Quality of pasteurised pineapple juice in the context of the Beninese marketing system

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GENERAL INTRODUCTION AND THESIS OUTLINE

PREFACE

In response to a call in 2007 by the Interdisciplinary Research and Education Fund (INREF) of Wageningen University, the Co-Innovation for Quality in African Food Chains (CoQA) project was formulated with the objective to design a set of quality co-innovations (i.e., integrated quality solutions combining approaches at different levels of analysis) that can support smallholder pineapple growers and juice manufacturers. The project was to be carried out in three countries, namely Ethiopia, South Africa and Benin. In each country a team of two or three PhD students from different disciplines was formed and together they have worked on the advancement of an agricultural commodity in an interdisciplinary approach. For Ethiopia, the research was focused on the agronomic and economic analysis of the seed potato system, the quality coordination in potato supply chains and on the quality of ware potatoes for different markets. In South Africa, PhD students focused their research on an innovative citrus supply chain structure and the citrus quality standards for export markets and value distribution. Finally, the Beninese team focused its attention on the agronomic tools to improve the quality of fresh pineapple, supply chain innovations in different pineapple supply chains and the marketing and processing of pineapple in Benin.

The Beninese team consisted of an agronomist, an economist and a food technologist. Together they conducted a preliminary survey to identify the different actors in the pineapple supply chains, to understand their function and the type of relationships existing between them and to assess the main challenges they face. During this investigation, several pineapple fields, farmers' associations, rural and urban markets, processing factories, NGO's and international organizations were visited. The agronomist focused his research on how to improve the planting materials and reduce their heterogeneity in weight, age and leaf number; the economist focused his work on the innovations and the governance structure of the Beninese pineapple supply chains (Arinloye, 2013). The objective of the food technologist was to propose solutions on how fresh pineapple should be marketed and processed into juice in the context of the Beninese pineapple marketing system. This thesis concerns the food technology and marketing research.

Due to the context of Benin where financial resources are very limited and information about the market is unavailable, the current pineapple marketing system was studied first. The outcome of this study was used to determine the most important technological issues that required further research.

CONTEXT

The Beninese economy is based essentially on the agricultural sector. About 70 % of the population is involved in this sector, which provides about 32.6 % of gross domestic product and 80 % of export income (UNICEF, 2009). For a long time cotton (*Gossypium sp.*) has been the most important crop for exports, providing more than 70 % of the agricultural export value (Sodjinou, Adegbola, & Bankole, 2011). However, from January 2001 to May 2002, world cotton prices fell by almost 40 %, from 64 dollar cents per pound to 39 dollar cents per pound (Minot & Daniels, 2005). This decline was essentially due to a decrease in demand, which started with the 1997 East Asian crisis, and to the high level of Chinese stocks (about 30 % of the world stocks). The crop also suffers from the competition of synthetic fibers, and in particular from polyester, of which the price has continuously declined since the 1960s (Traoré, 2011).

Due to the global difficulties in cotton chains, the strategic directions of development adopted by the Beninese government for the period 2006-2011 and the growth strategy for poverty reduction for the period 2007-2009, placed particular emphasis on the need to "promote the renewal of the economy and the diversification of the production particularly in rural areas" (Benin, 2007). Therefore, the promotion of food chains appeared as the major axis through which the agricultural sector would contribute to the implementation of these new policies (MAEP, 2009). On this basis, different national development agencies (Cellule d'Appui Technique du Programme de Relance du Secteur Privé and Association pour le Développement de l'Exportation) selected 4 agricultural commodities, namely shrimps, shea butter, cashew nut and pineapple, and advised the government to strengthen the production and supply chains of these products (Arouna & Affomasse, 2005).

PINEAPPLE, A PROMISING CROP FOR LOCAL AND REGIONAL MARKET

The production of pineapple is of great importance for Benin and has contributed to about 13 billion FCFA to the GDP in 2006. In that year this contribution represented a share of about 1.2 % of the total GDP and about 4.3 % of the agricultural GDP (INSAE, 2007). Agricultural land suitable for pineapple production represents 490,000 hectares, or 7 % of farmland nationwide. This shows the existing potential for pineapple chain development in Benin.

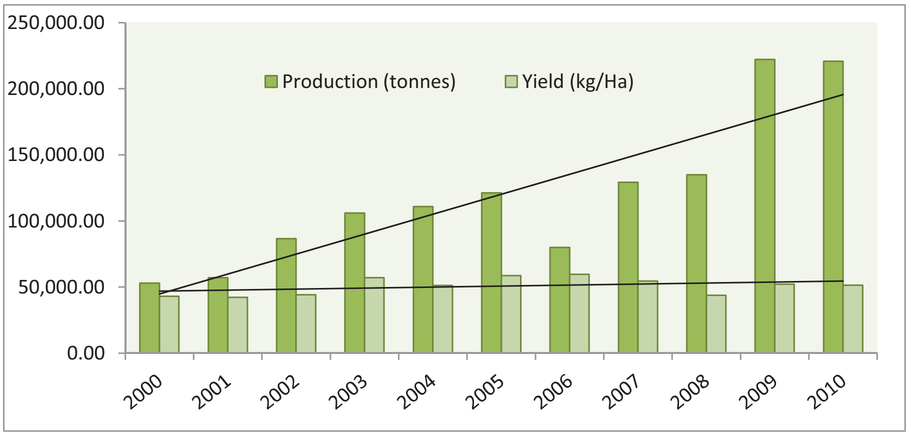

Figure 1.1

Facts and trends in pineapple production and yields in Benin (FAOSTAT, 2012)

The national pineapple production has been increasing over the years (Figure 1.1), because of the growing demand from regional markets, especially Nigeria, and despite the almost stagnant yield per ha of pineapple over the last decade and the low export to international markets. Obviously, the increase in the production was due to an increase in the cultivated area and not to an improvement in production techniques.

Quality is becoming an increasingly important issue in the marketing of food products (Henson & Reardon, 2005; Reardon & Farina, 2001) and smallholders from Benin usually have limited access to good quality planting materials, have poor storage and processing facilities, lack human and investment capital, and face high transaction costs (Arinloye, 2013; Fassinou Hotegni, Lommen, van der Vorst, Agbossou, & Struik, 2010). As a result, the quality of the product is heterogeneous and often below international market requirements (Fassinou Hotegni et al., 2010). In order to ensure a high quality and homogeneous product, large investments in technology, research and streamlined organization should be made. In the Beninese context, where small individual pineapple growers constitute the majority, the implementation of that kind of scenario will take time to be implemented. Therefore, the investigation of the potential of local and regional markets to improve the livelihood of small pineapple growers, traders and juice manufacturers is of utmost importance.

PASTEURISED PINEAPPLE JUICE PRODUCTION: CONTEXT, CHALLENGES, AND KNOWLEDGE GAPS

The main objective of the Beninese government in selecting pineapple as one of the main crops in the framework of agricultural diversification was to increase its export to international markets (MAEP, 2010). Because of the fast increase of the total production (Figure 1.1) and the high rejection rate of the pineapple at the international market, the production of pasteurised pineapple juice was introduced as a way to absorb a part of the high amount of pineapple that could not be consumed fresh or exported. The intervention was, however, implemented without a deeper understanding of the marketing system, the relationships between the existing actors like wholesalers and merchants, the ways in which they were doing business, and the preferences of the existing actors and the new group of pasteurised pineapple juice manufacturers that entered the system. To date, ten years after the introduction, a lack of clarity exists on the basic characteristics of the system and the impact of the intervention. Such knowledge is important because the system may affect the juice quality and quantity and the purchases of the juice manufacturers may in turn change the system and thus the supply of pineapples to consumers in Benin and surrounding countries in West Africa.

A direct consequence of the system on juice quality may come from the raw materials offered. Poor harvesting and transport conditions in Benin (Figure 1.2) cause physical damage to pineapples. The damage typically is a consequence of the characteristics of the agro-food system in developing countries because of poor infrastructure, low level of technology and low investment in food production systems (Prusky, 2011). In addition to that, pineapple growers and wholesalers lack storage facilities and therefore the fruits have to be stored at ambient temperatures (28 °C – 32 °C) before selling or processing. Currently, we do not know the effect of such physical damage and storage conditions on juice quality.

