a consequence of a significant improvement in the total

Natural maturity induction

Effects on:

Average fruit quality attributes			Variation in fruit quality attributes		
Weight attributes	**Height attributes**	**Other attributes**	**Weight attributes**	**Height attributes**	**Other attributes**
- increases infructescence weight in three out of four experiments (+) - no effect on crown weight in cv. Sugarloaf (0); increases crown weight in fruits from AFI plants (-) and did not affect crown weight in fruits from NFI plants (0) in cv. Smooth Cayenne - increases fruit weight in fruits from AFI plants in three out of four experiments (+); no consistent effect in fruits from NFI plants (0).	- no effect on infructescence height in three out of four experiments (0) - no consistent effect on crown height in fruits from AFI plants in cv. Sugarloaf (0); increases crown height in fruits from AFI plants in cv. Smooth Cayenne (-); no effect on crown height in fruits from NFI plants (0) - increases fruit height in fruits from AFI plants in three out of four experiments (+); no consistent effect on fruit height in fruits from NFI plants (0) - no consistent effect on ratio crown: infructescence height in fruits from AFI plants (0); no effect on ratio crown: infructescence height in fruits from NFI plants (0)	- no clear effect on percentage translucent flesh in cv. Sugarloaf (0); no consistent effect on percentage translucent flesh in fruits from AFI plants (0) and no effect on percentage translucent flesh in fruits from NFI plants (0) in cv. Smooth Cayenne - increases TSS (+) - no effect on juice pH in fruits from AFI plants (0); increases juice pH in fruits from NFI plants (+)	- no effect on variation in infructescence weight in three out of four experiments (0) - no effect on variation in crown weight in three out of four experiments (0) - no effect on variation in fruit weight in three out of four experiments (0)	- no effect on variation in infructescence height in three out of four experiments (0) - no clear effect on variation in crown height (0) - no effect on variation in fruit height in three out of four experiments (0) - no effect on variation in ratio crown: infructescence height in three out of four experiments (0)	- no effect on variation in percentage translucent flesh in three out of four experiments (0) - no consistent effect on variation in TSS (0) - no clear effect on variation in juice pH in cv. Sugarloaf (0); increases variation in juice pH fruits in cv. Smooth Cayenne (-)

Trade-offs

- increases the duration from flowering induction to harvesting of the fruits (-)
- increases number of harvesting of the fruits (-)
-no cost involved

AFI: artificially flowering-induced; NFI: Naturally flowering-induced
TSS: total soluble solids

(+) Positive effect (compared to what is desirable)
(-) Negative effect (compared to what is desirable)
(0) No effect

Increases percentage of exportable fruits to Europe in two experiments (+)

Figure 5.12. Effects and trade-offs of natural maturity induction vs. artificial maturity induction in a pineapple crop

soluble solids caused by the NMI.

Trade-offs of harvesting practice for pineapple quality and proportion of exportable fruits

Our results indicated that harvesting practice had no significant effect on weight and height attributes (Table S5.2; Figures 5.5 and 5.13). In all experiments, harvesting practice in general did not affect the percentage translucent flesh (Figure 5.6-A2-4); naturally maturity-induced fruits harvested at OH had higher TSS than the FH practice (Figure 5.6-D1-4). This was not the case for the AMI fruits where harvesting practice had in general no effect on the TSS. Harvesting practice in general did not affect the juice pH of the AMI fruits (Figure 5.6-C1-3). When considering the percentage of fruits exportable to Europe, our results showed no effect of harvesting practice on the percentage of exportable fruits in cv. Sugarloaf under NFI treatments (Figure 5.10-A1-2). In cv. Smooth Cayenne harvestings of the NMI fruits at OH increased the percentage of fruits exportable to Europe by 14-30% compared to the FH practice (Figure 5.10-A3 and A4).

The extra costs of obtaining fruits with higher TSS at OH were two fold (Figure 5.13). First, harvestings of the fruits at OH increased the duration from flowering induction to harvestings of the fruits by at least 1 day in cv. Sugarloaf and 2 days in cv. Smooth Cayenne compared to the FH practice (Figure 5.2). Second, harvestings of the fruits under NMI treatments at OH increased the number of harvestings of the fruits by 3-8 and 2-6 times compared to the FH practice in cvs Sugarloaf and Smooth Cayenne respectively. Such increase in the number of harvestings of the fruits might increase the harvesting costs because each time producers might need help to harvest the fruits.

The reason why harvestings of the fruits at OH gave higher TSS than the FH practice under NMI is that first, fruits matured naturally and second they were harvested individually at their 25% gold-yellow skin coloration. In these conditions the natural change in the TSS mainly the increase in the sucrose (Chen and Paull 2000) took place until harvestings of the fruits. This explains why the percentage of exportable fruits was higher in cv. Smooth Cayenne. In cv. Sugarloaf, the TSS was overall higher than in cv. Smooth Cayenne and was not a main export-limiting criterion. In the FH practice, since all fruits were harvested in one operation, the immature fruits or the fruits that did not reach their optimum harvesting time lowered the average TSS.

Optimum harvest

- **Effects on**
  - **Average fruit quality attributes**
    - **Weight attributes**
      - no effect on infructescence weight (0)
      - no effect on crown weight (0)
      - no effect on fruit weight (0)
    - **Height attributes**
      - no effect on infructescence height (0)
      - no effect on crown height (0)
      - no effect on fruit height (0)
      - no effect on ratio crown: infructescence height (0)
    - **Other attributes**
      - no effect on percentage translucent flesh in fruits from AFI plants in three out of four experiments (0); no effect on percentage translucent flesh in fruits from NFI plants in cvs. Sugarloaf and Smooth Cayenne (0).
      - no effect on TSS in three out of four experiments in AMI fruits (0); increases TSS in NMI fruits in cvs Sugarloaf and Smooth Cayenne (+)
      - no effect on juice pH in AMI fruits in three out of four experiments (0); no clear effect on juice pH in NMI fruits in cvs Sugarloaf and Smooth Cayenne (0)
  - **Variation in fruit quality attributes**
    - **Weight attributes**
      - no effect on variation in infructescence weight (0)
      - no effect on variation in crown weight (0)
      - reduces variation in fruit weight in NMI fruits from AFI plants in three out of four experiments (+)
    - **Height attributes**
      - no effect on variation in infructescence height (0)
      - no effect on variation in crown height (0)
      - reduces variation in fruit height in NMI fruits from AFI plants in three out of four experiments (+)
      - no effect on variation in ratio crown: infructescence height (0)
    - **Other attributes**
      - no effect on variation in percentage translucent flesh in NMI fruits from AFI plants in three out of four experiments (0)
      - no effect on variation in TSS in AMI fruits from AFI in cvs. Sugarloaf and Smooth Cayenne (0); reduces variation in TSS in AMI fruits from NFI plants in cv. Sugarloaf (+) and reduces variation in NMI fruits in cv. Smooth Cayenne (+)
      - no effect on variation in juice pH in NMI fruits from AFI plants in three out of four experiments (0)
- **Trade-offs**
  - increases duration from flowering induction to harvestings of fruits (-)
  - increases number of harvestings of fruits in NMI plants (-)

Increases percentage of exportable fruits to Europe in NMI fruits in cv. Smooth Cayenne (+)

AMI: Artificially maturity-induced
NMI: Naturally maturity-induced
AFI: Artificially flowering-induced
NFI: Naturally flowering induced
TSS: total soluble solids

(+) Positive effect (compared to what is desirable)
(-) Negative effect (compared to what is desirable)
(0) No effect

Figure 5.13. Effects and trade-offs of optimum harvest vs. farmers' harvest practice in a pineapple crop

5.4.2. Heterogeneity in fruit quality at harvest

Our research also aimed at (1) evaluating the effects of flowering and maturity induction practices on the heterogeneity in pineapple quality and (2) evaluating how harvesting practice could help to reduce the heterogeneity in fruit quality.

In cv. Sugarloaf, natural flowering induction reduced the variation in infructescence weight, fruit weight and infructescence height compared to AFI (Figures 5.7-A1, A2 and C1, C2 and 5.8-A1 and A2), whereas it increased the variation in percentage translucent flesh compared to AFI. In cv. Smooth Cayenne, NFI increased the variation in fruit height compared to AFI (Figure 5.8-D3 and D4) and reduced the variation in percentage translucent flesh compared to AFI.

Reasons why the variations in infructescence weight, fruit weight and infructescence height (in cv. Sugarloaf) were reduced might be related to the improvement of the small plants in these quality attributes since these plants were allowed to grow until the appropriate (natural) induction time. In cv. Smooth Cayenne the low variation in the percentage translucent flesh in fruits from NFI plants compared to that in fruits from AFI plants might be associated with the relatively low variation in TSS in fruits from NFI plants (Figure 5.9-B3 and B4) since transluceny and TSS are positively associated as shown by Chen and Paull (2000).

Harvesting practice had no consistent effect on the improvement of the variation in the fruit quality attributes except for a small reduction in the variation in TSS noticed when NMI fruits were harvested at the OH in cv. Smooth Cayenne (Figure 5.9-B3 and B4).

5.5. Conclusions and implications

Our experiments showed that flowering and maturity synchronisation are contributing to poor fruit quality and to a low percentage of fruits that are exportable to European markets. When crops were allowed to become naturally induced to flower, the infructescence weight and height of the pineapple fruit were higher; the crown weight and height were lower; the ratio crown: infructescence height was reduced; and a higher percentage of fruits were exportable to the European markets compared to crops receiving artificial flowering induction. The costs to gain these improvements in fruit quality attributes were: the long time from planting to flowering induction and from planting to harvesting, the high number of harvestings of the fruits and the low proportion of plants producing fruits compared to the crops from artificially flowering-induced plants. When maturity occurred naturally, the fruits had higher TSS concentrations making a larger proportion of the Smooth Cayenne fruits exportable, whereas only a slightly longer time from flowering induction to harvesting of the fruits longer was needed to obtain this.

Most of the fruits from the artificially flowering induced plants were not exportable because of the high ratio crown: infructescence height (greater than 1.5) in cv. Sugarloaf and low total soluble solids (less than 12 ºBrix) in addition to a high ratio crown: infructescence height (greater than 1.5) in cv. Smooth Cayenne. The ratio crown: infructescence height can probably also be reduced by some cultural practices. These include firstly the increase of the length of the vegetative period; later artificial flowering induction may help to reduce the ratio crown: infructescence height. Moreover, later artificial flowering induction would improve also other quality attributes at harvest, like infructescence weight. Another cultural practice could be an increase in the number of fertiliser applications which promotes vegetative growth. This will certainly increase the production cost but will increase plant vigour before flowering induction. The TSS concentration can be improved by either opting for natural maturity induction or harvesting the fruits at the optimum harvest time. The main cost of the improvement of the TSS was an increase in the number of harvestings of the fruits which might certainly lead to an increase of the harvestings costs. In these conditions selective harvestings of fruits falling within a range of the change in skin colour could help improve the average TSS while lowering the harvesting costs.

Acknowledgements

The authors are thankful to the North-South Interdisciplinary Research and Education Fund (INREF) of Wageningen University and Research Centre and the Netherlands Organisation for International Cooperation in Higher Education (NUFFIC) for their financial support through the Co-Innovation for Quality in African Foods Chains (CoQA) programme and the Netherlands Fellowship Programs (NFP), respectively.

References

Adams, S., Cockshull, K., & Cave, C. (2001). Effect of temperature on the growth and development of tomato fruits. *Annals of Botany, 88*(5), 869-877.

Adikaram, N., & Abayasekara, C. (2012). Pineapple. In D. Rees, G. Farrell & J. Orchard (Eds.), *Crop post-harvest: science and technology* (pp. 143-158). Oxford, UK: Blackwell Publishing Ltd.

Aggelopoulou, K., Wulfsohn, D., Fountas, S., Gemtos, T., Nanos, G., & Blackmore, S. (2010). Spatial variation in yield and quality in a small apple orchard. *Precision Agriculture, 11*(5), 538-556.

Barrena Ruiz, J., Nahuelhual Muñoz, L., Engler Palma, A., Echeverría Pezoa, R., & Cofré Bravo, G. (2013). Heterogeneity of farms entering export supply chains: the case of fruit growers from central-south Chile. *Spanish Journal of Agricultural Research, 11*(2), 281-293.

Bartholomew, D. P., & Kadzimin, S. B. (1977). Pineapple. In P. Alvim & T. T. Kozlowski (Eds.), *Ecophysiology of tropical crops* (pp. 113-156). New York: Academic Press.

Bartholomew, D. P., & Malézieux, E. (1994). Pineapple. In B. Schaffer & P. C. Andersen (Eds.), *Handbook of environmental physiology of fruit crops* (Vol. II. Sub-tropical and Tropical Crops, pp. 243-291). Boca Raton, Florida: CRC Press.

Bartholomew, D. P., Malézieux, E., Sanewski, G. M., & Sinclair, E. (2003). Inflorescence and fruit development and yield. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 167-202). Wallingford, UK: CABI Publishing.

Bartlett, M. (1936). The square root transformation in analysis of variance. *Supplement to the Journal of the Royal Statistical Society, 3*(1), 68-78.

Cetinkaya, B. (2011). Developing a sustainable supply chain strategy. In B. Cetinkaya, R. Cuthbertson, G. Ewer, T. Klaas-Wissing, W. Piotrowicz & C. Tyssen (Eds.), *Sustainable supply chain management: practical ideas for moving toward best practice* (pp. 17-55). Berlin, Heidelberg: Springer-Verlag.

Chen, C.-C., & Paull, R. E. (2000). Sugar metabolism and pineapple flesh translucency. *Journal of the American Society for Horticultural Science, 125*(5), 558-562.

Chuenboonngarm, N., Juntawong, N., Engkagul, A., Arirob, W., & Peyachoknakul, S. (2007). Changing in TSS, TA and sugar contents and sucrose synthase activity in ethephon-treated 'Pattavia' pineapple fruit. *Kasetsart Journal (Natural Sciences), 41*, 205-212.

Codex Alimentarius. (2005). Codex standard for pineapples. [Revision 1-1999, Amendment 1-2005]. Retrieved 10 January 2009, from www.codexalimentarius.net website:

http://www.codexalimentarius.net/ web/more _info.jsp?id_sta=313 .

Crochon, M., Teisson, C., & Huet, R. (1981). Effet d'une application d'ethrel avant la recolte sur la qualité gustative des ananas de Côte d'Ivoire. *Fruits, 36*, 409-415.

Cunha, G. A. P. (2005). Applied aspects of pineapple flowering. *Bragantia, 64*(4), 499-516.

Food and Agriculture Organization (FAO). (2012). *Statistical databases*. Retrieved 28 November 2013, from FAO http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E

Fassinou Hotegni, V. N., Lommen, W. J. M., van der Vorst, J. G. A. J., Agbossou, E. K., & Struik, P. C. (2012). Analysis of pineapple production systems in Benin. *Acta Horticulturae, 928*, 47-58.

Fernandez, G. C. (1992). Residual analysis and data transformations: important tools in statistical analysis. *HortScience, 27*(4), 297-300.

Friend, D. J., & Lydon, J. (1979). Effects of daylength on flowering, growth, and CAM of pineapple (*Ananas comosus* [L.] Merrill). *Botanical Gazette*, *140*(3), 280-283.

Gonzalez, R. (2009). *Data analysis for experimental design*. New York: Guilford Press.

Hatab, A. A., & Hess, S. (2013). Opportunities and constraints for small agricultural exporters in Egypt. *International Food and Agribusiness Management Review, 16*(4), 77-100.

Hepton, A. (2003). Cultural system. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 109-142). Wallingford, UK: CABI Publishing.

Kerns, K. R., Collins, J., & Kim, H. (1936). Developmental studies of the pineapple *Ananas comosus* (L) Merr. *New Phytologist*, *35*(4), 305-317.

Léchaudel, M., & Joas, J. (2007). An overview of preharvest factors influencing mango fruit growth, quality and postharvest behaviour. *Brazilian Journal of Plant Physiology, 19*(4), 287-298.

Luning, P. A., & Marcelis, W. J. (2006). A techno-managerial approach in food quality management research. *Trends in Food Science & Technology*, *17*(7), 378-385.

Malézieux, E., Côte, F., & Bartholomew, D. P. (2003). Crop environment, plant growth and physiology. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 69-107). Wallingford, UK: CABI Publishing.

Moneruzzaman, K., Hossain, A., Sani, W., & Saifuddin, M. (2008). Effect of stages of maturity and ripening conditions on the biochemical characteristics of tomato.

American Journal of Biochemistry and Biotechnology, 4(4), 336.

Moss, G. (1976). Temperature effects on flower initiation in sweet orange (*Citrus sinensis*). *Crop and Pasture Science, 27*(3), 399-407.

Muasya, R. M., Lommen, W. J. M., Auma, E. O., & Struik, P. C. (2006). Relationship between variation in quality of individual seeds and bulk seed quality in common bean (*Phaseolus vulgaris L.*) seed lot. *Netherlands Journal of Agricultural Science, 54*, 5-16.

Neven, D., Odera, M. M., Reardon, T., & Wang, H. (2009). Kenyan supermarkets, emerging middle-class horticultural farmers, and employment impacts on the rural poor. *World Development, 37*(11), 1802-1811.

Onaha, A., Nakasone, F., & Ikemiya, H. (1983). Induction of flowering with oil-coated calcium carbide in pineapples. *Journal of the Japanese Society for Horticultural Science, 52*(3), 280-285.

Paull, R. E., & Reyes, M. E. (1996). Preharvest weather conditions and pineapple fruit translucency. *Scientia Horticulturae, 66*(1), 59-67.

Py, C., Lacoeuilhe, J. J., & Teisson, C. (1987). *The pineapple: cultivation and uses* (*Maisonneuve ed.*). Paris: Editions Quae.

Reardon, T., Codron, J.-M., Busch, L., Bingen, J., & Harris, C. (2001). Global change in agri-food grades and standards:agribusines strategic responses in developing countries. *International Food and Agribusiness Management Review, 2*, 421-435.

Reid, M. S., & Wu, M. J. (1991). Ethylene in flower development and senescence. In A. K. Mattoo & J. C. Suttle (Eds.), *The plant hormone ethylene* (pp. 215-234). Boca Raton, FL: CRC Press Inc.

Royer, A., & Bijman, J. (2012). Towards an analytical framework linking institutions and quality: Evidence from the Beninese pineapple sector. *African Journal of Agricultural Research, 7*(38), 5344-5356.

Shewfelt, R. L. (1990). Sources of variation in the nutrient content of agricultural commodities from the farm to the consumer. *Journal of Food Quality, 13*(1), 37-54.

Siderius, C. P., & Krauss, B. H. (1938). Growth phenomena of pineapple fruits. *Growth, 1*, 181-196.

Singleton, V. L., & Gortner, W. A. (1965). Chemical and physical development of the pineapple fruit II. Carbohydrate and acid constituents. *Journal of Food Science, 30*(1), 19-23.

Trienekens, J., & Zuurbier, P. (2008). Quality and safety standards in the food industry, developments and challenges. *International Journal of Production Economics, 113*(1), 107-122.

VSN International. (2013). GenStat for Windows 16th Edition ed. Hemel Hempstead, UK: VSN International.

Vorley, B., & Fox, T. (2004). Global food chains: constraints and opportunities for smallholders. Prepared for the OECD DAC POVNET Agriculture and Pro-Poor Growth Task Team Helsinki Workshop 17-18 June 2004.

Wijesinghe, W., & Sarananda, K. (2002). Post-harvest quality of "Mauritius" pineapple and reasons for reduced quality. *Tropical Agricultural Research and Extension, 5*, 53-56.

Zúñiga-Arias, G., Ruben, R., & van Boekel, M. (2009). Managing quality heterogeneity in the mango supply chain: evidence from Costa Rica. *Trends in Food Science & Technology, 20*(3), 168-179.

Table S5.1. *P*-values of the F ratios from ANOVA for the effects of flowering induction practice, fruit maturity practice, harvesting practice and their interactions on time from planting to flowering induction, time from flowering induction to harvesting of the fruits, time from planting to harvesting of the fruits and on the number of harvestings of the fruits

Variates/Factor	Cv. Sugarloaf		Cv. Smooth Cayenne	
	Expt 1	Expt 2	Expt 3	Expt 4
Duration from planting to flowering induction				
Flower induction practice (FIP)	0.000 ***	**0.000** ***	0.000 ***	0.000 ***
Fruit maturity practice (FMP)	0.015 *	0.445	0.002 **	0.027 *
Harvesting practice (HP)	0.002 **	0.986	0.973	0.487
FIP × FMP	**0.015** *	0.445	**0.002** **	**0.027** *
FIP × HP	**0.002** **	0.986	0.973	0.487
FMP × HP	0.506	0.983	0.412	0.305
FIP × FMP × HP	0.506	0.983	0.412	0.305
Duration from flowering induction to harvesting of the fruits				
Flower induction practice (FIP)	0.000 ***	0.038	0.072	0.051
Fruit maturity practice (FMP)	0.000 ***	0.000 ***	0.000 ***	0.000 ***
Harvesting practice (HP)	0.000 ***	0.000 ***	0.000 ***	0.002 **
FIP × FMP	**0.000** ***	0.063	0.129	0.002 **
FIP × HP	0.561	0.825	0.004 **	0.003 **
FMP × HP	**0.000** ***	**0.000** ***	0.000 ***	0.002 **
FIP × FMP × HP	0.101	0.825	**0.004** **	**0.003** **
Duration from planting to harvesting of the fruits				
Flower induction practice (FIP)	0.000 ***	**0.000** ***	0.000 ***	0.000 ***
Fruit maturity practice (FMP)	0.027 *	0.796	0.006 **	0.833
Harvesting practice (HP)	0.001 **	0.784	0.623	0.654
FIP × FMP	**0.007** **	0.400	**0.001** **	**0.036** *
FIP × HP	**0.003** **	0.979	0.715	0.640
FMP × HP	0.349	0.782	0.191	0.432
FIP × FMP × HP	0.451	0.976	0.233	0.421
Number of harvestings of the fruits				
Flower induction practice (FIP)	**0.000** ***	0.000 ***	0.000 ***	0.003 **
Fruit maturity practice (FMP)	0.072	0.013 *	0.000 ***	0.000 ***
Harvesting practice (HP)	0.010 *	0.000 ***	0.000 ***	0.000 ***
FIP × FMP	0.465	0.837	0.080	0.001 **
FIP × HP	0.728	0.000 ***	0.036 *	0.039 *
FMP × HP	**0.000 *** **	0.000 ***	0.000 ***	0.000 ***
FIP × FMP × HP	0.180	**0.000** ***	**0.012** *	**0.010** *

*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

Values in bold indicate the *P*-value considered to establish the effect (main or interaction) of the flowering induction practice or the maturity induction or the harvesting practice

Table S5.2. *P*-values of the F ratios from ANOVA for the effects of flowering induction practice, fruit maturity practice, harvesting practice and their interactions on average and variation in infructescence, crown and fruit weights in the two experiments per cultivar

Fruit quality/Factor	Effect on average fruit quality				Effect on variation in fruit quality			
	Cv. Sugarloaf		Cv. Smooth Cayenne		Cv. Sugarloaf		Cv. Smooth Cayenne	
	Expt 1	Expt 2	Expt 3	Expt 4	Expt 1	Expt 2	Expt 3	Expt 4
Infructescence weight (kg)								
Flower induction practice (FIP)	**0.008** **	**0.048** *	**0.000** ***	**0.000** ***	**0.000** **	**0.012** *	0.123	0.053
Fruit maturity practice (FMP)	0.199	**0.033** *	**0.003** **	**0.004** **	0.377	0.196	0.380	0.336
Harvesting practice (HP)	0.742	0.510	0.546	0.261	0.081	0.268	0.916	0.555
FIP × FMP	0.192	0.568	0.058	0.529	0.275	0.189	**0.026** *	0.164
FIP × HP	0.520	0.943	0.935	0.495	0.505	0.955	0.672	0.823
FMP × HP	0.936	0.354	0.734	0.152	0.736	0.284	0.245	0.851
FIP × FMP × HP	0.344	0.295	0.386	0.775	0.157	0.185	0.241	0.328
Crown weight (kg)								
Flower induction practice (FIP)	**0.001** **	**0.000** ***	0.000 ***	0.000 ***	0.091	0.125	0.137	0.268
Fruit maturity practice (FMP)	0.996	0.692	0.004 **	0.014 *	0.010 *	0.412	0.209	0.438
Harvesting practice (HP)	0.304	0.257	0.820	0.389	0.255	0.795	0.680	0.071
FIP × FMP	0.053	0.130	**0.000** ***	**0.036** *	**0.011** *	0.053	0.676	0.261
FIP × HP	0.368	0.404	0.750	0.326	0.968	0.326	0.889	0.811
FMP × HP	0.057	0.895	0.821	0.134	0.750	0.195	0.556	0.511
FIP × FMP × HP	0.082	0.442	0.239	0.165	0.084	0.151	0.694	0.449
Fruit weight (kg)								
Flower induction practice (FIP)	0.060	0.457	0.001 **	**0.000** ***	0.000 ***	**0.018** *	0.557	0.176
Fruit maturity practice (FMP)	0.179	**0.033** *	0.002 **	**0.003** **	0.540	0.203	0.272	0.633
Harvesting practice (HP)	0.560	0.439	0.528	0.243	0.045*	0.388	0.828	0.618
FIP × FMP	0.426	0.676	**0.015** *	0.902	0.087	0.174	**0.009** **	0.157
FIP × HP	0.698	0.957	0.878	0.666	0.834	0.945	0.822	0.954
FMP × HP	0.572	0.366	0.785	0.303	0.470	0.466	0.299	0.820
FIP × FMP × HP	0.179	0.351	0.272	0.990	**0.039** *	0.313	0.161	0.504

*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

Values in bold indicate the *P*-value considered to establish the effect (main or interaction) of the flowering induction practice or the maturity induction or the harvesting practice

Table S5.3. *P*-values of the F ratios from ANOVA for the effects of flowering induction practice, fruit maturity practice, harvesting practice and their interactions on average and variation in infructescence and crown heights, ratio crown: infructescence height and fruit height in the two experiments per cultivar

Fruit quality/Factor	Effect on average fruit quality				Effect on variation in fruit quality			
	Cv. Sugarloaf		Cv. Smooth Cayenne		Cv. Sugarloaf		Cv. Smooth Cayenne	
	Expt 1	Expt 2	Expt 3	Expt 4	Expt 1	Expt 2	Expt 3	Expt 4
Infructescence height (cm)								
Flower induction practice (FIP)	**0.001** **	**0.000** ***	**0.002** **	**0.005** **	0.000 ***	**0.016** *	0.127	0.562
Fruit maturity practice (FMP)	0.125	0.189	0.318	**0.047** *	0.498	0.451	0.429	0.169
Harvesting practice (HP)	0.107	0.692	0.938	0.208	0.661	0.900	0.231	0.751
FIP × FMP	0.092	0.728	0.425	0.655	**0.028** *	0.836	0.258	0.441
FIP × HP	0.216	0.456	0.709	0.508	0.818	0.969	0.451	0.223
FMP × HP	0.572	0.222	0.192	0.199	0.819	0.881	0.300	0.858
FIP × FMP × HP	0.144	0.751	0.501	0.242	0.128	0.088	**0.017** *	0.849
Crown height (cm)								
Flower induction practice (FIP)	0.000 ***	0.000 ***	0.005 **	0.000 ***	0.079	**0.001** **	**0.046** *	**0.001** **
Fruit maturity practice (FMP)	0.016 *	0.035 *	0.002 **	0.032 *	**0.020** *	0.698	0.082	**0.003** **
Harvesting practice (HP)	0.566	0.135	0.208	0.522	0.054	0.935	0.916	0.663
FIP × FMP	0.953	**0.037** *	**0.000** ***	**0.011** *	0.052	0.066	0.795	0.069
FIP × HP	0.024 *	0.788	0.503	0.721	0.195	0.596	0.980	0.841
FMP × HP	0.024 *	0.618	0.916	0.779	0.173	0.401	0.248	0.125
FIP × FMP × HP	**0.019** *	0.930	0.658	0.728	0.522	0.876	0.637	0.052
Ratio								
Flower induction practice (FIP)	**0.000** ***	0.000 ***	0.000 ***	0.001 **	0.177	0.498	0.092	0.271
Fruit maturity practice (FMP)	0.079	0.160	0.006 **	0.447	0.070	0.293	0.186	0.597
Harvesting practice (HP)	0.250	0.053	0.446	0.968	0.130	0.314	0.572	0.578
FIP × FMP	0.589	**0.035** *	**0.000** ***	**0.004** **	**0.011** *	0.367	0.182	0.391
FIP × HP	0.212	0.227	0.957	0.346	0.938	0.814	0.704	0.398
FMP × HP	0.493	0.592	0.216	0.138	0.717	0.274	0.236	0.213
FIP × FMP × HP	0.695	0.522	0.788	0.350	0.480	0.988	0.126	0.098
Fruit height (cm)								
Flower induction practice (FIP)	0.014 *	**0.000** ***	0.050 *	0.067	0.015 *	0.064	**0.017** *	**0.000** ***
Fruit maturity practice (FMP)	0.149	**0.026** *	0.007 **	**0.028** *	0.825	0.986	0.133	0.545
Harvesting practice (HP)	0.525	0.379	0.310	0.352	0.250	0.360	0.830	0.910
FIP × FMP	0.089	0.107	**0.014** *	0.109	0.171	0.435	0.811	0.438
FIP × HP	0.017 *	0.836	0.428	0.949	0.539	0.703	0.600	0.791
FMP × HP	0.039 *	0.321	0.352	0.702	0.030 *	0.364	0.220	0.522
FIP × FMP × HP	**0.010** **	0.917	0.429	0.445	**0.001** **	0.073	0.379	0.323

*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

Values in bold indicate the *P*-value considered to establish the effect (main or interaction) of the flowering induction practice or the maturity induction or the harvesting practice

Table S5.4. *P*-values of the F ratios from ANOVA for the effects of flowering induction practice, fruit maturity practice, harvesting practice and their interactions on average and variation in percentage translucent flesh, total soluble solids and juice pH in the two experiments per cultivar

Fruit quality/Factor	Effect on average fruit quality				Effect on variation in fruit quality			
	Cv. Sugarloaf		Cv. Smooth Cayenne		Cv. Sugarloaf		Cv. Smooth Cayenne	
	Expt 1	Expt 2	Expt 3	Expt 4	Expt 1	Expt 2	Expt 3	Expt 4
Percentage translucent flesh								
Flower induction practice (FIP)	0.028 *	0.285	0.000 ***	0.002 **	0.000 ***	0.021 *	0.000 ***	0.006 **
Fruit maturity practice (FMP)	0.009 **	0.331	0.004 **	0.420	0.116	0.014 *	0.000 ***	0.886
Harvesting practice (HP)	0.096	0.041 *	**0.038** *	0.017 *	0.371	0.039 *	0.597	0.434
FIP × FMP	**0.000** ***	0.005 **	**0.002** **	0.613	**0.023** *	0.117	**0.000** ***	0.739
FIP × HP	**0.040** *	0.887	0.150	0.081	0.550	0.778	0.851	0.392
FMP × HP	0.471	0.000 ***	0.355	0.038 *	0.847	0.501	0.629	0.037 *
FIP × FMP × HP	0.458	**0.000** ***	0.072	**0.038** *	0.618	**0.033** *	0.451	**0.048** *
Total soluble solids								
Flower induction practice (FIP)	0.145	0.942	0.039 *	0.019 *	0.659	0.021 *	0.294	0.002 **
Fruit maturity practice (FMP)	**0.000*****	0.012 *	0.000 ***	0.000 ***	0.551	0.217	0.875	0.257
Harvesting practice (HP)	**0.000** ***	0.139	0.011 *	0.001 **	0.001 **	0.002 **	0.000 ***	0.000 ***
FIP × FMP	0.135	0.477	**0.000** ***	**0.003** **	0.161	0.024*	0.112	**0.019** *
FIP × HP	0.260	0.057	0.693	0.291	**0.004** **	0.474	0.174	0.582
FMP × HP	0.152	**0.024** *	**0.002** **	**0.015** *	0.330	0.661	**0.003** **	**0.005** **
FIP × FMP × HP	0.826	0.853	0.351	0.188	0.992	**0.000** ***	0.581	0.057
Juice pH								
Flower induction practice (FIP)	0.009 **	**0.000** ***	0.048 *	0.010 *	0.000 ***	**0.028** *	0.959	**0.014** *
Fruit maturity practice (FMP)	0.047 *	0.000 ***	0.003 **	0.001 **	0.743	0.495	0.000 ***	**0.014** *
Harvesting practice (HP)	0.802	0.786	0.000 ***	0.167	0.000 ***	0.234	0.750	0.411
FIP × FMP	**0.014** *	0.128	**0.018** *	**0.003** **	0.050	0.209	**0.002** **	0.643
FIP × HP	0.490	0.162	0.026 *	**0.000** ***	0.003 **	0.133	0.160	0.159
FMP × HP	**0.036** *	**0.031** *	**0.004** **	0.985	0.284	0.393	0.222	0.224
FIP × FMP × HP	0.091	0.630	0.066	0.198	**0.001** **	0.152	0.410	0.675

*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

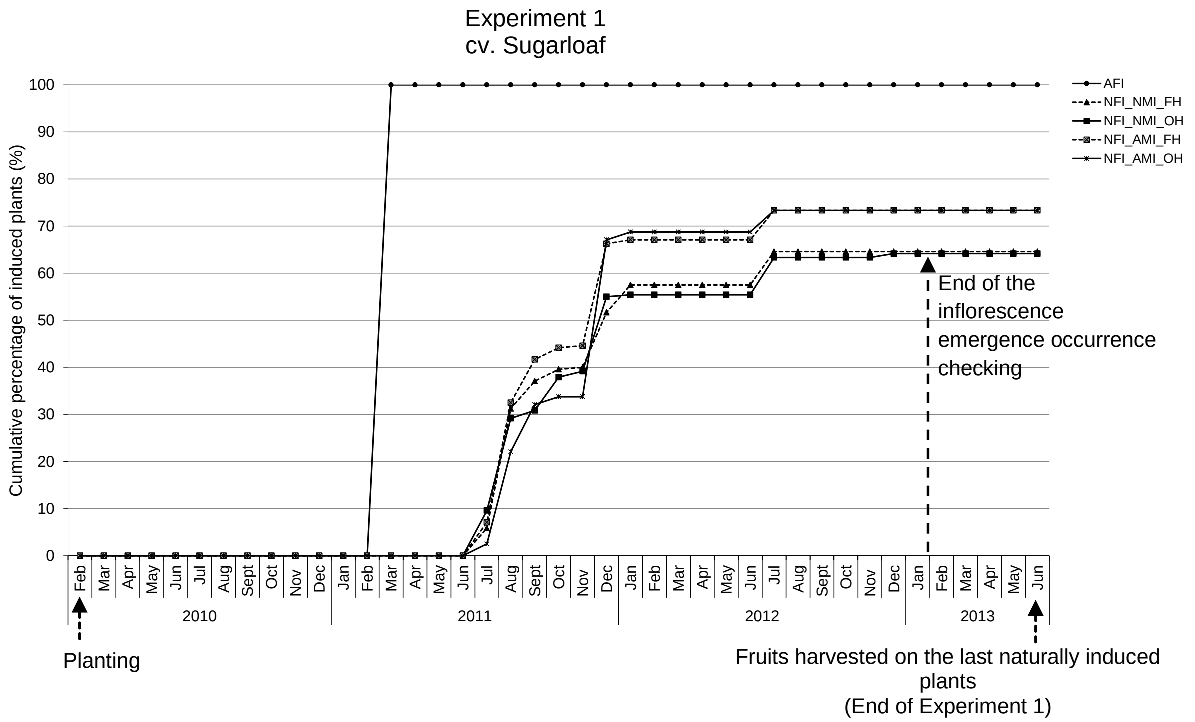
Values in bold indicate the *P*-value considered to establish the effect (main or interaction) of the flowering induction practice or the maturity induction or the harvesting practice

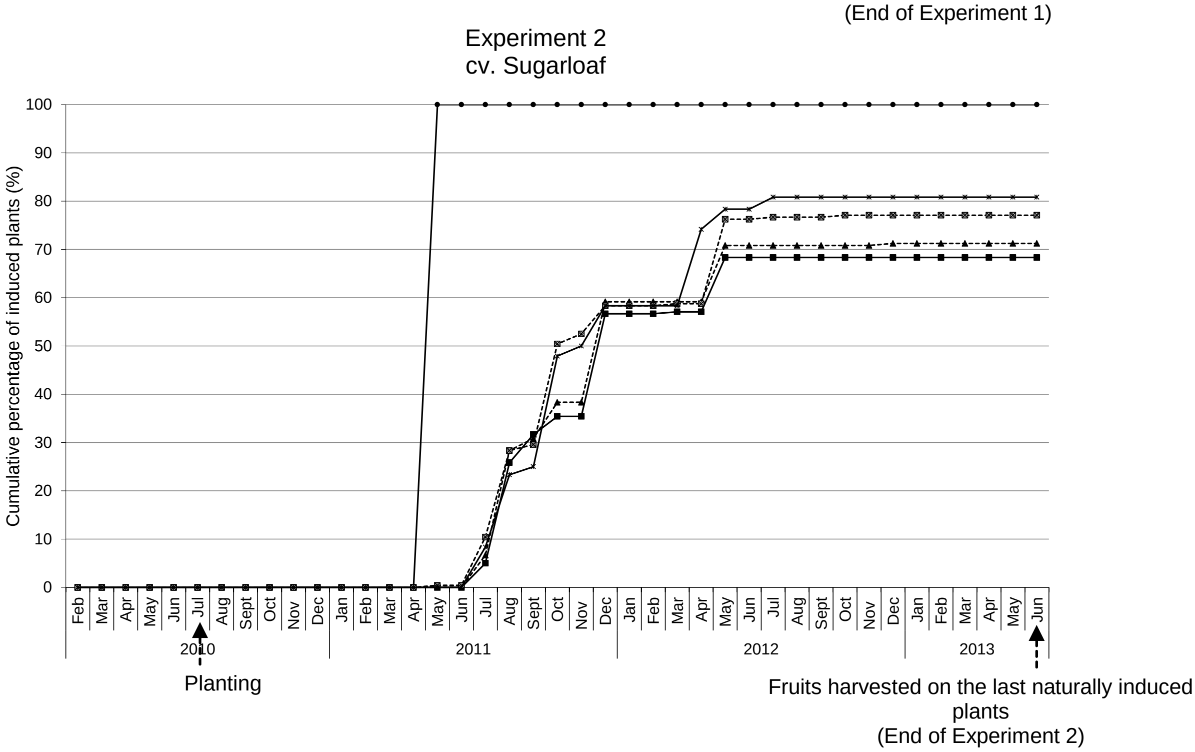
Table S5.5. *P*-values of the F ratios from ANOVA for the effects of flowering induction practice, fruit maturity practice, harvesting practice and their interactions on the percentage of fruits that are exportable to European markets in the two experiments per cultivar.

	Cv. Sugarloaf		Cv. Smooth Cayenne	
	Expt 1	Expt 2	Expt 3	Expt 4
Flower induction practice (FIP)	0.001 ***	0.000 ***	**0.000** ***	**0.003** **
Fruit maturity practice (FMP)	**0.003** **	0.011 *	0.050 *	**0.026** *
Harvesting practice (HP)	0.255	0.043 *	0.537	**0.037** *
FIP × FMP	0.911	**0.001** **	0.637	0.771
FIP × HP	**0.007** **	**0.002** **	0.328	0.118
FMP × HP	0.091	0.629	**0.013** *	0.866
FIP × FMP × HP	0.519	0.635	0.613	0.518

*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$; ***: Statistically significant at $P < 0.001$

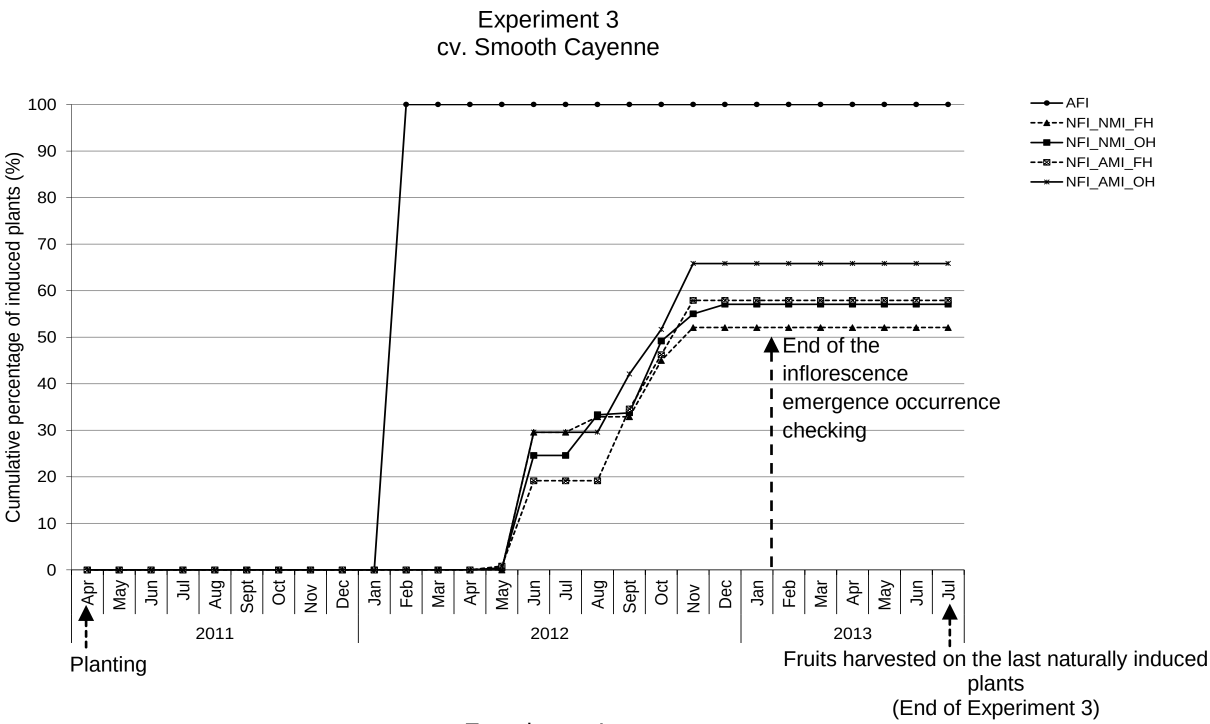
Values in bold indicate the *P*-value considered to establish the effect (main or interaction) of the flowering induction practice or the maturity induction or the harvesting practice

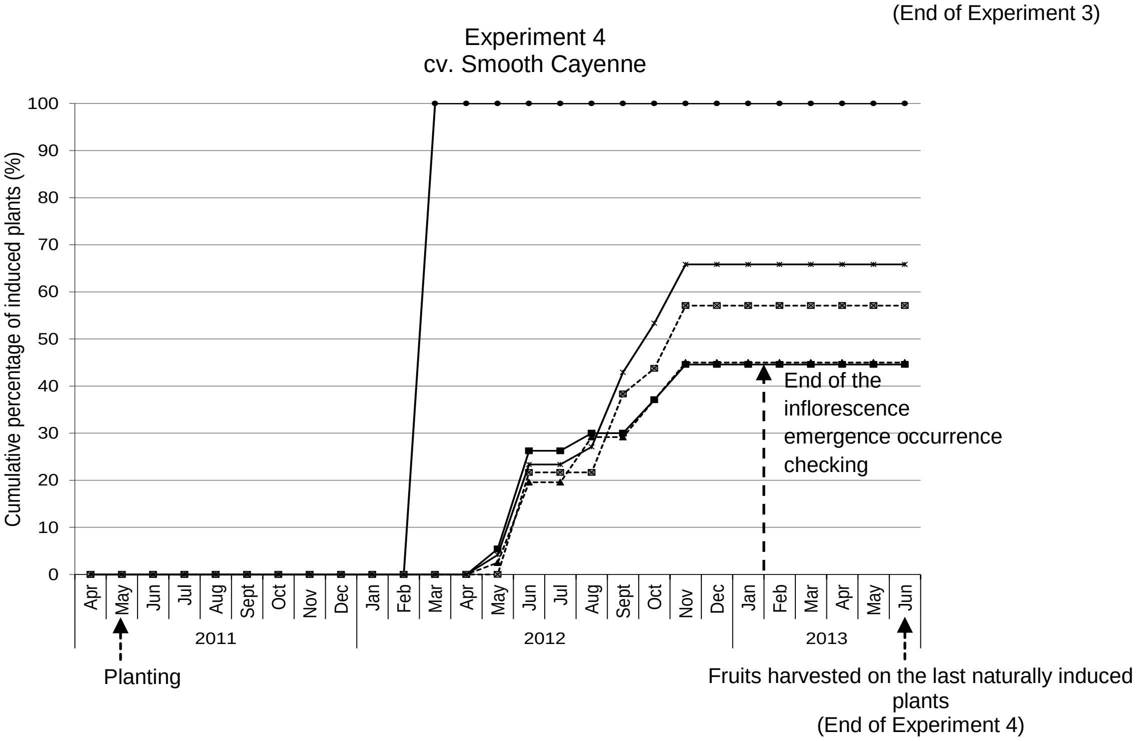




AFI: Artificially flowering-induced plants (included all the four AFI treatments combination);
NFI: Naturally flowering-induced plants; in February 2013, decision was made to stop the regular checking in the flowering emergence occurrence;
AMI: Artificially maturity-induced fruits;
NMI: Natural maturity-induced fruits;
FH: Farmers' harvest practice;
OH: Optimum harvest.

Figure S5.1. Cumulative percentage of flowering-induced plants in the different treatment combinations in cv. Sugarloaf, Experiments 1 and 2, until the harvesting of the fruits on the last naturally induced plants





AFI: Artificially flowering-induced plants (included all the four AFI treatments combination);
NFI: Naturally flowering-induced plants; in February 2013, decision was made to stop the regular checking in the flowering emergence occurrence;
AMI: Artificially maturity-induced fruits;
NMI: Naturally maturity-induced fruits;
FH: Farmers' harvest practice;
OH: Optimum harvest.

Figure S5.2. Cumulative percentage of flowering-induced plants in the different treatments combination in cv. Smooth Cayenne, Experiments 3 and 4, until the harvesting of the fruits on the last induced plants

CHAPTER 6

Fruit quality of pineapple and its variation as affected by weight and type of planting material*

V.N. Fassinou Hotegni[1,2], W.J.M. Lommen[1], E.K. Agbossou[2] and P.C. Struik[1]

[1] Centre for Crop Systems Analysis, Wageningen University, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands

[2] Faculté des Sciences Agronomiques, Université d'Abomey Calavi, 01 BP 526 Cotonou, Benin

* Submitted

Abstract

The improvement of agri-food product quality is one of the key factors for producers' access to lucrative markets. This paper focuses on the improvement of pineapple cultural practices allowing pineapple producers to produce high pineapple quality with low variation in quality. The objectives of this paper were (a) to investigate the effects of weight and type of planting material on the average fruit quality, heterogeneity in fruit quality, and proportion of fruits exportable to Europe and (b) to study the improvement in fruit quality attributes and in proportion of fruits exportable to Europe when flowering of the pineapple plants was induced at an optimum flowering induction time. Two experiments were carried out: one with cv. Sugarloaf and one with cv. Smooth Cayenne. In cv. Sugarloaf a split plot design was used with flowering induction time as main factor (farmers and optimum induction times) and weight of planting material as split factor (light, mixed weights, heavy). In cv. Smooth Cayenne a split-split plot design was used with the type of flowering induction time as main factor, the type of planting material as split factor (hapas, suckers, and a mixture of hapas and suckers) and the weight of planting material as split-split factor. Results showed that fruits from heavy planting material had heavier infructescence and fruit weights, longer infructescence height, but a shorter crown height and a smaller ratio crown: infructescence height than fruits from light planting material. The mixture of planting material weights with a wider range in weights had no significant effect on the coefficient of variation in most fruit quality attributes. The type of planting material (hapas and suckers) in cv. Smooth Cayenne had no significant effect on the average fruit quality attribute except on the crown height: fruits from hapas had shorter crowns than those from suckers. Mixing different types of planting material in cv. Smooth Cayenne had no effect on the coefficient of variation in most fruits quality attributes. Only the weight of planting material had a significant effect on the proportion of fruits exportable to Europe in Experiment 1 where slip was the planting material used: fruits from heavy slips had a higher proportion of fruits exportable to Europe than those from the other weight classes. The type of planting material had no effect on the proportion of fruits exportable to Europe. Flowering induction at the optimum induction time increased the proportion of fruits exportable to Europe in fruits from light and mixed slip weights and also in fruits from a mixture of heavy hapas plus suckers.

Keywords: *Ananas comosus*; cultural practices; hapas; suckers; slips; heterogeneity.

6.1. Introduction

Several recent reports stress the low export volume of fruits from developing countries to international markets (Subramanian and Matthijs 2007; Van Melle et al. 2013). This low export volume is due to the poor average quality of the fruits as well as the low uniformity in fruit quality (Joosten 2007; Temu and Marwa 2007; Van Melle et al. 2013). This is also the case for pineapple [*Ananas comosus* (L.) Merrill] from Benin (Fassinou Hotegni et al. submitted), where pineapple yield is high but pineapple quality is low and heterogeneous. Improvement of both average quality and uniformity in quality is crucial to improve the marketability of the produce. Since pineapple quality can hardly be improved after harvesting the fruits, this study concentrates on improving pineapple cultural practices at early and later crop stages.

In pineapple cultivation, the type and weight of planting material may affect average fruit quality as well as the uniformity in fruit quality attributes. The planting material consists of different types of side shoots sourced from plants kept in the field after fruit harvest: *slips* (side shoots produced on the peduncle at the base of the fruit), *hapas* (side shoots produced above ground on the stem at the junction of the stem and the peduncle), and *suckers* (side shoots originating below ground from the stem) (Hepton 2003). Their appearance and number depend on the pineapple cultivar (Norman 1976). At planting, pineapple producers often mix different types and weights of planting material, depending on their availability. Within the same type of planting material, larger or heavier planting material shows more vigorous growth than smaller or lighter planting material (Bhugaloo 2002; Mitchell 1962; Norman 1976; Reinhardt et al. 2003); mixing different weights within the same type of planting material may therefore increase the heterogeneity in plant vigour and may give more variable fruit quality than is the case in crops originating from a narrow range of planting material weight. The mixture of different types of planting material may also increase the heterogeneity in plant vigour and consequently may give more variable fruits than in crops originating from the same type of planting material. For instance, suckers have roots when planted, whereas hapas do not. Many authors claimed the need to have uniform planting material at planting time (Hepton 2003; Reinhardt et al. 2000) but information on the effect of uniformity of planting material on average fruit quality and its heterogeneity is lacking. In this paper, we hypothesise that using (1) a narrow weight range within the same type of planting material at planting time and (2) only one type of planting material leads to more uniform fruit quality at harvest compared to mixing different weights and types of planting material.

In pineapple cultivation in Benin, 9-13 months after planting (depending on the growing conditions), the transition from the vegetative phase to the generative phase is commonly induced artificially by applying a chemical releasing acetylene or ethylene on all plants. Such practice is called "artificial flowering induction" or "forcing". Pineapple producers are used to inducing all plants at a certain time, regardless of whether they originate from mixtures of different weights and types of planting material or not. Flowering induction at optimum induction time, i.e., the moment when most plants within each planting material type/weight interval are well developed and capable to yield marketable fruits, would improve average fruit quality and increase the proportion of fruits exportable to international markets compared to farmer's flowering induction time.

The objectives of this research were to first evaluate the effects of weight, type, and mixtures of different weights and types of planting material on the average fruit quality, heterogeneity in fruit quality and the proportion of fruits meeting the criteria for export to Europe. Second, we aimed at studying if flowering induction at the optimum time increases the average fruit quality and proportion of exportable fruits to Europe when compared to flowering induction at farmer's time.

6.2. Materials and methods

6.2.1. Experimental sites and cultural practices

Two experiments were carried out in the Atlantic department in the south of Benin between November 9, 2011 and September 20, 2013: one with cv. Sugarloaf and one with cv. Smooth Cayenne. Cv. Sugarloaf is grown by 97% of the pineapple producers in the department and is known to produce numerous slips; hence slips are the common planting material used for its propagation. In cv. Smooth Cayenne, a mixture of hapas and suckers is commonly used for planting; the fruits of cv. Smooth Cayenne are exported to European markets (Fassinou Hotegni et al. 2012). The mean monthly temperatures varied between 24.9 and 29.3 ºC during the experiments with the lowest mean temperature recorded in August 2012 and the highest mean temperature recorded in March 2012 and 2013. The total rainfall amount was 2346 mm during the experiment with cv. Sugarloaf and 2142 mm during the experiment with cv. Smooth Cayenne. Information on the field locations and cultural practices (all practices except flowering induction and harvesting times) is presented in Table 6.1.

6.2.2. Experimental design and treatments

The experimental design depended on the experiment due to the difference in the common planting material type between the two cultivars used. In the experiment with cv. Sugarloaf, a split-plot design was used with four replicated blocks and two factors: *the flowering induction time* was the main factor and had two levels: flowering induction following farmer's practice and flowering induction at the optimum time (see section 6.2.3); *the weight of the planting material* (slips were the only planting material used) was the split factor and had three levels: light planting material with a narrow interval [100-325] g; heavy planting material with a narrow interval [325-550] g and a mixture of planting material from the two previous intervals in the proportion half [100-325] g and half [325-550] g. In the experiment with cv. Smooth Cayenne a split-split-plot design was used with four replicated blocks and three factors: *the flowering induction time* was the main factor and had two levels: flowering induction following farmer's practice and flowering induction at the optimum time (see section 6.2.3); *the type of planting material* was the split factor and had three levels: hapas, suckers, and both hapas and suckers; *the weight of the planting material* was the split-split factor and had three levels: light planting material with a narrow interval [125-400] g; heavy planting material with a narrow interval [400-675] g and a mixture of planting material from the two previous intervals in the proportion half [125-400] g and half [400-675] g for the single planting material type. For the mixture of planting material types, i.e., hapas and suckers, proportions used were 75% hapas and 25% suckers (reflecting the farmer's practice in the mixture of the different types of cv. Smooth Cayenne planting material) except for the mixture of both the weights and types planting material where the ratio 67% hapas and 33% suckers was used.

In both experiments, each net plot consisted of 60 net plants arranged in 6 lines of 10 plants each. The net plots were surrounded by at least two guard rows and two guard plants in a row.

Table 6.1. Field information and cultural practices in the two experiments with cvs Sugarloaf or Smooth Cayenne

	Expt 1, Cv. Sugarloaf	Expt 2, Cv. Smooth Cayenne
Location	06°36'10.8''N and 02°16'58.1''E	06°33'21.2''N and 02°14'47.8''E
Municipality (district)	Zè (Tangbo Djevie)	Tori Bossito (Lankoutan)
Soil type	Ferralitic soil	Ferralitic soil
Climate	Subequatorial	Subequatorial
Planting time	24 February 2012	9 November 2011
Types of planting material used	Slips	Hapas and suckers
Planting material treatment before planting	Sorting in different weights classes	Sorting in different weights classes
Planting arrangement	Flat beds of two alternating rows	Flat beds of two alternating rows
Plant spacing: BP[a] × BR[b]/BDR[c] (cm)	35 × 40/70	40 × 45/80
Plant density (plants/m^2)	5.19	4.00
First Urea (46N) + NPK (10-20-20)	2 MAP[d] (30 April 2012)	5-6 MAP (23 April 2012)
Application form	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g Urea + g NPK)	6 + 3	6 + 3
Second Urea (46N) + NPK (10-20-20)	5 MAP (20 July 2012)	8 MAP (14 July 2012)
Application form	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g Urea + g NPK)	6 + 3	6 + 3
Third Urea (46N) + NPK (10-20-20)	Not applied	10 MAP (06 September 2012)
Application form	Not applied	Solid at the base of the plants
Dose per plant (g Urea + g NKP)	Not applied	3 + 6
Weed control	Hand weeding	Hand weeding

[a] BP, spacing between plants within a row
[b] BR, spacing between rows
[c] BDR, spacing between double rows
[d] MAP, months after planting

6.2.3. Flowering induction practice

Flowering induction was carried out by means of carbide of calcium (CaC_2)[1], a compound producing acetylene when it reacts with water. Using farmer's practices, 50 ml of a solution containing 10 g/l and 15 g/l of CaC_2 for Sugarloaf and Smooth Cayenne, respectively, was applied into the centre of the leaf rosette of each plant. This application was carried out once in cv. Sugarloaf and three times, with an interval of three days, in cv. Smooth Cayenne. Farmers induce flowering between 9-13 months after planting (Fassinou Hotegni et al. 2012). In the present experiments, flowering induction time according to farmers' practice was 12 months after planting. The optimum time for flowering induction was defined as the moment when 75% of the plants of a specific treatment showed a plant vigour expressed as the cross product of the number of functional leaves × the D-leaf length (the longest leaf on the pineapple plant) that was higher or equal to 1235 leaf.cm for cv. Sugarloaf and 2300 leaf.cm for cv. Smooth Cayenne. These values of the cross product in the two pineapple cultivars were based on recent experiments by Fassinou Hotegni et al. (unpublished) that indicated that fruit weight for export of pineapple to European markets were met for plants within a crop when the cross product of the number of functional leaves × the D-leaf length reached at least 1235 leaf.cm in cv. Sugarloaf and 2300 leaf.cm in cv. Smooth Cayenne.

Following farmers' practices (Fassinou Hotegni et al. 2012), maturity was only induced artificially in cv. Smooth Cayenne by spraying 3.5 ml of a solution of 14 ml/l Ethephon (2-chloroethylphosphonic acid), a compound producing ethylene, on the skin of each fruit. The application was carried out at 143 days after flowering induction and repeated 4 days later. The fruits were harvested following farmers' practice which was 7 days after the last application of Ethephon in cv. Smooth Cayenne. In cv. Sugarloaf, the harvesting time was when the skin colour had started to change from green to yellow in at least 25% of the plants in a net plot. All fruits in that net plot were harvested on that day and were individually processed.

Information on the flowering induction and harvesting times of the different treatments is summarised in Table S6.1.

[1] It is important to mention here that calcium carbide was only used to induce the flowering; it was not applied on the fruit.

6.2.4. Data collected

Three types of data were collected: data on the planting material before planting, data on the plant development status at flowering induction and data on the fruit quality at final harvest. Data on the planting material before planting included the weight classes of 1320 slips in cv. Sugarloaf and 1598 hapas and 910 suckers in cv. Smooth Cayenne, collected in farmers' fields from harvested plants. The lower and upper limit of the light and heavy planting material intervals in the experiments were derived from these data. The very light and very heavy planting material were discarded. Data on the plant development at flowering induction included the number of functional leaves and the D-leaf length collected per plant one week before the flowering induction in the plots induced at the farmers' flowering induction time. The cross product of both was computed. In the plots to be induced at the optimum flowering induction time, the number of functional leaves and the D-leaf length were collected from 10 months after planting until they were induced. The cross product of both was computed to determine the optimum flowering induction time following the criteria set for the optimum flowering induction time for each pineapple cultivar. Data on the fruit quality included: fruit, infructescence and crown weights and heights, the ratio crown: infructescence height, percentage of flesh translucency, internal browning, and total soluble solids concentration (TSS) in the fruit juice. The weight attributes were determined using a scale and the height attributes were determined using a ruler. For establishing the TSS, percentage of translucent flesh and internal browning, pineapples were cut longitudinally into two halves. The juice obtained from squeezing one half was used to determine TSS by a hand refractometer. The second fruit half was used to estimate visually the percentage of fruit with translucent flesh and internal browning following the methods of Paull and Reyes (1996). Minimum quality criteria for fruits to be exported to European markets include: the fruit weight should be between 0.70 and 2.75 kg, the ratio crown: infructescence height should be between 0.5 and 1.5 and TSS should be at least 12º Brix (Codex Alimentarius 2005). These criteria were used to compute the percentage of exportable pineapple fruits per treatment.

6.2.5. Data analysis

Data were analysed using GenStat for Windows 16th Edition (VSN International 2013). The distribution of planting material in the range of weight intervals used, was described per type of planting material using mean, median, coefficient of variation, range and skewness. The effect of the weight and/or type of planting material on (a) average fruit quality, (b) heterogeneity in fruit quality, and, (c) proportion of fruits meeting the minimum criteria for export of pineapple fruit to European markets were assessed considering only the data at farmers' flowering induction time by one-way ANOVA (Experiment 1) and two-way ANOVA for split plot (Experiment 2). Before analysis, the data on the percentage translucent flesh were transformed using square root transformation $(x + 0.5)^{1/2}$ (Bartlett 1936; Gonzalez 2009). The heterogeneity in fruit quality attributes was first described using different variation parameters: the coefficient of variation, the range 5-95%, the Mean-Median and the skewness. Among these variation parameters, focus was on the agronomically relevant variation parameter i.e. the coefficient of variation as used by Michaels et al. (1988) to establish variation in seed size and Woodward (2007) to establish variation in kiwifruit quality. The other variation parameters are presented for detailed understanding. Data on the proportion of fruits meeting the minimum European market criteria for pineapple were transformed using arcsine transformation on the square root of the proportion before analysis (Fernandez 1992). Proportions equal to 0 or 1 were replaced by (1/4n) and [1-(1/4n)] respectively, where n is the total number of fruits per net plot (Fernandez 1992). Means or variation parameters were separated using the LSD test, with different LSD values being used for comparisons between means within and across different types of planting material in Experiment 2 due to its split-plot design.

To compare the average fruit quality and proportion of exportable fruits at farmers' induction time with those at optimum flowering induction time a t-test was carried out for the individual planting material treatments. Differences between harvest times were reported as well as their significance.

6.3. Results

6.3.1. Description of the planting material lots before planting

The frequency distributions of the planting material weights from which the light and heavy planting material intervals were derived are presented in Figure 6.1. Within each planting material lot, the light planting material was most abundant as shown by a positive skewness for all three types of planting material. All planting material lots were variable with a coefficient of variation between 0.34 and 0.38 across the classes used in the experiments.

6.3.2. Effects of weight and type of planting material on average and variation in plant vigour at farmers' flowering induction time

The weight of the planting material had a significant effect on the average plant vigour at the farmers' flowering induction time (Figure 6.2). In both experiments, heavy planting material resulted in more vigorous plants than plants from light planting material (Figure 6.2). In Experiment 1, the mixture of planting material weights gave more vigorous plants than plants from light planting material, but no significant differences in plant vigour were found between plants from the mixture of planting material weights and those from heavy planting material (Figure 6.2). In Experiment 2, the plants from the mixture of planting material weights did not differ significantly in vigour from plants from light planting material, but had a lower vigour than plants from heavy planting material (Figure 6.2).

The type of planting material had no significant effect on average plant vigour at flowering induction (Figure 6.2).

The weight of planting material had no significant effect on the coefficient of variation in the vigour of the individual plants at flowering induction time (Table S6.2). The weight of planting material had a significant effect on the range 5-95% in plant vigour in Experiment 1 only (Table S6.2). Plants from the mixed weight classes had a higher range 5-95% in vigour than plants from light planting material, whereas the range in vigour of plants from the heavy planting material class was not differing significantly from any of the other two classes (Figure 6.3). When considering the other variation parameters, a significant effect of the weight of planting material was only found in Experiment 2 for Mean-Median. Plants from the mixed and light weight classes had a comparable variation in vigour, but higher than that of plants from heavy planting material (Figure 6.3).

In Experiment 2 where the differences between suckers, hapas, and their mixture were studied, the type of planting material had no significant effect on the variation in plant vigour at flowering induction time for any of the variation parameters (Table S6.2).

6.3.3. Effects of weight of planting material on average fruit quality attribute

In both experiments, regardless of the type of planting material used, fruits from heavy

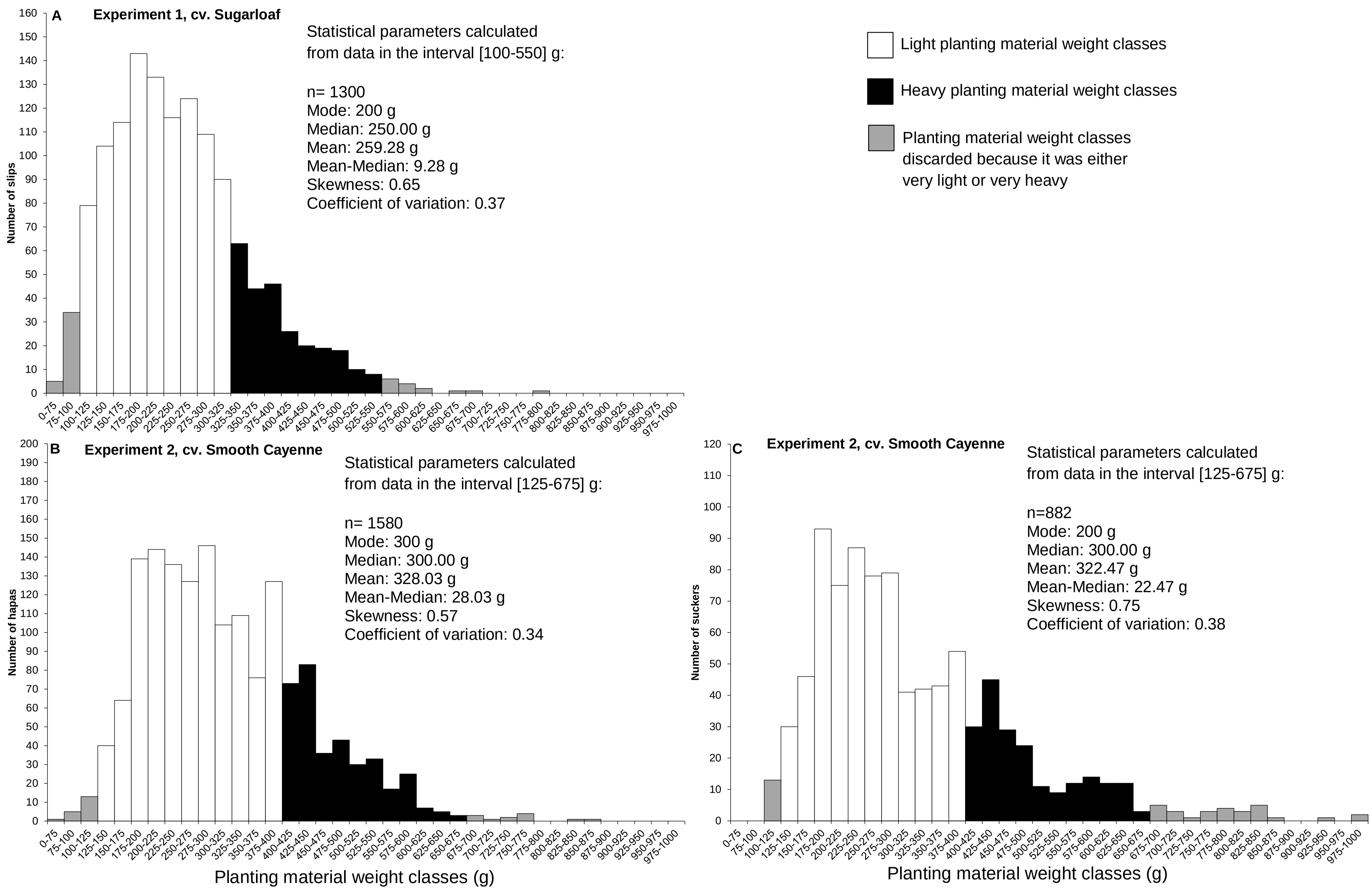
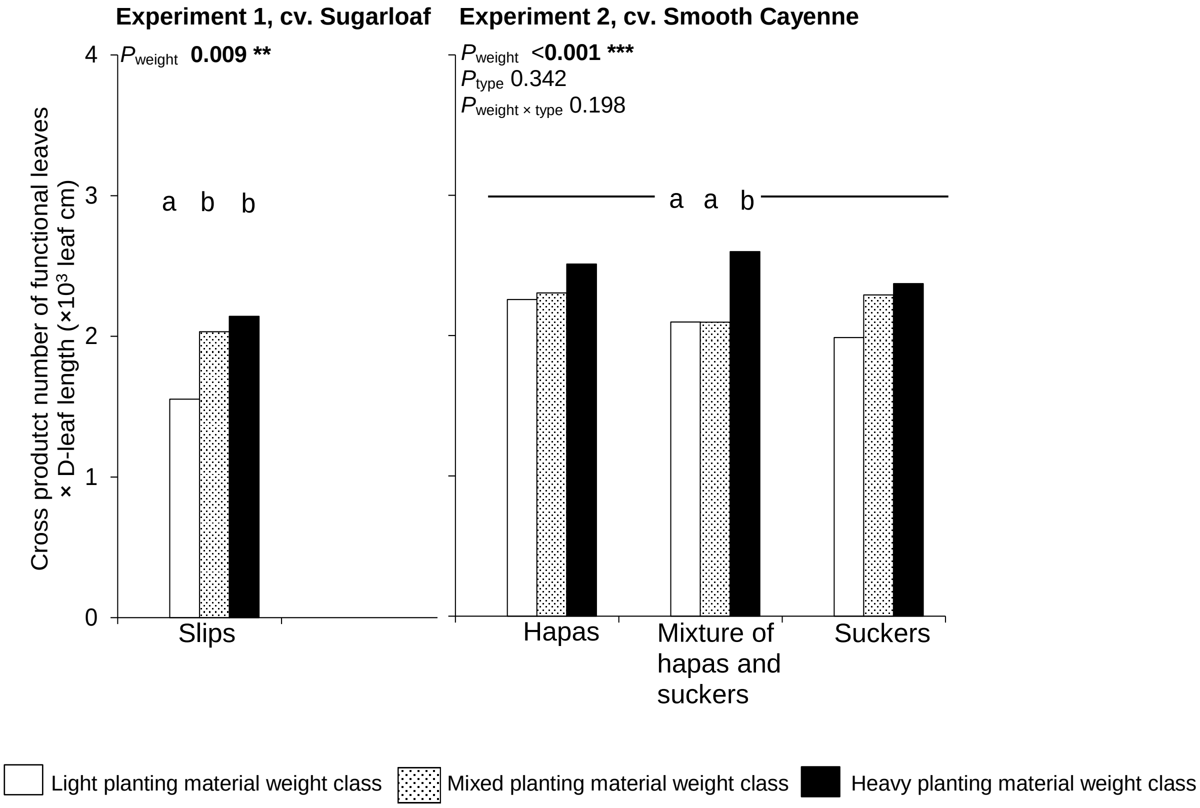


Figure 6.1. Frequency distribution of the planting material weights in the lots from which the classes used in Experiments 1 and 2 were derived: A: Slips (Expt 1); B: Hapas (Expt 2) and C: Suckers (Expt 2)



Similar letters at the top of each bar indicate that differences between weight classes within a planting material type are not significant according to the $LSD_{0.05}$. Significant *P*-values from the ANOVA results are in bold at the top of each figure; **: statistically significant at $0.01 > P \geq 0.001$; ***: statistically significant at $P < 0.001$.

Horizontal lines at the left and right of the letters at the top of the bar indicate that the letters are based on the main effects of the weight of planting material since no interaction with type of planting material was observed.

Figure 6.2. Average plant vigour at farmers' flowering induction time as affected by weight and type of planting material in Experiments 1 and 2

planting material had higher infructescence and fruit weights than fruits from light planting material (Figure 6.4-A, B and E, F). In Experiment 1, fruits from mixed slip weights had higher infructescence and fruit weights than fruits from light planting material, but did not differ significantly from those from heavy planting material (Figure 6.4-A and E). In Experiment 2, the infructescence and fruit weights of plants from the mixture of planting material weights were intermediate between those from the light and heavy planting material (Figure 6.4-B and F). An effect of planting material weight on the crown weight was only observed in Experiment 1 where fruits from plants from light slips and those from the mixed slip weights did not differ in crown weights, but had heavier crowns than fruits from heavy slips (Figure 6.4-C).

For both experiments, regardless the type of planting material used, fruits from plants from heavy planting material had a taller infructescence, a shorter crown and smaller ratio crown: infructescence height than those from light planting material (Figure 6.4-G to J and M, N).

In both experiments, fruits from mixed and light planting material did not differ in infructescence height (Figure 6.4-G and H). In Experiment 1, fruits from plants from mixed slips and those from light slips did not differ in crown height (Figure 6.4-I); in Experiment 2, fruits from plants from mixed planting material and those from plants from heavy planting material did not differ in crown height (Figure 6.4-J). In Experiment 1 the ratio crown: infructescence height in fruits from plants from mixed planting material did not differ significantly from the ratio in plants from light planting material, but was higher than the ratio in fruits from heavy planting material (Figure 6.4-M). In Experiment 2, the ratio crown: infructescence height of fruits from plants from mixed planting material was intermediate between the ratio from plants from light and heavy planting material (Figure 6.4-N).

An effect of the planting material weight on fruit height was found in Experiment 1 only; fruits from heavy and light slips did not differ in fruit height, but had a smaller height than fruits from mixed slip weights (Figure 6.4-K).

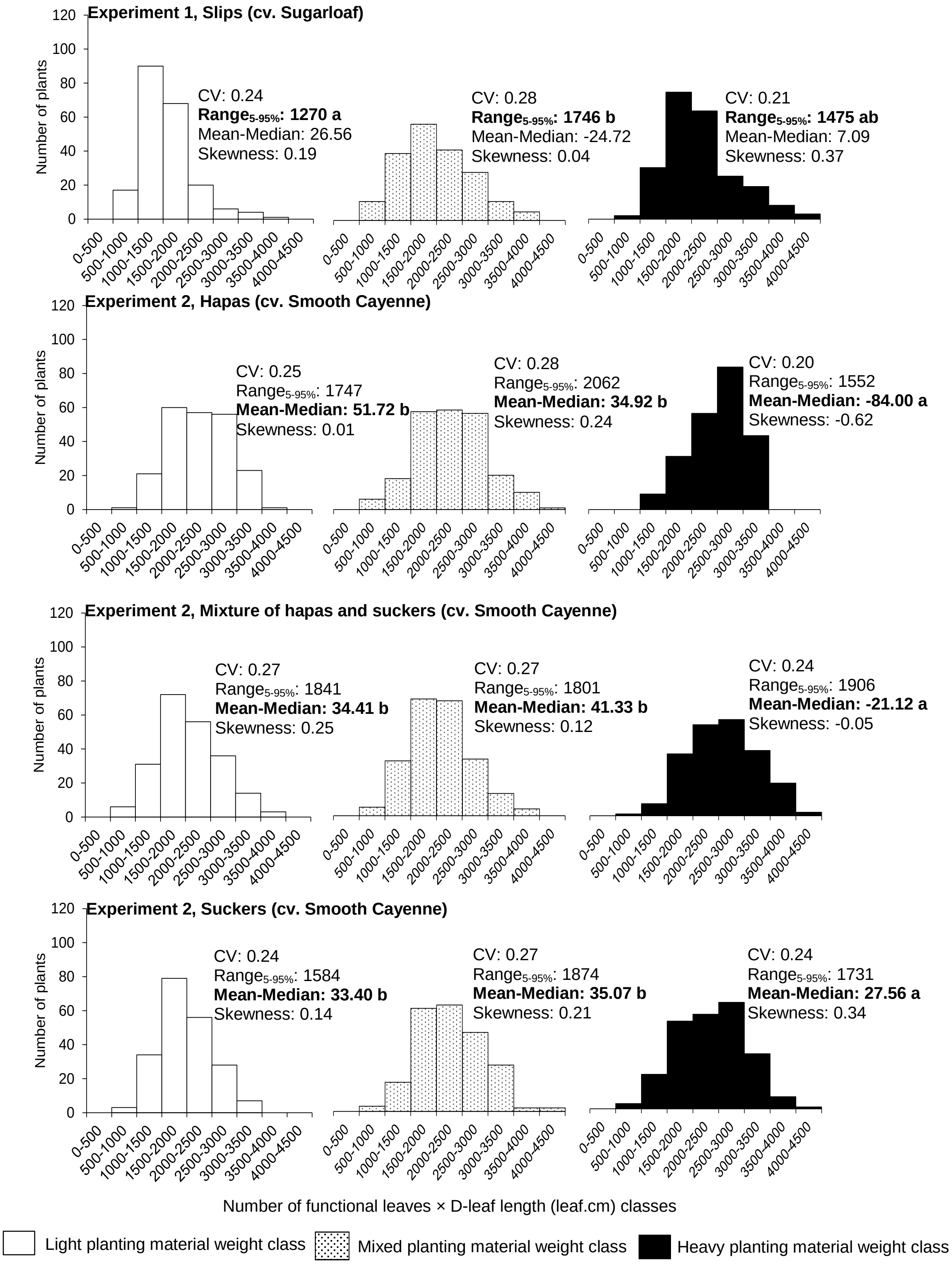
The effect of planting material weight on the percentage translucent flesh was only clear in Experiment 1: fruits from heavy slips had a higher percentage of translucent flesh than those from light slips (Figure 6.5-A). Fruits from plants from mixed slip weights did not differ in percentage translucent flesh from plants from light or heavy slips (Figure 6.5-A).

In both experiments, the weight of the planting material had no effect on the TSS (Figure 6.5-C, D).

6.3.4. Effects of type of planting material on average pineapple fruit quality attributes

The type of planting material as investigated in Experiment 2 had no significant effect on fruit weight attributes (Figure 6.4-B, D and F), and among fruit height attributes only on crown height: fruits originating from hapas had shorter crowns than those originating from suckers (Figure 6.4-J).

An effect of the type of planting material was observed on the percentage translucent flesh in Experiment 2 (Figure 6.5-B), but the effect was not clear enough to draw an unambiguous conclusion. There was no effect of the type of planting material on TSS (Figure 6.5-D).



CV: Coefficient of variation

Variation parameters in *bold* indicate the variation parameter for which main effects of the weight of planting material are significant based on the ANOVA results in Table S6.2.

Variation parameters values followed by similar letters indicate that differences between weight classes within a planting material type are not significant according to the $LSD_{0.05}$.

Figure 6.3. Frequency distribution of the cross product number of functional leaves × D-leaf length of in plants induced at farmers' flowering induction time and its variation (expressed in different variation parameters) as affected by the planting material weight and type

6.3.5. Effect of weight and type of planting material on variation in fruit quality attributes

The weight of planting material had significant effects on the coefficient of variation in crown weight and infructescence height in Experiment 1 and fruit height in Experiment 2 (Table S6.3). The weight of planting material had no significant effects on the coefficient of variation of the other quality attributes.

In Experiment 1, fruits from heavy slips had a higher coefficient of variation in crown weight (Figure 6.6) and lower coefficient of variation in infructescence height (Figure 6.7) than fruits from mixed and light slips. Fruits from mixed and light slips did not differ in coefficient of variation in crown weight and infructescence height (Figures 6.6 and 6.7). In Experiment 2, fruits from heavy planting material had a lower coefficient of variation in fruit height than fruits from mixed and light planting material (Figure 6.8). Plants from mixed and light slips did not differ in the coefficient of variation in fruit height (Figure 6.8).

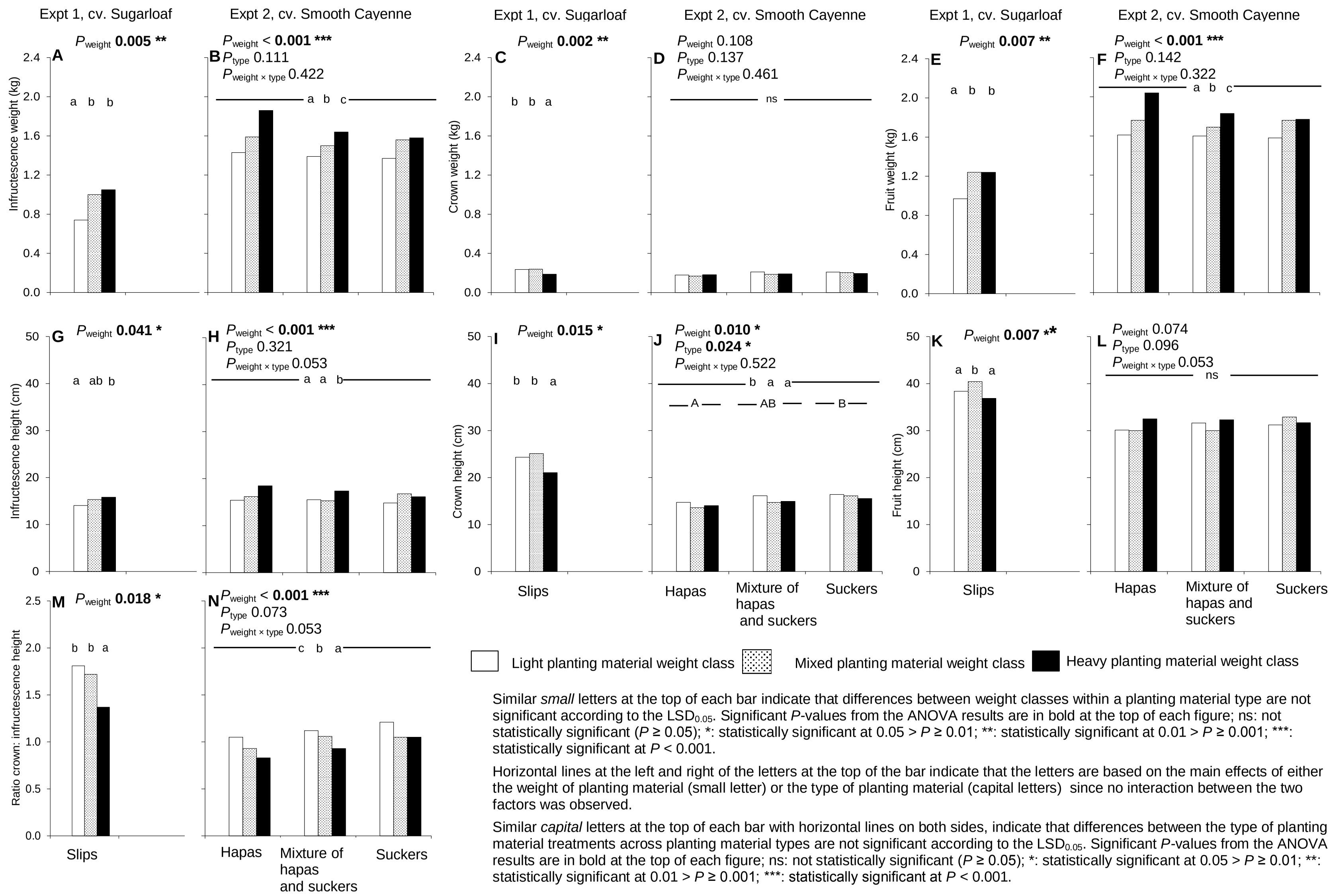
The type of planting material had a significant effect on the coefficient of variation in TSS in Experiment 2: fruits from hapas and suckers both had a higher coefficient of variation in TSS than fruits from mixed hapas and suckers; the coefficients of variation in TSS of fruits from hapas and suckers did not differ significantly (Figure 6.9).

Variation in the other quality attributes is presented in the supplementary materials (Figures S6.1-S6.5).

6.3.6. Effect of weight and type of planting material on percentage of fruits exportable to Europe

An effect of weight of planting material on percentage of fruits exportable to Europe was found in Experiment 1: plants from heavy slips gave a higher percentage of fruits exportable to Europe than plants from mixed and light slips (Figure 6.10).

In Experiment 2 where suckers, hapas, and their mixture were studied, the type of planting material had no significant effect on the percentage of fruits exportable to Europe (Figure 6.10).