Pasteurisation techniques are not standardized among juice manufacturers. Pineapple is processed into juice and then bottled in a recycled 0.25 L or 0.33 L bottle previously used for imported Heineken beer (Figure 1.5). The processing equipments are not always adapted to juice production and many juice manufacturers use basic equipment (Figure 1.3) whereas few of them use semi industrial equipments (Figure 1.4). The pasteurisation technique differs from one processor to another with respect to the time and temperature of pasteurisation. Moreover, the temperature of pasteurisation is accessed from the temperature of the water in which the bottles are submerged. In this condition, the pasteurisation temperature in the juice is not precisely known. This causes difficulties for assessing the impact that the pasteurisation has on the quality of the juice. Sallan (2007) reported a variability in the pasteurised pineapple juice quality of different juice manufacturers in terms of physicochemical, and microbiological quality. In our preliminary investigation[1], juice manufacturers reported a limited shelf life of some juice batches and a colour change into brown as the main quality issues they faced in the juice production. Such problems may be caused by the quality of the raw material, the conditions of pasteurisation and storage, or a combination of these. Due to a lack of research on the typical conditions of developing and emerging countries, the precise causes are not known and hence no effective remedies can be designed and implemented.

Figure 1.2

Pineapple transportation

Figure 1.3

Pasteurisation pots

Figure 1.4

Locally designed crusher for pineapple juice

Figure 1.5

Pasteurised pineapple juice

[1] The preliminary investigation was implemented with the other Beninese PhD students. Focus group discussions were implemented with farmers, traders and juice manufacturers to understand their function in the system and problems they are facing

SCIENTIFIC SIGNIFICANCE

The knowledge gaps described above are not only of practical relevance for the Beninese juice manufacturers and other actors in the pineapple system, they are also scientifically relevant for the domains of food technology, marketing, and the interdisciplinary domain at the conjunction of both.

For food technology, the main challenge of this research was to optimize the pasteurisation technology, a simple technique commonly used by juice manufacturers to extend the shelf life and to preserve the nutritional and the sensorial quality of the pineapple juice. In the past, several researchers have worked on the safety of fresh or processed pineapple juice (Badge & Tumane, 2011; Bermudez-Aguirre & Barbosa-Canovas, 2012; Carneiro, dos Santos Sa, dos Santos Gomes, Matta, & Cabral, 2002; Ewaidah, 1992; Ferreira, Rosenthal, Calado, Saraiva, & Mendo, 2009; Maresca, Donsì, & Ferrari, 2011; Rosenthal, MacKey, & Bird, 2002; Salomao, Slongo, & Aragao, 2007; Slongo & de Aragao, 2008; Tchango Tchango, Tailliez, Eb, Njine, & Hornez, 1997; Zimmermann, Miorelli, Massaguer, & Aragão, 2011; Zimmermann, Miorelli, Massaguer, & Falcão Aragão, 2011) as well as on its nutritional (Al-Jedah & Robinson, 2002; Camara, Diez, & Torija, 1995; de Carvalho, de Castro, & da Silva, 2008; Gawler, 1962; Uckiah, Goburdhun, & Ruggoo, 2009; Zheng & Lu, 2011) and sensorial quality (Chan, Chenchin, & Vonnahme, 1973; de Carvalho & da Silva, 2010; de Carvalho, da Silva, & Pierucci, 1998; Gassaye, Davin, Peuchot, & Aim, 1991). However, the effect of traditional heat treatments on the microbiological, nutritional and sensorial quality of pineapple juice is poorly understood (Hounhouigan, Linnemann, Soumanou, & van Boekel, 2014). A single technology approach is advocated, namely the QACCP procedure (i.e., Quality Analysis Critical Control Points) (Verkerk et al., 2007), for the processing of pineapple juice. This approach would identify the quality attributes that are relevant for the final product, identify the relevant chain actors, identify the critical control points within the chain that have a strong effect on quality and identify the measures that can be taken to align the quality performance to quality expectation.

In marketing, a growing interest for the typical characteristics of markets in developing and emerging countries is observed over the last decade (Burgess & Steenkamp, 2006; Dawar & Chattopadhyay, 2002; Ingenbleek, 2012; Tollens, Trijp, & Ingenbleek, 2010; van Tilburg, 2010). With economies in Asia, Latin America and Africa coming more to the forefront, marketing researchers have started to pay more attention to the generalizability of their theories to these parts of the world (Burgess & Steenkamp, 2006) and revived concepts that seemed particularly applicable, such as the aggregate marketing system (Layton, 2009). The aggregate marketing system describes the exchange interrelationships between multiple actors who jointly make up a system. The concept is particularly helpful to understand the role of marketing in development (Wilkie and Moore 1999). While marketing has been accused for playing a negative role in development, such as by advocating unhealthy habits and indoctrinating cultures by advertising (Witkowski, 2005), it can make a positive contribution by increasing the level of specialization in a system in response to heterogeneous customer needs. As advocators of so-called transformative marketing research claim, interventions may actively contribute to the development of marketing systems (Shultz et al., 2012). Empirical research is however still scarce. This study will analyze the pineapple marketing system in Benin at such an aggregate level to understand whether and how it has responded to the intervention of pasteurised juice-making.

Finally, this research is an application of how food technology and marketing are complementary in improving the quality of food and the position of smallholders in developing countries (van Boekel, 2010). Food technology and marketing have a long-standing tradition of collaboration. Most studies focus in that respect on consumer (sensorial) perceptions of changes in food technologies (Bourn & Prescott, 2002; Brunsø, Fjord, & Grunert, 2002; Cardello, 2003; Deliza, Rosenthal, Abadio, Silva, & Castillo, 2005; Dewettinck et al., 2008; Grunert et al., 2005; Issanchou, 1996; Oey, Lille, van Loey, & Hendrickx, 2008) and market research on consumer preferences that may serve as input for product development (Baker, 1999; Behe et al., 2013; de Pelsmacker, Janssens, Sterckx, & Mielants, 2005; Green & Srinivasan, 1978, 1990; Jaeger, Andani, Wakeling, & MacFie, 1998; Kayode, Adegbidi, Hounhouigan, Linnemann, & Robert Nout, 2005; Linnemann, Benner, Verkerk, & van Boekel, 2006; Yang & Allenby, 2003; Zander & Hamm, 2010). Such approaches may prevent a possible mismatch between the food's quality and expectations in the market. However, this approach would not capture the full context of the Beninese marketing system, which is important because the marketing system itself can influence the quality of the available pineapple products. Therefore, the combination of technology and marketing as an analysis of the upstream system rather than downstream perceptions and preferences, will bring valuable information into the analysis of factors affecting the juice quality. Interestingly, the combination of both disciplines can potentially reveal market opportunities for both pineapple wholesalers and juice manufacturers in the specific context of developing countries where transport and market infrastructure are lacking.

OBJECTIVES AND OUTLINE OF THESIS

The general objective of this thesis is to understand how the quality of pasteurised pineapple juice can be improved by placing the food technological issue in the context of the Beninese marketing system. Within the context of the marketing system, we address more important and relevant questions than when food technology is studied in isolation.

To achieve this goal the following specific objectives were defined:

i. evaluate the adaptation of Beninese marketing systems to the introduction of the pasteurised pineapple juice business;

ii. assess the extent to which pineapples with physical damage (i.e., of potential less quality) can be used for pineapple juice production;

iii. review the present state-of-the-art on the effect of processing on the quality of pineapple juice;

iv. evaluate the effect of pasteurisation on the microbiological, physicochemical and nutritional value of pineapple juice.