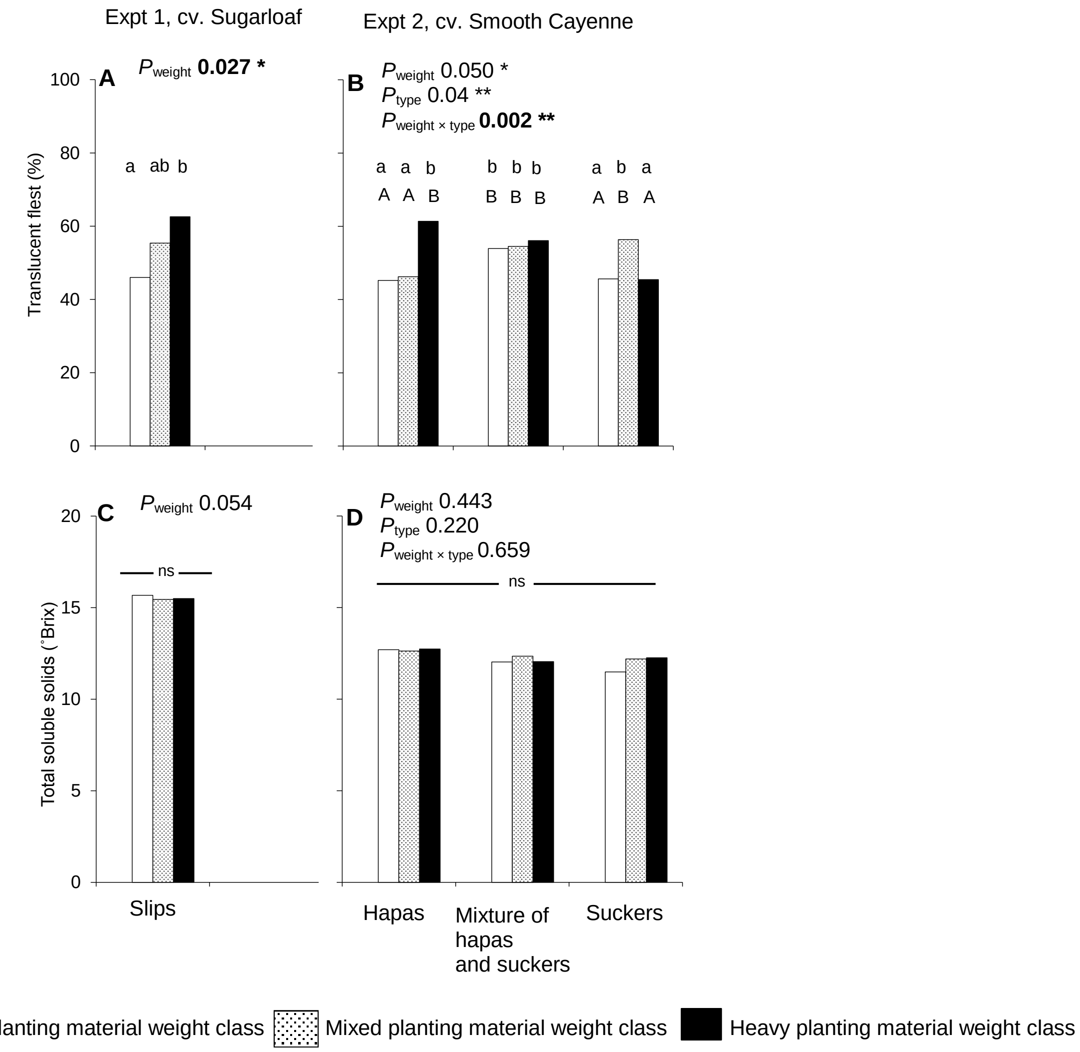


Similar *small* letters at the top of each bar indicate that differences between weight classes within a planting material type are not significant according to the $LSD_{0.05}$. Significant *P*-values from the ANOVA results are in bold at the top of each figure; ns: not statistically significant ($P \geq 0.05$); *: statistically significant at $0.05 > P \geq 0.01$; **: statistically significant at $0.01 > P \geq 0.001$; ***: statistically significant at $P < 0.001$.

Horizontal lines at the left and right of the letters at the top of the bar indicate that the letters are based on the main effects of either the weight of planting material (small letter) or the type of planting material (capital letters) since no interaction between the two factors was observed.

Similar *capital* letters at the top of each bar with horizontal lines on both sides, indicate that differences between the type of planting material treatments across planting material types are not significant according to the $LSD_{0.05}$. Significant *P*-values from the ANOVA results are in bold at the top of each figure; ns: not statistically significant ($P \geq 0.05$); *: statistically significant at $0.05 > P \geq 0.01$; **: statistically significant at $0.01 > P \geq 0.001$; ***: statistically significant at $P < 0.001$.

Figure 6.4. Effect of weight and type of planting material on average fruit weights attributes (A-F) and average fruit height attributes (G-N) in plants induced at farmers' flowering induction time



Similar *small* letters at the top of each bar indicate that differences between weight classes within a planting material type are not significant according to the $LSD_{0.05}$. Significant *P*-values from the ANOVA results are in bold at the top of each figure; ns: not statistically significant ($P \geq 0.05$); *: statistically significant at $0.05 > P \geq 0.01$; **: statistically significant at $0.01 > P \geq 0.001$; ***: statistically significant at $P < 0.001$. For the interaction between the planting material weight and the type of planting material all means are compared at $LSD_{0.05}$.

Horizontal lines at the left and right of the letters at the top of the bar indicate that the letters are based on the main effects of the weight of planting material since no interaction with type of planting material was observed.

Similar *capital* letters at the top of each bar with horizontal lines on both sides indicate that differences between the type of planting material treatments across planting material types are not significant according to the $LSD_{0.05}$. Significant *P*-values from the ANOVA results are in bold at the top of each figure; ns: not statistically significant ($P \geq 0.05$); *: statistically significant at $0.05 > P \geq 0.01$; **: statistically significant at $0.01 > P \geq 0.001$; ***: statistically significant at $P < 0.001$. In case of interaction between the planting material weight and the type of planting material all means are compared at $LSD_{0.05.}$

For the translucent flesh ANOVA was performed on transformed values.

Figure 6.5. Average translucent flesh and total soluble solids in fruits from plants induced at farmers' flowering induction time as affected by weight and type of planting material in Experiments 1 (A-B) and 2 (C-D)

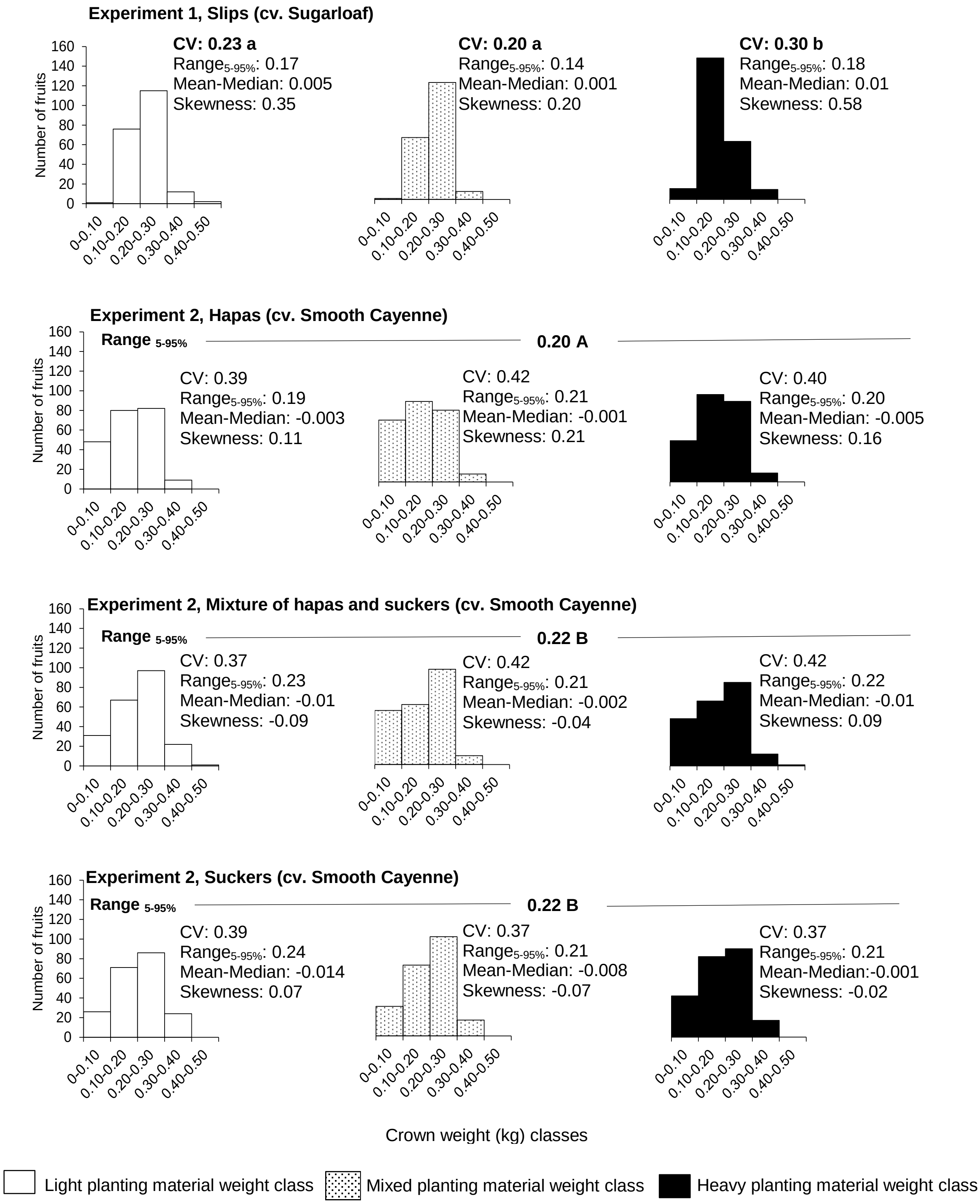
6.3.7. Effects of flowering induction at optimum time on average fruit quality attributes

Significant effects of changing from the farmers' flowering induction time to flowering induction at the optimum time were observed in both experiments. In Experiment 1, where the slips were the only planting material used, changing from farmers flowering induction time to induction at the optimum time reduced significantly the crown weight and height, the fruit height and the ratio crown: infructescence height in all classes of planting material (Table 6.2). The infructescence weight and height were not significantly affected (Table 6.2), but a slight but significant reduction in fruit weight was observed in fruits from light planting material (Table 6.2). Flowering induction at optimum time reduced the proportion of translucent flesh in fruits from light and heavy slips; it also reduced the total soluble solids in fruits from heavy and mixed slip weights (Table 6.2).

In Experiment 2, the response of each type of planting material studied, i.e., hapas, suckers, and mixed hapas and suckers to the change from the flowering induction at farmers' flowering induction time to flowering induction at optimum time was different for all quality attributes except for the ratio crown: infructescence height (Table 6.2).

When plants from hapas were induced at optimum time, the fruit weights attributes were significantly affected in plants from heavy hapas only: infructescence and fruit weights were reduced whereas a slight increase in the crown weight was observed (Table 6.2). When the plants from mixed hapas and suckers were induced at optimum time, there was no significant change in fruit weights attributes in any of the planting material classes (Table 6.2). When plants from suckers were induced at the optimum time the crown weight was the only fruit weight attribute to be significantly affected: a reduction in crown weight was observed in fruits from light and mixed suckers (Table 6.2).

When plants from hapas were induced at optimum time, the infructescence height was reduced in fruits from heavy hapas, but not the crown and fruit heights. Plants from mixed and light hapas showed an increase in the crown and fruit heights (Table 6.2). When plants from mixed hapas and suckers were induced at optimum time, there were no significant changes in infructescence, crown and fruit heights. When plants from suckers were induced at optimum time, only the fruit height was significantly affected: a reduction in fruit height was observed (Table 6.2).



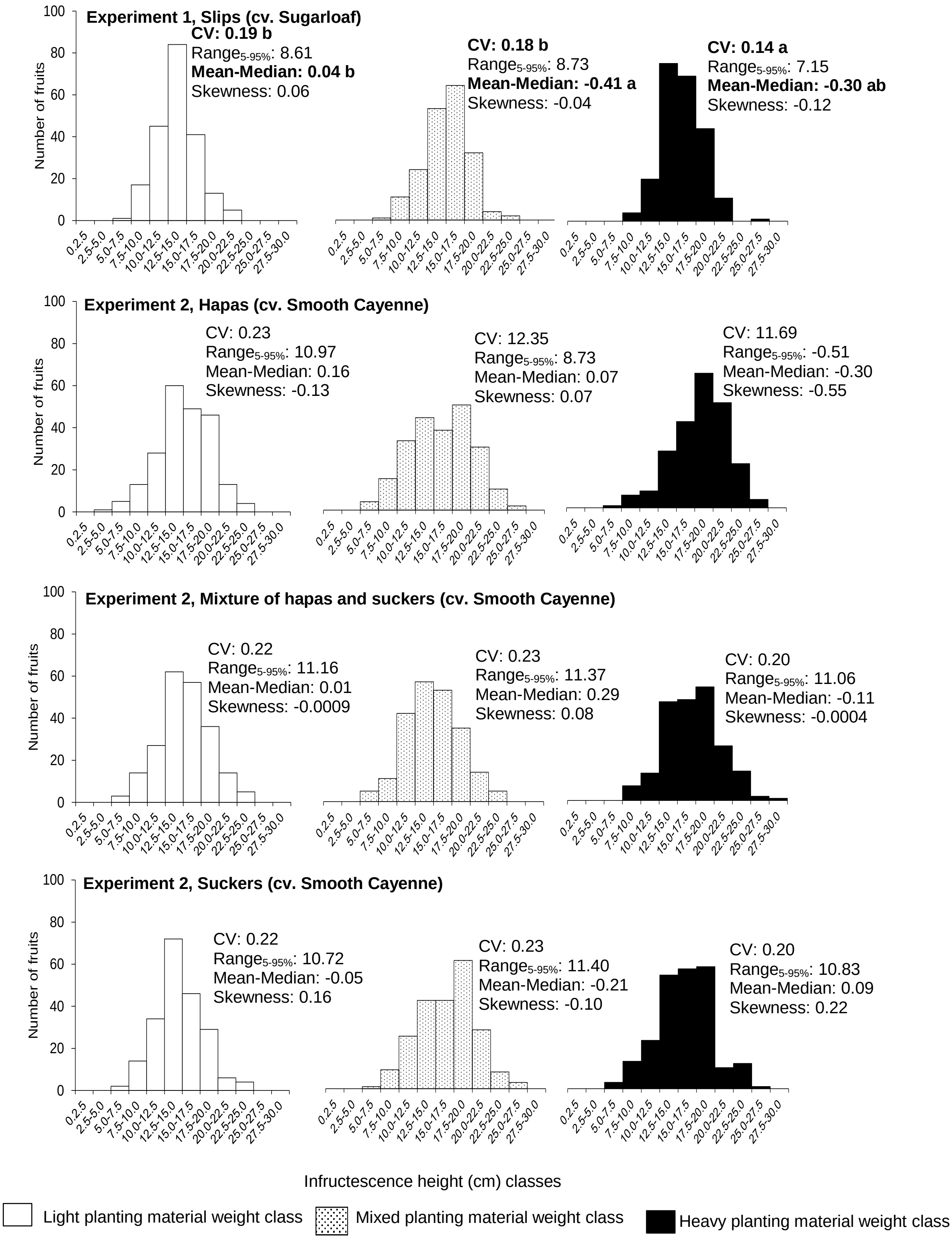
CV: Coefficient of variation

Variation parameters in **bold** indicate the variation parameter for which the effect of planting material weight or type is significant according to the ANOVA results in Table S6.3.

Variation parameters values followed by similar *small* letters indicate that differences between weight classes in the variation in crown weight within a planting material type are not significant according to the $LSD_{0.05}$.

Variation parameters values at the top of the graphs in Experiment 2 and followed by similar *capital* letters with lines at the left and right indicate that differences between the type of planting material in the variation in crown weight in treatment are not significant according to the $LSD_{0.05}$.

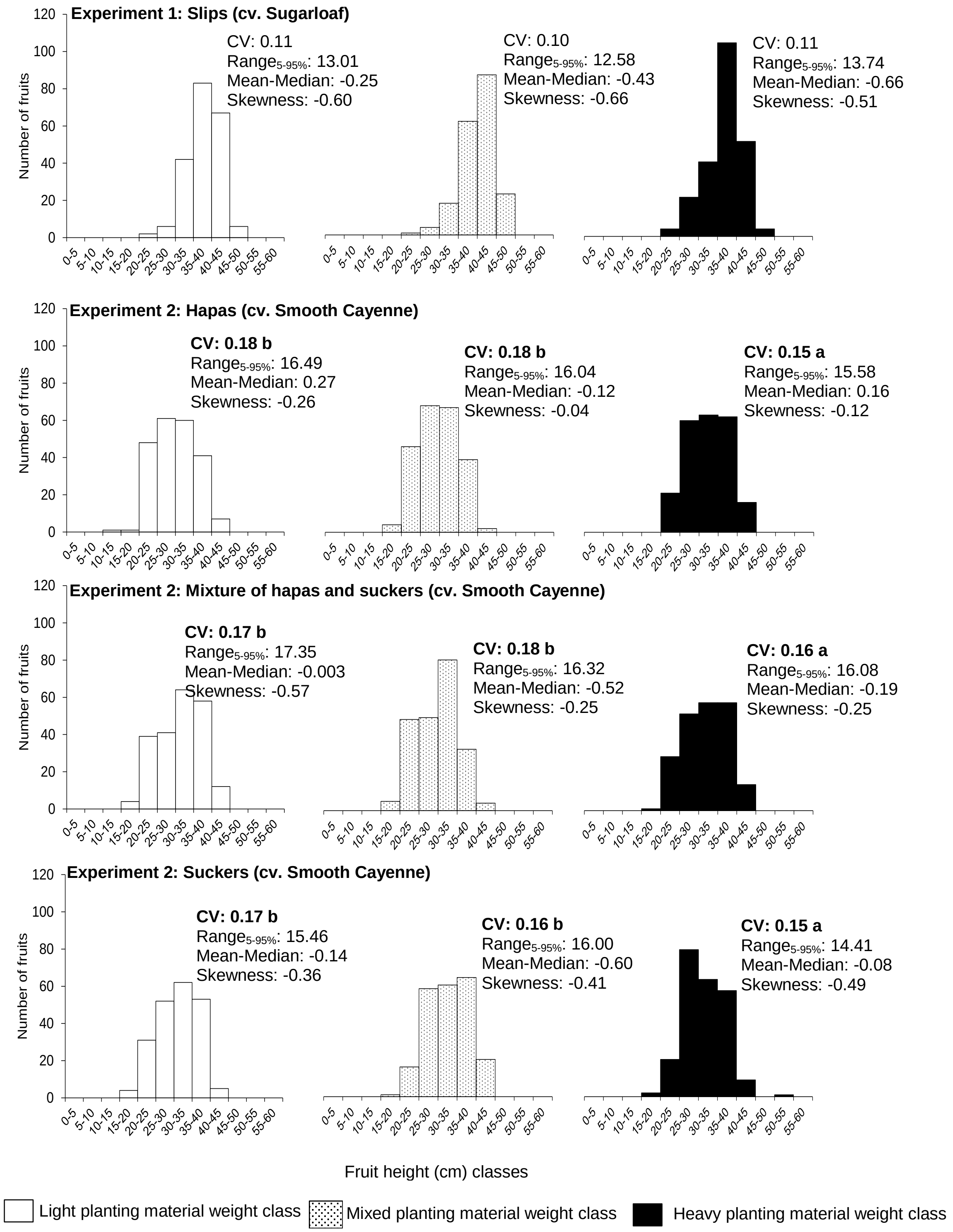
Figure 6.6. Frequency distribution and variation (expressed in different variation parameters) in crown weight as affected by the weight and type of planting material in fruits from plants induced at farmer's flowering induction time in Experiments 1 and 2



CV: Coefficient of variation
Variation parameters in *bold* indicate the variation parameter for which the effect of planting material weight or type is significant according to the ANOVA results in Table S6.3.

Variation parameters values followed by similar *small* letters indicate that differences between the weight classes in the variation in infructescence height within a planting material type are not significant according to the $LSD_{0.05}$.

Figure 6.7. Frequency distribution and variation (expressed in different variation parameters) in infructescence height as affected by the weight and type of planting material in fruits from plants induced at farmers' flowering induction time in Experiments 1 and 2

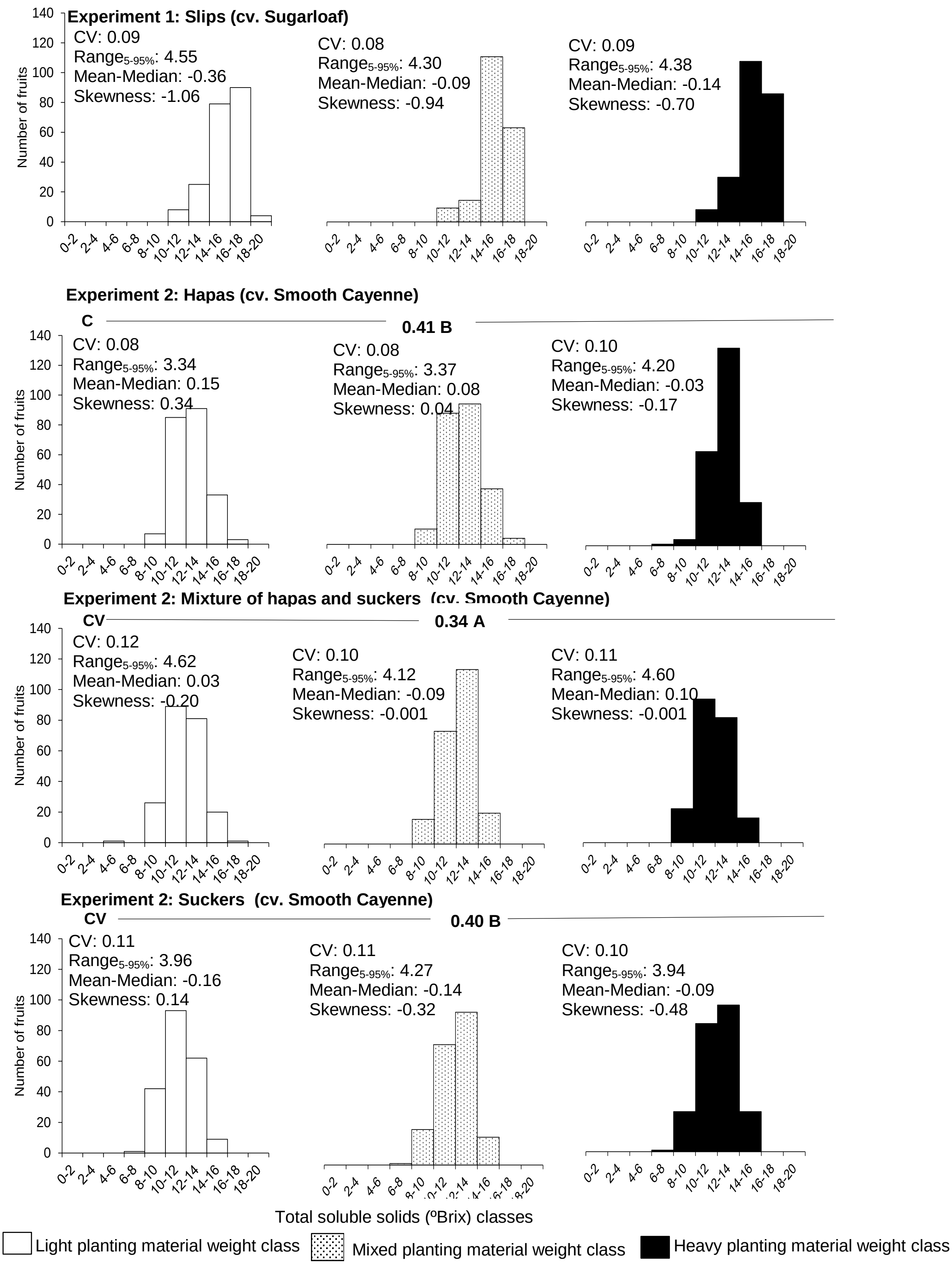


CV: Coefficient of variation

Variation parameters in *bold* indicate the variation parameter for which the effect of planting material weight or type is significant based on the ANOVA results in Table S6.3.

Variation parameters values followed by similar letters indicate that differences between the weight classes in the variation in fruit height within a planting material type are not significant according to the $LSD_{0.05}$.

Figure 6.8. Frequency distribution and variation (expressed in different variation parameters) in fruit height as affected by the weight and type of planting material in fruits from plants induced at farmers' flowering induction time in Experiments 1 and 2

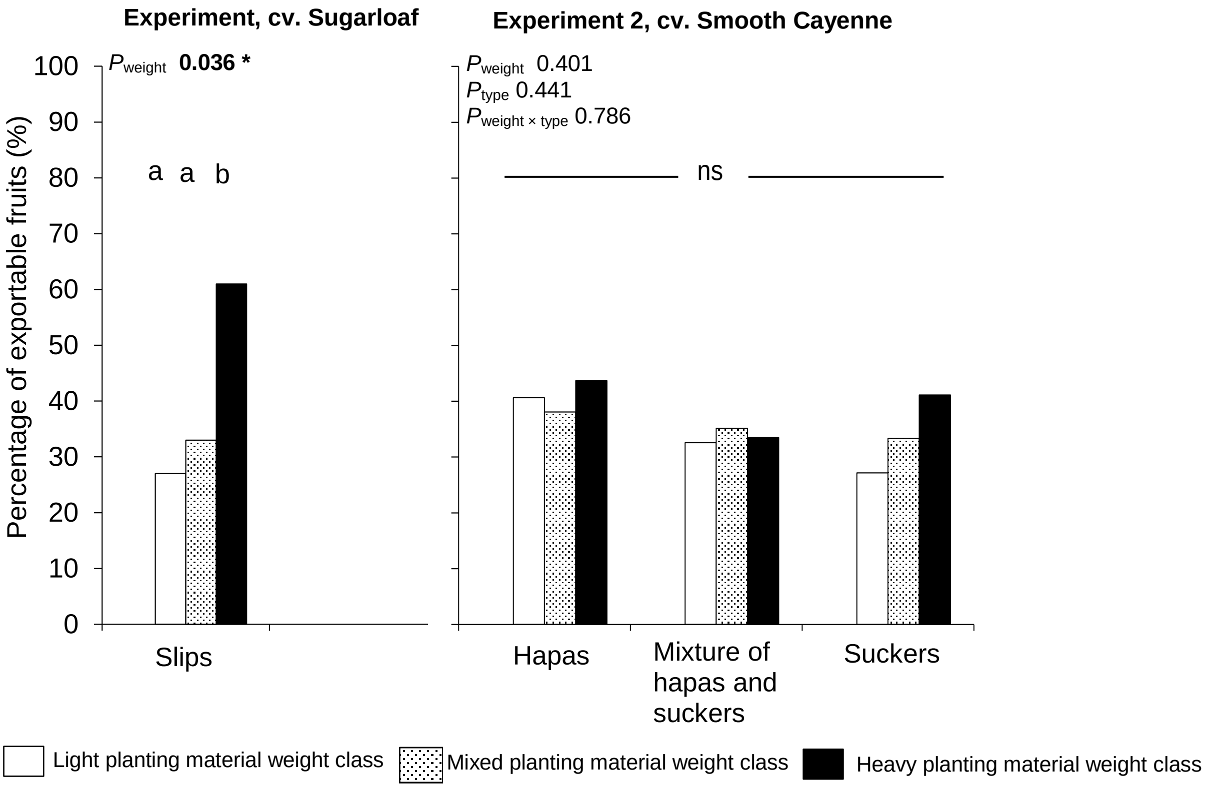


CV: Coefficient of variation

Variation parameters in *bold* indicate the variation parameter for which the effect of planting material weight or type is significant based on the ANOVA results in Table S6.3.

Variation parameters values at the top of the graphs in Experiment 2 and followed by similar letters with lines at the left and right indicate that differences between the type of planting material in the variation in crown weight are not significant according to the $LSD_{0.05}$.

Figure 6.9. Frequency distribution and variation (expressed in different variation parameters) in total soluble solids as affected by the weight and type of planting material in fruits from plants induced at farmers' flowering induction time in Experiments 1 and 2



Similar *small* letters at the top of each bar indicate that differences between weight classes within a planting material type are not significant according to the $LSD_{0.05}$. Significant *P*-values from the ANOVA results are in bold at the top of each figure; ns: not statistically significant ($P \geq 0.05$); *: statistically significant at $0.05 > P \geq 0.01$.

Figure 6.10. Percentages of exportable fruits to Europe in the lot of fruits from plants induced at farmers' flowering induction time as affected by weight and type of planting material in Experiments 1 and 2

Flowering induction at optimum time significantly increased the proportion translucent flesh in fruits from light and mixed hapas and reduced the proportion translucent flesh in fruits from heavy hapas. The TSS was only affected in fruits from heavy hapas: a reduction of the TSS was observed (Table 6.2). In fruits from mixed hapas and suckers, only the heavy weight class was significantly affected: an increase of both translucent flesh and TSS was observed. Flowering induction at optimum time significantly increased the translucent flesh in fruits from light and heavy suckers. Flowering induction at optimum time did not affect significantly the TSS in fruits from plants from suckers, independent of the weight of the suckers (Table 6.2).

6.3.8. Effects of flowering induction at optimum time on proportion of fruits exportable to Europe

Flowering induction at optimum time increased the proportion of fruits exportable to Europe in fruits from plants from light and mixed slips in Experiment 1 (Table 6.2). In Experiment 2, flowering induction at optimum time reduced the proportion of fruits exportable to Europe in plants from heavy hapas and increased the proportion of exportable fruits in plants from mixture of heavy hapas and heavy suckers (Table 6.2). Flowering induction at optimum time had no significant effect on the proportion of fruits exportable to Europe in fruits from plants from (a) light and mixed hapas, (b) light and mixed hapas and suckers, and (c) suckers (Table 6.2).

6.4. Discussion

6.4.1. Effects of weight and type of planting material on average fruit quality attributes

The first objective of this research was to evaluate effects of weight and type of planting material on average fruit quality. Our results showed that the weight of planting material significantly affected the fruit quality attributes (Figure 6.11). In both experiments, fruits from heavy planting material had heavier infructescence and fruit weights, longer infructescence height, a shorter crown height and smaller ratio crown: infructescence height than fruits from light planting material (Figure 6.4). These findings can be explained by the fact that heavy planting material might have more reserves at planting; they gave more vigorous plants at flowering induction compared to plants from light planting material (Figure 6.2). It is well known that more vigorous plants (quantified by the cross product of the number of functional leaves × the D-leaf length as used in the present study) within a pineapple crop at flowering induction time produced fruits with heavier infructescences and fruits, taller infructescences and a shorter crown and smaller ratio crown: infructescence height. The fact that heavy planting material produced higher fruit weight has been reported by many authors (Bhugaloo 2002; Mitchell 1962 and Reinhardt et al. 2000) but information on how the other quality attributes such as the crown height and the ratio crown: infructescence height are affected have not been reported so far.

In Experiment 1, fruits from mixed slip weights showed more or less intermediate

Table 6.2. Absolute differences between the average fruit quality and the percentage of exportable fruits (based on the number of fruits) from plants induced at the optimum flowering induction time and those from plants induced at the farmers' flowering induction time and the difference in the number of days between the two flowering induction dates per treatment in Experiments 1 and 2

Experiment and treatment	OFI-FFI[a] (days)	Quality attributes: Infructescence weight (kg)	Crown weight (kg)	Fruit weight (kg)	Infructescence height (cm)	Crown height (cm)	Fruit height (cm)	Ratio[b]	Translucent flesh (%)	TSS (°Brix)	Percentage of exportable fruits (%)
Expt 1, cv. Sugarloaf											
Slips											
Light	+57	-0.02 ns	**-0.12 *****	**-0.14 ***	+0.4 ns	**-8.5 *****	**-8.4 ****	**-0.71 *****	**-13 ***	-0.52 ns	**+41.8 *****
Mixture of weights	+37	+0.04 ns	**-0.11 *****	-0.06 ns	-1.3 ns	**-11.6 *****	**-12.9 *****	**-0.70 ****	+12 ns	**-1.22 *****	**+30.8 ***
Heavy	-29	-0.15 ns	**-0.03 ****	-0.18 ns	-1.0 ns	**-5.5 *****	**-6.6 *****	**-0.30 ***	**-14 ****	**-1.19 *****	+12.9 ns
Expt 2, cv. Smooth Cayenne											
Hapas											
Light	+68	-0.06 ns	+0.00 ns	-0.06 ns	+0.3 ns	+0.5 ns	+0.9 ns	+0.01 ns	**+16 ***	-0.17 ns	-1.6 ns
Mixture of weights	+55	+0.01 ns	+0.02 ns	+0.04 ns	+0.6 ns	**+1.6 ***	**+2.2 ***	+0.07 ns	**+19 ****	0.22 ns	+9.5 ns
Heavy	+ 5	**-0.28 ***	**+0.03 ***	**-0.24 ***	**-1.8 ***	+0.8 ns	-0.9 ns	+0.10 ns	**-14 ***	**-1.50 *****	**-20.6 *****
Mixture hapas and suckers											
Light	+74	+0.03 ns	-0.01 ns	+0.02 ns	+0.1 ns	-0.1 ns	+0.0 ns	+0.03 ns	+6 ns	+0.43 ns	+0.1 ns
Mixture of weights	+50	-0.10 ns	-0.00 ns	-0.11 ns	+1.0 ns	0.3 ns	+1.3 ns	-0.03 ns	+1 ns	+0.16 ns	-1.5 ns
Heavy	+50	-0.06 ns	+0.02 ns	-0.04 ns	-1.3 ns	-0.2 ns	-1.6 ns	+0.03 ns	**+10 ***	**+0.74 ***	**+13.0 ***
Suckers											
Light	+64	-0.12 ns	**-0.04 ****	-0.16 ns	-0.8 ns	+1.3 ns	+0.5 ns	+0.15 ns	**+26 *****	+0.79 ns	+8.7 ns
Mixture of weights	+64	-0.11 ns	**-0.02 ***	-0.14 ns	-2.4 ns	-1.4 ns	**-3.4 ***	+0.13 ns	+7 ns	+1.04 ns	+6.6 ns
Heavy	+15	+0.03 ns	-0.03 ns	+0.00 ns	-0.2 ns	-1.6 ns	-1.9 ns	-0.09 ns	**+20 ****	+0.98 ns	+8.7 ns

[a] OFI: Optimum flowering induction time; FFI: Farmers' flowering induction time

+ :an increase in the average quality attributes or in the percentage of exportable fruits

-: a decrease in the average quality attributes or in the percentage of exportable fruits

Values in *bold* indicate where absolute differences between the average fruit quality/percentage of exportable fruits, of fruits from plants induced at optimum and fruits from plants induced at farmer's flowering induction time are significant

ns: not statistically significant ($P \geq 0.05$); *: statistically significant at $0.05 > P \geq 0.01$; **: statistically significant at $0.01 > P \geq 0.001$; ***: statistically significant at $P < 0.001$

Higher planting material weight

Effects on

Plant vigour at flowering induction

- increases plant vigour (+)
- no effect on the coefficient of variation in plant vigour (0)

Average fruit quality attributes

Weight attributes	Height attributes	Other attributes
- increases infructescence weight (0) - reduces crown weight in cv. Sugarloaf (+); no effect on crown weight in cv. Smooth Cayenne (0) - increases fruit weight (0)	- no effect on infructescence height in cv. Sugarloaf (0); increases infructescence height in cv. Smooth Cayenne (+) - reduces crown height in cv. Sugarloaf (+); no effect on crown height in cv. Smooth Cayenne (0) - reduces fruit height in cv. Sugarloaf (-); no effect on fruit height in cv. Smooth Cayenne (0) - reduces the ratio crown: infructescence height (+)	- no effect on percentage translucent flesh in cv. Sugarloaf (0); no clear effect on percentage translucent flesh in cv. Smooth Cayenne (0) - no effect on TSS (0)

Variation in fruit quality attributes

Weight attributes	Height attributes	Other attributes
- no effect on coefficient of variation in infructescence weight (0) - increases coefficient of variation in crown weight in cv. Sugarloaf (-); no effect on coefficient of variation in crown weight in cv. Smooth Cayenne (0) - no effect on coefficient of variation in fruit weight (0)	- reduces coefficient of variation in infructescence height in cv. Sugarloaf (+); no effect on coefficient of variation in infructescence height in cv. Smooth Cayenne (0) - no effect on coefficient of variation in crown height (0) - no effect on coefficient of variation in fruit height in cv. Sugarloaf (0); reduces coefficient of variation in fruit height in cv. Smooth Cayenne (+) - no effect on coefficient of variation in ratio crown: infructescence height (0)	- no effect on coefficient of variation in percentage translucent flesh (0) - no effect on coefficient of variation in TSS (0)

Increase percentage of exportable fruits to Europe in cv. Sugarloaf (+); no effect on the percentage of exportable fruits to Europe in cv. Smooth Cayenne

TSS: total soluble solids

(+) Positive effect (compared to what is desirable)
(-) Negative effect (compared to what is desirable)
(0) No effect

Figure 6.11. Effects of higher planting material weight vs. lighter planting material weight in a pineapple crop

average quality between fruits from light and heavy slips. They gave fruits with higher infructescence and fruit weights, and higher fruit height (Figure 6.4) than fruits from light slips; they gave fruits with heavier and longer crown, and higher ratio crown: infructescence height than fruits from heavy slips (Figure 6.4). The reason why fruits from mixed slip weights had more or less intermediate quality attributes between fruits from light and heavy planting was because plants from mixed slip weights showed intermediate vigour between plants from light and heavy slips (Figure 6.2). Plants from mixed slip weights were more vigorous at flowering induction time than plants from light slips and were slightly less vigorous than those from heavy slips (Figure 6.2). It is known that the increase in the vigour of a pineapple crop at flowering induction time is associated with an increase in the infructescence and fruit weight, a diminution in crown weight and crown height and consequently a diminution of the ratio crown: infructescence height (Fassinou Hotegni et al. submitted).

In Experiment 2, fruits from mixed weight classes within each type of planting material investigated were also intermediate between fruits from light and heavy planting material for the infructescence and fruit weights and ratio crown: infructescence height (Figure 6.4). Reasons why fruits from mixed weight classes within each type of planting material were intermediate and therefore gave lower average quality than those from heavy planting material weights are the same as explained above, i.e., related to the existing difference in their respective plant vigour at flowering induction time as shown in Figure 6.2.

In Experiment 2, within each planting material type, fruits from mixed weight classes and those from light weight classes did not differ in infructescence height; fruits from mixed weights classes had lower crown height than those from light planting material (Figure 6.4-J). Within each planting material type, fruits from mixed weight classes had lower infructescence height than those from heavy planting material (Figure 6.4-H). The crown height of the fruits from plants from a mixture of planting material weights and those from plants from heavy planting material were comparable.

The effect of the weight of planting material on the percentage translucent flesh was not consistent enough to draw appropriate conclusions. The weight of planting material had no significant effect on total soluble solids. This result is in agreement with that of Bhugalloo (2001) who found that the size of the suckers did not affect the total soluble solids.

In Experiment 2, regarding the type of planting material, our results showed that fruits from hapas gave fruits with shorter crown than those from suckers (Figure 6.4-J). The presence or absence of roots in the two types of planting material at planting time might be involved in such differences in crown height. Hapas do not have roots while suckers do, because suckers are originated below ground on the stem (Hepton 2003). Such difference in the initial presence of roots between hapas and suckers might result in differences in the rate of root production as shown by Ddungu (1971) when using suckers, crowns, and slips as planting material. Ddungu (1971) found that the rate of root production in crowns and slips (planting material with no root at planting time) after planting was higher that that of suckers; new root production in the suckers occurred after the degenerescence of the old roots reducing the production rate of new roots. In the case of the present study with hapas and suckers, and in line with the findings by Ddungu (1971), hapas would have produced more roots than the suckers. Also, hapas might produce more leaves at flowering induction time than suckers since Norman (1978) showed that planting materials without initial roots at planting (crowns and slips) produced more leaves than suckers. In this study, we did not detect any significant difference between the hapas and suckers in the vigour of the plants originating from each of them at flowering induction time (Figure 6.2), although plants from hapas were slightly more vigorous than those from suckers. More vigorous planting material at flowering induction leads to fruits with shorter crowns (Fassinou Hotegni et al. submitted), a possible reason why fruits from hapas showed shorter crowns than those from suckers.

The effects of the type of planting material on the fruit weight attributes and other fruit height attributes were not significant (Figure 6.4). The non-significant effects of the type of planting material on the fruit weight and height were in agreement with the findings of Norman (1978) who, in his experiment, used crowns, slips, and suckers as planting material.

The type of planting material had no significant effect on the percentage of translucent flesh and total soluble solids in Experiment 2 (Figure 6.5). This suggests that the sugar concentration in the fruit is independent of the type of planting material when hapas and suckers are used.

6.4.2. Effects of weight and type of planting material on variation in fruit quality attributes

In this study, we aimed at evaluating the effects of weight and type of planting material on the variation in fruit quality. Our results indicated that the weight and the type of the planting material had no significant effects on the variation (expressed by the coefficient of variation) in fruit quality attributes except some significant effects of the weight of planting material on the coefficient of variation in crown weight and infructescence height in Experiment 1, and on the variation in fruit height in Experiment 2. It was expected that the mixture of slip weights (in Experiment 1), hapas or suckers or mixture of hapas and suckers weights (in Experiment 2) gave fruits with higher variation than those from light and heavy planting material with a narrow range. The variation in weight of planting material at planting might have been partly compensated during crop development. In addition other uncontrolled factors such as differences in soil conditions within the field may have contributed to the variation across plants. Especially in long duration crops like pineapple these may have a large effect on variation. Incidental effects of the weight of planting material on the variation in crown weight and infructescence height were reflected by fruits from plants from heavy slips showing higher coefficient of variation in crown weight and lower coefficient variation in infructescence height than fruits from mixed and light slips (Figures 6.6 and 6.7).

In Experiment 2, the type of planting material had no effect on the coefficient of variation in the different quality attributes except an incidental effect on the coefficient of variation in TSS. It was expected that using the mixture of hapas and suckers would increase the coefficient of variation in the different quality attributes compared to when a single type of planting material was used. This again suggests that the types of planting material in cv. Smooth Cayenne hardly differed.

6.4.3. Effects of weight and type of planting material on percentage of fruits exportable to Europe

In this study, we also aimed at evaluating the effect of the weight and type of planting material on the percentage of fruits exportable to Europe. Our results revealed that plants from heavy slips yielded more fruits exportable to Europe than plants from other weights classes in Experiment 1 (Figure 6.10). This was mainly due to the fact that fruits from heavy planting material have smaller crowns (Figure 6.4-I), taller infructescence height (Figure 6.4-G) and consequently a shorter ratio crown: infructescence height (Figure 6.4-M) than fruits from other weights classes. The weight of planting material had no effect on the percentage of fruits exportable to Europe in Experiment 2. This implies that the improvement in fruit quality in fruits from heavy planting material was not enough to affect significantly the proportion of fruits exportable to Europe.

The type of planting material (hapas or suckers) used to grow cv. Smooth Cayenne in

Experiment 2 had no significant effect on the proportion of fruit exportable to Europe (Figure 6.10) because the average quality attribute was not affected in most quality attributes.

6.4.4. Effects of induction at optimum time on average fruit quality attributes and proportion of fruits exportable to Europe

The last objective of our research was to study if flowering induction at the optimum time increased or reduced the average fruit quality and proportion of exportable fruits to Europe when compared to flowering induction at farmers' time. In Experiment 1, we found that flowering induction at optimum time reduced the crown weight and height, the fruit height and the ratio crown: infructescence height in cv. Sugarloaf (Table 6.2). These might be due to the time elapsing between the optimum induction time and the farmers' flowering induction time (Table 6.2), i.e., +57 days for plants from light slips; +37 days for plants from mixture of slip, and -29 days for plants from heavy slips. During that period of time (when positive) the plant will continue its growth producing new leaves and consequently increasing its vigour before the flowering induction time. The negative value obtained in plants from heavy planting material suggests the farmers' flowering induction time, i.e., 12 months after planting (Table S6.1) was too late for cv. Sugarloaf grown from heavy slips. The reduction in the fruit height was the consequence of the reduction in the crown height since the infructescence height was not affected by flowering induction at optimum time (Table 6.2). Flowering induction at optimum time did not affect the infructescence weight. Reduction in fruit weight was only significant in fruits from plants from light slips (Table 6.2); this reduction may be due to the significant reduction in the crown weight in fruits from plants from light slips. Flowering induction at optimum time increased the proportion of fruits exportable to Europe in plants from light and mixed slip weight intervals in cv. Sugarloaf (Table 6.2). Fassinou Hotegni et al. (Chapter 5) found that two factors limited the exportation of fruits from slips: these were the ratio crown: infructescence height higher than 1.5 and the fruit weight being small. In the present study, flowering induction at the optimum flowering induction time significantly reduced the ratio crown: infructescence height increasing the proportion of fruits exportable to Europe. The fruit weight was hardly affected (Table 6.2).

In cv. Smooth Cayenne in Experiment 2, very limited effects of the change from the flowering induction at the farmers' flowering induction time to the induction at the optimum time on the average fruit weight and height attributes quality were observed (Table 6.2); in addition it was found that flowering induction of cv. Smooth Cayenne at optimum time only increased the proportion of fruits exportable to Europe in fruits from a mixture of heavy hapas plus suckers (Table 6.2). This implies that in the other weights classes, other quality attributes were limiting the proportion of exportable fruits to Europe. The inconsistent trend in the reduction or increase in the flesh translucency and the TSS caused by the induction at optimum induction time might be due to different temperature conditions, shown by Paul and Reyes (1996) to affect the proportion translucent flesh in pineapple and by Pessarakli (2001) to affect the TSS in grape fruits.

6.5. Conclusions

Our experiments revealed that weight of planting material affected the fruit quality attributes. In both experiments, fruits from plants from heavy planting material had heavier infructescence and fruit weights, longer infructescence height, a shorter crown height and smaller ratio crown: infructescence height than fruits from light planting material. So far no literature has reported such differences in the individual infructescence and crown attributes caused by the weight of planting material used. When hapas or suckers were used as planting material, the type of planting material did not affect the average fruit quality attributes except the crown height where fruits from hapas had shorter crowns than those from suckers. The weight and type (hapas or suckers) of planting material had in overall limited or no effect on the variation in fruit quality attributes except some incidental effects found in few quality attributes.

Plants from heavy slips yielded more fruits exportable to Europe than plants from other slip weight classes in cv. Sugarloaf. When considering the hapas, suckers, and the mixture of hapas and suckers in cv. Smooth Cayenne, it was found that the weight and type of planting material had no effect on the proportion of fruits exportable to Europe. Flowering induction at optimum time increased the proportion of fruits exportable to Europe in light and mixed slip weight classes in cv. Sugarloaf due to a strong decrease in the ratio crown: infructescence height. In cv. Smooth Cayenne, flowering induction of the plants from the mixture of heavy hapas and heavy suckers at optimum time increased the proportion of fruits exportable to Europe due to the increase in the total soluble solids. The knowledge brought by this study is important to design appropriate cultural practices to produce higher pineapple quality fruits.

Acknowledgements

The authors are thankful to the North-South Interdisciplinary Research and Education Fund (INREF) of Wageningen University and Research Centre and the Netherlands Organisation for International Cooperation in Higher Education (NUFFIC) for their financial support through the Co-Innovation for Quality in African Foods Chains (CoQA) and the Netherlands Fellowship Programmes (NFP), respectively.

References

Bartlett, M. (1936). The square root transformation in analysis of variance. *Supplement to the Journal of the Royal Statistical Society, 3*(1), 68-78.

Bhugaloo, R. (2002). Crop cylce study in pineapple: preliminary results. *Food and Agricultural Research Council,* 53. Retrieved 10 January 2013, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.114.5837&rep=rep1&type=pdf#page=77 website.

Codex Alimentarius. (2005). Codex standard for pineapples. [Revision 1-1999, Amendment 1-2005]. Retrieved from www.codexalimentarius.net website: http://www.codexalimentarius.net/ web/more _info.jsp?id_sta=313

Ddungu, J. (1971). Rooting behaviour of different types of pineapple propagating material. *Acta Horticulturae, 33*, 155-159.

Fassinou Hotegni, V. N., Lommen, W. J. M., van der Vorst, J. G. A. J., Agbossou, E. K., & Struik, P. C. (2012). Analysis of pineapple production systems in Benin. *Acta Horticulturae, 928*, 47-58.

Fernandez, G. C. (1992). Residual analysis and data transformations: important tools in statistical analysis. *HortScience, 27*(4), 297-300.

Gonzalez, R. (2009). *Data analysis for experimental design*. New York: Guilford Press.

Hepton, A. (2003). Cultural system. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 109-142). Wallingford, UK: CABI Publishing.

Joosten, F. (2007). Development strategy for the export-oriented horticulture in Ethiopia. Retrieved 25 January 2014, from Ethiopian Horticultural Producers and Exporters Assocition (EHPEA) http://library.wur.nl/way/bestanden/clc/1891396.pdf

Michaels, H. J., Benner, B., Hartgerink, A., Lee, T., Rice, S., Willson, M. F., & Bertin, R. (1988). Seed size variation: magnitude, distribution, and ecological correlates. *Evolutionary Ecology, 2*(2), 157-166.

Mitchell, A. R. (1962). Plant development and yield in the pineapple as affected by size and type of planting material and times of planting and forcing. *Queensland Journal of Agricultural Science, Queensland, 22*, 409-417.

Norman, J. (1978). Influence of planting material on growth, flowering and fruiting of Sugarloaf pinapple, *Ananas comosus* (L.) Merr. *Acta Horticulturae, 84,* 191-198.

Norman, J. C. (1976). Influence of slip size, deslipping and decrowning on the 'Sugarloaf' pineapple. *Scientia Horticulturae, 5*(4), 321-329.

Paull, R. E., & Reyes, M. E. (1996). Preharvest weather conditions and pineapple fruit translucency. Scientia Horticulturae, 66(1), 59-67.

Pessarakli, M. (2001). *Handbook of plant and crop physiology*. New York, USA: Marcel Dekker, Inc. CRC Press.

Reinhardt, D., Souza, L. d. S., & Cabral, J. (2000). Abacaxi. Produção: aspectos técnicos. Cruz das Almas. *Embrapa Mandioca e Fruticultura, 7,* 41-44.

Reinhardt, D. H., Souza, A. P. M., Caldas, R. C., Alcântara, J. d. P., & Almeida, A. A. d. (2003). Management of slips and its effect on growth and production of Pérola pineapple plants. *Revista Brasileira de Fruticultura, 25*(2), 248-252.

Subramanian, U., & Matthijs, M. (2007). *Can sub-Saharan Africa leap into global network trade?* Policy Research Working Paper No. 4112. Washington, D.C: The World Bank.

Temu, A., & Marwa, N. W. (2007). Changes in the governance of global value chains of fresh fruits and vegetables: opportunities and challenges for producers in Sub-Saharan Africa. Retrieved 25 January 2014, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.193.8858&rep=rep1&type=pdf

Van Melle, C., Arinloye, D., Coulibaly, O., Vayssières, J., & Hell, K. (2013). Contribution to mango value chain development in Benin, a producer perception survey. *Acta Horticulturae, 975*, 607-613.

VSN International. (2013). GenStat for Windows 16th Edition ed. Hemel Hempstead, UK: VSN International.

Woodward, T. J. (2007). *Variation in 'Hayward' kiwifruit quality characteristics.* PhD thesis, The University of Waikato.

Table S6.1. Information on flowering induction and harvesting times in the two experiments with cvs Sugarloaf or Smooth Cayenne

	Experiment 1, cv. Sugarloaf	Experiment 2, cv. Smooth Cayenne
Planting time	24 February 2012	9 November 2011
Farmers' practice		
Farmers' flowering induction time[a]	18 February 2013 (360 DAP[b])	5 November 2012 (362 DAP)
Harvesting time		
Slips		
Light	19, 20 July 2013 (511, 512 DAP)	-[c]
Mixture of weights	19, 20 July 2013 (511, 512 DAP)	-
Heavy	18, 19, 21 July 2013 (510, 511, 513 DAP)	-
Hapas		
Light	-	8 April 2013 (516 DAP)
Mixture of weights	-	8 April 2013 (516 DAP)
Heavy	-	8 April 2013 (516 DAP)
Hapas + suckers		
Light	-	8 April 2013 (516 DAP)
Mixture of weights	-	8 April 2013 (516 DAP)
Heavy	-	8 April 2013 (516 DAP)
Suckers		
Light	-	8 April 2013 (516 DAP)
Mixture of weights	-	8 April 2013 (516 DAP)
Heavy	-	8 April 2013 (516 DAP)
Optimum practice		
Optimum flowering induction time		
Slips		
Light	16 April 2013 (417 DAP)	-
Mixture of weights	27 March 2013 (397 DAP)	-
Heavy	20 January 2013 (331 DAP)	-
Hapas		
Light	-	12 January 2013 (430 DAP)
Mixture of weights	-	30 December 2012 (417 DAP)
Heavy	-	10 November 2012 (367 DAP)

Table S6.1. Continued

	Experiment 1, cv. Sugarloaf	Experiment 2, cv. Smooth Cayenne
Optimum flowering induction time		
Hapas + suckers		
Light	-	8 January 2013 (426 DAP)
Mixture of weights	-	8 January 2013 (426 DAP)
Heavy	-	20 November 2012 (377 DAP)
Suckers		
Light	-	18 January 2013 (436 DAP)
Mixture of weights	-	25 December 2012 (412 DAP)
Heavy	-	25 December 2012 (412 DAP)
Harvesting time		
Slips		
Light	17, 19 and 20 Sept. 2013 (571, 573, 574 DAP)	-
Mixture of weights	26, 27 and 28 Aug. 2013 (549, 550 , 551 DAP)	-
Heavy	21, 22 and 24 June 2013 (483, 484, 486 DAP)	-
Hapas		
Light	-	15 June 2013 (584 DAP)
Mixture of weights	-	2 June 2013 (571 DAP)
Heavy	-	13 April 2013 (521 DAP)
Hapas + suckers		
Light	-	11 June 2013 (580 DAP)
Mixture of weights	-	11 June 2013 (580 DAP)
Heavy	-	23 April 2013 (531 DAP)
Suckers		
Light	-	21 June 2013 (590 DAP)
Mixture of weights	-	28 May 2013 (566 DAP)
Heavy	-	28 May 2013 (566 DAP)

[a] All treatments have been induced
[b] DAP, days after planting
[c] not applicable because of the type of planting material

Table S6.2. *P*-values for the effects on variation in vigour of individual plants at farmers' flowering induction time of weight and type of planting material and their interaction, in cvs Sugarloaf (Experiment 1) and Smooth Cayenne (Experiment 2). Vigour was assessed as the cross product of the number of functional leaves × the D-leaf length. Variation is expressed in different variation parameters

Variation parameter and factor	Expt 1, cv. Sugarloaf (Slips)	Expt 2, cv. Smooth Cayenne (Hapas, suckers, and mixture of hapas and suckers)
Coefficient of variation in vigour of individual plants		
Weight of planting material (Weight)	0.065	0.183
Type of planting material (Type)	-[a]	0.599
Weight × Type	-	0.875
Range 5-95% in vigour of individual plants		
Weight of planting material (Weight)	**0.035 ***	0.433
Type of planting material (Type)	-	0.283
Weight × Type	-	0.597
Mean-Median in vigour of individual plants		
Weight of planting material (Weight)	0.344	**0.022 ***
Type of planting material (Type)	-	0.404
Weight × Type	-	0.258
Skewness in vigour of individual plants		
Weight of planting material (Weight)	0.617	0.091
Type of planting material (Type)	-	0.239
Weight × Type	-	0.065

[a] not applicable because type of planting material was not a factor in this experiment.

*: Statistically significant at $0.05 > P \geq 0.01$.

Values in bold indicate the *P*-value of the effect (main or interaction) considered to draw conclusions in the text.

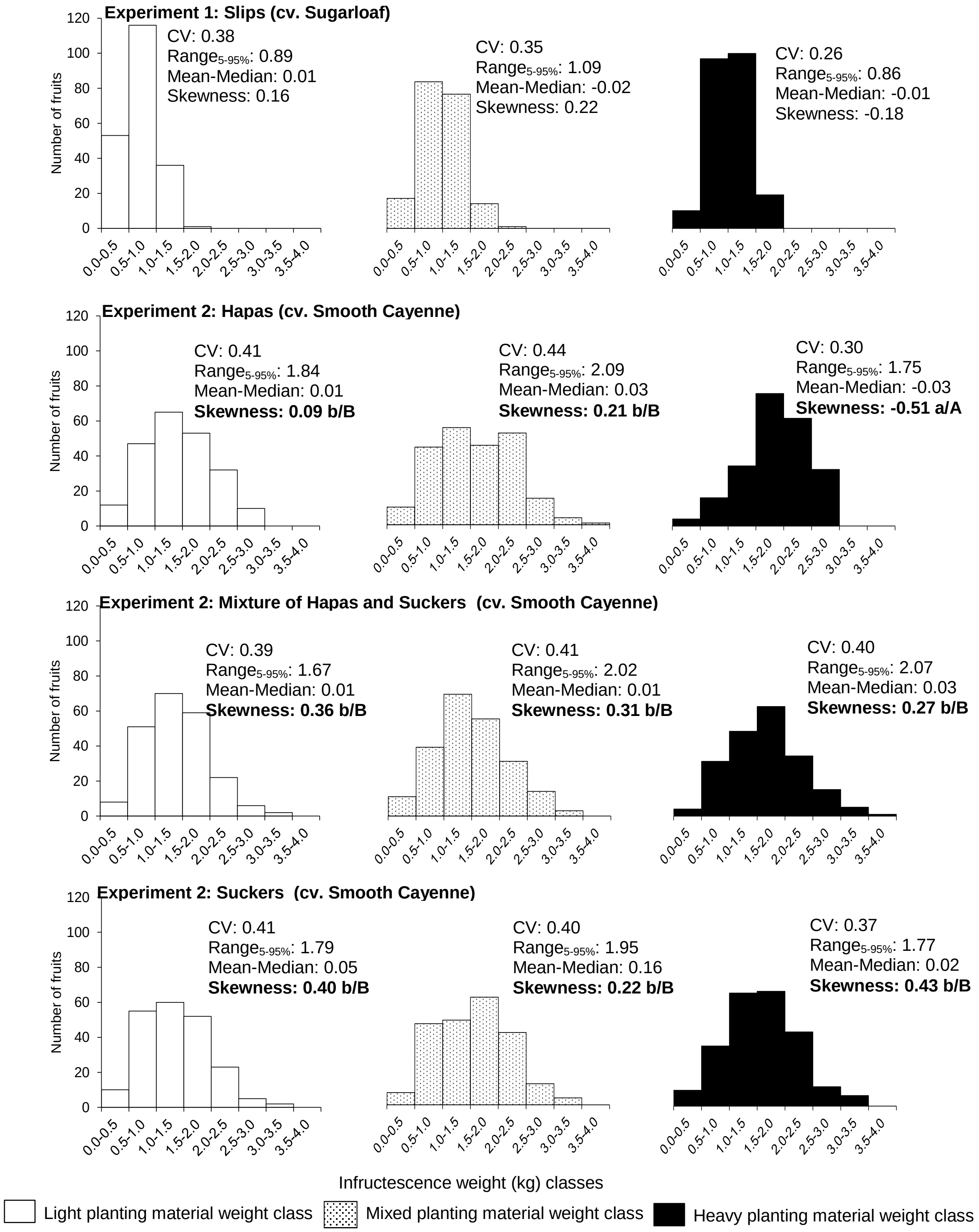
Table S6.3. *P*-values for the effects of type and weight of planting material and their interactions on variation in fruit weight and height attributes and on variation in translucent flesh and total soluble solids at farmers' flowering induction time in cvs Sugarloaf (Experiment 1) and Smooth Cayenne (Experiment 2). Variation is expressed as coefficient of variation (CV), range 5-95%, Mean-Median and skewness

Quality attributes and factors	Experiment 1, cv. Sugarloaf (Slips)				Experiment 2, cv. Smooth Cayenne (Hapas, suckers, and mixture of hapas and suckers)			
	CV[a]	5 - 95%	Mean - Median	Skewness	CV	5 - 95%	Mean - Median	Skewness
Infructescence weight (kg)								
Weight of planting material (Weight)	0.053	0.106	0.348	0.284	0.107	0.170	0.621	0.182
Type of planting material (Type)	-[b]	-	-	-	0.412	0.382	0.846	0.059
Type × Weight	-	-	-	-	0.382	0.573	0.199	**0.035 ***
Crown weight (kg)								
Weight of planting material (Weight)	**0.012 ***	0.189	0.231	0.533	0.487	0.233	0.689	0.864
Type of planting material (Type)	-	-	-	-	0.675	**0.011 ***	0.732	0.482
Type × Weight	-	-	-	-	0.137	0.490	0.824	0.675
Fruit weight (kg)								
Weight of planting material (Weight)	0.128	0.106	0.086	0.393	0.130	0.266	0.238	0.290
Type of planting material (Type)	-	-	-	-	0.701	0.182	0.702	0.040 *
Type × Weight	-	-	-	-	0.374	0.696	0.429	**0.042 ***
Infructescence height (cm)								
Weight of planting material (Weight)	**0.021 ***	0.087	**0.047 ***	0.495	0.164	0.482	0.189	0.509
Type of planting material (Type)	-	-	-	-	0.606	0.497	0.690	0.344
Type × Weight	-	-	-	-	0.941	0.956	0.061	0.056
Crown height (cm)								
Weight of planting material (Weight)	0.299	0.769	0.313	0.506	0.635	0.307	0.179	0.245
Type of planting material (Type)	-	-	-	-	0.708	**0.030 ***	0.322	0.288
Type × Weight	-	-	-	-	0.145	0.179	0.666	0.340
Fruit height (cm)								
Weight of planting material (Weight)	0.705	0.882	0.604	0.877	**0.032 ***	0.340	0.203	0.581
Type of planting material (Type)	-	-	-	-	0.461	0.268	0.315	0.711
Type × Weight	-	-	-	-	0.863	0.907	0.994	0.705
Ratio crown: infructescence height								
Weight of planting material (Weight)	0.304	**0.005 ****	0.092	0.293	0.655	**0.034 ***	0.394	0.699
Type of planting material (Type)	-	-	-	-	0.462	0.415	0.203	0.085
Type × Weight	-	-	-	-	0.439	0.782	0.745	0.751

Table S6.3. Continued

Quality attributes and factors	Experiment 1, cv. Sugarloaf (Slips) CV	5 - 95%	Mean - Median	Skewness	Experiment 2, cv. Smooth Cayenne (Hapas, suckers, and mixture of hapas and suckers) CV	5 - 95%	Mean - Median	Skewness
Translucent flesh (%)								
Weight of planting material (Weight)	0.626	0.528	0.836	0.150	0.565	0.603	0.398	0.335
Type of planting material (Type)	-	-	-	-	0.181	0.379	0.929	0.269
Type × Weight	-	-	-	-	0.263	0.509	0.091	0.247
Total soluble solids (º Brix)								
Weight of planting material (Weight)	0.751	0.929	0.202	0.527	0.792	0.590	0.895	0.112
Type of planting material (Type)	-	-	-	-	**0.020 ***	0.139	0.235	0.114
Type × Weight	-	-	-	-	0.539	0.551	0.441	0.222

[a] Coefficient of variation
[b] Not applicable because the type of planting material was not a factor in this experiment.
*: Statistically significant at $0.05 > P \geq 0.01$ **: statistically significant at $0.01 > P \geq 0.001$
Values in bold indicate the *P*-value for the effects (main or interaction) considered



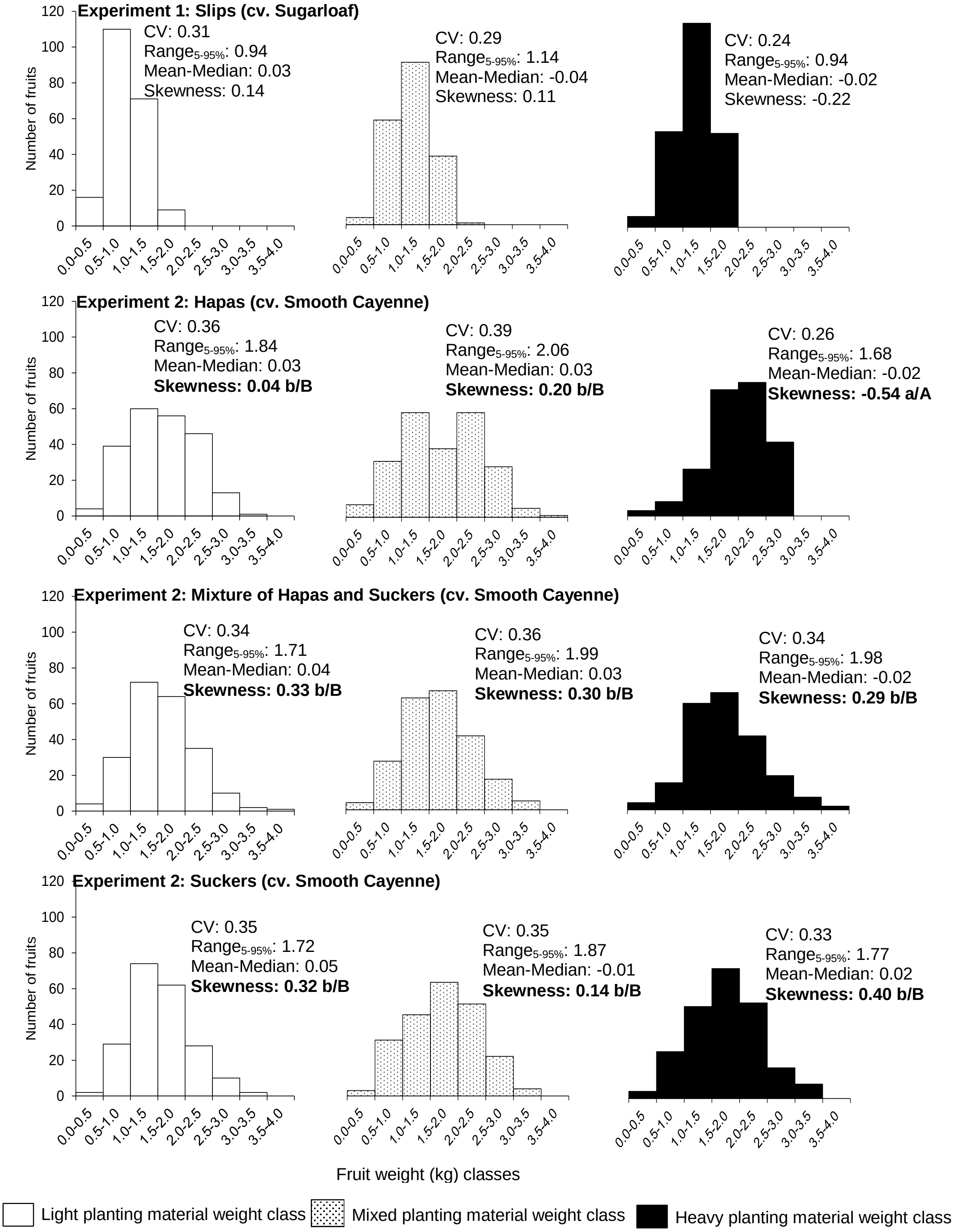
CV: Coefficient of variation

Variation parameters in *bold* indicate the variation parameter for which the effect of planting material weight or type is significant based on the ANOVA results in Table S6.3.

Variation parameters values followed by similar *small* letters indicate that differences between the weight classes in the variation in infructescence weight within a planting material type are not significant according to the $LSD_{0.05}$.In case of interaction all means are compared at $LSD_{0.05}$.

Variation parameters values followed by similar *capital* letters indicate that differences between types of planting material in variation in infructescence weight are not significant according to the $LSD_{0.05}$. In case of interaction all means are compared at $LSD_{0.05}$.

Figure S6.1. Frequency distribution of the infructescence weight (kg) in plants induced at farmer's flowering induction time and its variation (expressed in different variation parameters) as affected by the planting material weight and type



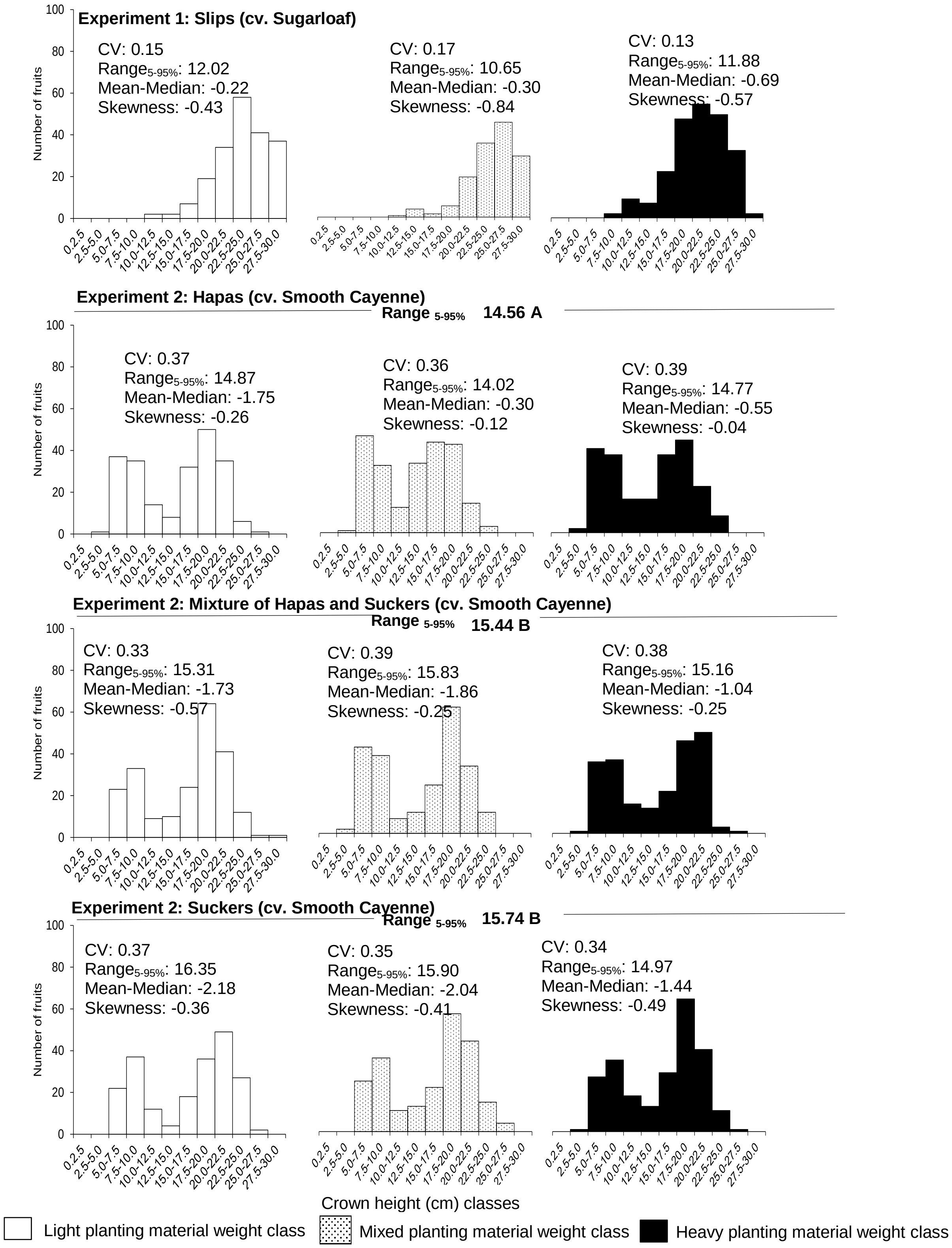
CV: Coefficient of variation

Variation parameters in **bold** indicate the variation parameter for which the effect of planting material weight or type is significant based on the ANOVA results in Table S6.3.

Variation parameters values followed by similar *small* letters indicate that differences between the weight classes in the variation in fruit weight within a planting material type are not significant according to the $LSD_{0.05}$. In case of interaction all means are compared at $LSD_{0.05}$.

Variation parameters values followed by similar *capital* letters indicate that differences between the type of planting material in the variation fruit weight are not significant according to the $LSD_{0.05}$. In case of interaction all means are compared at $LSD_{0.05}$.

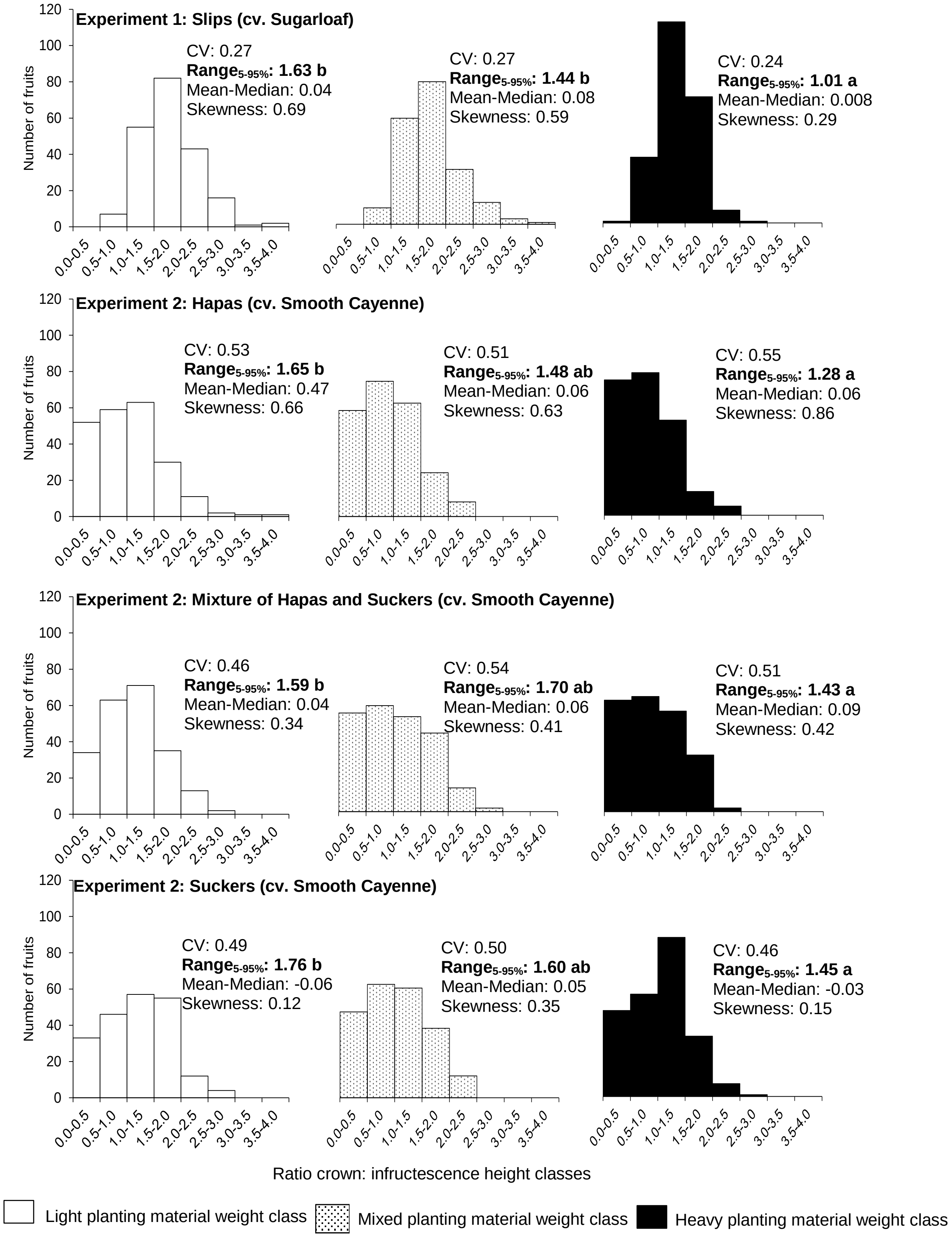
Figure S6.2. Frequency distribution of the fruit weight (kg) in plants induced at farmer's flowering induction time and its variation (expressed in different variation parameters) as affected by the planting material weight and type



CV: Coefficient of variation
Variation parameters in *bold* indicate the variation parameter for which the effect of planting material weight or type is significant based on the ANOVA results in Table S6.3.

Variation parameters values at the top of the graphs in Experiment 2 and followed by similar letters with lines at the left and right indicate that differences between the type of planting material in the variation in crown height are not significant according to the $LSD_{0.05}$.

Figure S6.3. Frequency distribution and variation (expressed in different variation parameters) in crown height as affected by the weight and type of planting material in fruits from plants induced at farmer's flowering induction time in Experiments 1 and 2



CV: Coefficient of variation

Variation parameters in *bold* indicate the variation parameter for which the effect of planting material weight or type is significant based on the ANOVA results in Table S6.3.

Variation parameters values followed by similar letters indicate that differences between the weight classes in the variation in ratio crown: infructescence height within a planting material type are not significant according to the $LSD_{0.05}$.

Figure S6.4. Frequency distribution and variation (expressed in different variation parameters) in ratio crown: infructescence height as affected by the weight and type of planting material in fruits from plants induced at farmer's flowering induction time in Experiments 1 and 2

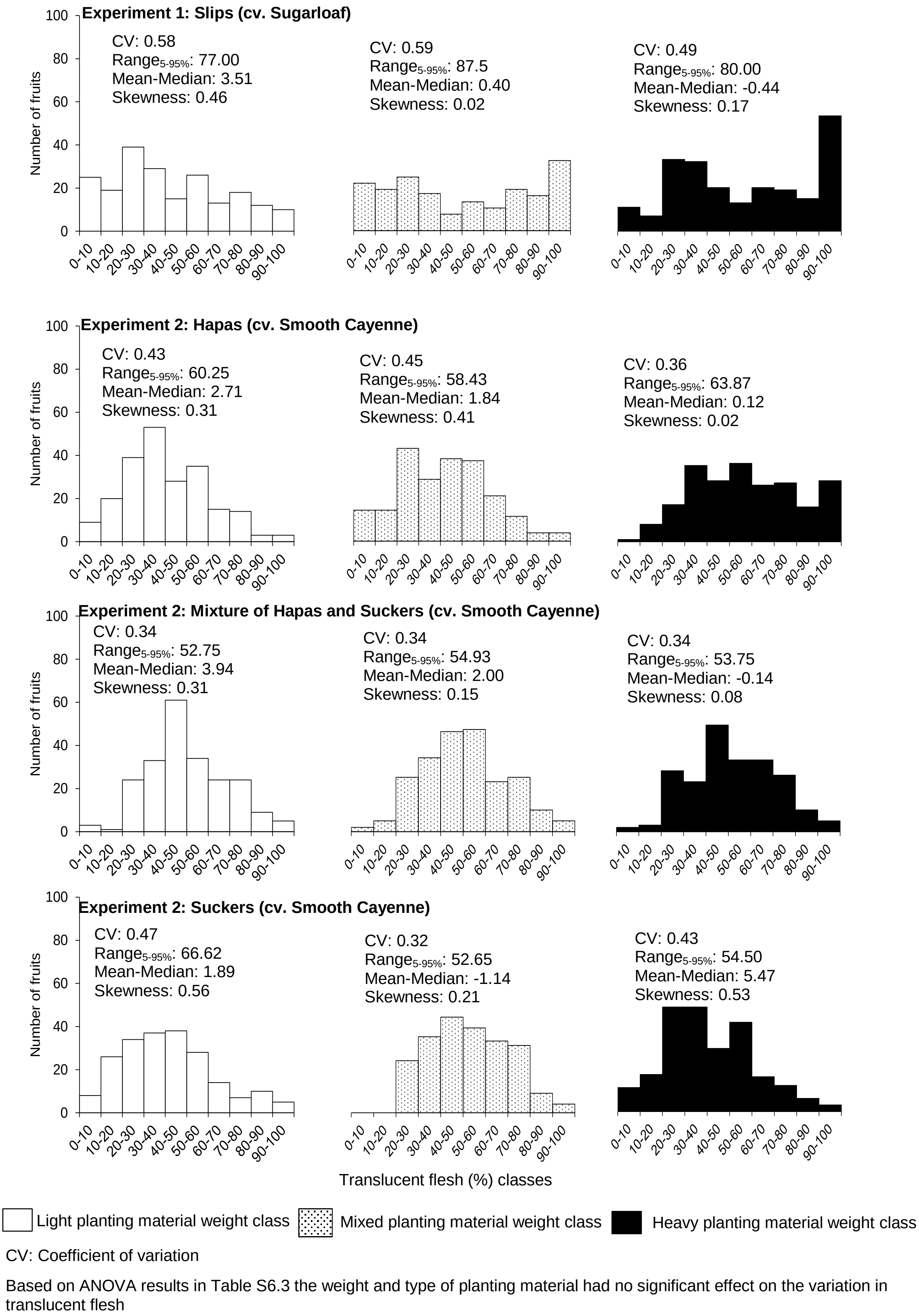


Figure S6.5. Frequency distribution and variation (expressed in different variation parameters) in translucent flesh as affected by the weight and type of planting material in fruits from plants induced at farmer's flowering induction time in Experiments 1 and 2

CHAPTER 7

Selective slip pruning in pineapple plants as means to reduce heterogeneity in fruit quality*

V.N. Fassinou Hotegni[1,2], W.J.M. Lommen[1], E.K. Agbossou[2] and P.C. Struik[1]

[1] Centre for Crop Systems Analysis, Wageningen University, Droevendaalsesteeg 1, 6708 PB Wageningen, the Netherlands

[2] Faculté des Sciences Agronomiques, Université d'Abomey Calavi, 01 BP 526 Cotonou, Benin

* Submitted

Abstract

Heterogeneity in fruit quality (size and taste) is a major problem in pineapple production chains. The possibilities were investigated of reducing the heterogeneity in pineapple in the field by pruning slips on selected plants, in order to promote the fruit growth on these plants. Slips are side shoots that develop just below the pineapple fruit during fruit development. Specific objectives were to determine (a) the effect of slip pruning on fruit quality; (b) whether the effect of slip pruning depends on the pruning time; and (c) whether slip pruning from the least developed plants results in more uniformity in fruit quality. Split plot design was set in two on-farm experiments in commercial fields with cv. Sugarloaf. The slips were pruned at 2 or 3 months after flowering emergence. Different fractions of plants were pruned at each pruning time: no plants pruned (control); slips pruned on the one-third least developed plants; slips pruned on the two-thirds least developed plants; and slips pruned on all plants. Fruit quality measured at harvest time included the fruit weight and height, the infructescence weight and height, the crown weight and height, the ratio crown height: infructescence height, the total soluble solids, the juice pH and the flesh translucency. Results indicated that pruning of slips of any fraction of the plants at 2 or 3 months after flowering emergence did not lead to a consistent improvement in quality or uniformity. Consequently farmers are not recommended to prune the slips.

Keywords: *Ananas comosus*; pruning time; slip; uniformity; variation in quality; variation within a field.

7.1. Introduction

In developing countries, many producers – especially the smallholder producers – face difficulties in entering the international market because of the high quality standards and the need to supply high and regular quantities of product (Murphy 2012). Nowadays, the uniformity in product quality also has become an important criterion. As a proof of that, the Codex Alimentarius, an organization focusing on the establishment of food quality and safety rules for export products to which most developing countries belong, elaborated a set of export criteria for individual food quality attributes as well as for acceptable product heterogeneity (Codex Alimentarius 2005). Many studies have been carried out on different agri-food chains and it was shown that the heterogeneity in quality of the product delivered constitutes a major constraint to the success of the chain (Fassinou Hotegni et al. unpublished; Zúñiga-Arias et al. 2009). This heterogeneity in quality is caused by many factors including the way the product is obtained (Luning and Marcelis 2006), i.e. the environmental conditions and cultural practices underlying its production. It then becomes important to find ways to reduce heterogeneity in fruit quality by designing crop management strategies yielding a more uniform product quality at harvest. The present research focuses on the reduction of pineapple [*Ananas comosus* (L.) Merrill] fruit quality heterogeneity at harvest.

In pineapple cultivation, three partly overlapping phases exist: the vegetative phase (from planting to flowering induction); the generative phase (from flowering initiation to fruit maturity) and the propagative phase in which new shoots are produced (begins at the generative phase and continues after the fruit has been harvested). The generative phase and the propagative phase overlap and consequently the generative phase is not only characterized by development and growth of the fruit; also new shoots develop during that phase, such as slips (produced on the peduncle at the base of the fruit), hapas (produced above ground from the stem at the junction of the stem and the peduncle), suckers (side shoots originating below ground from the stem) (Hepton 2003) and the crown. These vegetative organs can be used as propagules for planting a next crop. The most common shoots produced are the slips and the crown with the crown being borne on the infructescence. The slips are initiated just after the end of the initiation of the florets (Kerns et al. 1936). Studies on the effect of removing the slips -called pruning - on the fruit size gave contradictory results. Wee and Ng (1970) removed all slips in excess to the two slips that were kept on the plants and found no significant effect of slip pruning on fruit weight and fruit height. Norman (1976) removed the slips when the fruits started to develop and found that slip pruning increased fruit weight and had no effect on the total soluble solids (TSS) concentration in the fruit juice. Recent studies on the other hand revealed that slips could be important sources of assimilates for fruit growth and maintenance (Marler 2011). Such conflicting results emphasize the need to improve the understanding on the effect of slip pruning on fruit quality.