Beninese Pineapple Marketing System

Knowledge gap	**Chapter**	**Research objective**
	Chapter 1: General Introduction	
Understanding of the marketing system	**Chapter 2:** Evaluate the adaptability of Marketing Systems to Interventions in Developing countries: Evidence from the Pineapple System in Benin	*Evaluating the responsiveness of the Beninese marketing system*
Effects of raw materials on juice quality	**Chapter 3:** Effect of Physical Damage on the Pineapple Juice quality	*Creating an understanding on whether a pineapple with physical damage could be used for pineapple juice production*
Knowledge about the effect of processing on the quality of pineapple juice	**Chapter 4:** Critical Review on the Effect of Processing on the Pineapple juice Quality (State of art on pineapple juice technologies)	*Creating insight into pasteurised pineapple juice technologies that may help in improving pasteurised pineapple juice quality*
Causes of problems in pasteurised pineapple juice quality	**Chapter 5:** Effect of pasteurisation on the quality of pineapple juice	*Evaluating the effect of pasteurisation on the pineapple juice quality*
	Chapter 6: General Discussion and Implications	

Figure 1.6

Structure of the thesis

This thesis consists of six chapters in which four address the four research objectives that respond to the four abovementioned knowledge gaps. The four chapters are preceded by a general introduction and concluded by a general discussion and implications (Figure 1.6).

Chapter 2 discusses the adaptation of the Beninese pineapple marketing system to pineapple juice introduction (Figure 1.6). In this section, market information such as the main market actors, their relationships, their preferences in terms of the pineapple quality, and the knowledge of juice manufacturers about the relation between the quality of the fresh pineapple and the quality of the pasteurised pineapple juice were collected. The marketing study showed that juice manufacturers are less demanding about the quality attributes of pineapple compared with traders (wholesalers & retailers); they do not believe that the quality of the raw material for juice production has a direct impact on juice quality. Such a link had not been demonstrated in the prior literature. However, the juice manufacturers mentioned challenges related to juice quality such as insufficient knowledge about juice processing, high cost of the fresh pineapple, lack of processing equipments, non-existence of suitable packaging materials. Besides these constraints, physical damages are developed during transport from farm to juice manufacturers and wholesalers and may affect the quality of derived juice. Juice manufacturers do not care about using these damaged pineapples for their production (Chapter 2). Therefore, in chapter 3, we investigated the effect of the pineapple quality in terms of physical damage and storage conditions on the pineapple juice quality (Figure 1.6).

As a follow-up to the marketing research, the exploratory study of pineapple juice manufacturers showed a wide variation of pasteurisation conditions (temperature and time) and juice quality from one processor to another. Moreover, consumers and juice manufacturers complained about the dark brown colour of pasteurised pineapple juice. We therefore tried to assess the link between processing technologies of pineapple juice and its quality through a critical literature review (Chapter 4) (Figure 1.6).

The review showed the lack of data on the effect of the traditional pasteurisation on the quality of the pineapple juice. Consequently, our last study (Chapter 5) investigated these relationships by focusing on the effect of pasteurisation on the yeast inactivation, nutritional quality (vitamin C) and other physicochemical parameters such as pH, degree Brix, organic acids, sugar content and the hydroxymethylfurfural (HMF) content, the latter being the main indicator of non enzymatic browning known as the Maillard reaction (Figure 1.6). Finally, Chapter 6 discussed the main contribution of this thesis and implications at the different levels of the pineapple chain.

2

THE ADAPTABILITY OF MARKETING SYSTEMS TO INTERVENTIONS IN DEVELOPING COUNTRIES: EVIDENCE FROM THE PINEAPPLE SYSTEM IN BENIN

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ABSTRACT

In general marketing theory, marketing systems are assumed to adapt for facilitating further economic development. Such adaptability may be less obvious in the context of developing countries due to features in the social matrix of these countries. The present study explores adaptation in the Beninese pineapple marketing system, in the first ten years after the introduction of the pasteurisation process as a development intervention. Qualitative and quantitative insights across a broad spectrum of actors in the pineapple system reveal that adaptability to the intervention has been very slow and virtually absent at an aggregate level. These findings suggest that to make optimal use of the economic development effects of interventions, effects need to be considered beyond the primary actor on which they are targeted. This may require complementary marketing interventions at different actors in the system. The marketing systems approach adopted in this study appears useful to identify these key actors for complementary interventions.

Keywords: Marketing systems, Development policy, Developing markets, Emerging markets, Subsistence marketplaces, Conjoint analysis.

INTRODUCTION

Marketing systems make important contributions to the quality of life of the general public by distributing goods and services to meet consumers' basic needs, and by developing assortments of various items to satisfy specific wants (Layton, 2007, 2009; Wilkie & Moore, 1999). Through innovation, they respond to persistent discrepancies between the assortments offered and those desired by customer groups, and they therefore contribute directly to economic growth (Layton, 2009; Layton, 2011). These contributions are especially notable at higher levels of aggregation, such as sectors or countries (cf. Layton 2007), because a greater number of actors increases the chances that at least one of them will respond to an emerging opportunity. Wilkie and Moore (1999) describe aggregate systems as adaptive, and Vargo and Lusch (2004) adopt this notion in their service-dominant logic.

Although often taken for granted, the adaptability depends on the social matrix of economic, social, cultural, and physical characteristics in which marketing systems are embedded (Layton 2011). In more developed economies the characteristics of the social matrix often support the adaptability of marketing systems, but in developing or less-developed regions those characteristics may hinder it. Weaker infrastructures, lower levels of education, and insufficient regulative institutions (e.g., Burgess and Steenkamp 2006; Sheth 2011), for example, impact on flows of goods, numeracy and literacy skills that facilitate transactions, and protection against malpractices in the marketplace, respectively (e.g., Viswanathan et al., 2010a, 2012). In their attempts to serve the interests of the general public in terms of employment, economic growth, and quality of life, policy makers might intervene in marketing systems to improve their functioning and, in the words of the U.K. Department for International Development and the African Development Bank, "make markets work for the poor" (Poole, 2010). Marketing and public policy literature has investigated some of these interventions, such as the establishment of Fair Trade agreements (Arnould, Plastina, & Ball, 2009), the provision of microcredit to Ghanaian smallholders (Dadzie, Dadzie, Winston, & Blankson, 2013), or economic support programs that strengthen connections with export markets (Arnould 2001).

The present study explores the adaptability of a marketing system in a developing country to an intervention. As a complement of research into the direct impact of interventions at their target groups (Arnould et al., 2009; Dadzie et al., 2013; Umashankar & Srinivasan, 2013), this study examines whether and how interventions initiate a pattern of change, through which the marketing system at a higher level of aggregation reorganizes in response and thus benefits the general public. By empirically examining the adaptation of a marketing system in a developing country in response to an intervention, this study introduces the theoretical notion of marketing system adaptability in developing countries (Layton 2011) to empirical marketing literature.

Specifically, this study examines the responsiveness of the pineapple system in Benin to the introduction of pasteurised juice-making techniques, a decade later. Benin is located at the Atlantic Coast of West Africa. Poverty is widespread in the country, with 75 % of the population living on less than $2 a day (World Bank, 2010). The Beninese economy is based on mono-cropping agriculture (cotton). Consistent with its colonial past, its infrastructure is characterized predominantly by main roads from coastal harbor cities, moving inland to production areas. These traits have constrained the development of other marketing systems, such as that of pineapple, despite the country's favorable agricultural conditions.

When the production of pineapple intensified in the late 1990s, in an effort to stimulate economic growth, the marketing system failed to sell the increasing supplies to existing or new customer groups (in particular, to the intended export markets), leading to significant losses of the perishable fruits. The introduction of pasteurisation techniques sought to make better use of the available pineapple supplies for the purposes of food security, economic development, and quality of life in general. This study evaluates, ten years after the intervention, how the marketing system adapted, using both qualitative and quantitative methods, including a conjoint analysis to obtain insights into the preferences of different groups within the aggregate marketing system.

The next section provides relevant background on marketing systems and development interventions. Next, the study methods are described and the results presented. The article ends with a discussion, conclusion, and implications.

INTERVENTIONS IN MARKETING SYSTEMS IN DEVELOPING COUNTRIES

Layton (2011, p. 259) defines a marketing system as "a network of individuals, groups, and/or entities; embedded in a social matrix; linked directly or indirectly through sequential or shared participation in economic exchange; which jointly and/or collectively creates economic value with and for customers, through the offer of assortments of products, services, experiences, and ideas and that emerge in response to or anticipation of customer demand." Marketing systems can be described in terms of their structural and functional elements, which include the exchange logic and context, flows and roles, networks (including their dynamics), and governance. They also can be described by the distinctive features of the customer groups whose needs are served by their operations or the nature of the assortments generated in response to these needs (Layton 2009, 2011). Marketing systems also refer to different levels, varying from two transaction partners in a micro-system to aggregate systems that span entire sectors in a country (Layton 2007).