Since the production of the slips overlaps with fruit development and growth, slips may compete with the fruit for assimilates available in the plant especially at an earlier stage of their development when they are not yet capable of producing their own assimilates. Thus, earlier slip pruning may have more positive effects on average fruit quality when compared to later pruning. It was shown in pineapple that the least developed plants at flowering induction produce lighter fruit than well-developed plants (Fassinou Hotegni et al. unpublished). We therefore assume that a higher uniformity in fruit weight and height might be achieved by pruning the slips of the least developed plants. The objectives of this paper are to determine (1) the effect of slip pruning on the fruit quality; (2) whether the effect of slip pruning depends on the pruning time; and (3) if slip pruning from the least developed plants results in more uniformity in fruit quality.

7.2. Materials and methods

7.2.1. Experimental sites and set up

Two on-farm experiments were conducted in two commercial pineapple fields in the Atlantic department in the south of Benin between October 2010 and August 2012. Different producers of cv. Sugarloaf were selected per experiment based on (a) the age of their pineapple crop being close to the common artificial flowering induction time and (b) whether they applied the common practices for this cultivar, as described by Fassinou Hotegni et al. (2012). The cv. Sugarloaf was selected because (1) it is grown by 97% of the pineapple producers in the department (Fassinou Hotegni et al. 2012) and (2) cv. Sugarloaf produces numerous slips during the generative phase (Fassinou Hotegni et al. unpublished; Norman 1976). Information on the fields and cultural practices from planting until harvest time is presented in Table 7.1. In each experiment, a split-plot design was used, with two factors. The slip pruning time was the main factor and had two levels: (1) pruning at 2 months after flowering emergence (Figure 7.1-B) and (2) pruning at 3 months after flowering emergence

Table 7.1. Information on sites and cultural practices for the two experiments with cv. Sugarloaf

Field information and cultural practices	Experiment 1	Experiment 2
Location	06°36'35.7"N and 02°14'28.7"E	06°35'06.4"N and 02°15'55.4"E
Municipality (district)	Zè (Tangbo Djevie)	Zè (Tangbo Djevie)
Soil type	Ferralitic soil	Ferralitic soil
Climate	Subequatorial	Subequatorial
Planting time[a]	October 2010	March 2011
Type of planting material used[a]	Slips	Slips
Planting material treatment before planting[a]	No treatment	No treatment
Plant arrangement at planting	Flat beds of two rows	Flat beds of two rows
Plant spacing (cm): BP[b] × BR[c]/ BDR[d]	35 × 47/75	40 × 50/70
Plant density (plants/m^2)	4.69	4.17
First Urea (46N) + NPK (10-20-20) application	6 MAP[e] (18 April 2011)	7 MAP (11 October 2011)
Application form	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (g Urea + g NPK)	6 + 3	6 + 4
Second Urea (46N) + NPK (10-20-20) application	12 MAP (13 October 2011)	11 MAP (16 February 2012)
Application form	Solid at the base of the plants	Solid at the base of the plants
Dose per plant (*g Urea* + *g NPK*)	3 + 7	3 + 7
Artificial flowering induction time	13 MAP (13 November 2011)	12 MAP (17 March 2012)
Inflorescence emergence	14 MAP (17 December 2011)	13 MAP (20 April 2012)
First removal of slips (2 MFE[f])	16 MAP (17 February 2012)	15 MAP (20 June 2012)
Second removal of slips (3 MFE)	17 MAP (17 March 2012)	16 MAP (20 July 2012)
Weed control	Hand weeding	Hand weeding
Harvest time	18 MAP (15, 16, 17 and 18 April 2012)	17 MAP (20, 21, 22 and 23 August 2012)

[a] Information gathered from pineapple producer (field owner)
[b] BP, spacing between plants within a row
[c] BR, spacing between rows
[d] BDR, spacing between double rows
[e] MAP, months after planting
[f] MFE, months after flowering emergence

(Figure 7.1-C), with flowering emergence being the stage at which the inflorescence can be seen at the centre of the leaf rosette (Figure 7.1-A). The fraction of plants pruned per experimental unit was the split factor and had four levels: (1) no slips pruned; (2) slips pruned on the one-third least developed plants; (3) slips pruned on the two-thirds least developed plants; and (4) slips pruned on all plants.

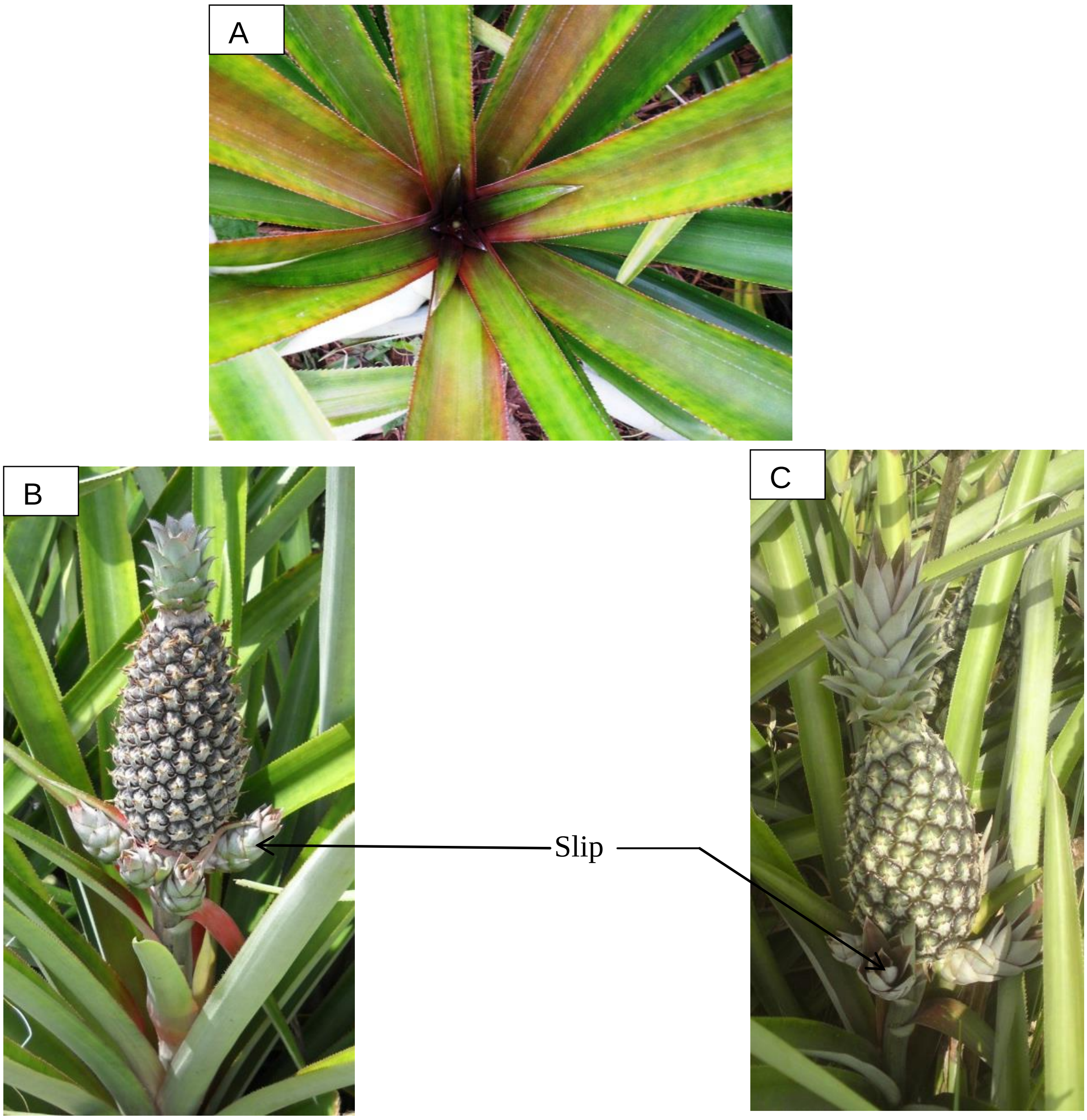


Figure 7.1. Pineapple plants at different stages of the generative phase: (A) flowering emergence at the center of the leaf rosette; (B) pineapple plant at 2 months after flowering emergence showing the slips; (C) pineapple plant at 3 months after flowering emergence showing the slips. Pictures (A), (B) and (C) were taken from different plants.

The height of the developing infructescence at the moment of pruning was used as the criterion to identify the least developed plants. Each experiment had four replicated blocks. Each net plot consisted of 60 net plants arranged in 6 lines of 10 plants each. The net plots were surrounded by at least 2 guard rows and 2 guard plants in a row. The pineapple fruits were harvested following farmers' practice which was at the moment when the skin colour had started to change from green to yellow in at least 25% of the plants in a net plot (i.e. 15 out of 60 plants). All fruits per plot were harvested on that day and were individually processed.

7.2.2. Collected data

Data were collected on individual plants per net plot before pruning and at harvest. Before pruning, data were collected on the number of slips per plant and the infructescence height. From the infructescence height data, the one- or two-third(s) least developed plants i.e. the plants with the lower infructescence heights, were selected and their slips were pruned depending on the treatment. At harvest time, data on fruit quality attributes were collected: fruit (infructescence + crown) weight, infructescence weight, crown weight, fruit height, infructescence height, crown height, the ratio crown height: infructescence height, the TSS in the pineapple juice, the juice pH and the flesh translucency. All these quality attributes are important for pineapple export (Codex Alimentarius 2005). Data collection followed the procedures described by Fassinou Hotegni et al. unpublished), with TSS being measured in the pineapple juice in Brix using a hand refractometer and the juice pH using a hand-held pH meter. Flesh translucency was based on the percentage of fruit flesh that was translucent; it was visually estimated on a cut half pineapple following the method of Paull and Reyes (1996).

7.2.3. Data analysis

Data were analysed using GenStat for Windows 15th Edition (VSN International 2012). The initial status of the plants at pruning time was described in two ways. First, the proportion of the plants with slips and the total number of slips produced were checked for being similar across treatments. A two-way ANOVA for a split-plot design was used; data on the proportion of plants with slips were transformed using arcsine transformation on the square root of the proportions before the analysis. Second, sextiles were calculated. Plants were ranked according to infructescence height from the smallest to highest values per plot and then allocated to six classes. The number of plants with slips was counted per class. Data from all plants at one pruning time were combined and graphs were plotted to evaluate the initial status of the plants at each pruning time. Because not all plants had produced slips, two data sets were created: (1) *data based on all plants per plot* (with or without slips at pruning time) and (2) *data based on plants with slips* at pruning time. A two-way ANOVA for a split plot design was performed on each data set to test the effect of pruning time and fraction of plants pruned on the average quality of the fruit quality attributes and on fruit quality heterogeneity. Flesh translucency data were transformed using square root transformation ($\sqrt{x+0.5}$) before analysis (Bartlett 1936; Gonzalez 2009). Fruit quality heterogeneity was calculated per plot using the coefficient of variation, i.e. the measure of the variability in the value in a population relative to the mean, for the two data sets: all plants and plants with slips at pruning time. When the F value was significant, LSD was used to separate means or coefficients of variation.

7.3. Results

7.3.1. Initial status of the plants at pruning time

The pruning time, the fraction of plants pruned and their interaction were confirmed to have no effect on the proportion of plants with slips and the number of slips at pruning (Table 7.2).

Table 7.2. *P* values of the F ratios testing the effect of pruning time, fraction of plants pruned and their interaction on the proportion of plants with slips and the total number of slips produced

Proportion of plants with slips	Expt 1	Expt 2
Pruning time (PT)	0.269	0.860
Fraction plants pruned (FP)	0.101	0.747
PT × FP	0.307	0.419
Total number of slips		
Pruning time (PT)	0.738	0.762
Fraction plants pruned (FP)	0.789	0.696
PT × FP	0.312	0.378

This shows that plants with and without slips were evenly distributed across the plots at the moment the treatments started. However, the more developed plants within in the crops, i.e. those plants with a higher infructescence height at pruning time, were more likely to have produced slips than plants with a lower infructescence height (Figure 7.2), in which fraction of most of the plants that had to be pruned fell. This meant that a possible effect of pruning on fruit quality was diluted by the plants that could not be pruned because they did not have slips. Therefore, data were split into two sets: (1) *data based on all plants per plot* (with or without slips at pruning time) and (2) *data based on the plants with slips* at pruning time. The first set will be useful for showing the relevance of pruning for commercial practice and the second set for understanding the effect of slip pruning *per se*.

7.3.2. Effects of fraction of plants pruned and pruning time on fruit quality

The significances of the effects of pruning time, the fraction of plants pruned and their interactions on the fruit quality attributes are presented in Table 7.3. In both data sets - data on all plants per plot and data on the plants with slips at pruning time - results were comparable. The interaction between pruning time and fraction of plants pruned was not significant for any of the quality attributes. In both data sets, the fraction of plants pruned had no significant effect on average quality, except on juice pH in Expt 1 (Table 7.3), where pruning of the two-thirds least developed plants led to higher juice pH than no pruning or pruning all plants (Table 7.4). This trend in juice pH was not found in Expt 2.

In both data sets, pruning time had no significant effect on the average fruit quality attributes, except on crown weight in Expt 1 (Table 7.3) where pruning at 2 months after inflorescence emergence resulted in heavier crowns than pruning at 3 months after inflorescence emergence (Table 7.4). In Expt 2, differences in crown weight were not significant.

7.3.3. Effects of fraction of plants pruned and pruning time on the heterogeneity in fruit quality

The significances of the effects of pruning time, the fraction of pruned plants and their interaction on the variation in fruit quality attributes are presented in Table 7.3.

When considering all plants, the interaction between the pruning time and fraction of

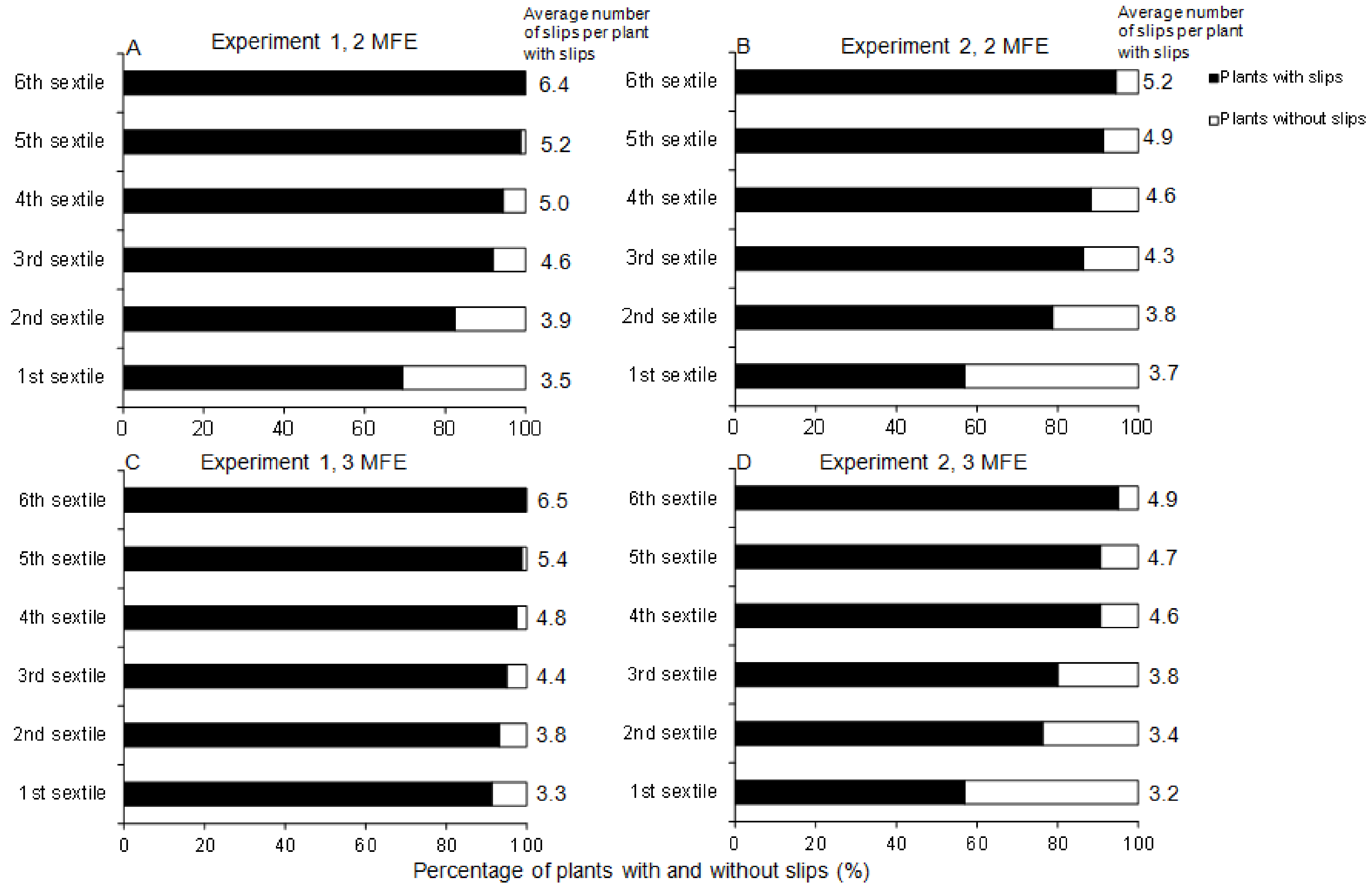


Figure 7.2. Proportion of plants with and without slips and average number of slips per plant as a function of infructescence height arranged from smallest (1st sextile) to highest (6th sextile) at 2 MFE (months after inflorescence emergence) (A and B) and 3 MFE (C and D) in Experiments 1 and 2

Table 7.3. *P*-values of the F ratios from ANOVA for the effects of pruning time, fraction of plants pruned and their interaction on average pineapple fruit quality attributes and variation in quality (CV) in two experiments for data based on all plants and on plants with slips only

Fruit quality/Factor	Effect on average fruit quality				Effect on variation in fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Fruit weight (kg)								
Pruning time (PT)	0.923	0.754	0.995	0.740	0.048 *	0.392	0.194	0.183
Fraction plants pruned (FP)	0.974	0.363	0.953	0.286	0.917	0.758	0.693	0.342
PT × FP	0.515	0.287	0.668	0.132	0.388	0.570	0.717	0.032*
Infructescence weight (kg)								
Pruning time (PT)	0.892	0.791	0.968	0.776	0.106	0.358	0.170	0.152
Fraction plants pruned (FP)	0.985	0.465	0.959	0.395	0.886	0.851	0.606	0.490
PT × FP	0.507	0.281	0.661	0.120	0.335	0.347	0.678	0.028 *
Crown weight (kg)								
Pruning time (PT)	0.021 *	0.528	0.002 **	0.553	0.058	0.691	0.141	0.954
Fraction plants pruned (FP)	0.158	0.510	0.178	0.657	0.120	0.735	0.111	0.699
PT × FP	0.395	0.686	0.434	0.845	0.448	0.790	0.666	0.950
Fruit height (cm)								
Pruning time (PT)	0.923	0.890	0.954	0.886	0.070	0.930	0.016 *	0.891
Fraction plants pruned (FP)	0.995	0.404	0.986	0.520	0.295	0.699	0.755	0.772
PT × FP	0.961	0.356	0.966	0.495	0.995	0.247	0.841	0.672
Infructescence height (cm)								
Pruning time (PT)	0.744	0.796	0.819	0.783	0.344	0.573	0.972	0.909
Fraction plants pruned (FP)	0.973	0.557	0.915	0.478	0.425	0.811	0.903	0.767
PT × FP	0.906	0.524	0.972	0.370	0.683	0.311	0.737	0.360

Table 7.3. Continued

	Effect on average fruit quality				Effect on variation in fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Crown height (cm)								
Pruning time (PT)	0.297	0.551	0.177	0.613	0.353	0.795	0.655	0.559
Fraction plants pruned (FP)	0.897	0.609	0.893	0.687	0.041 *	0.765	0.134	0.678
PT × FP	0.716	0.713	0.697	0.846	0.297	0.247	0.200	0.505
Ratio crown height: Infructescence height								
Pruning time (PT)	0.543	0.422	0.587	0.404	0.865	0.898	0.910	0.489
Fraction plants pruned (FP)	0.830	0.681	0.750	0.645	0.337	0.671	0.606	0.572
PT × FP	0.754	0.754	0.858	0.678	0.294	0.064	0.241	0.130
Total soluble solids (Brix)								
Pruning time (PT)	0.914	0.868	0.901	0.914	0.700	0.353	0.858	0.418
Fraction plants pruned (FP)	0.531	0.332	0.587	0.302	0.973	0.143	0.816	0.076
PT × FP	1.000	0.416	0.998	0.477	0.966	0.498	0.871	0.589
Juice pH								
Pruning time (PT)	0.838	0.810	0.691	0.796	0.606	0.359	0.706	0.312
Fraction plants pruned (FP)	0.011 *	0.781	0.013 *	0.742	0.775	0.273	0.703	0.347
PT × FP	0.339	0.397	0.291	0.447	0.806	0.776	0.848	0.775
Translucent flesh (%)								
Pruning time (PT)	0.911	0.947	0.817	0.967	0.871	0.987	0.994	0.970
Fraction plants pruned (FP)	0.722	0.324	0.842	0.283	0.903	0.935	0.807	0.778
PT × FP	0.072	0.140	0.113	0.274	0.151	0.142	0.184	0.163

*: Statistically significant at $0.05 > P \geq 0.01$; **: Statistically significant at $0.01 > P \geq 0.001$.

Table 7.4. Effect of fraction of plants pruned and pruning time, and both, on average and variation in different fruit quality attributes in two experiments, for data based on all plants and plants with slips only

	Average fruit quality				Coefficient of variation in fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Fruit weight (kg)								
Pruning treatment								
NP[a]	0.95	0.90	0.97	0.95	0.25	0.26	0.24	0.23
1/3P[b]	0.97	0.88	0.98	0.92	0.26	0.25	0.25	0.22
2/3P[c]	0.95	0.93	0.96	0.97	0.26	0.24	0.26	0.21
AP[d]	0.96	0.95	0.99	0.99	0.26	0.26	0.24	0.23
Pruning time								
2MFE[e]	0.95	0.93	0.97	0.97	**0.27 b**	0.26	0.25	0.23
3MFE	0.96	0.90	0.97	0.94	**0.25 a**	0.25	0.24	0.22
Pruning treatments at 2MFE								
NP	0.95	0.96	0.97	1.01	0.26	0.25	0.25	**0.22 b**
1/3P	0.97	0.85	0.99	0.91	0.26	0.27	0.25	**0.22 b**
2/3P	0.96	0.93	0.98	0.96	0.27	0.26	0.26	**0.23 b**
AP	0.91	0.98	0.96	1.01	0.28	0.26	0.26	**0.24 b**
Pruning treatments at 3MFE								
NP	0.95	0.85	0.96	0.88	0.24	0.26	0.23	**0.24 b**
1/3P	0.96	0.90	0.97	0.94	0.26	0.24	0.25	**0.22 b**
2/3P	0.94	0.93	0.95	0.98	0.25	0.23	0.25	**0.19 a**
AP	1.01	0.92	1.02	0.96	0.24	0.26	0.23	**0.22 b**
Infructescence weight (kg)								
Pruning treatments								
NP	0.85	0.76	0.87	0.80	0.28	0.30	0.26	0.27
1/3P	0.87	0.74	0.88	0.78	0.29	0.30	0.28	0.26
2/3P	0.85	0.78	0.86	0.82	0.29	0.29	0.29	0.25
AP	0.86	0.80	0.89	0.84	0.29	0.30	0.27	0.26
Pruning time								
2MFE	0.85	0.78	0.87	0.82	0.30	0.30	0.28	0.27
3MFE	0.87	0.76	0.88	0.80	0.28	0.29	0.27	0.26

Table 7.4. Continued (1)

	Effect on average fruit quality				Effect on variation on fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Infructescence weight (kg)								
Pruning treatments at 2MFE								
NP	0.85	0.81	0.88	0.86	0.29	0.30	0.28	**0.26 b**
1/3P	0.87	0.71	0.88	0.76	0.29	0.31	0.27	**0.25 b**
2/3P	0.86	0.77	0.88	0.80	0.29	0.31	0.29	**0.28 b**
AP	0.81	0.83	0.85	0.86	0.31	0.29	0.28	**0.27 b**
Pruning treatments at 3MFE								
NP	0.85	0.71	0.87	0.74	0.26	0.31	0.25	**0.28 b**
1/3P	0.86	0.77	0.87	0.80	0.29	0.28	0.28	**0.26 ab**
2/3P	0.85	0.79	0.85	0.84	0.29	0.27	0.28	**0.23 a**
AP	0.92	0.78	0.92	0.81	0.26	0.30	0.26	**0.27 b**
Crown weight (kg)								
Pruning treatments								
NP	0.093	0.142	0.094	0.145	0.17	0.19	0.17	0.18
1/3P	0.099	0.140	0.100	0.144	0.19	0.19	0.18	0.17
2/3P	0.100	0.149	0.101	0.152	0.21	0.18	0.21	0.17
AP	0.094	0.146	0.095	0.148	0.18	0.20	0.17	0.19
Pruning time								
2MFE	**0.099 b**	0.148	**0.100 b**	0.151	0.20	0.19	0.19	0.18
3MFE	**0.095 a**	0.141	**0.095 a**	0.143	0.17	0.19	0.17	0.18
Pruning treatments at 2MFE								
NP	0.093	0.145	0.094	0.148	0.18	0.20	0.18	0.17
1/3P	0.104	0.141	0.104	0.146	0.19	0.20	0.19	0.18
2/3P	0.105	0.158	0.106	0.159	0.22	0.18	0.22	0.17
AP	0.094	0.149	0.095	0.151	0.20	0.20	0.19	0.19

Table 7.4. Continued (2)

	Effect on average fruit quality				Effect on variation on fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Crown weight (kg)								
Pruning treatments at 3MFE								
NP	0.093	0.140	0.093	0.143	0.17	0.19	0.17	0.18
1/3P	0.096	0.140	0.096	0.141	0.19	0.17	0.18	0.17
2/3P	0.096	0.141	0.096	0.144	0.19	0.18	0.19	0.17
AP	0.095	0.143	0.096	0.146	0.15	0.20	0.16	0.19
Fruit height (cm)								
Pruning treatments								
NP	30.97	36.28	31.23	36.95	0.08	0.09	0.08	0.08
1/3P	30.85	35.80	31.03	36.52	0.08	0.09	0.08	0.08
2/3P	30.91	36.91	31.11	37.39	0.09	0.09	0.09	0.08
AP	30.84	36.40	31.19	36.89	0.09	0.09	0.09	0.08
Pruning time								
2MFE	30.80	36.44	31.19	37.04	0.09	0.09	**0.09 b**	0.08
3MFE	30.98	36.26	31.10	36.83	0.08	0.09	**0.08 a**	0.08
Pruning treatments at 2MFE								
NP	30.83	36.65	31.16	37.44	0.09	0.09	0.08	0.07
1/3P	30.95	35.19	31.20	36.15	0.09	0.10	0.09	0.08
2/3P	30.74	37.36	31.07	37.65	0.09	0.08	0.09	0.08
AP	30.70	36.56	31.32	36.90	0.10	0.09	0.09	0.08
Pruning treatments at 3MFE								
NP	31.11	35.92	31.31	36.46	0.08	0.09	0.07	0.08
1/3P	30.74	36.41	30.87	36.88	0.08	0.09	0.08	0.08
2/3P	31.09	36.46	31.15	37.12	0.08	0.09	0.08	0.08
AP	30.97	36.24	31.06	36.87	0.08	0.09	0.08	0.07

Table 7.4. Continued (3)

	Effect on average fruit quality				Effect on variation on fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Infructescence height (cm)								
Pruning treatments								
NP	15.37	15.54	15.58	15.96	0.16	0.15	0.15	0.13
1/3P	15.28	15.28	15.41	15.68	0.15	0.16	0.15	0.14
2/3P	15.13	15.77	15.26	16.11	0.16	0.15	0.16	0.13
AP	15.27	16.05	15.55	16.36	0.17	0.15	0.16	0.14
Pruning time								
2MFE	15.01	15.55	15.29	15.92	0.16	0.15	0.16	0.13
3MFE	15.52	15.77	15.61	16.13	0.16	0.15	0.16	0.13
Pruning treatments at 2MFE								
NP	15.29	15.76	15.55	16.25	0.16	0.16	0.16	0.13
1/3P	15.11	14.72	15.28	15.22	0.16	0.16	0.16	0.14
2/3P	14.78	15.60	14.99	15.85	0.16	0.15	0.15	0.14
AP	14.85	16.13	15.35	16.38	0.17	0.14	0.16	0.13
Pruning treatments at 3MFE								
NP	15.45	15.33	15.62	15.67	0.15	0.15	0.15	0.14
1/3P	15.45	15.84	15.55	16.14	0.15	0.15	0.15	0.14
2/3P	14.48	15.94	15.52	16.37	0.16	0.14	0.16	0.13
AP	15.70	15.96	15.75	16.35	0.16	0.16	0.16	0.14
Crown height (cm)								
Pruning treatments								
NP	15.60	20.74	15.65	20.99	**0.10 a**	0.14	0.10	0.13
1/3P	15.56	20.53	15.62	20.84	**0.12 b**	0.14	0.12	0.13
2/3P	15.78	21.14	15.85	21.27	**0.12 b**	0.13	0.11	0.12
AP	15.56	20.35	15.64	20.52	**0.11 ab**	0.13	0.11	0.13
Pruning time								
2MFE	15.79	20.89	15.90	20.11	0.12	0.13	0.12	0.12
3MFE	15.46	20.49	15.49	20.70	0.11	0.14	0.11	0.13

Table 7.4. Continued (4)

	Effect on average fruit quality				Effect on variation on fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Crown height (cm)								
Pruning treatments at 2MFE								
NP	15.54	20.90	15.61	21.19	0.11	0.15	0.12	0.13
1/3P	15.84	20.48	15.92	20.93	0.12	0.14	0.12	0.13
2/3P	15.96	21.76	16.08	21.80	0.12	0.12	0.12	0.11
AP	15.85	20.43	15.97	20.53	0.12	0.13	0.11	0.12
Pruning treatments at 3MFE								
NP	15.66	20.58	15.69	20.79	0.09	0.13	0.10	0.14
1/3P	15.29	20.57	15.32	20.75	0.12	0.13	0.12	0.13
2/3P	15.60	20.52	15.62	30.75	0.11	0.14	0.12	0.14
AP	15.28	20.28	15.31	20.52	0.11	0.14	0.11	0.14
Ratio crown: infructescence height								
Pruning treatments								
NP	1.05	1.38	1.04	1.35	0.20	0.23	0.20	0.22
1/3P	1.06	1.39	1.05	1.37	0.22	0.22	0.22	0.22
2/3P	1.09	1.38	1.09	1.36	0.21	0.22	0.21	0.20
AP	1.06	1.31	1.04	1.29	0.22	0.22	0.21	0.22
Pruning time								
2MFE	1.09	1.39	1.08	1.36	0.21	0.22	0.21	0.21
3MFE	1.04	1.34	1.03	1.32	0.21	0.22	0.21	0.22
Pruning treatments at 2MFE								
NP	1.05	1.38	1.04	1.34	0.21	0.24	0.22	0.22
1/3P	1.09	1.45	1.08	1.42	0.21	0.23	0.21	0.22
2/3P	1.13	1.44	1.12	1.41	0.21	0.22	0.20	0.20
AP	1.11	1.30	1.07	1.28	0.22	0.20	0.21	0.19

Table 7.4. Continued (5)

	Effect on average fruit quality				Effect on variation on fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Ratio crown: infructescence height								
Pruning treatments at 3MFE								
NP	1.05	1.38	1.04	1.36	0.18	0.22	0.19	0.21
1/3P	1.03	1.33	1.02	1.32	0.22	0.22	0.22	0.22
2/3P	1.05	1.33	1.05	1.30	0.22	0.21	0.22	0.20
AP	1.01	1.31	1.01	1.29	0.21	0.24	0.21	0.24
Total soluble solids (ºBrix)								
Pruning treatments								
NP	13.85	14.86	13.89	15.02	0.07	0.08	0.06	0.07
1/3P	13.59	15.21	13.62	15.35	0.07	0.09	0.06	0.08
2/3P	13.88	14.80	13.87	14.95	0.06	0.10	0.06	0.09
AP	13.83	14.98	13.82	15.08	0.06	0.09	0.06	0.08
Pruning time								
2MFE	13.76	14.99	13.77	15.12	0.07	0.08	0.06	0.08
3MFE	13.82	14.93	13.84	15.08	0.06	0.09	0.06	0.09
Pruning treatments at 2MFE								
NP	13.83	14.88	13.85	15.10	0.07	0.08	0.07	0.06
1/3P	13.55	15.16	13.60	15.34	0.07	0.09	0.06	0.09
2/3P	13.84	14.70	13.81	14.79	0.06	0.09	0.06	0.09
AP	13.81	15.24	13.80	15.25	0.07	0.08	0.06	0.07
Pruning treatments at 3MFE								
NP	13.87	14.85	13.94	14.95	0.06	0.08	0.06	0.07
1/3P	13.63	15.26	13.63	15.35	0.06	0.09	0.07	0.08
2/3P	13.92	14.90	13.92	15.11	0.06	0.10	0.06	0.09
AP	13.86	14.71	13.85	14.91	0.06	0.10	0.06	0.09

Table 7.4. Continued (6)

	Effect on average fruit quality				Effect on variation on fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Juice pH								
Pruning treatments								
NP	**4.00 ab**	3.81	**4.01 ab**	3.83	0.03	0.05	0.03	0.04
1/3P	**4.08 bc**	3.80	**4.08 bc**	3.82	0.03	0.05	0.03	0.04
2/3P	**4.12 c**	3.80	**4.12 c**	3.82	0.03	0.06	0.04	0.05
AP	**3.96 a**	3.85	**3.97 a**	3.88	0.04	0.06	0.04	0.05
Pruning time								
2MFE	4.04	3.80	4.05	3.82	0.03	0.06	0.03	0.05
3MFE	4.04	3.83	4.04	3.86	0.03	0.05	0.03	0.04
Pruning treatments at 2MFE								
NP	3.95	3.80	3.96	3.82	0.04	0.05	0.03	0.04
1/3P	4.10	3.72	4.10	3.75	0.03	0.05	0.03	0.05
2/3P	4.14	3.80	4.16	3.81	0.04	0.06	0.04	0.06
AP	3.96	3.88	3.99	3.90	0.04	0.06	0.04	0.06
Pruning treatments at 3MFE								
NP	4.06	3.82	4.06	3.85	0.03	0.05	0.03	0.05
1/3P	4.06	3.87	4.04	3.89	0.04	0.04	0.04	0.04
2/3P	4.10	3.81	4.10	3.84	0.03	0.05	0.04	0.05
AP	3.96	3.83	3.96	3.86	0.03	0.05	0.03	0.05
Translucent flesh (%)								
Pruning treatments								
NP	3.93	4.76	4.04	5.00	1.46	1.23	1.39	1.16
1/3P	4.13	4.71	4.18	5.00	1.39	1.14	1.34	1.05
2/3P	4.19	5.17	4.23	5.47	1.52	1.17	1.51	1.03
AP	3.82	5.36	3.93	5.63	1.38	1.24	1.31	1.14

Table 7.4. Continued (7)

	Effect on average fruit quality				Effect on variation on fruit quality			
	All plants		Plants with slips		All plants		Plants with slips	
Translucent flesh	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Pruning time								
2MFE	4.07	5.05	4.20	5.31	1.46	1.19	1.39	1.10
3MFE	3.96	4.95	3.99	5.25	1.41	1.20	1.39	1.09
Pruning treatments at 2MFE								
NP	4.30	4.64	4.46	4.89	1.38	1.17	1.30	1.12
1/3P	4.03	4.32	4.11	4.72	1.72	1.36	1.63	1.24
2/3P	4.61	5.28	4.67	5.50	1.34	1.19	1.33	1.08
AP	3.34	5.94	3.55	6.12	1.42	1.03	1.29	0.97
Pruning treatments at 3MFE								
NP	3.56	4.88	3.62	5.12	1.54	1.28	1.48	1.21
1/3P	4.23	5.09	4.26	5.27	1.05	0.92	1.04	0.86
2/3P	3.76	5.06	3.79	5.45	1.71	1.15	1.70	0.97
AP	4.30	4.78	4.31	5.15	1.33	1.44	1.33	1.31

[a] No slips pruned on the plants
[b] Slips pruned on the one-third least developed plants
[c] Slips pruned on the two-thirds least developed plants
[d] Slips pruned on all plants
[e] Months after inflorescence emergence
Values followed by the same letters in the same columns for each quality attribute, are not significantly different based on $LSD_{0.05}$. There are indicated by the set of numbers in bold

plants pruned was not significant for variation in any of the quality attributes (Table 7.3). The fraction of plants pruned had only a significant effect on the variation in crown height in Expt 1; fruits from plots where no slips were pruned, showed the lowest variation in crown height, although not significantly different from fruits from plots in which slips were pruned from all plants (Table 7.4). An effect of pruning time on the variation in fruit quality was only significant for fruit weight in Expt 1 (Table 7.3) where the fruit weights in the plots in which plants whose slips were pruned at 2 months after inflorescence emergence were more variable than the fruit weights in the plots of plants pruned at 3 months after emergence (Table 7.4). In Expt 2, the same observations were made although differences were not significant. In both experiments, also the variation in the underlying infructescence and crown weights were higher when plants were pruning at 2 months after inflorescence emergence than in plants pruned at 3 months after inflorescence emergence (Table 7.4); but these effects were not statistically significant.

For the plants that had slips at pruning time, the interaction between the pruning time and the fraction of plants pruned was significant for variation in fruit and infructescence weight in Expt 2 (Table 7.3); pruning of the two-thirds least developed plants at 3 months after inflorescence emergence reduced significantly the variability in fruit weight and infructescence weight when compared to no slips pruning, but this was not found when pruning at 2 months after inflorescence emergence. For variation in the other quality attributes, no main effects of the fraction of plants pruned were significant (Table 7.3). For the same fraction pruned at the two pruning times, interaction in Expt 2 indicated significant reduction in variability in fruit weight and infructescence weight at 3 months after flowering emergence when compared to variability at 2 months after inflorescence emergence only when two-thirds least developed plants were pruned. A main effect of the pruning time on the variation in other quality attributes was significant for fruit height in Expt 1 (Table 7.3) where pruning at 3 months after inflorescence emergence gave lower variation in fruit height compared to pruning at 2 months after inflorescence emergence.

7.4. Discussion

7.4.1. Infructescence height and slip production

Infructescence height is an easy criterion for farmers to differentiate between plants. Our results showed that plants with higher infructescence height at pruning were more likely to produce slips and produced more slips than plants with lower infructescence height (Figure 7.2). Plants with high infructescence height at pruning were regarded to be the more vigorous plants and it was shown in previous studies that more vigorous plants at flowering induction were associated with higher infructescence height as well as higher slips number at harvest (Fassinou Hotegni et al., unpublished). This was also found in the present study (data not shown). The higher number of slips in more vigorous plants suggests that the pineapple plants adjust the number of side shoots -slips- to be produced to the assimilates available at an early stage of the generative phase.

7.4.2. Effects of pruning on fruit quality and variation in fruit quality

In both data sets, our results indicated that the fraction of plants pruned and pruning time had no consistent effect on fruit quality as well as on variation in fruit quality (Tables 7.3 and 7.4). The lack of any consistent effect on average quality was quite surprising because slip development overlaps with the fruit development and it was obvious that competition for available assimilates within a plant might take place between the developing slips and the fruit as is the case in many crops producing fruits and side shoots, e.g. in tomato (Heuvelink 1997) and tangelo (Morales et al. 2000). Also the size of the side shoots to be removed at pruning time (Figure 7.1) and their number (Figure 7.2) were considerable. To confirm the results, we additionally evaluated if the effect of pruning might have been different for plants having a different infructescence height at the moment of pruning. This was done by comparing the associations between infructescence height at pruning and fruit weight at harvest across individual plants in plots where no slips were pruned to those where all slips were pruned. Results showed very similar relationships with no differences in the R^2 adjusted, indicating again no effect of pruning and also no different effects in fruits from smaller and higher infructescence height (data not shown). The few significant effects shown by 9 out of the 240 P-values (Table 7.3) were always small (Table 7.4) and never consistently significant in both experiments (Table 7.3); they therefore most likely might have occurred by chance. The lack of an effect of pruning on quality is confirmed by the fact that the P-values in the data set containing only plants with slips were not clearly lower than the P-values in the data set including all plants.

Lack of effect of pruning on the average fruit quality attributes might be caused by the fact that slips become autotrophic at a very earlier stage of their development and that slips are only initiated when the plant is likely to support their growth. Over the time during generative phase, the fruits components (mainly the infructescence) are completely formed before the slips are initiated (Kerns et al. 1936). Since the fruit is a stronger sink (Malézieux et al. 2003), the fruit would tend to take more assimilates from the plant than the other sinks. In these conditions, the slips, at the earlier stage of their development, i.e. when they appear like a bud at the upper part of the peduncle, would also take assimilates from the plants but not in a way to limit the assimilates needed for the fruit development and growth. When the slips turn from the bud stage to the leaf production stage, they certainly start producing their own assimilates for their development and growth, hence they become autotrophic. This view agrees with absence of slips or the lower number of slips produced in less vigorous plants (Figure 7.1); it suggests that the pineapple plant adjusts the number of slips so that their need for assimilates at an early stage of development does not compromise the needs for assimilates of the fruit. The lack of a consistent significant effect of pruning on the variation in fruit quality attributes might be a direct consequence of the lack of effect of pruning on individual fruit quality.

7.5. Implications

Pruning of slips, either in selected plants or across all plants did not lead to a consistent significant improvement in the average quality of the harvested pineapple fruits nor in the variation in quality compared to no pruning. Practical implications of the results are that farmers are not recommended to prune slips. Further studies should be done to determine how the pineapple plant adjusts the available assimilates at flowering induction to the number of the side shoots to be produced.

Acknowledgements

The authors are thankful to the North-South Interdisciplinary Research and Education Fund (INREF) of Wageningen University and Research Centre and the Netherlands Organisation for International Cooperation in Higher Education (NUFFIC) for their financial support through the Co-Innovation for Quality in African Foods Chains (CoQA) program and the Netherlands Fellowship Programs (NFP), respectively.

References

Bartholomew, D. P., Malézieux, E., Sanewski, G. M., & Sinclair, E. (2003). Inflorescence and fruit development and yield. In D. P. Bartholomew, Paull, R.E. and Rohrbach, K.G (Ed.), *The pineapple: botany, production and uses* (pp. 167-202). Wallingford, UK: CABI Publishing.

Bartlett, M. (1936). The square root transformation in analysis of variance. *Supplement to the Journal of the Royal Statistical Society, 3*(1), 68-78.

Codex Alimentarius. (2005). Codex standard for pineapples. [Revision 1-1999, Amendment 1-2005]. Retrieved 10 January 2009, from www.codexalimentarius.net website: http://www.codexalimentarius.net/ web/more _info.jsp?id_sta=313 .

Fassinou Hotegni, V. N., Lommen, W. J. M., van der Vorst, J. G. A. J., Agbossou, E. K., & Struik, P. C. (2012). Analysis of pineapple production systems in Benin. *Acta Horticulturae, 928*, 47-58.

Gonzalez, R. (2009). *Data analysis for experimental design*. New York: Guilford Press.

Hepton, A. (2003). Cultural system. In D. P. Bartholomew, Paull, R.E. and Rohrbach, K.G (Ed.), *The pineapple: botany, production and uses* (pp. 109-142). Wallingford, UK: CABI Publishing.

Heuvelink, E. (1997). Effect of fruit load on dry matter partitioning in tomato. *Scientia Horticulturae, 69*(1), 51-59.

Kerns, K. R., Collins, J., & Kim, H. (1936). Developmental studies of the pineapple Ananas comosus (L.) Merr. *New Phytologist, 35*(4), 305-317.

Luning, P. A., & Marcelis, W. J. (2006). A techno-managerial approach in food quality management research. *Trends in Food Science & Technology, 17*(7), 378-385.

Malézieux, E., Côte, F., & Bartholomew, D. P. (2003). Crop environment, plant growth and physiology. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 69-107). Wallingford, UK: CABI Publishing.

Marler, T. E. (2011). Leaf gas exchange of pineapple as influenced by fruit. *Acta Horticulturae, 902*, 239-243.

Morales, P., Davies, F. S., & Littell, R. C. (2000). Pruning and skirting affect canopy microclimate, yields, and fruit quality of Orlando Tangelo. *HortScience, 35*(1), 30-35.

Murphy, S. (2012). *Changing perspectives: Small-scale farmers, markets and globalization (revised version)*. London/The Hague: International Institute for Environment and

Development and Humanist Institute for Development Cooperation IIED/Hivos.

Norman, J. C. (1976). Influence of slip size, deslipping and decrowning on the 'Sugarloaf' pineapple. *Scientia Horticulturae, 5*(4), 321-329.

Paull, R. E., & Reyes, M. E. (1996). Preharvest weather conditions and pineapple fruit translucency. *Scientia Horticulturae*, *66*(1), 59-67.

VSN International, (2012). GenStat for Windows 15th Edition. from http://www.vsni.co.uk/software/genstat?ref=www.genstat.co.uk

Wee, Y., & Ng, J. (1970). Decrowning and deslipping of the Singapore Spanish pineapple. *Tropical Agriculture, Trinidad and Tobago, 47*(1), 73-75.

Zúñiga-Arias, G., Ruben, R., & van Boekel, M. (2009). Managing quality heterogeneity in the mango supply chain: evidence from Costa Rica. *Trends in Food Science & Technology, 20*(3), 168-179.

CHAPTER 8

General discussion

This study, as stated in the general introduction section, is part of the research programme "Co-Innovation for Quality in African Food Chains" (CoQA), which is a collaboration of Wageningen University with four universities in Africa: Hawassa and Addis Ababa Universities in Ethiopia, University of Abomey-Calavi in Benin and the University of Fort Hare in South Africa. The objective of the COQA programme is to elaborate quality improvement options for one African food chain in each African country involved: pineapple in Benin, deciduous fruit in South Africa and potato in Ethiopia. In Benin, three PhD were involved in pineapple quality issues and its improvement at three different levels. The objective of the first PhD was to find options for the improvement of pineapple quality and its uniformity at field level as well as in related logistics processes in the pineapple chains; the second PhD aimed at improving the pineapple processing and marketing system, and the third PhD aimed at improving the governance structure in the pineapple supply chains. In the current thesis, related to the first PhD research, the general objectives were to:

(1) understand how fresh pineapple supply chains for different markets are organised in Benin, especially with regards to quality requirements for different actor groups in the chains, and identify the bottlenecks for delivering the right pineapple to the right market;

(2) increase the knowledge on the cultural practices in use by pineapple producers to produce pineapple fruits;

(3) understand how cultural practices affect pineapple quality and harvesting time; and

(4) propose and discuss the trade-offs between cultural practices to improve pineapple quality and its uniformity.

The general objectives were split into research questions (RQ1-6) that were answered in Chapters 2, 3, 4, 5, 6 and 7 respectively. In this Chapter 8, these findings are discussed and their implications for the pineapple community but also for people working in other agri-food products are presented. This general discussion concentrates on:

(1) the description of the present fresh pineapple chains including the logistic processes in the chains, and the bottlenecks for delivering high pineapple quality to customers;

(2) the description of the present pineapple production systems, and how the production systems hamper the production of high quality pineapple;

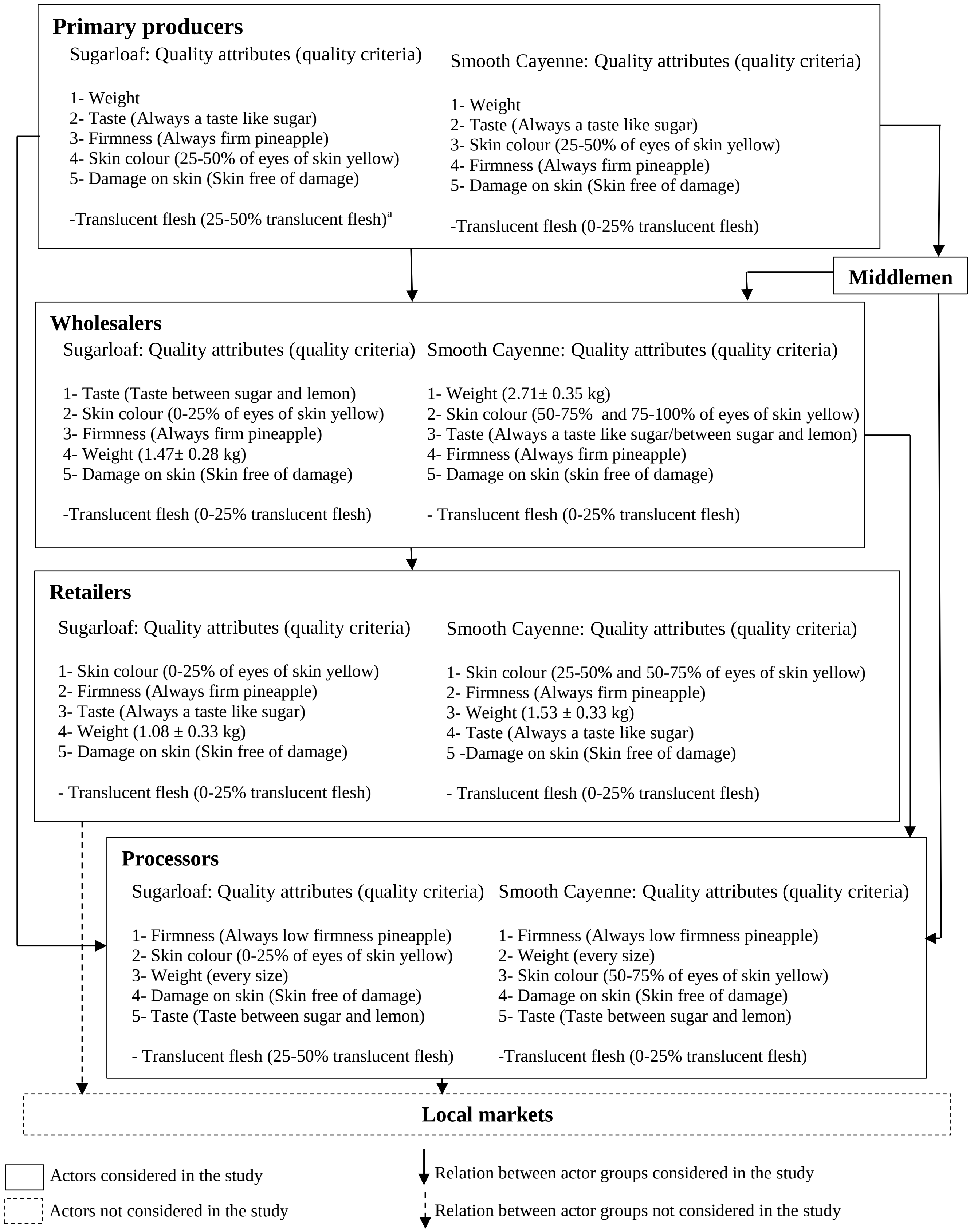
(3) the improvement options for high pineapple quality production; and

(4) the importance of the findings of the thesis and future research directions in pineapple.

8.1. Fresh pineapple supply chains in Benin and their bottlenecks

Pineapple is among the main crops in the southern part of Benin and is regarded a strategic crop for improving the livelihood of the actor groups involved in the pineapple sector (Tidjani-Serpos 2004). Results from the interviews (Chapter 2) indicated that there were two dominant pineapple cultivars in Benin: cvs Sugarloaf and Smooth Cayenne with Sugarloaf being the most cropped/sold cultivar for local and regional markets. Cv. Smooth Cayenne was the most exported cultivar to the international markets, especially the European markets (Chapter 2). Six main actor groups were operating in the fresh pineapple supply chains: primary producers, middlemen, wholesalers, retailers, processors and exporters. Chains to the different markets involved different number of actor groups: five actor groups were active in the chains to the local markets: primary producers, middlemen, wholesalers, retailers and processors (Figure 8.1); three actor groups were active in the chains to the regional markets: primary producers, middlemen, and wholesalers, and two actor groups were active in Benin in the chains to the European markets: primary producers and exporters (Figure 8.2; Chapter 2).

The term quality can be defined in different ways. In this thesis, quality was viewed as meeting or exceeding consumers expectation, in line with the definition of Evans and Lindsay (2002). The interviews conducted in Chapter 2 showed that, in the fresh pineapple supply chains, the bottlenecks for delivering the right pineapple to the right market were of three types: (1) the way the pineapple was produced, (2) the way people handled the fresh pineapple in the chains until it reached the customers or consumers and (3) the alignment across actor groups between the supplied and expected quality attributes and criteria. The bottlenecks related to the way the pineapple was produced will be described in the next section. Regarding the second type of bottlenecks, several reasons were found for not delivering the right pineapple to the right market. First, the interviews conducted in Chapter 2 revealed that during transport from one actor group to another, the fruits were disposed side by side, in trucks in non-controlled conditions and there were no cold facilities at the airport. Sivakumar et al. (2011) studying fresh agri-food chains (mango export chains) argued that improper transport conditions and the lack of control of the temperature during the transportation were factors reducing the quality of produced mango fruits including their shelf life. This could also be the case in the fresh pineapple supply chains in Benin where dense fruit packing under non-controlled transportation conditions may reduce the quality of the fruits (mainly the firmness) resulting in a delivery of fragile fruits with short shelf life to the



[a] Translucent flesh was not included in the list of quality attributes for ranking

Figure 8.1. Structure of the fresh pineapple chains to the local markets and quality attributes ranked from the most valued to the least valued as well as the desired quality criteria for each quality attribute per cultivar along the actor groups in the chains

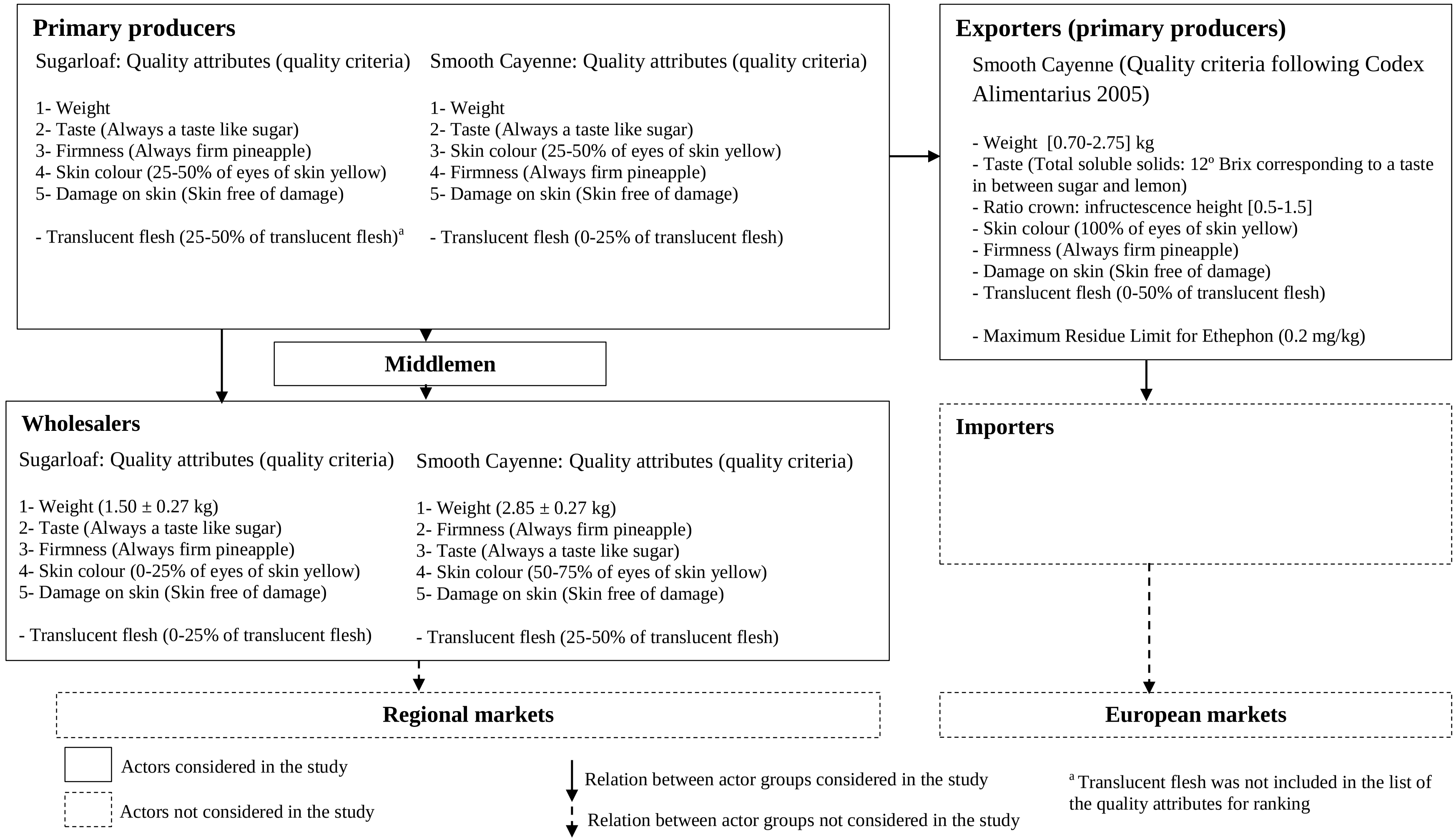


Figure 8.2. Structure of the fresh pineapple chains to the regional and European markets and quality attributes for cvs Sugarloaf and Smooth Cayenne ranked from the most valued to the least valued as well as the desired quality criteria for each quality attribute along the actor groups in the chains

next actor group in the chains. In addition, it was found that at wholesaler and processor's level, the pineapples were left in the sun, a practice that could affect negatively the fruit shelf life due to the exposure of the fruits to a high temperature. Second, the interviews conducted in Chapter 2 showed that exporters were facing problems with the unavailability of boxes for export, which limited their exporting capacity. Considering the third type of bottlenecks, the results showed a mismatch in pineapple quality supplied versus quality preferred by the actor groups in different markets as depicted in Figures 8.1 and 8.2 and a high heterogeneity in delivered pineapple quality (Chapter 2). This problem of mismatch in quality perception between actor groups in agri-food chains has also been reported by Ruben et al. (2007) who argued that the differences in actor groups' expectations in quality are the major problem in agri-food chains. The problem of the heterogeneity in pineapple quality is tackled in detail in the next sections.

8.2. Pineapple production systems in Benin and how they hamper the production of high quality pineapple

8.2.1. Pineapple production systems

Pineapple crop development and cultivation in Benin followed in general three main and partly overlapping development phases: (1) the vegetative phase between planting and flowering induction, (2) the generative phase between flowering induction and fruit harvest, and the (3) propagative phase during which side shoots are produced that can be used as planting material (Figure 8.3). The cultural practices carried out during these phases are described below.

The vegetative phase

In Benin, the vegetative phase between planting and flowering induction lasts 9-13 months (Chapter 3; Table 8.1).

Results from the interviews with pineapple farmers in Benin revealed that the types of planting material used were slips, hapas and suckers, with the slips being the common planting material used in cv. Sugarloaf and hapas and suckers being commonly used in cv. Smooth Cayenne (Chapter 3). The slips, hapas, and suckers were collected from plants on the

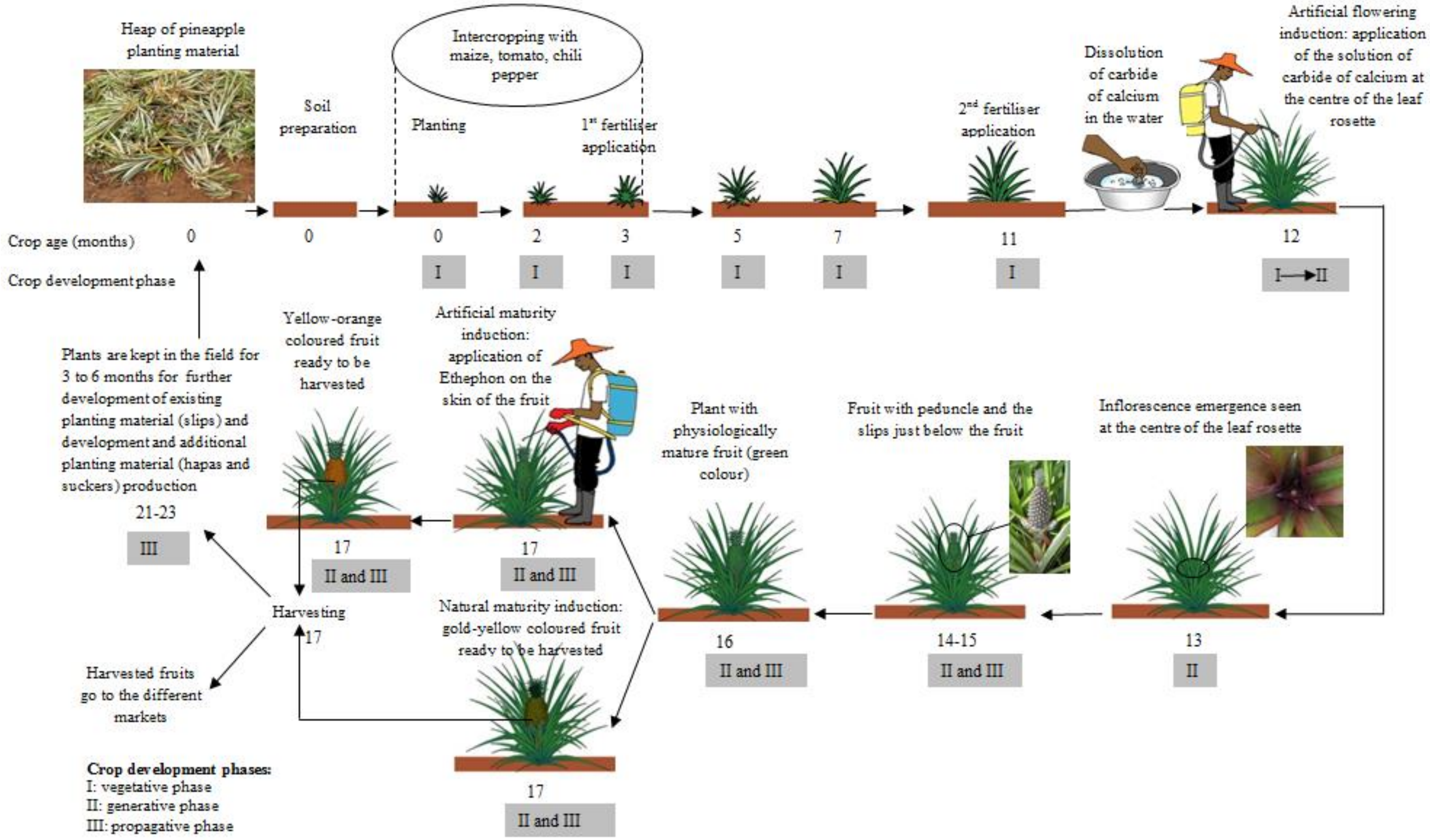


Figure 8.3. Overall time line of the pineapple growth and development cycle in Benin. Information on the number of months was taken from Fassinou Hotegni et al. (2012) and other chapter of this thesis. I: Vegetative phase, II: Generative phase, III: Propagative phase. Cultural practices during the vegetative and generative phases are described in Tables 1, 2 and 3

Table 8.1. Duration of the vegetative phase and cultural practices in cvs Sugarloaf and Smooth Cayenne during the vegetative phase in Benin (compiled data from Chapters 3 and 4)

Cultural practices	Cv. Sugarloaf	Cv. Smooth Cayenne
Duration of the vegetative phase (MAP[a])	9-13	9-13
Type of planting material	Slips	Hapas and suckers
Average planting density/range (plants/m^2)	8.6 ± 0.35 /4-17	5.2 ± 0.40/4-11
Frequent intercrop used	Maize	Maize
Intercropping duration (months)	3-4	3-4
First fertiliser application		
Type[b]	Urea (46N) + NPK (10-20-20)	Urea (46N) + NPK (10-20-20)
Application form	Solid at the base of the plants	Solid at the base of the plants
Application time (MAP)	3-4	3-4
Dose per plant (g Urea + g NPK)[c]	6 + 3	5 + 4
Second fertiliser application		
Type	NPK (10-20-20)	Urea (46N) + NPK (10-20-20)
Application time (weeks before flowering induction)	2-3	2-3
Dose per plant (g NPK[c] or g Urea + g NPK)	7	4 + 5
Flowering induction		
Compound	Carbide of calcium	Carbide of calcium
Concentration (g/l)	10	15
Application time (MAP)/average	9-13/12	9-13/12
Amount applied per plant per application (ml)[c]	50	50
Frequency of application (number of times)	1	3
Interval between application (days)	n.a.[d]	3

[a] MAP, months after planting
[b] used by most of pineapple producers
[c] average dose/amount applied by pineapple producers
[d] not applicable

fields from which the fruits already were harvested and stored in a pile before being planted, without sorting them according to size or type.

The preferred planting time was the long rainy season from March to July. At planting, most pineapple farmers arranged the plants in beds of two alternating rows at an average density of 8.6 ± 0.35 plants/m^2 (range 4-17 plants/m^2) in cv. Sugarloaf and 5.2 ± 0.40 plants/m^2 (4-11 plants/m^2) in cv. Smooth Cayenne (Chapter 3, Table 8.1).

Because of the long vegetative phase, more than 75% of the pineapple producers in Benin intercropped pineapple with maize (*Zea mays*), tomato (*Solanum lycopersicum*) or chili pepper (*Capsicum annuum*) (Figure 8.3; Chapter 3) during the rainy season just after pineapple planting. Maize was the most common intercrop, used by more than 75% of the farmers that used intercropping; the intercropping system used was the row-intercropping system with a duration of 3-4 months, corresponding to the development cycle of maize.

During the vegetative phase, most of the interviewed pineapple farmers indicated to carry out two fertiliser applications: the first at 3 months after planting and the second at 2 or 3 weeks before the artificial flowering induction time (Chapter 3).

Artificial flowering induction is a common practice in pineapple cultivation (Chen et al. 2011; Cunha 2005; Hepton 2003; Onaha et al. 1983; Reid and Wu 1991; Reinhardt et al. 2000) and is defined as the application of a growth regulator releasing acetylene or ethylene at the centre of the leaf rosette or on the whole plant to induce the flowering (Figure 8.3) in order to have more or less all plants flower at the same time. The interviews conducted in Chapter 3 revealed that pineapple was artificially induced in Benin to predict the harvesting time and harvest all fruits at the same time. Carbide of calcium (CaC_2), which releases acetylene, was used to artificially induce the flowering (Figure 8.3). The carbide of calcium was first dissolved in the water (Figure 8.3) to obtain a concentration of 10 g/l and 15 g/l in cvs Sugarloaf and Smooth Cayenne respectively. Fifty millilitre of the obtained solution was dropped into the centre of the leaf rosette once in cv. Sugarloaf and three times with an interval of three days in cv. Smooth Cayenne. Table 8.1 summarises the cultural practices applied in cvs Sugarloaf and Smooth Cayenne during the vegetative phase.

The generative phase

Results from the field experiments on commercial pineapple fields in Chapters 4, 5 and 7 revealed that the generative phase between flowering induction and fruit harvest of a pineapple crop in Benin lasts 150-157 days (Table 8.2). This phase is mainly characterised by the inflorescence emergence and the fruit development and growth. Inflorescence emergence occurred in most plants 34 days after flowering induction (Chapter 7). Within these 34 days, some producers growing cv. Smooth Cayenne applied K-based fertilisers.

When the pineapple fruit was physiologically mature, fruit maturity was artificially induced in cv. Smooth Cayenne. Artificial induction is a common practice in some pineapple cultivars and consists of applying an ethylene-releasing compound on the skin of the fruit (Chuenboonngarm et al. 2007; Crochon et al. 1981; Saltveit 1999). The main objective of artificial maturity induction was to accelerate the change in the skin colour from green to yellow resulting in a uniformly yellow skin colour as requested by importers in the European markets (Figure 8.2). Results from the interviews in Chapter 3 indicated that most of the Smooth Cayenne farmers induced fruit maturity at 143 days after flowering induction by applying Ethephon (Table 8.2). The Ethephon application was done twice with an interval of 4 days. The results also revealed that artificial maturity induction was not common practice in cv. Sugarloaf; instead, natural maturity induction was dominant (Chapter 3). Fruits were harvested by hand. In the case of natural maturation, fruits were harvested when 25% of the pineapple fruits in the field had started to change their skin colour from green to gold yellow (Figure 8.3). In the case of artificial maturation, fruits were harvested 7 days after the second application of the Ethephon (Table 8.2). No intercropping was used during the generative phase. Table 8.2 summarises the duration of the development and growth as well as the cultural practices applied in cvs Sugarloaf and Smooth Cayenne during the generative phase.

The propagative phase

The propagative phase is the period during which the side shoots that are produced are used as planting material. This phase starts during the generative phase and continue thereafter. Differences in the duration of the overlapping period between the propagative and the generative phases were found between cultivars. In cv. Sugarloaf, the two phases generally overlapped for a long period. The initiation of the slips used as planting material in cv. Sugarloaf occurred within 2-3 months after flowering induction) (Chapter 7) and their development and growth lasted up to 4-6 months after harvesting. The number of slips can reached 15 per plant at the time of harvesting of the fruit (Chapter 4). In cv. Smooth Cayenne the generative and propagative phases overlap for a short period of time: the initiation of the

Table 8.2. Duration of the development phases and cultural practices in cvs Sugarloaf and Smooth Cayenne during the generative phase in Benin (compiled data from Chapters 3, 4 and 7)

Cultural practices	Cv. Sugarloaf	Cv. Smooth Cayenne
Duration generative phase (days after flowering induction)	150-157	154
Inflorescence emergence (days after flowering induction)	34	34
Fertiliser application[a]		
Type	n.a.[b]	K_2SO_4
Application form	n.a.	solid at the base of the plants
Application time (days after flowering induction)	n.a.	1-34
Dose per plant (g K_2SO_4)	n.a.	d.a[c]
Artificial maturity induction		
Compound	n.a.	Ethephon
Concentration (ml/l)	n.a.	14
Application time (days after flowering induction)	n.a.	143
Amount applied per plant (ml)[d]	n.a.	3.5
Frequency of application (number of times)	n.a.	2
Interval between application (days)	n.a.	4
Harvesting time (days after flowering induction)	150-157	153

[a] only few producers applied fertilisers during the generative phase in cv. Smooth Cayenne. It was worth to mention it although not widely applied
[b] not applicable
[c] data not available
[d] average dose/amount applied by pineapple producers

hapas used as planting material generally occurred 4 months after flowering and lasted up to 6 months after harvesting of the fruit. The number of hapas was either 1 or 2 per plant at the time of harvesting of the fruit. The initiation of suckers often occurred after harvesting of the fruits and lasted up to 6 months after harvesting of the fruit. In cv. Smooth Cayenne, the leaves of the harvested plants were trimmed and the peduncle was cut to promote the production of numerous hapas and suckers. In cv. Sugarloaf no cultural practice was applied after harvesting of the fruits (Table 8.3).

Table 8.3. Duration of side shoots development and cultural practices in cvs Sugarloaf and Smooth Cayenne during the propagative phase in Benin (compiled data from Chapters 3 and 7 and author's own observations)

	Cv. Sugarloaf	Cv. Smooth Cayenne
Slip		
Initiation (MAF[a])	2-3	n.a.[b]
Duration of development (months)	6-9	n.a.
Hapas		
Initiation (MAF)	n.a.	4
Duration of development (months)	n.a.	7
Sucker		
Initiation (MAF)	n.a.	≥5
Duration of development (months)	n.a.	6
Leaves trimmed and peduncle cut after harvesting of the fruit	No	Yes

[a] MAF, months after flowering induction
[b] not applicable

Other cultural practices

In Benin, the total number of weeding in pineapple cultivation ranged from 10-15 (Chapter 3).

In some countries, the pineapple crop is kept in the field after harvesting for another round of fruit production. This is called a ratoon crop. The number of side shoots is reduced and one is left on the plant to produce another fruit (Malézieux and Bartholomew 2003). In Brazil where such a practice is common, the ratoon cycle often lasts 12 to 14 months (Reinhardt et al. 2000). This practice was not applied in the pineapple cultivation in Benin, as revealed by the interviews conducted in Chapter 3.

Overall, the production systems in Benin were found to be very diverse with large differences in planting density, flowering induction time, and fertiliser application time; for that reason it was not possible to categorise the different production systems into realistic clusters (Chapter 3).

8.2.2. How do production systems hamper the production of high quality pineapple with low heterogeneity in quality?

The way the pineapple was produced in Benin affected negatively the pineapple quality and its uniformity. Cultural practices that could hamper the pineapple quality and its uniformity comprised the planting material management at planting, the planting density, the intercropping practice, the fertiliser management, the artificial flowering and maturity induction practices, the harvesting practices, and the overall diversity in the production systems. Other factors not directly related to the cultural practices were the lack of producers affiliation to producer's organisation, the lack of producer's capacity building and the lack of financial assistance.

Planting material management

After removal of the side shoots to be used as planting material from the plants, it was common practice in the planting material management to keep the planting material unsorted in heaps on the cleared field until the end of soil preparation (Chapter 3). The heaping may lead to some planting material to dry out. In addition, the longer the planting material remains at the bottom of the heap, the higher will be the risk of rotting and/or fungus development (Rohrbach and Johnson 2003); hence producers will be unable to use these shoots or if used they may not survive. This practice may therefore lead to variation in the planting material, especially when stored longer under these conditions.

The planting materials were planted as a mixture of sizes (both cultivars) and types (Smooth Cayenne). A higher weight of the planting material at planting time resulted in a higher vigour of the plants at the flowering induction when compared to lower weight of planting material (Chapter 6). It was found that more vigorous plants at flowering induction gave fruits with higher heavier infructescence and fruit weights, longer infructescence height, but a shorter crown height and smaller ratio crown: infructescence height (Chapter 4), hence fruits from heavy planting material gave better average fruit quality than those from light planting material. In the experiments in Chapter 6 which included a mixture of planting material weights as carried out by pineapple producers, results indicated that plants from a mixture of slips of different weights in cv. Sugarloaf gave fruits with higher crown height and higher ratio crown: infructescence height than fruits from plants from heavy planting material with a narrow weight range and consequently a lower percentage of fruits met the export criteria to Europe (Chapter 6). In addition, in cv. Sugarloaf, plants from mixed slip weights gave fruits with higher coefficient of variation in infructescence height than those from plants from heavy slips with a narrow weight range. In cv. Smooth Cayenne, plants from mixed planting material weight within a planting material type gave fruits with lower infructescence and fruit weights, lower infructescence height and higher ratio crown: infructescence height than fruits from plants from heavy hapas or suckers with a narrow weight range (Chapter 6). The reduction in the average quality attributes in cv. Smooth Cayenne did not affect the percentage of fruits exportable to Europe; but, the income from selling fruits from plants from mixed planting material weights in cv. Smooth Cayenne will be lower than that from the fruits from heavy planting material with a narrow weight range since the price of pineapple at export is kilogram-based. In cv. Smooth Cayenne, fruits from mixed planting material weights gave fruits with a higher coefficient variation in fruit height than those from plants from heavy planting material weight with a narrow weight range (Chapter 6).

Another factor hampering the production of high pineapple quality and linked to the planting material management and indicated by pineapple producers during the interviews in Chapter 3 was the unavailability of planting material, mainly the hapas and suckers in cv. Smooth Cayenne. The problem of unavailability of the vegetative propagules has been raised by Fujardo (2010) who listed it as a factor limiting producers to be competitive. Singh (2002) argued that the availability of good planting material increases the chance to successfully assure the crop production.

Planting density, intercropping and fertiliser management in pineapple production

Increasing planting density reduces individual plant growth (Zhang and Bartholomew 1995; Zhang and Bartholomew 1992), reduces average fruit weight (Dodson 1968; Hepton 2003) and reduces the total soluble solids concentration (Bartholomew et al. 2003; Mustaffa 1988). Increasing planting density was also found to reduce fruit length (Norman 1978) and to increase the fruit acidity (Dodson 1968) leading to fruits with a taste comparable to lemon taste. Therefore, the wide range in planting density may increase the heterogeneity between lots in fruit weight, total soluble solids and fruit length, which makes it more difficult for exporters to collect pineapple from individual producers to meet the demand of the importers. High planting densities, however, also reduce the number of side shoots per plant (Dodson 1968) that can be used as planting material.

Intercropping systems only work if the intercrop is of the right type (Singh et al. 1961), i.e. if the competition for available resources between the crops is reduced to a minimum. Uriza-Ávila et al. (2005) studied the effect of the intercropping of pineapple plants with some short cycles crops such as maize, or tomato and chili pepper in Mexico. They intercropped pineapple planted at a density of 3.5 plants/m^2 with these crops at planting time and found that the quality of the pineapple fruit was not affected. In Benin the average planting density observed was about the double of that used by Uriza-Ávila et al. (2005) (Table 8.1) and the average quality of the fruit might be affected by intercropping due to competition for resources (light and nutrients). This competition for resources may have occurred between the intercrop and the pineapple crop in Benin leading to a reduction in the pineapple growth and a reduction in the vigour of the pineapple plants at flowering induction and consequently to a lower average fruit quality.

During the interviews conducted in Chapter 3, pineapple producers indicated the unavailability of fertilisers as a factor hampering the production of high pineapple quality. Such a situation of lack of fertilisers would lead some pineapple producers not to apply any fertilisers at all after intercropping the pineapple with maize. It is well known that during the development and growth, maize uptake in N and K is high and that the pineapples' requirements in N and K increase significantly from 4 months after planting until flowering induction (Malézieux and Bartholomew 2003). N and K are the two most important elements influencing the pineapple fruit quality: N increases the plant growth and consequently the fruit weight; K increases the total soluble solids (Malézieux et al. 2003; Spironello et al. 2004) and the vitamin C concentration in the fruit (Spironello et al. 2004). So, in conditions where no fertilisers would be applied to the pineapple crop after the intercropping with maize, the vigour of the plants will be negatively affected and the plants will yield poor average fruit quality.

Artificial flowering, maturity induction and harvesting practices

Artificial flowering and maturity induction (Figure 8.3) were also among the cultural practices hampering the production of high pineapple quality as identified in the field experiments in Chapter 5. Artificial flowering induction led to fruits with lower infructescence weight and height, heavier and higher crown, higher ratio crown: infructescence height and lower proportion of fruits exportable to Europe than natural flowering induction (Chapter 5) which suggests that the full potential of the plants was not achieved under the present practices. When considering the present European market criteria for the two cultivars (cv. Smooth Cayenne is exported to European market but cv. Sugarloaf not), the quality attributes limiting the percentage of fruits exportable to Europe from artificially induced plants were a too high ratio crown: infructescence height (higher than 1.5) in cv. Sugarloaf; in cv. Smooth Cayenne both a too high ratio crown: infructescence height and a too low total soluble solid (TSS) concentration (less than 12 ˚Brix) were the limiting quality attributes (Chapter 5). The field experiments described in Chapter 5 revealed that artificial flowering induction increased also the heterogeneity in infructescence and fruit weights and in infructescence height in cv. Sugarloaf. Artificial maturity induction reduced the total soluble solids (Chapter 5) thus reduced also the proportion of fruits exportable to Europe.

Harvesting of fruits with natural maturity induction as done in cv. Sugarloaf i.e. harvesting all fruits at the same time was found to reduce the average TSS compared to the harvesting of individual fruits at their optimum harvesting time (Chapter 5).

Diversity of the production systems

The high diversity of the pineapple production systems across producers (Chapter 3) could also be a reason for the high heterogeneity in pineapple quality across different lots. In the current fresh pineapple chains exporters often collected pineapple from other producers to meet the demand in fruits of importers (Chapter 2). Such practice would increase the heterogeneity in the pineapple lot as argued by Willems (2007), reducing the capacity of producers to export fruit to Europe.

Other factors hampering the production of high pineapple quality

Other factors hampering the production of high pineapple quality were the lack of producers affiliation to producers organisation, lack of producer’s capacity building and the lack of financial assistance.

The interviews conducted in Chapter 2 revealed that 58% of producers were not member of a producer's organisation. As argued by Kaganzi et al. (2009) and Markelova et al. (2009) the lack of being a member of a producer's organisation weakens the producers capacity to produce better fruit quality, to access to the markets and to respond to the costumers demand in volume of fruits

More than 50% of the pineapple producers surveyed in Chapter 2 agreed that they did not receive training on pineapple cultural practices. The negative effects of the lack of producers training on the quality of the produced product has been reported by Subramanian and Matthijs (2007) and Cetinkaya (2011) who characterised the lack of producer training as a critical factor for high quality production.

Recent studies by Arinloye (2013) on the pineapple supply chains in Benin revealed the difficulty in accessing financial support as one of constraints faced by pineapple producers. The reason of such difficulty in getting financial support is related to the long pineapple production cycle (Figure 8.3) and the high interest rate (36-47%) set by micro finances structures (Arinloye 2013).

8.3. Improvement options for high pineapple quality production

Based on the bottlenecks in the chains and the constraints in the pineapple production two improvement options are needed:

(1) improvement options along the whole fresh pineapple chains; and
(2) improvement options in pineapple production depending on the trade-offs across them

8.3.1. Improvement options along the whole fresh pineapple chains in Benin

For the effectiveness of the fresh pineapple chains in supplying high pineapple quality with low uniformity in quality, several actions need to be taken. First, there is a need to improve the transport and storage conditions in the chains especially the export chain. Putting the pineapples in stackable crates during transport in the trucks might help to reduce the effects that the present transportation conditions might have on the average fruit quality. For the export chains, there is a need to establish a cold pineapple chain i.e. from harvesting until the airport, and at the airport, the pineapple should be under a temperature of 8 ^{o}C as is the case in the fresh pineapple export chains in Ghana (Fassinou Hotegni 2013). In the local and regional markets, there is a need to implement cold storage facilities to allow wholesalers and processors to keep the quality of the pineapple for a long time. Second, the government should either make the boxes needed by exporters available in the country or stimulate the private sector to take it up. This would create opportunities for off-farm employment and incite exporters to continue producing pineapple for European countries and even target other lucrative markets. The pineapple exporters can also create their association so as to group their production and their demand fertilisers and boxes instead of making independent orders and independent supply in pineapple, so that the transactions costs would be reduced. Finally, there is a need to implement a platform that would facilitate cooperation and information exchange between actor groups in the chain. Such platform should be a melting pot where actor groups can meet and discuss about their quality attributes and criteria as well as constraints for not producing/delivering the right quality.

8.3.2. Improvement options in pineapple production depending on the trade-offs

For pineapple producers to produce pineapple with high average quality and low heterogeneity in fruit quality, there is a need to propose improvement options to the present cultural practices (Table 8.4). First, there is a need to make the planting material available and improve the planting material management before planting. The planting material can be made available by either producer's organisations or CARDER (Regional Action Centre for Rural Development, formerly CeRPA; a structure aiming at training and providing advices to producers) through the implementation of specialised planting material production sites (Table 8.4) that will aim at producing and selling uniform and heavy planting material to producers with a narrow weight range of [325-550] g in cv. Sugarloaf and [400-675] g in cv. Smooth Cayenne, no matter the type of planting material. The field experiments in Chapter 6 showed plants from heavy planting material to yield a better average fruit quality than those from light planting material. An addition to the implementation of the planting material production sites could be the application of N based fertilisers (Urea for instance) to the plants after fruit harvest, to promote the growth of side shoots and increase their vigour, and use the heavy shoots as planting material for pineapple production. Producers should be encouraged to only harvest the planting material when they are ready to plant to avoid having to store the planting material in a heap. In Ghana for instance, the harvested planting material is disposed with the basal part skyward for 2 days to prevent fungal growth before planting (Fassinou Hotegni 2013). Such practice can also be applied in the planting material management in pineapple production systems in Benin.

At planting, a reduction of the planting density might improve the fruit quality but at the same time the yield might be reduced. Since pineapple was intercropped during the first 3-4 months, especially with maize which has a high N and K uptake, fertiliser application to the maize plants would decrease the possible competition for nutrients that might occur between the two crops. After the harvesting of the maize, the replenishment of the uptake in N and K by the maize plants is important. So, a second application of fertiliser at 4-5 months after pineapple planting, but this time to the pineapple plant would help to accelerate the growth of the pineapple plants and improve their vigour since pineapple requirements in N and K increase with growth until flower induction (Malézieux et al. 2003). A third fertiliser application before the flowering induction, mainly K-based fertiliser would help improve not only the vigour of the plants -because K improves the photosynthesis through increase in plant mass and the leaf area (Teixeira et al. 2011) and consequently the fruit weight- but also the total soluble solids (Spironello et al. 2004). Moreover, the weight of the side shoots - the slips in cv. Sugarloaf - will also be positively impacted since the field experiments in Chapter 4 showed a positive association between the plant vigour at flowering induction and the weight of the slips produced, and thus on the production of vigorous planting material for the next growing season.