The analysis of marketing systems has a long tradition in marketing literature, starting with early comparisons of U.S. marketing systems with those in other countries (Cundiff, 1982). These researchers recognized that lower levels of economic development were associated with less advanced marketing systems. However, the studies likely followed a deterministic approach, in that they did not distinguish whether marketing also contributed actively to development, beyond passively following economic development and seizing opportunities in markets where wealth already had increased (Hosley & Wee, 1988). The idea that marketing could make active contributions to development through interventions in marketing systems fell on fertile ground (Cundiff, 1982; Slater, 1974). Development planners argued, at the macro level, that marketing institutions, cooperatives, and boards could contribute to economic growth through marketing system interventions that set in motion channel specialization in labor, including role specialization in trade systems, and the development of broader assortments to fulfill the wants and needs of consumers (Layton 2009).

By changing the exchange logics, contexts, flows, roles, networks, and governance of transactions, marketing systems also can adapt to external events (Layton 2011). Empirical research offers several success stories in which marketing systems effectively adapted to new conditions and contributed to economic growth. For example, marketing systems unified the once fragmented U.S. market, then segmented it (Tedlow, 1990); they helped the countries of the former Yugoslavia recover from a war (Shultz, Burkink, Grbac, & Renko, 2005); and they helped Vietnam transition from a planned economy to a steadily growing, market-based economy (Shultz, 2012). Fast and effective adaptation is not guaranteed though, because the components of any marketing system are embedded in the social matrix, which does not necessarily support adaptation.

The social matrix in developing and emerging countries differs from that in the more developed economies to such an extent that they may demand specific or adjusted theories (Ray, 1998; Sheth 2011). Studies within the so-called subsistence marketplace movement investigate the marketplaces of the poor from the bottom up, seeking an understanding of marketplace phenomena based on their typical characteristics (Viswanathan et al., 2008, 2010a). These studies show, among other things, that deeply ingrained resource scarcity and poor literacy prompts oral transactions (Ingenbleek, 2014). Their businesses are strongly embedded in social networks of friends and relatives, so that they can make better use of the resources that are available. Viswanathan et al. (2010a) identify how micro-entrepreneurs use their families as buffers to grant and collect favors from customers and vendors. Low literacy levels also lead people to think in more concrete terms and pictographically (Gau et al., 2012). But such factors may hinder entrepreneurs from seizing new opportunities or changing their existing processes. As Arnould and Mohr (2005) explain, to be able to integrate with the world market, artisanal leather workers in Niger (West Africa) had to depend on the presence of formal companies that had more traditional resources (e.g., investment capital, market knowledge) and that took the lead in the chain. Without such companies, the cluster could adapt only to customer groups at local markets.

Several studies also suggest directions for interventions that seemingly should strengthen the development of marketing systems. Arnould (2001) derives recommendations from an analysis of the onion system in West Africa, such as packaging and branding onions with country-of-origin labels. Manfredo and Shultz (2007), on the basis of a system analysis in the post-war former Yugoslavia, offer directions for financial interventions that could stimulate development marketing systems. Viswanathan et al. (2007) design for an educational intervention stems from an analysis of a subsistence marketing system in India. Several studies also measure the impacts of interventions, including the effects of a training program on Indian sex workers (Umashankar and Srinivasan 2013) or fair trade certification (Arnould et al., 2009) and micro loans (Dadzie et al., 2013) for small-scale African farmers.

The impacts of the intervention on the wider marketing system usually are beyond the scope of such studies.

Development economists frequently draw on a transaction cost framework to understand the responsiveness to, and identify the needs for interventions in marketing systems (Barrett, 2008; Stephens & Barrett, 2011). Transaction cost theory suggests that the costs of a stronger relationship depend on specific investments, behavioural uncertainty (opportunistic behaviour), and uncertainty in terms of volume and technology (Geyskens, Steenkamp, & Kumar, 2006). When actors are prevented from entering certain markets or marketing channels, institutional factors such as infrastructure, capital, and tariffs may further raise the costs of a transaction and constrain the adaptation of marketing systems. To enable marketing system adaptation, development interventions may induce changes at the institutional level aimed at removing factors that increase transaction costs. From a transaction cost perspective, the adaptation of marketing systems therefore depends on whether the costs of a transaction are lowered sufficiently. In marketing systems theory, such costs pertain to flows of ownership, possession, risk, finance, and information in the system (Layton, 2011). The marketing system approach therefore broadens, but does not replace or exclude, a transaction cost approach. It broadens the approach because it allows also influences of the social matrix on transaction that go beyond costs, like cognition (which influences among others the perception of market opportunities) or cultural norms and habits (which influence the willingness and ability to seize opportunities). Our analysis will explore such alternative influences.

METHODS

The field study reported herein is part of a larger interdisciplinary investigation that aims to increase understanding of how pineapple production and marketing might strengthen the development of Benin. The study of the marketing system was included to understand whether the preferences of key actors in the system aligned with the supply provided. The three-stage data collection started with ethnographic methods, to obtain insights in the key characteristics of the traditional marketing system for pineapples in Benin and its historic development. We interviewed two academic experts and conducted desk research, gathering insights from policy documents, research reports, and thesis from local universities. To understand the characteristics of the traditional pineapple system in Benin, we collected historic sources and asked questions about the functioning of the system in the past. With these resources, we were able to understand the functioning of the system that experienced the intervention, as well as the changes to and continuities in the system after the intervention. In three markets, we used observation techniques and conducted 25 semi-structured interviews and focus group discussions with wholesalers, fresh pineapple consumer-merchants (retailers), and fruit juice manufacturers (pineapple juice manufacturers). Participants thus covered the most important groups of actors in the system, and were coming from different cities and regions. Most of them were female as trading of pineapple is female-dominated. The techniques provided information regarding the quantity, quality, and varieties of pineapples sold in the market, as well as the trading practices and origins of buyers and sellers. We also observed the practices of five pineapple growers and interviewed two food technologists.

Next, we collected quantitative data from key actors in the system to clarify the networks, buyer characteristics, buyer preferences, and their satisfaction with the assortments offered. We followed the recommendations of Ingenbleek et al. (2013) for quantitative field research in subsistence contexts. That is, we collected information with structured questionnaires in personal interviews, conducted by the first author, from 125 respondents (25 juice manufacturers, 30 wholesalers, and 70 consumer-merchants). Beninese pineapple juice manufacturers are organized in an association with 27 members, of which 25 were interviewed at their processing unit (2 were abroad at this time). Prestudy interviews suggested that the wholesalers constituted a fairly homogeneous group, in terms of pineapple quality, quantity, varieties, and origins of customers and suppliers, so we used a quota sample of 30 (5 per market) wholesalers from six markets in southern Benin. In addition, we selected 70 pineapple consumer-merchants from seven major cities in southern Benin (10 from each city).

Respondents indicated their satisfaction with the pineapple supplies they generally received. We used four items from Oliver's (1997) satisfaction scale and reworded them to match the context of this study, according to our interviews and focus group discussions. The items were as follows: (1) "I often don't buy pineapple because the quality is not what I look for," (2) "Finding pineapple of good quality is a problem for me," (3) "I often have problems obtaining the quality of pineapples that customers want," and (4) "I often have problems findings the quality of pineapple that I want." All items used five-point scales, ranging from "strongly disagree" to "strongly agree." After removing the fourth item, the reliability of the scale was satisfactory (Cronbach's alpha = 0.80, M = 3.50, S.D. = 0.80). The item loadings in a one-factor confirmatory factor analysis reached 0.620, 0.797, and 0.844, respectively.[1] For ease of interpretation, we reversed the scores, so that higher scores indicated greater satisfaction. In addition, we asked key questions about trading relationships, such as the number of customers and suppliers, the strength of the relationships with main customers and suppliers (measured as contact frequency; (Hansen, 1999), target markets, specialization (whether actors had sources of income other than their pineapple business), experience (number of years active in the business), and demographics (see Table 2.1).

We used a conjoint study to obtain deeper insights into differences in the preferences of juice manufacturers, wholesalers, and consumer-merchants. The most important pineapple attributes considered in the marketing system and their levels (Table 2.2), were selected for inclusion in the conjoint study from biological descriptions (Soler, 1992) and three focus group discussions (one with five wholesalers, one with five consumer-merchants, and one with five juice manufacturers). These attributes refer to pineapple variety, colour, and maturity, as well as the presence of fungus, physical damage, ethephon, and insects or pests. (Ethephon is an organophosphate compound used to obtain homogeneous flowering and accelerate fruit ripening. It initiates degreening of the pineapple and thus may make pineapple look more mature than it really is.) For more details on the design and validation of the conjoint study, see Appendix 2.1.

To facilitate the interpretation of the quantitative data in relation to the adaptation of the system, we conducted 20 additional semi-structured interviews to confront key actors (10 wholesalers and 10 juice manufacturers) in the system with our findings from the quantitative study. Following the insights from the main study, these questions focused on the networks and governance of transactions in the system.

Table 2.1

Wholesalers, Consumer-merchants, and Juice manufacturers

	Wholesalers (n = 30)	Consumer-merchants (n = 70)	Juice manufacturers (n = 25)
Satisfaction (means)	3.72	3.59	2.98
Experience			
<1 year	-	11.4 %	-
1-3 years	-	22.9 %	24 %
4-5 years	10 %	14.3 %	28 %
6-10 years	6.7 %	27.1 %	24 %
>10 years	83.3 %	24.3 %	24 %
Other income generating activities			
Yes	93.3 %	54.3 %	0 %
No	6.7 %	45.7 %	100 %
Monthly pineapple sales			
<400	-	7.1 %	-
400-2000	-	28.6 %	-
2001-4000	30 %	48.6 %	-
>4000	70 %	15.7 %	-
Period of selling pineapples / juice			
Occasionally	0 %	7.1 %	0 %
Whole year	100 %	92.9 %	100 %
Number of customers			
10-25	0 %	8.5 %	12 %
26-50	0 %	17.14 %	16 %
51-100	3.3 %	24.28 %	16 %
>100	96.7 %	50 %	56 %
Communication frequency with customers			
Every month	0 %	1.4 %	0 %
Every two weeks	0 %	0 %	36 %
About once a week	6.6 %	25.7 %	16 %
More than once a week	46.7 %	45.7 %	20 %
Every day	46.7 %	25.7 %	28 %
Number of suppliers			
1	16.7 %	27 %	4 %
2-5	33.3 %	42.9 %	24 %
6-10	20 %	17.1 %	8 %
>10	30 %	12.9 %	64 %
Communication frequency with suppliers			
Rarely	0 %	2.9 %	4 %
Every month	0 %	0 %	8 %
Every two weeks	3.3 %	1.4 %	36.1 %
About once a week	96.7 %	95.7 %	52 %

Table 2.2

Quality attributes and levels in the conjoint experiment

Attributes	Levels	
Variety	1.	Smooth Cayenne
	2.	Kona Sugarloaf
Size	1.	Small
	2.	Medium
	3.	Big
Colour	1.	Colouring in bottom quarter
	2.	Bottom half is coloured
	3.	About two-thirds is coloured
	4.	Whole fruit is coloured
Maturity	1.	White flesh
	2.	Yellow flesh
Fungus presence	1.	Yes
	2.	No
Ethephon presence	1.	Yes
	2.	No
Insect/pest presence	1.	Yes
	2.	No
Physical damage	1.	Yes
	2.	No

Source: Adapted from Soler (1992).

RESULTS

To present these results, we first describe the traditional pineapple system, then detail the intervention in the system and its consequences. Next, we provide the results of the quantitative data collection related to satisfaction, preferences, and networks. Finally, we report the insights from the post hoc interviews.

Traditional channels in the pineapple marketing system

Pineapple was introduced in West Africa as early as 1548 by Portuguese traders who planted the relatively sweet 'Kona Sugarloaf' variety. The southern part of Benin, near the Atlantic coast, has a tropical climate that is suitable for growing tropical fruits. This part of the country accounts for more than 90 % of Benin's annual pineapple harvest (see Figure 2.1).
Prior to the introduction of the pasteurisation technology, the marketing system showed many similarities with descriptions of other West African marketing systems (Arnould 2001; Arnould and Mohr 2005; Fafchamps 2004). Downstream from the growers, the market consisted of several specialized intermediaries in an informal sector that supplied the domestic market and engaged in informal cross-border trade to surrounding countries. Domestic markets and markets in other West African countries (Togo, Nigeria, Niger, and Burkina-Faso) consumed an estimated 80 % of the traded pineapples; the share of formal exports was relatively small. In 2007, only 2 % of Beninese pineapple production was sold through official export channels (mainly to France, Belgium, and Italy). The remaining 18 % were lost to physical damage or pest incidence (Helvetas-Benin, 2007).

Because the pineapple growing regions and major markets are all in the South, there were relatively fewer stages between growers and consumers than there would be in systems in growing areas further away from the main markets in the South (cf. Arnould 2001). The system consisted of three stages: farmers, wholesalers, and consumer-merchants. In addition, a few brokers helped make connections with oversees export markets. More than 3,000 growers from the tropical south of the country cultivated pineapple as a cash crop, often next to other crops such as maize used for home consumption. They sold pineapple, usually directly to wholesalers who would grade, sort, and resell them. The wholesalers also bought from one another at major outdoor marketplaces in the same part of the country. The largest market (Dantokpa) is in Cotonou, Benin's economic capital (see Figure 1.1). Another important market is located closer to the production area (Sekou), and another appears at the border with Nigeria (Sèmè Kraké). Wholesalers bought pineapples in large quantities (usually in batches of 40) and sold them in smaller quantities at secondary markets, located along the main roads between or near the major urban areas in the southern part of the country.

Wholesalers are a relatively wealthy group in this channel. During the qualitative interviews, it became clear that many of them ran other businesses on the side, such as trading in other fruits and vegetables. These activities may help them accumulate sufficient capital to pay farmers directly during the transaction, though some take the pineapples on credit and pay on their next visit. Such practices do not necessarily indicate a lack of cash but rather a habit, because according to one informant, “This is how we have always done it.” Farmers and wholesalers have relatively stable relationships with informal, oral agreements, some of which have been passed from one generation to another, such that they are characterized by high levels of trust and commitment. As one of the wholesalers explained, “I have taken over this business from my mother; she has been working with some of my farms already for many years.”

The dominant customer group in the traditional system, adopting the terminology of Viswanathan et al. (2010), is consumer-merchants, also known as periodic traders (Dewar, 2005). Viswanathan et al. (2010a) introduce this term to refer to resource-poor micro-entrepreneurs that have close relationships with consumers (and use unsold items for their own consumption). Pineapple consumer-merchants take pineapples in a basket and transport them on foot, carrying the basket on their head, or on the back of a motorcycle. They rarely have fixed locations but instead visit marketplaces where consumers go for their daily food purchases, as well as other busy places, such as hospitals, administration offices, and city centers. Some chop the pineapple in pieces that they sell to travelers as a snack. Most consumer-merchants operate in urban areas in the south of the country, in both poor parts of the cities and sections where middle classes live. With the growth of these cities in recent decades, the number of consumer-merchants has increased as well, according to the observations of some experts and wholesalers (though no official records are available). In addition, some have started to develop more specialized trade between the market and urban areas farther away from the market, creating a new stage in the supply chain. We observed wholesalers sort and grade the pineapples into different quality levels, saving the ripe pineapples of the best size for their loyal customers and keeping the damaged ones for bargain hunters. This phenomenon is relatively common among African traders in agricultural products that exhibit natural quality variety (Fafchamps 2004).