Natural flowering induction was found to improve the average fruit quality as well as the proportion of fruits exportable to Europe when compared to artificial flowering induction (Chapter 5), but the trade-offs between the two practices were that natural flowering induction increased the vegetative phase by at least 200 and 150 days in cv. Sugarloaf and Smooth Cayenne respectively, increased the number of harvesting of the fruits up to 20 times and the reduce the proportion of plants producing fruits when compared to artificial flowering induction (Chapter 5); all these will increase the total pineapple production cost. Therefore natural flowering is not a suitable alternative to the present practice. An alternative to the artificial flowering induction would be to increase the duration of the vegetative phase by flowering induction at a later, optimum time. The field experiments in Chapter 6 showed that, an increase in the duration of the vegetative phase by up to 2 months compared to the (farmers') practice of inducing flowering after 12 months significantly reduced the crown and fruit heights and ratio crown: infuctescence height in fruits from light and mixed slip weights in cv. Sugarloaf (Chapter 6); consequently, the proportion of fruits exportable to Europe increased. In fruits from heavy slips this improvement in fruit quality attributes did not significantly affect the proportion of exportable fruits; thus plants from heavy planting material can be induced at 12 months after flowering induction.

Table 8.4. Improvement options in pineapple production systems in Benin

Bottlenecks in pineapple quality and uniformity in pineapple quality production	Improvement option
Unavailability of planting material	Establishment of planting material production sites
Planting material in heaps before planting[a]	Spread on the mother plant with the basal part directed skyward to allow drying of the basal part
Mixture of planting material of different weights within planting material types[a]	Planting material sorting at planting Use of heavy planting material with a narrow weight range: [325-550] g of slip in cv. Sugarloaf and [400-675] g of hapas or [400-675] g of suckers or mixed hapas and suckers weighting [400-675] g
High planting density[b]	Reduction of the planting density
Intercropping[b]	Fertiliser application during the intercropping period
Artificial flowering induction[a]	Natural flowering induction / flowering induction at optimum time
Artificial maturity induction in cv. Smooth Cayenne[a]	Natural maturity induction in cv. Smooth Cayenne
Harvesting practices[a]	Harvesting of individual fruits at optimum harvesting time
Planting material production in harvested plants kept in the field[b]	Fertiliser application to the harvested plants

[a] found in the study
[b] not found in the study but regarded as practices that could reduce the fruit quality

In cv. Smooth Cayenne, an increase in the vegetative phase up to 74 days did not have a big effect on the improvement in the quality attributes. This suggests that in cv. Smooth

Cayenne a vegetative period of 12 months was long enough to achieve maximum average quality in most planting material classes.

After flowering induction, the inflorescence emerged and side shoots started to develop, but at different positions and time for the different cultivars. Existing literature indicates both a positive effect of pruning slips on the average fruit weight (Norman 1976) and a negative effect (Marler 2011). Results from the field experiments in Chapter 7 with cultivar Sugarloaf revealed that neither slips pruning at 2 or 3 months after flowering induction, nor pruning slips on the least advanced plants only did affect the average quality and the heterogeneity in fruit quality (Chapter 7). So, slips pruning in cv. Sugarloaf could not be used as improvement tools; instead, it is advised to pineapple producers not to prune the slips not only because of the absence of the effect on the fruit quality attributes but also because of the loss in valuable planting material.

Natural maturity-induced fruits had higher TSS than artificially maturity-induced fruits; consequently a higher proportion of fruits were found to be exportable to Europe in two out of the four experiments conducted in Chapter 5. In cv. Smooth Cayenne, where natural maturity induction was not a common practice (Chapter 3), after artificial flowering induction producers had to wait at least 11 days longer compared to the artificial maturity induction to obtain the naturally matured fruits with higher TSS. So, natural flowering induction could be an option to improve the TSS and therefore improve the proportion of fruits exportable to Europe.

Individual harvesting of the fruits from naturally maturity induced fruits in cv. Sugarloaf at optimum maturity i.e. when 25% of the skin of an individual fruit had changed from green to gold yellow can be a suitable practice to improve the total soluble solids in the fruits compared to harvesting of all fruits at the same time as revealed by the field experiments in Chapter 5.

All pineapple producers (including the exporters) should be encouraged by the CeRPA to become part of a producers’ organisation so that they can improve their production, share information on best cultural practices, improve their access to different markets (Markelova et al., 2009) and even buy fertilisers at reduced cost and store them, thus reducing the problem of unavailability and high costs of fertilisers.

8.4. Importance of findings and future research directions in pineapple

8.4.1. Importance of the findings of the thesis

In the thesis, the bottlenecks in the supply chains as well as the production systems levels have been described, discussed and improvement options have been suggested. Based on the importance of the pineapple in Benin and precisely in the southern part of Benin, there is no doubt that if the improvement options highlighted and discussed in this thesis are combined with those from the two other PhDs in the CoQA project and taken into consideration, the whole pineapple sector will be highly improved.

For the scientific community, the importance of the thesis can be found at different levels. First the framework adapted to the study and used in Chapter 2 to analyse the chains and find the bottlenecks for not delivering high pineapple quality with low heterogeneity in fruit quality can be used to diagnose other agri-food chains mainly in developing countries where there is a great need to understand and improve the agri-food chains. Second, it has been demonstrated in the thesis that the heterogeneity in plant vigour -expressed in the cross product number of functional leaves × the D-leaf length- at artificial flowering induction was associated with the heterogeneity in external fruit quality attributes at harvest. Such results have not been reported before in the literature. In addition, the cross product number of functional leaves × the D-leaf length was found to better express the plant vigour than the number of functional leaves and the D-leaf length separately which are frequently used to predict the fruit weight. Third, the work presented in the thesis is the first, to our knowledge to establish the trade-offs between artificial and natural inductions in a pineapple crop. Such knowledge is important to understand the potential of the plants and evaluate the gap in the quality attributes in order to design best agricultural practices. Fourth, there have been discussions and conflicting findings on the effect of slips pruning on the average fruit quality. In this thesis, the effects of slips pruning on average fruit quality attributes was established and it became clear that slips pruning had no effect on average fruit as well as heterogeneity in pineapple quality. Finally, the findings of the thesis indicated that the weight of the planting material had significant effects on the average fruit quality attributes including the crown height and the ratio crown: infructescence height. This implies that at planting time, producers can have an idea of the quality of the fruit they will obtain depending on the weight of the planting material used.

From the above we conclude that the findings of the thesis are important for the pineapple sector in Benin and also for the scientific community working on pineapple or other agri-food products. For the pineapple sector in Benin, the findings of the thesis are important for the improvement of the pineapple production systems and the pineapple supply chains in Benin.

8.4.2. Future research directions

Based on the bottlenecks found in the thesis and the improvement options studied and not studies there is a need to pursue research on:

(1) the determination of optimal planting density for higher average pineapple quality production in Benin;
(2) the intercropping effect on the pineapple vigour and the average pineapple quality as well as the uniformity in quality;
(3) the effect of plant-specific fertiliser application on quality and the uniformity in fruit quality attributes;
(4) the costs and benefits of the different improvement options to study whether that cost is offset by the price the actor in the chains are willing to pay for the pineapple produced; and
(5) the designing of a pineapple model capable to predict the average fruit quality.

References

Arinloye, D.-D. A. A. (2013). *Governance, marketing and innovations in Beninese pineapple supply chains: a survey of smallholder farmers in South Benin.* PhD Thesis, Wageningen University, The Netherlands. (ISBN 978 94 6173 534 8)

Bartholomew, D. P., Paull, R. E., & Rohrbach, K. G. (2003). *The pineapple: botany, production and uses*. Wallingford, UK: CABI Publishing.

Cetinkaya, B. (2011). Developing a sustainable supply chain strategy. In B. Cetinkaya, R. Cuthbertson, G. Ewer, T. Klaas-Wissing, W. Piotrowicz & C. Tyssen (Eds.), *Sustainable supply chain management: practical ideas for moving toward best practice* (pp. 17-55). Berlin, Heidelberg: Springer-Verlag.

Chen, S.-J., Shü, Z.-H, Kuan, C. S., & Tang, C.-H. (2011). Current situation of pineapple production in Chinese Taipei. *Acta Horticulturae, 902*, 63-67.

Chuenboonngarm, N., Juntawong, N., Engkagul, A., Arirob, W., & Peyachoknakul, S. (2007). Changing in TSS, TA and sugar contents and sucrose synthase activity in ethephon-treated 'Pattavia' pineapple fruit. *Kasetsart Journal (Natural Sciences), 41*, 205-212.

Codex Alimentarius. (2005). Codex standard for pineapples. [Revision 1-1999, Amendment 1-2005]. Retrieved 10 January 2009, from www.codexalimentarius.net website: http://www.codexalimentarius.net/ web/more _info.jsp?id_sta=313

Crochon, M., Teisson, C., & Huet, R. (1981). Effet d'une application d'ethrel avant la recolte sur la qualite gustative des ananas de Cote d'Ivoire. *Fruits, 36*, 409-415.

Cunha, G. A. P. (2005). Applied aspects of pineapple flowering. *Bragantia, 64*(4), 499-516.

Dodson, P. (1968). Effects of spacing, nitrogen and hormone treatment on pineapple in Swaziland. *Experimental Agriculture, 4*(2), 103-115.

Evans, J. R., & Lindsay, W. M. (2002). *The management and control of quality*. Cincinnati, USA: West Publishing Company.

Fassinou Hotegni, V. N. (2013). Exploring the fresh pineapple export chains in Ghana. *Spring Newsletter 2013. West African Research Association*,13-14.

Fujardo, J. (2010). *Quality declared planting material: protocols and standards for vegetatively propagated crops*. Rome: FAO.

Hepton, A. (2003). Cultural system. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 109-142). Wallingford, UK: CABI Publishing.

Kaganzi, E., Ferris, S., Barham, J., Abenakyo, A., Sanginga, P., & Njuki, J. (2009). Sustaining linkages to high value markets through collective action in Uganda. *Food Policy, 34*(1), 23-30.

Kerns, K. R., Collins, J., & Kim, H. (1936). Developmental studies of the pineapple *Ananas comosus* (L.) Merr. *New Phytologist, 35*(4), 305-317.

Malézieux, E., & Bartholomew, D. P. (2003). Plant nutrition. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 143-165). Wallingford, UK: CABI Publishing.

Malézieux, E., Côte, F., & Bartholomew, D. P. (2003). Crop environment, plant growth and physiology. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 69-107). Wallingford, UK: CABI Publishing.

Markelova, H., Meinzen-Dick, R., Hellin, J., & Dohrn, S. (2009). Collective action for smallholder market access. *Food Policy, 34*(1), 1-7.

Marler, T. E. (2011). Leaf gas exchange of pineapple as influenced by fruit. *Acta Horticulturae, 902*, 239-243.

Mustaffa, M. M. (1988). Influence of plant population and nitrogen on fruit yield and quality and leaf nutrient content of 'Kew' pineapple. *Fruits, 43*(7), 455-458.

Norman, J. C. (1976). Influence of slip size, deslipping and decrowning on the ‘Sugarloaf’ pineapple. *Scientia Horticulturae, 5*(4), 321-329.

Norman, J. C. (1978). Responses of Sugarloaf pineapple, *Ananas comosus* (L.) Merr. to plant population densities. *Gartenbauwissenschaft, 43*, 237-240.

Onaha, A., Nakasone, F., & Ikemiya, H. (1983). Induction of flowering with oil-coated calcium carbide in pineapples. *Journal of the Japanese Society for Horticultural Science, 52*(3), 280-285.

Reid, M. S., & Wu, M. J. (1991). Ethylene in flower development and senescence. In A. K. Mattoo & J. C. Suttle (Eds.), *The plant hormone ethylene* (pp. 215-234). Boca Raton, FL: CRC Press Inc.

Reinhardt, D., Souza, L. d. S., & Cabral, J. (2000). Abacaxi. Produção: aspectos técnicos. Cruz das Almas. *Embrapa Mandioca e Fruticultura, 7*, 41-44.

Rohrbach, K. G., & Johnson, M. W. (2003). Pests, diseases and weeds. In D. P. Bartholomew, R. E. Paull & K. G. Rohrbach (Eds.), *The pineapple: botany, production and uses* (pp. 203-251). Wallingford, UK: CABI Publishing.

Ruben, R., van Tilburg, A., Trienekens, J., & van Boekel, M. (2007). Linking market integration, supply chain governance, quality, and value added in tropical food chains. In R. Ruben, M. van Boekel, A. Van Tilburg & J. Trienekens (Eds.), *Tropical food chains: governance regimes for quality management* (pp. 13-46). Wageningen: Wageningen Academic Publishers.

Saltveit, M. E. (1999). Effect of ethylene on quality of fresh fruits and vegetables. *Postharvest Biology and Technology, 15*(3), 279-292.

Siderius, C. P., & Krauss, B. H. (1938). Growth phenomena of pineapple fruits. *Growth, 1*, 181-196.

Singh, B. P. (2002). Nontraditional crop production in Africa for export. In J. W. Janick (Ed.), *Trends in new crops and new uses.* (pp. 86-92). Alexandria: ASHS Press.

Singh, K., Grewal, K., & Jawanda, J. (1961). Improved cultural practices for citrus and mangoes. *Punjab Horticulture Journal, 1*, 135-145.

Sivakumar, D., Jiang, Y., & Yahia, E. M. (2011). Maintaining mango (*Mangifera indica* L.) fruit quality during the export chain. *Food Research International, 44*(5), 1254-1263.

Spironello, A., Quaggio, J. A., Teixeira, L. A. J., Furlani, P. R., & Sigrist, J. M. M. (2004). Pineapple yield and fruit quality effected by NPK fertilization in a tropical soil. *Revista Brasileira de Fruticultura, 26*(1), 155-159.

Subramanian, U., & Matthijs, M. (2007). *Can sub-Saharan Africa leap into global network trade?*. Policy research working paper No. 4112. Washington, D.C: The World Bank.

Teixeira, L. A. J., Quaggio, J. A., Cantarella, H., & Mellis, E. V. (2011). Potassium fertilization for pineapple: effects on plant growth and fruit yield. *Revista Brasileira de Fruticultura, 33*(2), 618-626.

Tidjani-Serpos, A. (2004). *Contribution de la production d'ananas à l'amélioration des conditions de vie des producteurs: cas des Communes d'Abomey-Calavi et d'Allada dans le département de l'Atlantique (Sud-Bénin).* Thèse d'Ingénieur, Université d'Abomey-Calavi (UAC), Cotonou, Benin.

Uriza-Ávila, D., Rebolledo-Martínez, A., & Rebolledo-Martínez, L. (2005). Short cycle crops intercropped with pineapple: an option to increase productivity. *Acta Horticulturae, 666*, 287-294.

Willems, S. (2007). Meeting and beating markets requirement: competing in a big league. In R. Ruben, M. van Boekel, A. Van Tilburg & J. Trienekens (Eds.), *Tropical food chains: governance regimes for quality management* (pp. 69-84). Wageningen: Wageningen Academic Publishers.

Zhang, J., & Bartholomew, D. (1995). Effect of plant population density on growth and dry-matter partitioning of pineapple. *Acta Horticulturae, 425*, 363-376.

Zhang, J., & Bartholomew, D. P. (1992). Simulation of pineapple growth, development and yield. *Acta Horticulturae, 334*, 205-220.

Summary

Summary

Poor average quality of agri-foods and heterogeneity in quality are important issues especially in less developed countries producing tropical fruits. This is also the case for pineapple in Benin where less than 2% of produced pineapple is exported to international markets. The remaining pineapple is delivered to local and regional markets with lower average quality standards; nevertheless, the bulk of this pineapple loses its quality before being consumed. At the onset of this study, it was unknown how the fresh pineapple supply chains were organised, how the pineapple was grown and how cultural practices affected quality and its uniformity. Therefore the first objective of this study was to understand how fresh pineapple supply chains were organised. The second objective was to increase the knowledge on the agronomic tools used by pineapple producers. Next, the agronomic factors affecting the pineapple quality were studied and trade-offs between different cultural practices were analysed.

In *Chapter 2*, the fresh pineapple supply chains were analysed and the bottlenecks for delivering high pineapple quality to different markets were highlighted. First, 54 semi-structured interviews were held with key informants to obtain an overview of the actor groups in the chains, their activities, the information and product flow between actors and the most important quality attributes. Based on the results of the semi-structured interviews and from literature studies, a framework was designed and adapted to the study. Second, 173 structured interviews using in-depth questionnaires were held with different supply chain actors. The questions in the in-depth questionnaires were constructed based on the framework selected.

Results indicated that pineapples were sold to three markets: the local, regional (neighbouring countries) and European markets. Six actor groups prevailed in the fresh pineapple chains: primary producers, exporters, wholesalers (those selling at local markets and those selling at regional markets), processors, retailers, and middlemen. Two pineapple cultivars were grown: Sugarloaf and Smooth Cayenne, with Sugarloaf being dominant in local and regional markets. Cv. Smooth Cayenne is mainly sold to European markets. Cv. Sugarloaf was produced by 97% of the growers and cv. Smooth Cayenne by 30%. Results indicated that two types of fresh pineapple supply chains prevailed to reach the local and regional markets: (1) chains where primary producers directly deliver their pineapples to retailers, wholesalers, and processors, and (2) chains where pineapples are delivered to these groups through middlemen. For the European markets, the exporters sent their own pineapples to importers, but incidentally bought pineapples from other primary producers

(non-exporters) to meet demand.

When analysing these fresh pineapple supply chains, several constraints were found. First, storage and transport conditions were not appropriate to maintain pineapple quality. Thirty-two per cent of the wholesalers and 70% of the processors stored the pineapple in piles in sunlight without covering them. There were no storage facilities with temperature control at the airport for export pineapple. The pineapples were stacked side by side during the transport by trucks without temperature control. Second, there was poor information exchange between producers and other actor groups since 30% of the primary producers producing Sugarloaf and 33% of the primary producers producing Smooth Cayenne had no selling agreement with customers at the time of harvesting of the fruits. Third, more than 50% of primary producers agreed on not receiving training on pineapple cultural practices. Fourth, exporters indicated that there were no boxes for export in the country and that they were obliged to go to neighbouring countries to get them. Fifth, there were no standard quality attributes defined for the local and regional markets; quality attributes were those set by the actor groups except the middlemen whose role was to serve as an intermediate between primary producers and other actor groups in the chains. Quality attributes for the European market were those set by the Codex Alimentarius (2005), requiring minimum levels for fruit weight, the ratio crown: infructescence height, and total soluble solids (TSS), and low heterogeneity within each quality attribute. Sixth, there was a mismatch in the most important quality attributes across actor groups in the chains (except between primary producers and wholesalers in regional markets for cv. Sugarloaf). In addition, there was a mismatch between the quality supplied and the preferred quality criteria within each quality attribute across actor groups in the local and regional markets. For instance, the study showed that wholesalers preferred heavier pineapples than retailers regardless the cultivar sold. So, in the chains where wholesalers supplied the retailers with fresh pineapple, the wholesalers will always fail to meet the retailers' requirement. In addition, exporters faced difficulties to meet the pineapple quality export criteria. Actor groups also indicated the heterogeneity in pineapple quality to be high and problematic and wholesalers indicated reducing the price of the pineapple in case of poor average quality.

The findings emphasized the need to analyse the pineapple production systems to assess which practices contributed to this high heterogeneity in pineapple quality and the reduced overall pineapple fruit quality. This was done in Chapter 3 through interviews with pineapple farmers, and in Chapters 4, 5 and 6 by means of experiments on commercial pineapple fields.

In *Chapter 3*, the pineapple production systems of cvs Sugarloaf and Smooth Cayenne were described based on interviews with 100 pineapple producers. The results were analysed and constraints reducing the quality of pineapple produced were identified. In cv. Smooth Cayenne cultivation, hapas and suckers were used as planting material while in cv. Sugarloaf, slips were the dominant planting material used. Slips, hapas and suckers are side shoots, originating from different parts of the plants. The slips, hapas, and suckers were all collected from plants on the fields from which the fruits had already been harvested. At planting, most pineapple farmers arranged the plants in beds of two rows at an average density of 8.6 ± 0.35 plants/m^2 (range 4-17 plants/m^2) in cv. Sugarloaf and 5.2 ± 0.40 plants/m^2 (4-11 plants/m^2) in cv. Smooth Cayenne. Eighty nine percent of pineapple producers intercropped pineapple with maize (*Zea mays*), tomato (*Solanum lycopersicum*) or chili pepper (*Capsicum annuum*). Fertilisers were generally applied at 3-4 months after planting and at 2 or 3 weeks before artificial flowering induction. Artificial flowering induction was carried out in both cultivars between 9-13 months after planting by applying carbide of calcium (CaC_2) at the centre of the leaf rosette to induce all plants, synchronise flowering and make the harvest moment synchronous and predictable. Within 34 days after artificial flowering induction K_2SO_4 was applied by 60% of Smooth Cayenne producers and 32% of Sugarloaf producers. Fruit maturity was often induced artificially by the growers in cv. Smooth Cayenne by applying Ethephon at 143 days after flowering induction. The role of Ethephon is to accelerate the change of the skin colour of the fruit from green to yellow. In cv. Sugarloaf, natural maturity induction was common practice. Fruits were hand harvested. Within each cultivar, the production systems were very diverse with regards to planting density, fertiliser application time and type, and timing of artificial flowering induction.

The constraints indicated by pineapple producers reducing the quality of the pineapple were unavailability of appropriate planting material, unavailability and high cost of fertilisers, and heterogeneity in planting material weight. In addition, when analysing the cultural practices, the artificial flowering and maturity inductions practices were regarded as constraints since plants differ in development stage at flowering induction time and fruits differ in development stage at maturity induction time. These practices of artificial flowering and maturity inductions were investigated in Chapters 4 and 5.

In *Chapter 4*, four experiments (two per pineapple cultivar) were carried out in commercial pineapple fields to assess if heterogeneity in vigour of individual plants within a field at the time of artificial induction was associated with heterogeneity in fruit quality at harvest. The number of functional leaves (NL), the D-leaf length (the length of the longest leaf) (DL) and the cross product of number of functional leaves × the D-leaf length (NL × DL) were used to express the plant vigour at artificial flowering induction time. Fruit quality measured at harvesting time included external and internal quality attributes. Results showed that the heterogeneity in fruit weight, infructescence weight and height, number of fruitlets, and ratio crown height: infructescence height in pineapple crops were a direct consequence of the heterogeneity in plant vigour at the time of artificial flowering induction of these crops. Higher plant vigour was associated with higher fruit and infructescence weights, higher infructescence height, more fruitlets and lower ratio crown: infructescence height. The cross product NL × DL was found to be the vigour variate explaining the largest proportion of variance in these quality attributes. Plant vigour at flowering induction was weakly and not consistently associated with TSS, juice pH and the proportion of translucent flesh. These results imply that cultural practices reducing the variation in the vigour of the plant (NL × DL) at flowering induction may yield fruits with lower variation in infructescence and fruit weights, infructescence and fruit height and ratio crown: infructescence height, and number of fruitlets. The results of the study in Chapter 4 also revealed that in cv. Sugarloaf the slip weight also was (weakly) associated with the variation in fruit weight, infructescence weight and fruit height in addition to the plant vigour variate NL × DL.

In *Chapter 5*, trade-offs between flowering and maturity induction for pineapple quality were investigated using the same four experiments as in Chapter 4. In these experiments, eight treatments were derived from the combination of two flowering induction practices (artificial and natural), two maturity induction practices (artificial and natural) and two harvesting practices (farmer's harvesting practice and optimum harvesting practice). Under the natural flowering induction treatments, plants were let to flower by themselves. Under the natural maturity induction treatments, fruits were let to mature by themselves. The farmer's harvesting time was defined as the moment when 25% of the fruits in a plot had changed their skin colour from green to yellow; all fruits in the plot were harvested. The optimum harvesting time was the moment when 25% of the skin of an individual fruit had changed from green to yellow. Each treatment was applied to 240 plants split into plots of 60 plants each. Results indicated that most natural flowering inductions occurred during the coldest months (August and December) in cv. Sugarloaf and the wettest (reduction of the hours of solar radiation) month (June) in cv. Smooth Cayenne. Furthermore, plants exposed to artificial flowering induction gave fruits with (1) lower infructescence weight and height, (2) heavier and longer crown, and (3) a higher ratio crown: infructescence height than the natural flowering-induced plants. Consequently, the percentage of fruits exportable to Europe from artificially-induced plants was lower than that of fruits from naturally induced-plants. Moreover, artificial flowering induction increased the variation in infructescence and fruit weights and in infructescence height in cv. Sugarloaf.

The results also showed that fruits exposed to artificial maturity induction had a lower TSS concentration than fruits with natural maturity induction; artificial maturity induction reduced significantly the percentage of fruits meeting the export criteria to Europe in two out of the four experiments. Natural maturity induced fruits harvested at optimum harvesting time gave fruits with higher TSS than those harvested at farmers harvesting time.

The results from Chapter 5 also revealed that the reason why a high percentage of fruits was not exportable to Europe when artificial flowering induction was carried out was a ratio crown: infructescence height higher than 1.5 in cv. Sugarloaf; in cv. Smooth Cayenne both the ratio crown: infructescence being higher than 1.5 and a TSS less than 12 ˚Brix reduced the proportion of fruits exportable to Europe. When natural flowering would be viewed as an option to improve the pineapple quality, the costs to obtain naturally flowering-induced fruits were a prolonged vegetative phase by at least 200 days in cv. Sugarloaf and 150 days in cv. Smooth Cayenne; an increase in the number of harvesting of the fruits up to 20 times and a decrease in the proportion of plants producing fruits when compared to artificial flowering-induced plants. The trade-offs of obtaining the sweeter fruits from the natural maturity induction was that the period from flowering induction until harvest was at least 1 day longer in cv. Sugarloaf (where natural maturity induction is already a common practice as found in Chapter 3) and 11 days longer in cv. Smooth Cayenne. So, to improve the TSS, natural maturity induction could be an option. Natural flowering induction cannot be an improvement option for the other quality attributes, given the listed trade-offs. This implies that other improvement options needed to be investigated. These improvement options were studied in Chapters 6 and 7.

In *Chapter 6*, the effects of weight and type of planting material on the average fruit quality and variation in fruit quality were studied. Two experiments were conducted (one per cultivar). Planting material was collected from farmer’s fields, and sorted in three weight classes: light, mixture of weights, and heavy. In cv. Smooth Cayenne where hapas and suckers are used as planting material, the effect of the type of the planting material was also studied. Hapas and suckers were mixed following farmers' practice. Flowering induction was carried out following farmers' practice at 12 months after planting or at an optimum induction time determined from data collected from the experiments in Chapter 4. For NL × DL higher than 1235 leaf.cm for cv. Sugarloaf and 2300 leaf.cm for cv. Smooth Cayenne there was a high chance to obtain high volume of fruits falling within the range of fruit weights suitable for exportation to European markets. These values of plant vigour were used to define the optimum flowering induction time and the plants were induced when 75% of the plants under the optimum flowering induction treatments showed a plant vigour equal to or higher than 1235 leaf.cm for cv. Sugarloaf and 2300 for cv. Smooth Cayenne.

Results revealed that, when flowering was induced 12 months after planting, the weight of planting material affected the fruit quality at harvesting time. The use of heavy planting material in the two cultivars gave fruits with heavier infructescence and fruit weights, longer infructescence height, but a shorter crown height and smaller ratio crown: infructescence height than fruits from light planting material. Heavy planting material gave fruits with lower variation in infructescence height than other planting material weights classes, and increased also the proportion of fruits exportable fruits to Europe compared to other weight classes in cv. Sugarloaf. Using heavy slips for cv. Sugarloaf could be an improvement option to reduce the ratio crown: infructescence height indicated as a limiting quality criterion for export in Chapter 5. In cv. Smooth Cayenne the type of planting material had no effect on average fruit quality attributes except that hapas gave fruits with shorter crown than suckers. Flowering induction at optimum flowering induction highly improved average fruit quality in fruits from light and mixed slip weights, hence the proportion of exportable fruits to Europe in fruits from these planting materials increased. Flowering induction at optimum time also increased the proportion of fruits exportable to Europe in fruits from a mixture of heavy hapas plus suckers.

In *Chapter 7*, it was studied if selective slip pruning in cv. Sugarloaf could reduce the heterogeneity in pineapple quality and improve the overall quality level. Two experiments were conducted on commercial fields with cv. Sugarloaf. Four treatments were applied: (1) no plants pruned (control); (2) slips pruned on the one-third least developed plants; (3) slips pruned on the two-thirds least developed plants; (4) slips pruned on all plants. The height of the developing infructescence at the moment of pruning was used as the criterion to identify the least developed plants. The four treatments were applied at 2 or 3 months after inflorescence emergence. Inflorescence emergence is the moment when the inflorescence can be seen at the heart of the leaf rosette. It was found that slip pruning had no consistent effects on the average pineapple quality and also no consistent effects on the variation in fruit quality attributes. This suggests that slip pruning is not an improvement option for the average pineapple quality and the heterogeneity in quality.

Chapter 8 discusses the findings of the present study and proposes options to improve the average pineapple quality and its uniformity at the pineapple production systems level as well as at the supply chain level. At the production systems level, the unavailability of planting material at planting would reduce the capacity of the producers to increase the volume of their production, so, there is a need to establish planting material production sites that will provide producers with heavy planting material. Artificial flowering induction practice reduced the average fruit quality and the proportion fruits exportable to Europe, but Sugarloaf plants from heavy planting material can be induced at 12 months after planting without quality loss. In cv. Smooth Cayenne, natural maturity induction would help improve the TSS and consequently the proportion of fruits exportable to Europe, but, since natural maturity induction occurs progressively and not uniformly, maturity induction at the moment when natural maturity starts would be an option to both increase the TSS and improve the uniformity in fruit skin colour. In addition, producers should be regularly trained on best pineapple cultural practices so that the diversity in the production systems would be reduced.

At the supply chain level, the improvement of the transport and storage facilities would help to keep the quality of produced pineapple. It is advised to put the pineapple in stackable crates during the transport in the trucks and to implement a cold pineapple chain i.e. a chain where the temperature is controlled and set at 8 ˚C from harvesting until airport. There is also a need to implement cold storage facilities at the airport to maintain pineapple quality. Unavailability of boxes for export reduces capacity of exporters to increase volume of exported pineapple. So, the government should provide boxes in the country or encourage the private sector to invest in their production. Being member of a producer's organisation has many advantages such as reduction of transaction cost, improvement of market access, etc. Producers including exporters should be encouraged by the CARDER (Regional Action Centre for Rural Development) to be part of a producer organisation. There is also a need to establish a platform where all actor groups in the chains can meet and discuss issues related to market access and share quality attributes and criteria. Such a platform would help to reduce the mismatch between the quality supplied and the preferred quality.

This thesis has contributed to identifying bottlenecks for production of uniform pineapples of high quality in Benin. It suggests improvement options that can be used to increase the fruit quality attributes for the markets and also the proportion of fruits exportable to Europe.

Résumé

Résumé

La mauvaise qualité des produits agro-alimentaires ainsi que l'hétérogénéité en qualité constituent des problèmes importants, principalement dans les pays sous-développés producteurs de fruits tropicaux. C'est le cas de l'ananas produit au Bénin dont seulement 2% est exporté vers les marchés internationaux. Le reste de la production, dont la qualité est inférieure au regard des standards, est vendu sur les marchés locaux et régionaux ; de plus, une partie importante de cet ananas est perdue avant la consommation. Au début des études entrant dans le cadre de la présente thèse, il n'y avait pas d'information sur (1) l'organisation des chaînes de production et de commercialisation de l'ananas frais, (2) les pratiques culturales de l'ananas, et, (3) l'effet des pratiques culturales sur la qualité et l'uniformité de la production. Par conséquent, le premier objectif de la présente thèse était de comprendre l'organisation des chaînes de production et de commercialisation de l'ananas frais. Le second objectif était d'inventorier les pratiques culturales utilisées par les producteurs d'ananas. Le troisième objectif consistait à étudier et analyser les pratiques culturales qui affectent la qualité de l'ananas.

Dans le *Chapitre 2*, les chaînes de production et de commercialisation de l'ananas frais ont été analysées et les contraintes à l'approvisionnement des différents marchés en ananas de très bonne qualité ont été mises en exergue. Dans un premier temps, 54 entretiens semi-structurés ont été conduits avec des personnes ressources afin d'obtenir une vue générale des groupes d'acteurs dans les chaînes, de leurs activités, du flux d'information et de produit entre les acteurs, et des attributs de qualité les plus importants par groupe d'acteur. A partir de des résultats de ces entretiens et des études bibliographiques, le cadre logique a été élaboré et adapté à l'étude. Dans un second temps, 173 entretiens structurés ont été conduits avec les différents acteurs de la chaîne de production et de commercialisation. Le questionnaire utilisé lors des entretiens structurés a été conçu sur la base du cadre logique précédemment élaboré.

Les résultats indiquent que les ananas produits au Bénin sont vendus sur trois types de marché : le marché local, le marché régional (pays voisins du Bénin) et les marchés Européens. Six groupes d'acteurs ont été recensés dans les chaînes de production et de commercialisation de l'ananas frais à savoir : les producteurs, les exportateurs, les grossistes (opérant sur les marchés locaux et régionaux), les transformateurs, les détaillants et les intermédiaires. Deux variétés d'ananas sont cultivées : la Cayenne lisse et le Pain de sucre, avec une dominance du pain de sucre sur les marchés locaux et régionaux et de la Cayenne lisse sur les marchés Européens. Le Pain de sucre était produit par 97% des producteurs contre 30% pour la Cayenne lisse. Pour l'approvisionnement des marchés locaux et régionaux, deux types de chaîne de production de commercialisation d'ananas frais ont été identifiées : (1) les chaînes où les producteurs offrent directement leur production d'ananas aux détaillants, aux grossistes et aux transformateurs, et, (2) les chaînes où l'approvisionnement des différents groupes d'acteurs se fait par le biais des intermédiaires. Pour les marchés Européens, les exportateurs envoient leur production aux importateurs, mais, parfois, ajoutent la production des producteurs à leur production dans le but de répondre aux quantités d'ananas demandés par les importateurs.

L'analyse des chaînes de production et de commercialisation de l'ananas a révélé plusieurs contraintes. Les résultats ont révélé que les conditions de stockage et de transport n'étaient pas appropriées pour maintenir la qualité de l'ananas. Trente-deux pour cent des grossistes et 70% des transformateurs stockent les ananas en piles au soleil sans couverture. Aucune infrastructure de stockage muni d'un système de contrôle de température n'existait à l'aéroport pour l'exportation de l'ananas. Les ananas sont entassés côte à côte durant le transport par les bâchées sans contrôle de température. Les résultats ont également révélé qu'il y avait très peu d'échanges d'information entre les producteurs et les autres groupes d'acteurs puisque 30% des producteurs de Pain de sucre et 33% des producteurs de Cayenne lisse ne disposaient pas de contrat de vente avec les clients au moment de la récolte des fruits. En plus, 50% des producteurs étaient d'accord sur le fait qu'ils n'ont reçu aucune formation sur les pratiques culturales de production de l'ananas. Autre contrainte, les exportateurs indiquaient que l'approvisionnement en cartons pour l'ananas à l'export n'était guère possible au Bénin mais seulement dans les pays avoisinants. Au niveau des marchés locaux et régionaux, il n'existait pas d'attributs de qualité définis ; dans ces marchés, les attributs de qualité étaient ceux des groupes d'acteurs à l'exception des intermédiaires dont le rôle est de mettre en relation les producteurs et les autres groupes d'acteurs des différentes chaînes. Les attributs de qualité des marchés européens sont ceux qui ont été définis par le Codex Alimentarius (2005). Il s'agit des valeurs minimales de masse de fruits, du ratio longueur couronne : longueur du fruit sans la couronne, de la teneur totale en solides solubles, et d'une faible hétérogénéité au niveau des fruits pour chaque attribut de qualité. Les résultats ont aussi révélé qu'il y avait une discordance dans les attributs de qualité les plus importants entre les groupes d'acteurs dans les chaînes (sauf entre les producteurs et les grossistes sur les marchés régionaux pour le Pain de sucre). En plus, il y avait une discordance entre la qualité de

l'ananas offert et le critère de qualité désiré pour chaque attribut de qualité entre les groups d'acteurs sur les marchés locaux et régionaux. Par exemple, l'étude a montré que les grossistes préfèrent des ananas plus gros comparés aux détaillants quelque soit la variété d'ananas vendue. Ainsi, dans cette situation, dans les chaînes où les grossistes approvisionnaient les détaillants en ananas frais, ils ne satisferont jamais leurs exigences. De même, les exportateurs n'arrivaient pas à satisfaire les exigences de qualité à l'export. Les groupes d'acteurs indiquèrent aussi le caractère élevé et problématique de l'hétérogénéité de la qualité de l'ananas. Les grossistes indiquèrent une réduction du prix de l'ananas quand la qualité de l'ananas n'est pas bonne.

Les résultats obtenus mettent l'accent sur la nécessité d'analyser les systèmes de production dans le but de déterminer quelles pratiques culturales contribueraient à cette forte hétérogénéité de la qualité et à la faible qualité de l'ananas. Ces aspects ont été étudiés dans le Chapitre 3 à travers des entretiens avec les producteurs d'ananas, et dans les Chapitres 4, 5 et 6 par le biais d'expérimentations dans des champs d'ananas à but commercial.

Dans le *Chapitre 3,* les systèmes de production du Pain de sucre et de la Cayenne lisse ont été décrits sur la base des interviews de 100 producteurs d'ananas. Les résultats ont été analysés et les contraintes qui réduisent la qualité de l'ananas produit ont été identifiées. Dans la culture de la Cayenne lisse, les rejets de type cayeux de tige (hapas) et cayeux souterrains (suckers) sont utilisés dans la propagation alors que pour le Pain de sucre, les bubilles (slips) sont les plus utilisés. Les bubilles, les cayeux de tiges et les cayeux souterrains sont des rejets latéraux provenant de différentes parties des plants. Ces trois rejets sont collectés sur les plants dont les fruits ont déjà été récoltés. A la plantation, la majorité des producteurs d'ananas disposent les plants en bandes alternées de deux lignes à une densité moyenne de 8,6 ± 0,35 plants / m^2 (entre 4 et 17 plants / m^2) pour le Pain de sucre contre 5,2 ± 0,40 plant / m^2 (entre 4 et 11 plants / m^2) pour la Cayenne lisse. Quatre-vingt neuf pour cent des producteurs d'ananas cultivent l'ananas en association avec le maïs (*Zea mays*), la tomate (*Solanum lycopersicum*) ou le piment (*Capsicum annuum*). Les engrais sont généralement appliqués 3 à 4 mois après plantation et 2 à 3 semaines avant l'induction florale artificielle. Pour les deux variétés, l'induction florale artificielle est effectuée 9-13 mois après la plantation par application de carbure de calcium (CaC_2) au cœur de la plante. Ainsi, toutes les plantes sont induites et la floraison est synchronisée rendant la récolte groupée et prévisible. Trente-quatre jours après l'induction florale artificielle, le sulfate de potassium (K_2SO_4) est appliqué par 60% des producteurs de Cayenne lisse et 32% des producteurs de Pain de sucre. La maturité

des fruits est souvent induite artificiellement par les producteurs de Cayenne lisse par application de l'Ethéphon, 143 jours après l'induction florale. L'Ethéphon a pour rôle d'accélérer le changement de couleur de la peau du fruit passant du vert au jaune. Pour le Pain de sucre, l'induction naturelle de la maturité est pratique courante. Les fruits sont récoltés manuellement. Au niveau de chaque variété, les systèmes de production sont très variés en fonction de la densité à la plantation, du moment fertilisation, du type de fertilisant, et du moment d'induction florale artificielle.

Selon les producteurs d'ananas, les contraintes qui expliqueraient la réduction de la qualité de l'ananas sont le manque de rejets appropriés, l'indisponibilité et le coût élevé des fertilisants, et l'hétérogénéité de la masse des rejets. De plus, l'analyse des pratiques culturales révèle que les pratiques artificielles d'induction de la floraison et de la maturité sont considérées comme des contraintes puisque l’induction se fait souvent sur des plants et des fruits à différent stades de développement. Les pratiques artificielles d'induction de floraison et de maturité ont été étudiées dans les Chapitres 4 et 5.

Dans le *Chapitre 4*, quatre expérimentations (deux par variétés) ont été conduites dans des champs de production d'ananas à but commercial pour évaluer si l'hétérogénéité en vigueur des plants individuels d'ananas au moment de l'induction florale artificielle, induit une hétérogénéité de la qualité du fruit à la récolte. Le nombre de feuilles fonctionnelles (NF), la longueur de la feuille D (LD) et le produit nombre de feuilles fonctionnelles × longueur de la feuille D (NF × LD) sont utilisés pour exprimer la vigueur du plant au moment de l'induction florale artificielle. Les paramètres de qualité externes et internes sont mesurés au niveau de chaque fruit. Les résultats ont montré que l'hétérogénéité de la masse des fruits avec et sans la couronne, de la longueur du fruit sans la couronne, du nombre d’yeux sur le fruit et du ratio longueur couronne : longueur fruit sans couronne étaient une conséquence directe de l'hétérogénéité de la vigueur des plants au moment de l'induction florale artificielle. Une grande vigueur des plants est associée à une masse de fruit avec et sans couronne élevée, à une grande longueur du fruit sans la couronne, à plus d’yeux sur l’ananas et à un faible ratio longueur couronne : longueur fruit sans couronne. Le produit NF × LD est la variable (exprimant la vigueur) qui expliquait une large variabilité des attributs de qualité de l'ananas pré-cités. La vigueur de la plante à l'induction florale est faiblement (ou pas) associée avec la teneur en solides solubles, le pH du jus et la proportion de chair translucide. Ces résultats impliquent que les pratiques culturales réduisant la variation de la vigueur des plants (NF × LD) au moment de l'induction florale pourraient engendrer une faible hétérogénéité de la

masse des fruits avec et sans la couronne, dans la longueur des fruits avec et sans la couronne, dans le ratio longueur couronne : longueur fruit sans couronne et le nombre d'yeux sur le fruit. Les résultats présentés dans le Chapitre 4 révèlent aussi que pour le Pain de sucre, le masse des bubilles est (faiblement) associé à la variation de la masse du fruit avec et sans la couronne et à la longueur du fruit en plus de la variable NF × LD exprimant la vigueur des plants.

Dans le *Chapitre 5*, les pratiques d'induction florale et d'induction de la maturité sur la qualité de l'ananas ont été étudiées en utilisant les mêmes expérimentations décrites dans le Chapitre 4. Ainsi, huit traitements ont découlé de la combinaison de deux pratiques d'induction florale (artificielle et naturelle), deux pratiques d'induction de maturité (artificielle et naturelle) et deux pratiques de récolte des fruits (récolte suivant les pratiques paysanne et récolte optimale). Sous les conditions d'induction florale naturelle, les plantes fleurissaient d'elles-mêmes. Sous les conditions d'induction naturelle de la maturité, les fruits murissaient d'eux-mêmes. L'indicateur de récolte suivant les pratiques paysannes était défini comme le moment où la couleur de la peau de 25% des fruits dans chaque unité parcellaire passait du vert au jaune ; à ce moment, tous les fruits au niveau de l'unité parcellaire étaient récoltés. L'indicateur de récolte optimale était défini comme le moment où 25% de la peau de chaque fruit passait du vert au jaune-or. Chaque traitement est appliqué sur 240 plants divisés en 4 unités parcellaires de 60 plants chacun. Les résultats ont montré que la survenue de l'induction florale naturelle intervient dans les mois les plus froids de l'année (Août et Décembre) pour le Pain de sucre et le mois le plus humide de l'année (Juin) pour la Cayenne lisse. Comparativement aux plantes dont la floraison est naturellement induite, celles induites artificiellement produisent des fruits avec (1) une masse et une longueur faibles de fruit sans la couronne, (2) des couronnes plus longues et plus lourdes, et 3) un ratio longueur couronne : longueur fruit sans la couronne plus élevé. Par conséquent, le pourcentage de fruits exportables en Europe issu des plants à floraison induite artificiellement est plus faible que celui issu des plants induits naturellement. De plus, l'induction artificielle de la floraison accroît l'hétérogénéité en masse des fruits avec et sans la couronne, ainsi que celle de la longueur des fruits sans la couronne dans le cas du Pain de sucre.

Les fruits dont la maturité a été artificiellement induite ont une teneur en solides solubles plus faible que celle des fruits à maturité naturellement induite. L'induction artificielle de la maturité réduit significativement le pourcentage de fruits conformes aux normes d'exportation vers le marché Européen dans deux des quatre expérimentations. Les fruits dont la maturité a été artificiellement induite et qui sont récoltés au moment optimal de récolte ont une teneur en solides solubles plus élevée que celle des fruits récoltés suivant la pratique paysanne.

Les principales raisons qui justifient le pourcentage élevé de fruits non exportable vers l'Europe pour les plants dont la floraison a été artificiellement induite, sont le fait d’un ratio longueur couronne : longueur fruit sans la couronne supérieur à 1,5 pour le Pain de sucre, et, à la fois d’un ratio longueur couronne : longueur fruit sans la couronne supérieur à 1.5 et d’une teneur en solides solubles inférieur à 12 °Brix pour la Cayenne lisse. L'induction florale naturelle pourrait donc être perçue comme un moyen d’améliorer la qualité de l'ananas avec comme contraintes: (1) une phase végétative prolongée de 200 jours pour le Pain de sucre et 150 jours pour la Cayenne lisse; (2) un accroissement jusqu'à vingt du nombre de récolte, et une réduction de la proportion de plants qui fructifient. Le prix à payer pour obtenir des fruits plus sucrés issus d’une maturation naturelle, est un allongement de la période allant l’induction florale à la récolte des fruits d’au moins une journée dans le cas du Pain de sucre (où la maturation naturelle des fruits est déjà pratique courante) et de 11 jours dans le cas de la Cayenne lisse. Par conséquent, l’induction naturelle de la maturité des fruits pourrait constituer une option d’amélioration du total solubles solides. Ceci implique que des voies d’amélioration des autres critères de qualité devraient être investiguées. Ces voies ont été étudiées dans les Chapitres 6 et 7.

Dans le *Chapitre 6*, les effets du type et de la masse des rejets sur la qualité moyenne et la variation de la qualité du fruit ont été étudiés. Deux expérimentations ont été conduites à raison d'une par variété. Les rejets ont été collectées au niveau des champs des producteurs et catégorisés en trois classes de masse: les rejets légers, les rejets lourds et le mélange des deux types précédents. Dans le cas de la Cayenne lisse, où les rejets de types cayeux de tige et cayeux souterrains sont utilisés, l’effet du type de rejet a été étudié. La pratique paysanne a été simulée en mélangeant les deux types de rejet. L’induction florale a été effectuée à 12 mois après la plantation comme le font la majorité des producteurs, ou, à un moment d’induction optimale des plants déterminé à partir des résultats issus du Chapitre 4. Ainsi avec des valeurs de NF × LD supérieures à 1235 feuilles.cm pour le Pain de sucre et 2300 feuilles.cm pour la Cayenne lisse, la probabilité d'obtention d'un volume élevé de fruits ayant une masse adéquate pour l'exportation vers les marchés européens est forte. Ces valeurs de vigueur des plants ont permis de définir le moment optimal d'induction qui est le moment où

75% des plants ayant reçu le même traitement parviennent à une vigueur supérieure ou égale à 1235 feuilles.cm pour le Pain de sucre et 2300 pour la Cayenne lisse.

Les résultats ont montré que lorsque l'induction florale est réalisée à 12 mois après plantation, la masse des rejets affecte la qualité des fruits à la récolte. En effet, pour les deux variétés, les lourds rejets donnent une masse élevée de fruit avec ou sans couronne, un fruit sans la couronne plus long et un faible ratio longueur couronne : longueur fruit sans la couronne. Les lourds rejets de Pain de sucre produisent des fruits avec une faible variation de la longueur des fruits sans la couronne, et augmentent le pourcentage de fruits exportable vers l'Europe comparé aux autres masses de rejets. Les lourds rejets peuvent donc être utilisés pour améliorer le ratio longueur couronne : longueur fruit sans la couronne qui est le facteur limitant l'exportation et révélé dans le Chapitre 5. Par contre, le type de rejet (dans le cas de la Cayenne lisse) n'a aucun effet sur les attributs de qualité moyenne des fruits à l'exception du fait que les cayeux de tiges donnent des fruits à couronnes plus courtes que les cayeux souterrains. L'induction florale au moment optimale, améliore fortement la qualité moyenne des fruits issus des bubilles légers ou mélangés, et de ce fait accroît la proportion de Pain de sucre exportables vers l'Europe. L'induction florale au moment optimal accroît alors la proportion de fruits exportables vers l'Europe pour les fruits issus des mélanges de lourds rejets de cayeux de tiges et souterrains.

Dans le *Chapitre 7*, l'effet de la suppression sélective des bubilles de Pain de sucre sur l'hétérogénéité de la qualité de l'ananas et l'amélioration de la qualité de façon globale a été étudié. Deux expérimentations ont été conduites sur des champs à but commercial de Pain de sucre. Quatre traitements ont été appliqués : (1) pas de suppression de bubilles sur les plants (Témoin), (2) bubilles supprimées sur un tiers des plants les moins développés (3) bubilles supprimées sur deux-tiers des plants les moins développés, iv) bubilles supprimées sur tous les plants. La hauteur de du fruit sans la couronne au moment de la suppression des bubilles a été utilisée pour identifier les plants les moins développés. Les quatre traitements sont appliqués 2 ou 3 mois après l'apparition de l'inflorescence. L'apparition de l'inflorescence est définie comme le moment où l'inflorescence peut être vue au cœur de la plante. La suppression des bubilles n'avait pas d'effet consistant sur la qualité moyenne et la variation des attributs de la qualité des fruits. Cela suggère que la suppression des bubilles ne constitue pas une voie d'amélioration de la qualité moyenne, ni de la réduction de l'hétérogénéité de la qualité.

Le *Chapitre 8* discute les divers résultats trouvés dans la présente thèse et propose des voies d'amélioration de la qualité moyenne de l'ananas au champ et dans les chaînes de commercialisation. Au niveau des systèmes de production, l'indisponibilité des rejets au moment de la plantation pourrait réduire la capacité des producteurs à accroître le volume de leur production, et donc, il y a un besoin de mettre en place des sites de production de rejets qui produiraient des rejets lourds. L'induction florale artificielle réduit la qualité moyenne des fruits et la proportion de fruits exportables vers l'Europe. Les plants de Pain de sucre obtenus à partir des rejets lourds peuvent être induits 12 mois après plantation sans perte de qualité. Pour la Cayenne lisse, l'induction naturelle de la maturité aiderait à améliorer la teneur en solides solubles, et par conséquent la proportion de fruits exportables vers l'Europe, mais étant donné que l'induction naturelle de la maturité intervient progressivement et de manière non uniforme, l'induction de la maturité au moment où la maturité naturelle débute, serait une option d'amélioration à la fois de la teneur en solides solubles et de l'uniformité de la couleur du fruit. De plus, les producteurs devraient régulièrement suivre des formations sur les bonnes pratiques de culture de l'ananas afin de réduire la diversité existante de systèmes de production.

Au niveau de la chaîne ce commercialisation, l'amélioration des infrastructures de transport et de stockage contribuerait au maintien de la qualité de l'ananas produit. Il est donc recommandé d'entreposer les ananas dans des caisses empilables pour le transport en camions et de mettre en place une chaîne de froid c'est-à-dire un environnement à température contrôlée à + 8 ºC pour le transport de la récolte à l'aéroport. Ces conditions de température contrôlée doivent aussi être prévues pour le maintien de la qualité à l'aéroport. L'indisponibilité des cartons pour l'ananas à l'export réduit la capacité des exportateurs à réduire le volume d'ananas à exporter. Le gouvernement devrait donc fournir ces cartons dans le pays ou encourager le secteur privé à investir dans la production locale des cartons. Etre membre d'une organisation de producteurs a beaucoup d'avantages tels que la réduction des coûts de transport, l'amélioration de l'accès au marché, etc. Les producteurs, exportateurs y compris, doivent être encouragés par les CARDER (Centre d'Action Régionale pour le Développement Rural; un centre visant la formation et l'assistance – conseil aux producteurs) à être membre des organisations de producteurs. Il y a aussi la nécessité de mettre en place une plateforme où tous les groupes d'acteurs des chaînes peuvent se rencontrer et discuter des préoccupations liées à l'accès au marché et s'entendre sur les critères et attributs de qualité.

Une telle plateforme pourrait limiter les désaccords entre la qualité offerte et la qualité désirée.

La présente thèse a contribué à identifier les contraintes de production uniforme d'ananas de qualité élevé et plus uniformes au Bénin. Elle suggère des voies d'amélioration qui pourraient être utilisées pour accroître la qualité des fruits pour les marchés et aussi la proportion de fruits exportables vers l'Europe.

Samenvatting

Samenvatting

Een slechte gemiddelde kwaliteit van agro-voedingsmiddelen en heterogeniteit in kwaliteit zijn belangrijke kwesties, vooral in minder ontwikkelde landen die tropische vruchten produceren. Dit is ook het geval voor ananas in Benin waar minder dan 2% van de geproduceerde ananas wordt geëxporteerd naar internationale markten. De resterende ananasvruchten worden geleverd aan plaatselijke en regionale markten met lagere kwaliteitsnormen; niettemin verliest het grootste deel van deze ananasvruchten zijn kwaliteit vóór het moment van consumptie. Aan het begin van deze studie was onbekend hoe afzetketens van verse ananas waren georganiseerd, hoe ananas werd verbouwd en hoe de gebruikte teeltmethoden de kwaliteit en uniformiteit van het product beïnvloedden. Daarom was de eerste doelstelling van deze studie te begrijpen hoe de afzetketens voor verse ananasvruchten naar verschillende markten zijn georganiseerd. Het tweede doel was om de kennis te vergroten over de agronomische instrumenten die de ananastelers gebruiken. Vervolgens werden studies uitgevoerd naar agronomische factoren die de kwaliteit van de ananas bepalen en werden de voor- en nadelen van de verschillende teeltmethoden geanalyseerd.

In *Hoofdstuk 2* worden de afzetketens voor verse ananas geanalyseerd en worden de knelpunten voor het leveren van hoge kwaliteit ananas aan verschillende markten geïdentificeerd. Allereerst werden 54 semigestructureerde interviews met sleutelpersonen gehouden om een overzicht te krijgen van de verschillende actoren in de ketens, hun activiteiten, de informatie- en de productstromen tussen actoren en de belangrijkste kwaliteitskenmerken van ananas voor elke actor. Op basis van de resultaten van deze interviews en literatuurstudie werd een raamwerk voor onderzoek ontworpen. Vervolgens werden 173 gestructureerde interviews gehouden met de verschillende actoren in de keten waarbij verdiepende vragenlijsten werden gebruikt. De vragen in deze lijsten waren geformuleerd op basis van het ontworpen raamwerk.

De resultaten toonden aan dat verse ananas werd verkocht aan drie markten: de lokale, regionale (naburige landen) en de Europese markten. Zes groepen actoren prevaleerden in de verse ananas ketens: de telers, de exporteurs, de groothandelaren (die verkochten op lokale markten en degenen die verkochten op regionale markten), de producenten van ananassap, de detailhandelaren en de tussenpersonen. Er bleken twee ananascultivars te worden geteeld: Sugarloaf en Smooth Cayenne, waarbij Sugarloaf de lokale en regionale markten domineerde.

Cultivar Smooth Cayenne werd voornamelijk verkocht aan Europese markten. Cultivar Sugarloaf werd geproduceerd door ongeveer 97% van de telers en cv. Smooth Cayenne door 30%. De resultaten gaven aan dat twee typen afzetketens voor verse ananas de overhand hadden in het bereiken van de lokale en regionale markten: (1) ketens waar telers rechtstreeks hun ananas leveren aan detailhandelaren, groothandelaren en sapproducenten, en (2) ketens waar ananas wordt geleverd aan deze groepen via tussenpersonen. Voor afzet naar Europese markten stuurden de exporteurs hun zelf-geteelde ananas naar importeurs, maar kochten incidenteel ook ananas bij van andere telers (niet-exporteurs) om aan de vraag te kunnen voldoen.

Tijdens de analyse van de ananasketens werden verschillende tekortkomingen gevonden. Ten eerste waren de omstandigheden tijdens de bewaring en het vervoer niet geschikt om de kwaliteit van de ananas te behouden. Tweeëndertig procent van de groothandelaren en 70% van de sapproducenten bewaarden de ananasvruchten in stapels in de volle zon zonder ze af te dekken. Tijdens het vervoer in bestelwagens werden de ananasvruchten naast elkaar gestapeld en was er geen temperatuurregeling. Ook voor export-ananas waren er geen bewaarvoorzieningen met temperatuurregeling op de luchthaven. Ten tweede was er weinig informatie-uitwisseling tussen de telers en de andere actoren; dertig procent van de telers van cv. Sugarloaf en 33% van de telers van cv. Smooth Cayenne hadden geen verkoopovereenkomst met klanten op het moment van oogsten van de vruchten. Ten derde, meer dan 50% van de ananastelers was het eens met de stelling dat ze geen training hadden ontvangen op het gebied van teelttechnieken van ananas. Ten vierde, exporteurs gaven aan dat er geen dozen voor de export van ananas beschikbaar waren in het land en dat zij genoodzaakt waren om deze in buurlanden te halen. Ten vijfde waren er zijn geen formele kwaliteitskenmerken en -eisen gedefinieerd voor de lokale en regionale markten; de kwaliteitskenmerken waaraan voldaan moest worden waren die van de klanten, waarbij de tussenpersonen slechts dienden als intermediair tussen de telers en andere actorgroepen in de ketens. Kwaliteitseisen voor de Europese markt kwamen uit de Codex Alimentarius (2005), die minimumeisen stelt aan het vruchtgewicht, de verhouding kroonhoogte: vruchtgestelhoogte, het totaalgehalte aan oplosbare vaste stoffen (*TSS, total soluble solids*), en lage heterogeniteit binnen elk kwaliteitskenmerk. Ten zesde was er geen overeenstemming tussen de verschillende actorgroepen in de keten over wat de meest belangrijke kwaliteitskenmerken waren (behalve tussen de telers en groothandelaren op de regionale markten voor cv. Sugarloaf). Daarnaast was er in alle schakels in de afzetketens naar lokale en regionale markten voor ieder individueel kwaliteitskenmerk een *mismatch* tussen de geleverde kwaliteit en de geprefereerde kwaliteit. De studie toonde bijvoorbeeld aan dat groothandelaren een voorkeur hadden voor zwaardere ananassen dan de detailhandelaren prefereerden, ongeacht de verkochte cultivar. Dus, in ketens waarin groothandelaren de verse ananas leverden aan detailhandelaren, slaagden ze er nooit in aan de eisen van de detailhandelaren te voldoen. Ook hadden de exporteurs problemen om te voldoen aan de kwaliteitseisen voor export. Alle actorgroepen gaven aan dat de heterogeniteit in ananaskwaliteit in het algemeen te hoog en problematisch was en de groothandelaren gaven aan de prijs van de ananas te verlagen wanneer de gemiddelde kwaliteit slecht was.

Deze bevindingen benadrukten de noodzaak om de teeltsystemen van ananas te analyseren om vast te stellen welke teeltpraktijken bijdroegen aan deze hoge heterogeniteit in ananaskwaliteit en aan de lage kwaliteit in het algemeen. Dit is gedaan in Hoofdstuk 3 middels interviews met de telers van ananas, en in Hoofdstukken 4, 5 en 6 middels experimenten op commerciële productiepercelen.

In *Hoofdstuk 3* zijn de ananasproductiesystemen voor de cultivars Sugarloaf en Smooth Cayenne beschreven, gebaseerd op interviews met 100 ananastelers. De resultaten werden geanalyseerd en knelpunten die leidden tot vermindering van de kwaliteit van de geproduceerde ananas werden geïdentificeerd. In de teelt van cv. Smooth Cayenne werden *hapas* en *suckers* gebruikt als plantmateriaal terwijl het plantmateriaal van cv. Sugarloaf voornamelijk bestond uit *slips*. *Slips*, *hapas* en *suckers* zijn zijscheuten, die afkomstig zijn van verschillende delen van de plant. De *slips*, *hapas* en *suckers* worden verzameld van planten op percelen waarvan eerder de vruchten waren geoogst. Het plantmateriaal werd door de meeste ananastelers geplant in bedden van twee rijen, bij een gemiddelde plantdichtheid van 8,6 ± 0,35 planten/m^2 (4-17 planten/m^2) voor cv. Sugarloaf en 5,2 ± 0,40 planten/m^2 (4-11 planten/m^2) voor cv. Smooth Cayenne. Negenentachtig procent van de ananastelers gebruikte een mengteeltsysteem van ananas met maïs (*Zea mays*), tomaat (*Solanum lycopersicum*) of chili peper (*Capsicum annuum*) in de eerste fase na planten. Kunstmest werd over het algemeen 3-4 maanden na het planten toegediend plus 2 of 3 weken voor het moment waarop de bloei kunstmatig werd geïnduceerd. De kunstmatige bloei-inductie werd in beide cultivars 9-13 maanden na planten uitgevoerd door carbid (CaC_2) aan te brengen in het midden van het bladrozet om zo alle planten tot bloei te induceren, de bloei te synchroniseren en het oogstmoment synchroon en voorspelbaar te maken. Binnen 34 dagen na kunstmatige bloei-inductie werd bemest met K_2SO_4 door 60% van de telers van Smooth Cayenne en 32% van de telers van Sugarloaf. De rijpheid werd in het algemeen kunstmatig geïnduceerd in cv. Smooth Cayenne door toediening van Ethefon, 143 dagen na bloei-inductie. De functie van Ethefon is het versnellen van de verandering van de huidskleur van de vrucht van groen naar geel. In cv. Sugarloaf was het gebruikelijk dit proces natuurlijk te laten verlopen. De ananasvruchten werden met de hand geoogst. Binnen elke cultivar waren de productiesystemen zeer variabel wat betreft plantdichtheid, tijdstip en type van bemesting, en de timing van de kunstmatige bloei-inductie.

Knelpunten die door de ananastelers werden aangegeven en die de kwaliteit van de ananas kunnen verminderen waren: gebrek aan geschikt plantmateriaal, gebrek aan en hoge kosten van meststoffen, en heterogeniteit in het gewicht van het plantmateriaal. Daarnaast is uit de analyse van de teeltmethoden naar voren gekomen dat de kunstmatige bloei- en rijpheidinducties mogelijk kwaliteitsbeperkend kunnen zijn omdat de planten binnen een gewas verschillen in ontwikkelingsstadium op het moment van bloei-inductie en de vruchten verschillen in rijpheidstadium op het moment van rijpheidinductie. Deze praktijken van kunstmatige bloei- en rijpheidinductie zijn onderzocht in Hoofdstukken 4 en 5.

In *Hoofdstuk 4* zijn vier experimenten (twee per ananascultivar) beschreven die werden uitgevoerd in commerciële ananasvelden om te beoordelen of de heterogeniteit in de groeikracht van individuele planten binnen een veld op het moment van kunstmatige bloei-inductie was geassocieerd met de heterogeniteit in vruchtkwaliteit bij de oogst. Het aantal functionele bladeren (NL), de D-blad lengte (de lengte van het langste blad) (DL) en het product van het aantal functionele bladeren × de D-blad lengte (NL × DL) werden gebruikt als parameters voor groeikracht van een plant op het tijdstip van kunstmatige bloei-inductie. De kwaliteitskenmerken gemeten bij de oogst van de vruchten omvatten interne en externe kwaliteitsparameters. De resultaten toonden aan dat de heterogeniteit in het gewicht van de hele ananasvrucht, het gewicht en de hoogte van het vruchtgestel (het deel van de ananasvrucht zonder de kroon), het aantal individuele vruchtjes (‘’ogen’’) in het vruchtgestel en de verhouding kroonhoogte: vruchtgestelhoogte in ananasgewassen een direct gevolg waren van de heterogeniteit in groeikracht van de individuele planten op het moment van kunstmatige bloei-inductie van deze gewassen. Een hogere groeikracht was geassocieerd met hogere gewichten van vrucht en vruchtgestel, een grotere hoogte van het vruchtgestel, meer individuele vruchtjes per vruchtgestel en een lagere verhouding kroonhoogte: vruchtgestelhoogte. Van de groeikrachtparameters verklaarde het product NL × DL het grootste deel van de variantie in de kwaliteitskenmerken van de vruchten. De groeikracht van de planten tijdens bloei-inductie was zwak en niet consistent geassocieerd met TSS, de pH van het sap en het percentage doorschijnend vruchtvlees. Deze resultaten suggereren dat teeltmaatregelen die leiden tot een geringere variatie in de groeikracht (NL × DL) van individuele planten op het moment van bloei-inductie vruchten kunnen opleveren met een geringere variatie in gewicht en hoogte van het vruchtgestel en totale vrucht, in de verhouding kroonhoogte: vruchtgestelhoogte, en in het aantal vruchtjes per vruchtgestel. In Hoofdstuk 4 bleek ook dat in cv. Sugarloaf het *slip*-gewicht (zwak) geassocieerd was met de variatie in vruchtgewicht, vruchtgestelgewicht en vruchthoogte in aanvulling op de groeikrachtparameter NL × DL.

In *Hoofdstuk 5* zijn de *trade-offs* tussen bloei- en rijpheidinductie en ananaskwaliteit onderzocht in dezelfde vier experimenten als in Hoofdstuk 4. In deze experimenten werden acht behandelingen uitgevoerd, te weten alle mogelijke combinaties van twee bloei-inductie methoden (kunstmatige en natuurlijke), twee rijpheidinductie methoden (kunstmatige en natuurlijke) en twee oogstmethoden (gangbaar en optimale oogsttijd). Onder de natuurlijke bloei-inductie methode werd geen kunstmatige bloei-inductie toegepast. De gangbare oogsttijd werd gedefinieerd als het moment waarop de schilkleur van 25% van de vruchten in een netto veldje was veranderd van groen naar geel; alle vruchten in een veldje werden geoogst op dat moment. De optimale oogsttijd werd gedefinieerd als het moment wanneer de kleur van 25% van de schil van een individuele vrucht was veranderd van groen naar geel. Elke behandeling werd toegepast op 240 planten, verdeeld over vier herhalingen van 60 planten. De resultaten gaven aan dat de natuurlijke bloei-inductie de meeste voortgang boekte tijdens de koudste maanden (augustus en december) in cv. Sugarloaf en tijdens de natste maand (vermindering van de uren van de zonnestraling) (juni) in cv. Smooth Cayenne. Verder gaven planten die waren blootgesteld aan kunstmatige bloei-inductie vruchten met (1) een lager gewicht en hoogte van het vruchtgestel, (2) een zwaardere en langere kroon, en (3) een hogere verhouding kroonhoogte: vruchtgestelhoogte dan planten onder natuurlijke bloei-inductie. Daardoor was het percentage vruchten dat exporteerbaar was naar Europa in kunstmatig-geïnduceerde planten lager dan dat in natuurlijk-geïnduceerde planten. Bovendien verhoogde kunstmatige bloei-inductie de variatie in gewicht van de vruchten en de vruchtgestellen en de hoogte van het vruchtgestel in cv. Sugarloaf.

De resultaten toonden ook aan dat vruchten blootgesteld aan kunstmatige rijpheidinductie een lagere TSS-concentratie hadden dan vruchten onder natuurlijke rijpheidinductie; kunstmatige rijpheidinductie verminderde het percentage vruchten die voldeden aan de exportcriteria naar Europa significant in twee van de vier experimenten. Natuurlijk tot rijpheid geïnduceerde vruchten die waren geoogst op de optimale oogsttijd hadden een hoger TSS-gehalte dan vruchten die werden geoogst op het gangbare oogstmoment.

Uit de resultaten van Hoofdstuk 5 blijkt ook de belangrijkste reden waarom een hoog percentage vruchten niet exporteerbaar was naar Europa in geval van kunstmatige bloei-inductie, namelijk een verhouding kroonhoogte : vruchtgestelhoogte hoger dan 1,5 voor cv. Sugarloaf. In cv. Smooth Cayenne verminderden zowel een verhouding kroonhoogte : vruchtgestelhoogte hoger dan 1,5 en een TSS-gehalte van minder dan 12 °Brix het aandeel vruchten dat exporteerbaar was naar Europa. Wanneer natuurlijke bloei zou worden beschouwd als een optie om de ananaskwaliteit te verbeteren, zijn de kosten voor het verkrijgen van natuurlijk tot bloei geïnduceerde vruchten: een langere vegetatieve fase, van ten minste 200 dagen langer in cv. Sugarloaf en 150 dagen in cv. Smooth Cayenne; een toename van het aantal oogsten van de vruchten tot 20 keer en een daling van het aandeel planten dat vruchten produceert, in vergelijking met kunstmatige tot bloei geïnduceerde planten. De *trade-off* van het verkrijgen van de zoetere vruchten door natuurlijke rijpheidinductie was dat de periode van bloei-inductie tot oogst ten minste 1 dag langer werd in cv. Sugarloaf (waar natuurlijke rijpheidinductie al een gangbare praktijk is zoals gevonden in Hoofdstuk 3) en 11 dagen langer werd in cv. Smooth Cayenne. Dus, ter verbetering van het TSS-gehalte kan natuurlijke rijpheidinductie een optie zijn. Natuurlijke bloei-inductie kan geen optie zijn voor de verbetering van de andere kwaliteitskenmerken, gegeven de genoemde *trade-offs*. Dit betekent dat andere verbeteropties moesten worden onderzocht. Deze verbeteropties zijn bestudeerd in Hoofdstukken 6 en 7.

In *Hoofdstuk 6* zijn de effecten bestudeerd van het gewicht en type van plantmateriaal op de gemiddelde vruchtkwaliteit en de variatie in vruchtkwaliteit. Er werden twee experimenten uitgevoerd (één per cultivar). Plantmateriaal werd verzameld uit commerciële velden en in drie gewichtsklassen gesorteerd: licht, een mengsel van gewichten, en zwaar. In cv. Smooth Cayenne waar *hapas* en *suckers* als plantmateriaal worden gebruikt, werd ook het effect van het type plantmateriaal bestudeerd. Bovendien werden *hapas* en *suckers* gemengd volgens de door telers gebruikte methode. Bloei-inductie vond 12 maanden na planten plaats volgens de gangbare methode of op een optimaal inductiemoment dat werd bepaald op basis van gegevens van de experimenten beschreven in Hoofdstuk 4. Uit die experimenten was gebleken dat voor planten die op het moment van bloei-inductie een NL × DL hadden hoger dan 1235 leaf.cm voor cv. Sugarloaf en hoger dan 2300 leaf.cm voor cv. Smooth Cayenne, er een hoge kans was om vruchten te produceren met gewichten die vallen binnen het bereik van gewichten die geschikt zijn voor export naar de Europese markten. Deze waarden voor groeikracht zijn gebruikt om het optimale tijdstip voor bloei-inductie te definiëren. De planten werden geïnduceerd toen 75% van de planten onder die behandeling een groeikracht had die gelijk was aan of hoger dan 1235 leaf.cm voor cv. Sugarloaf en 2300 voor cv. Smooth Cayenne.

Uit de resultaten blijkt dat wanneer de bloei 12 maanden na het planten werd geïnduceerd, het gewicht van het plantmateriaal de vruchtkwaliteit op het moment van oogsten beïnvloedde. Het gebruik van zwaar plantmateriaal gaf in beide cultivars vruchten met zwaardere gewichten van vruchtgestel en vrucht, een grotere vruchtgestelhoogte maar een lagere kroonhoogte en een lagere verhouding kroonhoogte: vruchtgestelhoogte dan vruchten uit licht plantmateriaal. Zwaar plantmateriaal gaf vruchten met een lagere variatie in hoogte van het vruchtgestel en ook een hoger aandeel vruchten die exporteerbaar waren naar Europa in vergelijking met andere gewichtsklassen in cv. Sugarloaf. Het gebruik van zware *slips* in cv. Sugarloaf zou een optie kunnen zijn voor verbetering van de verhouding kroonhoogte: vruchtgestelhoogte die in Hoofdstuk 5 werd geïdentificeerd als een beperkend kwaliteitscriterium voor de export. In cv. Smooth Cayenne had het type plantmateriaal geen effect op de gemiddelde vruchtkwaliteitskenmerken behalve dat *hapas* vruchten gaven met een kortere kroon dan *suckers*. Bloei-inductie op het optimale tijdstip verbeterde de gemiddelde vruchtkwaliteit sterk in vruchten van lichte *slips* en *slips* van gemengd gewicht, waardoor het aandeel vruchten dat exporteerbaar was naar Europa steeg in deze klassen plantmateriaal. Door bloei-inductie op het optimale moment i.p.v. na 12 maanden steeg ook het aandeel vruchten dat exporteerbaar was naar Europa wanneer een mengsel van zware *hapas* en *suckers* werd gebruikt als plantmateriaal.

In *Hoofdstuk 7* is bestudeerd of selectief verwijderen van *slips* in cv. Sugarloaf de heterogeniteit in ananaskwaliteit kan verminderen en het algehele kwaliteitsniveau kan verbeteren. Er werden twee experimenten uitgevoerd op commerciële percelen met cv. Sugarloaf. Vier behandelingen werden toegepast: (1) geen verwijdering van *slips* (controle); (2) verwijdering van *slips* op de een-derde minst ontwikkelde planten; (3) verwijdering van *slips* op de twee-derde minst ontwikkelde planten; (4) verwijdering van alle *slips*. Als criterium om de minst ontwikkelde planten te identificeren werd de hoogte van het zich ontwikkelende vruchtgestel op het moment van verwijderen van de *slips* gebruikt. De vier behandelingen werden 2 of 3 maanden na verschijnen van de bloeiwijze uitgevoerd. Het verschijnen van de bloeiwijze is het tijdstip waarop de bloeiwijze zichtbaar is in het hart van de bladrozet. Het bleek dat verwijderen van *slips* geen consistente effecten had op de gemiddelde vruchtkwaliteit van de ananas en ook geen consistente effecten had op de variatie in vruchtkwaliteitskenmerken. Dit suggereert dat verwijderen van *slips* geen optie is voor verbetering voor de gemiddelde ananaskwaliteit en de heterogeniteit in kwaliteit.

In *Hoofdstuk 8* worden de bevindingen van de huidige studie besproken en opties voorgesteld waarmee de gemiddelde ananaskwaliteit en -uniformiteit kunnen worden verbeterd op het niveau van het productiesysteem en de keten. Op het niveau van het productiesysteem zou het gebrek aan beschikbaar plantmateriaal op het moment van planten de mogelijkheden van telers verminderen om de omvang van hun productie te verhogen; dus, er is behoefte om productielocaties voor plantmateriaal op te richten die de telers kunnen voorzien van zwaar plantmateriaal. De gangbare methode om kunstmatige bloei-inductie te gebruiken verlaagt de gemiddelde vruchtkwaliteit en het aandeel vruchten dat exporteerbaar is naar Europa, maar Sugarloaf planten uit zwaar plantmateriaal kunnen 12 maanden na planten tot bloei worden geïnduceerd zonder kwaliteitsverlies. In cv. Smooth Cayenne zou natuurlijke inductie van de rijpheid het TSS-gehalte kunnen helpen verhogen en bijgevolg het aandeel naar Europa exporteerbare vruchten, maar aangezien natuurlijke rijpheidinductie geleidelijk plaatsvindt en niet uniform zou het ook een optie kunnen zijn de rijpheid kunstmatig te induceren op het moment dat de eerste vruchten van nature beginnen te rijpen om zo zowel het TSS-gehalte te verhogen als de uniformiteit in huidskleur van de vruchten te verbeteren. Bovendien moeten telers regelmatig training ontvangen in de beste teeltmethoden voor ananas zodat de diversiteit in de productiesystemen kan worden teruggebracht.

Op ketenniveau zou verbetering van de transport- en opslagfaciliteiten kunnen helpen om de kwaliteit van de geproduceerde ananas op niveau te houden. Aangeraden wordt om de ananasvruchten in stapelbare kratten te transporteren tijdens het vervoer in de bedrijfswagens en een ananas koelketen te implementeren, d.w.z. een keten waarin de temperatuur wordt gecontroleerd en wordt ingesteld op 8 ˚C van oogst tot luchthaven. Daarnaast zijn gekoelde opslagfaciliteiten op de luchthaven nodig om de ananaskwaliteit te behouden. Het niet beschikbaar zijn van dozen voor export vermindert de mogelijkheden van exporteurs om het volume geëxporteerde ananassen te verhogen. Daarom zou de regering dozen moeten aanbieden of moeten stimuleren dat de private sector gaat investeren in de productie daarvan. Lidmaatschap van een telersvereniging heeft veel voordelen zoals vermindering van de transactie kosten, verbetering van de toegang tot de markt, enz. Telers, met inbegrip van de exporteurs, zouden moeten worden aangemoedigd door de CARDER (Regionaal Actie Centrum voor Rurale Ontwikkeling; een organisatie die gericht is op het opleiden van en het geven van advies aan telers), om lid te worden van een telersvereniging. Het is ook gewenst een platform op te richten waar alle ketenactoren elkaar kunnen ontmoeten, kwesties kunnen bediscussiëren met betrekking tot toegang tot de markt, en hun kwaliteitskenmerken en -criteria delen. Een dergelijk platform zou helpen om de *mismatch* tussen de geleverde kwaliteit en de gewenste kwaliteit in alle schakels van de keten te verbeteren.

Dit proefschrift heeft bijgedragen aan het identificeren van knelpunten voor de productie van uniforme ananasvruchten van hoge kwaliteit in Benin. In het proefschrift worden opties gesuggereerd die gebruikt kunnen worden om de kwaliteitseigenschappen van vruchten voor de afzetmarkten te verbeteren en het percentage vruchten dat naar Europa geëxporteerd kan worden te verhogen.

List of publications

Peer reviewed publications

Fassinou Hotegni, V.N., Lommen, W.J.M., van der Vorst, J.G.A.J., Agbossou, E.K. and Struik, P.C. (2012). Analysis of pineapple production systems in Benin. *Acta Horticulturae*, 928: 47-58.

Achigan-Dako, E. G, Abike A. C., N'Danikou, S., **Fassinou Hotegni, V.N.,** Agbangla, C. and Ahanchédé, A. (2014). Drivers of conservation and utilization of pineapple genetic resources in Benin. *SpringerPlus*, 3: 1-11.

Fassinou Hotegni, V.N., Lommen, W.J.M., van der Vorst, J.G.A.J., Agbossou, E.K. and Struik, P.C. (2014). Bottlenecks and opportunities for quality improvement in fresh pineapple supply chains in Benin. Accepted for publication in the International Food and Agribusiness Management Review.

Submitted papers

Fassinou Hotegni, V.N., Lommen, W.J.M., Agbossou, E.K. and Struik, P.C. (Submitted). Heterogeneity in pineapple fruit quality results from plant heterogeneity at flowering induction.

Fassinou Hotegni, V.N., Lommen, W.J.M., Agbossou, E.K. and Struik, P.C. (Submitted). Selective plants pruning as a means to reduce heterogeneity in pineapple fruit quality.

Fassinou Hotegni, V.N., Lommen, W.J.M., Agbossou, E.K. and Struik, P.C. (Submitted). Trade-offs of flowering and maturity synchronisation for pineapple quality.

Fassinou Hotegni, V.N., Lommen, W.J.M., Agbossou, E.K. and Struik, P.C. (Submitted). Fruit quality of pineapple and its variation as affected by weight and type of planting material.

Thesis

Fassinou Hotegni, V.N. 2007. Effet de l'étuvage sur les paramètres physiques, culinaires et organoleptiques du riz (*Oryza sp*). Mémoire d'Ingénieur Agronome. Faculté des Sciences Agronomiques. Université d'Abomey Calavi. Abomey Calavi. 82 pages.

Newsletter

Fassinou Hotegni, V.N. (2013). Exploring the fresh pineapple supply chains in Ghana. West Africa Research Association. Newsletter 2013. Boston, USA. pp 13-15.

Posters

Fassinou Hotegni, V.N., Lommen, W.J.M., van der Vorst, J.G.A.J., Agbossou, E.K. and Struik, P.C. (2010). Analysis of fresh pineapple supply chains in Benin: Bottlenecks and opportunities for improvement. Poster. 28th International Horticultural Congress, Lisboa, Portugal.

Fassinou Hotegni, V.N., Lommen, W.J.M., van der Vorst, J.G.A.J., Agbossou, E.K. and Struik, P.C. (2010). Analysis of pineapple production systems in Benin: Poster. 28th International Horticultural Congress, Lisboa, Portugal.

PE&RC Training and Education Statement

With the training and education activities listed below, the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (6 ECTS)
- Pineapple cultural practices and their impact on fruit quality and uniformity in fruit quality

Writing of project proposal (4.5 ECTS)
- Using agronomic tools to improve pineapple quality and its uniformity in Benin

Post-graduate courses (7.5 ECTS)
- Advanced supply chain management; Wageningen University (2009)
- Mixed linear model; Wageningen University (2011)
- Multivariate analysis; Wageningen University (2012)

Laboratory training and working visits (4.5 ECTS)
- Exploring the fresh pineapple export chains in Ghana; Ghana (2013)

Deficiency, refresh, brush-up courses (2 ECTS)
- Simulation in decision science (2009)

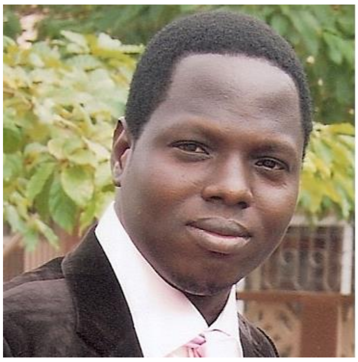
Competence strengthening / skills courses (2.6 ECTS)
- Working with Endnote; Wageningen University (2008)
- Techniques for writing and presenting a scientific paper; Wageningen University (2009)
- Reviewing a scientific paper; Wageningen University (2012)
- Research methodology and proposal writing; University of Abomey-Calavi (2011)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.2 ECTS)
- PE&RC Weekend (2009)
- PE&RC Day (2013)

Discussion groups / local seminars / other scientific meetings (7.5 ECTS)
- First CoQA workshop Wageningen (2008)
- Second CoQA workshop in Wageningen (2009)
- Frontier literature in plant physiology (2009/2011)
- Workshop in Benin on updating scientific research in pineapple, Shea and shrimp (2011)

International symposia, workshops and conferences (8.5 ECTS)
- XXVII International horticultural congress in Portugal (2010)
- First international CoQA workshop in Ethiopia (2010)
- Second international CoQA workshop in Benin (2011)
- Third international CoQA workshop in Benin (2013)

Curriculum Vitae



Vodjo Nicodème Fassinou Hotegni was born in Porto Novo, Benin, on 14 September, 1984. After he completed his higher school education, he joined the Faculty of Agronomic Sciences of the University of Abomey-Calavi (Benin) in 2002 and obtained the degree of Agronomist in 2006. From 2006 to 2007, he specialised in Plant Sciences and obtained the Engineer Agronomist degree with honour. In October 2008, he started his PhD research at the Centre for Crop Systems Analysis Wageningen University. During his PhD he conducted fields experiments, farmer surveys, and assessed quality issues related in agri-food in supply chains. Since 2013, he is member of West African Research Association. Vodjo Nicodème Fassinou Hotegni is now interested in investigating and improving the performance of existing cropping systems, developing new cropping systems in line with markets requirements and in improving the access of smallholders to more lucrative markets. He can be contacted on nicodemef@gmail.com or nicodemef@yahoo.fr.

Funding

The research described in this thesis was financially supported by North-South Interdisciplinary Research and Education Fund (INREF) of Wageningen University and Research Centre through the Co-Innovation for Quality in African Foods Chains (CoQA) programme.

The research was also financially supported by the Netherlands Organisation for International Cooperation in Higher Education (NUFFIC) through the Netherlands Fellowship Programs (NFP) (NFP-PhD/ CF7551/2011).

LEB Foundation also contributed to the dissemination of the findings from this research by funding our participation to the 28th International Horticultural Congress in Portugal (Grant 2010-023A).

The field work research in Ghana was financially supported by the West African Research Association (WARA) through the WARC travel grant, Boston, USA.

Financial support for the printing of the thesis was obtained from Dr Judith Zwart Foundation, Wageningen, The Netherlands.

The content of this thesis reflects only the views of the author. The funding parties did not have any role in study design, data collection, analysis and interpretation of the data.

Cover, design and layout

The cover was designed by V. Nicodème Fassinou Hotegni
and the painting realised by Joel Hounsounou

Printing

GVO drukkers & vormgevers B.V., Ponsen & Looijen