The consumer-merchants are typically resource poor and have reciprocal relationships with wholesalers and consumers. They obtain and offer credit from and to their transaction partners, then collect favors in return. Depending on the location, their business mainly consists of short-lived, anonymous transactions, though they also likely have one or more stable market relationships with loyal customers who are also social acquaintances. In these more stable relationships, the exchange even might be a barter, trading pineapples for other food items without exchanging money. That is, these transactions are tailor-made, meaning that consumer-merchants sort the pineapples preferred by certain consumers and potentially add value by slicing them into pieces. Prices may vary between customers, and loyal customers sometimes receive extra pieces or pineapples that specifically meet their preferences and that the consumer-merchant reserves for them, to reward their loyalty. As one explained, “I save the best pineapples for my best customers.”

These characteristics of the marketing channel, from wholesalers to consumer-merchants, can be classified according to the marketing system detailed by Layton (2011) (see Table 2.3, middle column). The typical characteristics of a traditional channel—including relational exchanges in which pineapples are sold on credit and sales of small quantities to a high number of resource-poor and low-literacy merchants—strongly contrast with the characteristics of the new customer group of juice manufacturers who appeared after the intervention.

Figure 2.1

Pineapple production areas in Benin and primary markets

Note. The pineapple regions in the south are indicated in grey, main pineapple markets are indicated with a dot.

Table 2.3

Comparison of channels by marketing system characteristics

	Consumer-Merchants	**Juice manufacturers**
Buyer characteristics	Resource-poor, low-literate, survivalist.	Middle class, relatively well-educated
Networks and network dynamics	Numerous Add value by distributing pineapples from wholesale markets to consumer groups elsewhere in the region Transport on the back of motorcycles and on foot Tailor-made offerings through sorting, grading and sometimes slicing pineapples. High stability, but the size of the group increases with urbanization in southern Benin, leading some to specialize as intermediaries to other resellers.	Relatively small number. Add value through technical transformation. Pasteurisation enables juice to maintain calories and vitamins for a longer time, beyond the harvest season. Appearance in the network was a shock, created through an intervention.
Flows and roles	Consumer-merchants are gate-keepers to consumers, They buy often and in small quantities, often on credit. Intense communication with wholesalers; sometimes sell on credit. They sometimes resell on credit or through barter trade.	Usually no credit is necessary because juice manufacturers have sufficient capital to fund their transactions. Demand depends on the production process, juice sales, juice stock, and availability of complementary items (e.g., bottles).
Exchange logic and context	Exchange with wholesalers is highly relational, prices are negotiated, With customers many transactions are short-lived; credit is granted to loyal customers.	Short-lived transactions of larger quantities, at arm's-length.
Governance	Informal market, based on social contracting, oral agreements, and reciprocity.	Short-lived market transactions, sourced informally then brought in a (semi-)formal context.
Assortments offered to buyer groups	Sorted and graded by suitability for reselling on the basis of ripeness, colour, size (ease of transport), damage, and infections	The same assortment is offered, suggesting that the system didn't adapt to the entry of the juice manufacturers.

Intervention in the pineapple system

During the late 1990s, the government of Benin started to intensify pineapple production to target export markets with high purchasing power in the European Union and elsewhere, thereby diversifying Benin's exports, which then depended mostly on a single crop (cotton). The Beninese government encouraged growers to plant the pineapple variety that was dominant on the world market at the time, the 'Smooth Cayenne'. The 'Smooth Cayenne' was less sweet than the 'Kona Sugarloaf', but it had a longer shelf-life and was juicier. Total pineapple production increased to 50,000 tons in 2000 (on a surface of less than 1,000 hectares) and to 150,000 tons in 2007 (on 2,200 hectares) (Dohou, 2008).

However, the export plan failed, because the 'Smooth Cayenne' soon became outdated when the companies that dominated the international pineapple trade switched to yet another variety, the MD2 from Latin America (Willems, Ruben, van Boekel, van Tilburg, & Trienekens, 2007). Unable to sell pineapples in export markets, overproduction led to low market prices during the peak of the production season, as well as spoilage; pineapples cannot be stored for much longer than two weeks before they start to perish. Although the fruit could be processed into marmalade and dried snacks, which kept longer, those products were not in high demand. The much more popular form, pineapple juice, instead offered a more viable means to improve food security in the country if it could be kept longer. Juice-making was conducted only occasionally by a few people who processed pineapples into juice for themselves and their relatives. At ambient temperatures, the juice stayed fresh for no more than one day. Thus the stage was set for an invention: pasteurisation of pineapple juice.

To relieve the threat of an oversupply of pineapples, a project in 2000 introduced pasteurised juice processing techniques. The Danish government sponsored the project with development funds. The pasteurisation process extended the shelf life of pineapple juice to more than six months, while preserving its calories and vitamins. The introduction of pasteurised juice potentially could contribute to both economic development and food security. Five female entrepreneurs were educated and trained in the pasteurisation process by Beninese food technologists. These women were educated and had some available investment capital for their business, from either a loan or their families. Some had just finished their university education in food technology, and others had been housewives.

The prospects for the juice manufacturers seemed good. The potential market in the southern part of Benin was growing, especially as people moved from the rural north to the urban and peri-urban areas in the southern part of the country. Infrastructure projects removed some of the challenges of reaching these communities, and increasing income differentiation offered the potential for products slightly above the subsistence level (Domínguez-Torres & Foster, 2011). Some juice manufacturers reported that they had begun developing new marketing channels geared toward new target markets, including modern hotels, restaurants, and expatriates. As one of them said, "It is much more beneficial to sell the juice to hotels and restaurants because they pay cash and they have a regular and constant demand." That is, they recognized demand among these newly identified customer groups and innovated in response to the discrepancies in the assortments that were demanded and offered. The most important input material (pineapple) is also abundant in the area and not expensive. Furthermore, the pasteurisation technique gave the newly trained juice manufacturers an important competitive advantage over juice manufacturers that had not adopted this technique, because the juice could be stored longer, peaks in demand and supply could be absorbed, and the technological process could be optimized to offer stable quality, potentially connected to a brand name.

During the next ten years the technology was adopted by more than 20 other juice manufacturers that copied the techniques without formal training. The new adopters were often socially connected to juice manufacturers trained in the pasteurisation technique; they tended to be educated and represent from the middle class of society, with access to the necessary investment capital for processing equipment. They also organized into an industry association to serve their common interests. From the juice manufacturers' perspective, the intervention was successful, because training of just five entrepreneurs led to the creation of a new industry. For the general public, the intervention also increased employment and secured incomes for juice manufacturers, in addition to contributing to food security and increasing assortments, which affected the quality of life of Beninese consumers. Several juice manufacturers noted their happiness with positive customer feedback, sharing anecdotes such as, "One day I received a call from a customer who had drunk my juice at Hotel du Port in Cotonou. He liked the juice so much that he asked for my phone number and started to buy the juice directly from me."

The intervention thus had impacts downstream (from juice manufacturers to consumers); whether the upstream system of growers and wholesalers also adapted remains unclear. The wholesalers seemingly should have identified differences in preferences and incorporated them in sorting and grading activities. We consider the preferences of the two customer groups next.

Preferences of consumer-merchants and juice manufacturers

Figure 2.2 presents the mean partworth estimates for wholesalers, consumer-merchants, and juice manufacturers, as obtained from the conjoint task. Table 2.4 reports the F-, p-, and partial η^2-values from the analyses of variance on the partworth estimates, in which we control for the actors' level of experience. Table 2.5 contains the estimated marginal means and post hoc comparisons among juice manufacturers, wholesalers, and consumer-merchants. In general, the results show that preferences related to safety (e.g., physical damage, presence of pests, fungus) appeared most important.

The conjoint results for the juice manufacturers highlight that their preferences for pineapple differ from those of the consumer-merchants on three important points. First, the pineapples least liked by the consumer-merchants represent an attractive market offering for the more price-sensitive juice manufacturers. Consumer-merchants reject damaged pineapples, which are difficult to sell for fresh consumption, but for juice-making, the damaged part of the pineapple can easily be cut off, leaving the remaining part for processing (in Table 2.5, the estimated marginal means are 0.802 and 0.570, respectively, for consumer-merchants and juice manufacturers, $p < 0.001$). Consumer-merchants also dislike large pineapples, which are difficult to transport on their heads or motorcycles. Large pineapples take up the space of two small pineapples but do not offer double earnings. Juice manufacturers appear to find large pineapples acceptable (estimated marginal means are 0.544 and 0.077, $p < 0.001$).

Second, juice manufacturers prefer pineapples that strengthen the juice quality, such as the 'Kona Sugarloaf' variety, which makes the juice sweeter without adding sugar (Wardy, Saalia, & Steiner-Asiedu, 2009) (estimated marginal means are 0.054 and 0.164, $p < 0.05$). For the same reason, the juice manufacturers show a smaller preference for colour C1, which corresponds with a mature 'Cayenne Lisse' (estimated marginal means are 0.354 and 0.096, $p < 0.001$).

Third, the results indicate a minimum condition for the pineapples preferred by juice manufacturers, namely, the absence of fungus (estimated marginal means are 0.862 and 1.062, $p < 0.01$). The juice manufacturers attach significantly greater importance to this attribute than the consumer-merchants, because juice manufacturers would ruin an entire batch of juice if they accidently used just one pineapple with fungus.

The conjoint study therefore specifies the differences in preference between consumer-merchants and juice manufacturers, which represent an opportunity for sorting and grading and thus for further specialization to refine the marketing system. If wholesalers keep particularly large, damaged pineapples separate for the juice manufacturers, they offer a more valuable proposition to the consumer-merchants while also satisfying price-sensitive juice manufacturers. They can appeal to quality-sensitive juice manufacturers by offering them more 'Kona Sugarloafs', and in general they will increase the satisfaction of juice manufacturers if they remove any pineapples affected with fungus as early as they can.

Table 2.4

Analyses of variance: differences among juice manufacturers, consumer-merchants, and wholesalers in preferences for attribute levels

Attribute	*F*	*df1; df2*	*P*	*Partial* η^2
Variety	3.983	2; 121	<0.05	0.062
Fungus	5.539	2; 121	<0.01	0.084
Size	23.027	3.21; 194.02[a]	<0.001	0.276
Colours	5.674	5.58; 337.85[a]	<0.001	0.086
Physical damage	14.039	2; 121	<0.001	0.188
Maturity	3.046	2; 121	<0.10	0.048
Ethephon	0.923	2; 121	NS	0.015
Pests	0.316	2; 121	NS	0.005

[a] Degrees of freedom adjusted with Greenhouse-Geisser correction. NS = non-significant. The analyses controlled for experience (number of years the actor has been active in pineapple sector), because more experienced actors may have developed stronger preferences. In the case of the attributes *Size* and *Colour,* repeated-measures analyses of variance were conducted because they have more than two levels.

Table 2.5

Estimated marginal means for differences in attribute-level preferences and p-values from post hoc pairwise comparisons (sidak) among juice manufacturers, consumer-merchants, and wholesalers

Attribute	*Levels*	*Estimated Marginal Means*		
		Wholesalers	*Consumers merchants*	*Juice manufacturers*
Variety	Kona Sugarloaf-Smooth Cayenne	0.128^{ab}	0.054^{a}	0.164^{b}
Fungus	No-Yes	1.060^{d}	0.862^{c}	1.062^{d}
Size	Medium-Small	0.187^{f}	0.010^{e}	0.089^{ef}
	Medium-Large	0.191^{g}	0.544^{h}	0.077^{g}
Colour	C1-C2	0.181^{ij}	0.354^{j}	0.096^{i}
	C2-C3	0.076^{k}	0.211^{k}	0.287^{k}
	C3-C4	-0.326^{m}	-0.503^{l}	-0.452^{lm}
Physical damage	No-Yes	0.972^{p}	0.802^{o}	0.570^{n}
Maturity	Yellow-White	0.176^{r}	0.104^{qr}	0.036^{q}
Ethephon	No-Yes	0.144^{s}	0.180^{s}	0.238^{s}
Pests	No-Yes	0.926^{t}	0.884^{t}	0.862^{t}

Notes. Post hoc pairwise comparisons were conducted for each difference in attribute-level preferences separately. Estimated marginal means that share the same superscript character are not significantly different from each other.

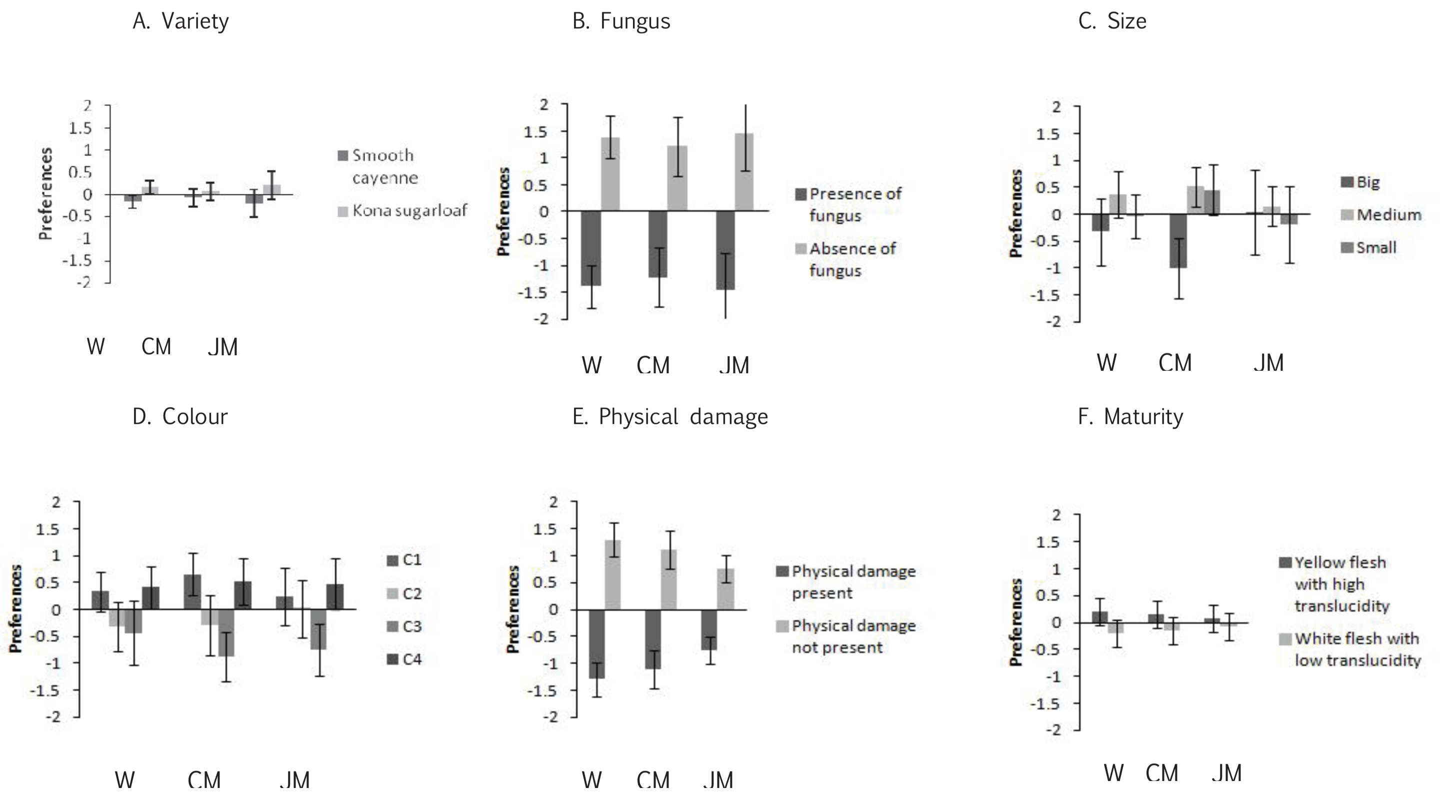
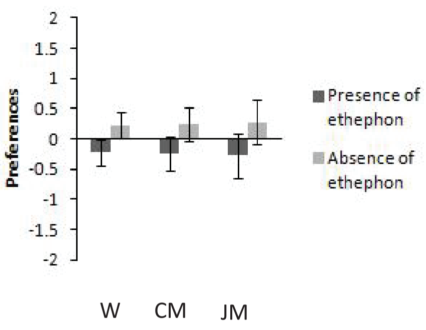


Figure 2.2

Actors' preferences for pineapple attributes (conjoint results)

G. Ethephon



H. Pests

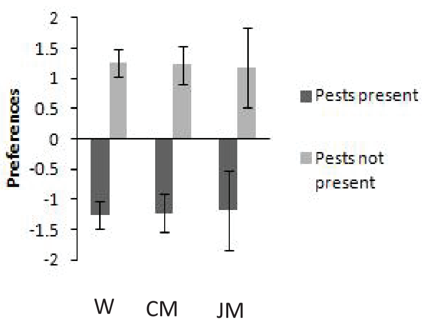


Figure 2.2 (continued)

Actors' preferences for pineapple attributes (conjoint results)

Satisfaction of consumer-merchants and juice manufacturers

According to the results related to satisfaction, customers' preferences are not being effectively met by wholesalers. The marketing system leaves the juice manufacturers significantly less satisfied than the consumer-merchants ($F_{(2, 121)} = 5.76$, $P < 0.01$, partial $\eta^2 = 0.087$). Tukey post-hoc comparisons of the three groups indicate that the juice manufacturers are less satisfied (M = 2.98, 95 % confidence interval [CI 2.81, 3.42]) than both wholesalers (M = 3.72, 95 % CI [2.06, 2.55]) and consumer-merchants (M = 3.59, 95 % CI [2.17, 2.54]). The difference in means between consumer-merchants and wholesalers is not significant. Thus, wholesalers appear largely unresponsive to the preferences of juice manufacturers and allow a persistent discrepancy to remain between the pineapple assortment they offer and the one preferred by juice manufacturers. We explore whether this persistent discrepancy coincides with the network relationships in the system.

Network relationships

Strong connections between wholesalers and juice manufacturers represent an exception rather than the rule in the system. According to the survey results, juice manufacturers source their pineapples from more suppliers than do consumer-merchants, and the analysis of variance indicates an overall significant result ($F_{(2, 125)} = 10.90$, $p < 0.001$), [2] indicating (according to Tukey post-hoc comparisons) a significant difference between juice manufacturers (M = 4.20, 95 % CI [3.7, 4.7]) and the consumer-merchants (M = 3.36, 95 % CI [2.41, 3.07]). Juice manufacturers also indicate lower communication frequency than consumer-merchants (see Table 2.1), which may result logically from the fewer visits they make to the market, when they purchase larger quantities.

The quantitative findings confirm our qualitative findings regarding the strong connections in the traditional marketing channel (see Table 2.1). Among the wholesalers, 50 % relied on a maximum of five suppliers, and nearly 97 % of them contacted their most important supplier at least once a week. These wholesalers supply many customers (more than 100), which confirms their central role in the system. About 93 % see their most important customers at least once a week, signaling the strong relationships in the traditional channel. The picture is confirmed by the consumer-merchants, of which around 70 % purchased pineapples from no more than five wholesalers and more than 95 % indicated that they saw their most important suppliers at least once a week. The consumer-merchants distributed the pineapples further and managed to reach many consumers; close to 75 % of them indicated that they serviced more than 50 customers, and 50 % had more than 100 customers. Finally, around 70 % noted that their most important customer saw them more than once a week, and more than 25 % interacted with this customer daily.

Because juice manufacturers are less satisfied and less connected to the wholesalers than the consumer-merchants, it appears at the aggregate level that the marketing system had not adapted to the intervention. In other words: the failure to offer juice manufacturers pineapples that are in line with their preferences, seems to be rooted in the marketing system relationships. To check for exceptions, that is, wholesalers that show signs of adaptation to the juice manufacturers, we checked the wholesaler data for evidence of different segments or outliers, using cluster analyses and box plots, which could indicate if certain wholesalers specialize in selling more to juice manufacturers. However, no clear clusters of such specialized wholesalers emerged.[3] The outlier analysis similarly revealed no individual wholesalers that matched juice manufacturers' preferences. In the qualitative post hoc interviews, we zoomed in even closer on lower levels of aggregation in the marketing system, to seek out explanations for our findings.

Post hoc interview findings

In the post hoc interviews, wholesalers were asked whether they knew of other wholesalers that focused on juice manufacturers. Wholesalers stated that they were not aware of colleagues that had stronger relationships with or engaged in specific sorting and grading activities for juice manufacturers. They argued that they "sell good quality pineapples to everyone" and did not receive feedback from juice manufacturers, "not even complaints." They also complained about juice manufacturers' unwillingness to pay for quality, but when they were asked whether they knew what exact quality juice manufacturers sought, they asserted the juice manufacturers were just looking for cheap pineapples. Thus, the wholesalers revealed their lack of knowledge of the juice manufacturers' preferences. Their weak response to the juice manufacturers doesn't seem to be caused by a transaction cost barrier. Most wholesalers already engage in some sorting and grading for consumer-merchants, so extra sorting and grading for juice manufacturers would not entail much extra cost.

The juice manufacturers also exerted little effort to strengthen their network relationships with wholesalers. Not all juice manufacturers were aware that the type of pineapples used for juice production had a direct impact on juice quality, so the quality they produced likely varied. This gap indicates a lack of not only technical knowledge but also marketing knowledge; they had little comprehension of the impact of juice quality on consumers' potential repurchases. Most juice manufacturers also could not articulate how they intended to increase sales or describe how their sales and returns had changed over the years. Their sourcing practices typically involved a wide search across different vendors and markets to purchase pineapples as cheaply as possible. They shared little information and communicated essentially only about price. Several wholesalers complained that juice manufacturers were not loyal customers, so investing time in identifying and meeting their specific preferences would be wasteful: "I worked with three juice manufacturers and used to bring pineapples for them from a specific production area, but now they aren't coming anymore and I don't know why!".

Juice manufacturers were also asked whether they had different ways of governing their relationships with suppliers to accommodate their preferences. Two exceptions arose: One juice-maker had her own growers, such that she eliminated wholesalers from her supply chain (direct sourcing route in Figure 2.3). She located her factory in the countryside, where she sourced directly from growers in the same community where she lived. In addition, two juice manufacturers explicitly discussed the available variety, the size of the fruit, the maturity, and physical aspects of the fruit with their suppliers. When asked, they stressed that they would be willing to pay up to 10 % extra for a 'Kona Sugarloaf' without fungus and insects, as compared with a 'Cayenne Lisse' of the same size and similar other properties. Both these juice manufacturers had received technical training directly from the university engineers, possessed more detailed knowledge on how pineapple quality affects juice quality, and made explicit attempts to source 'Kona Sugarloafs' with the desired characteristics. Such knowledge did not lead to stronger relationships with their suppliers though. Rather, these juice manufacturers just spent more time exploring the market.

Beyond technical training in pasteurisation techniques, the juice manufacturers received no additional training in business practices, marketing, or sourcing. The wholesalers were not included in the development intervention—an exclusion they noted, expressing a sense of abandonment by the government and development organizations: “Everyone is interested in the juice manufacturers and the pineapple growers, but no one in us, the traders.”

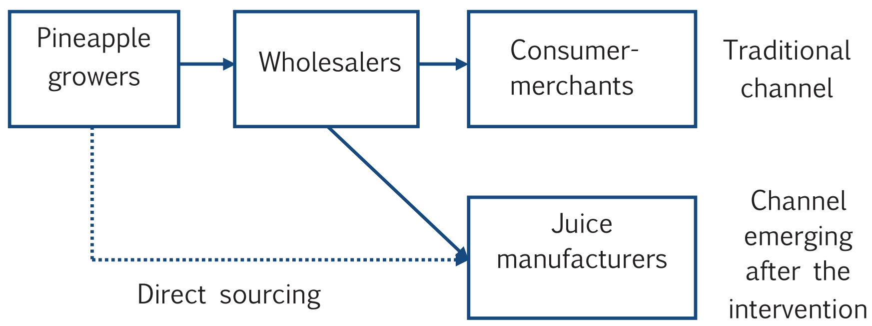


Figure 2.3

Schematic display of traditional and emerging channels in the system

DISCUSSION

We have explored the adaptation of the Beninese pineapple system to a technical intervention that established a new customer group of juice manufacturers. While the introduction of the pasteurisation technique was in itself successful in that the technology disseminated and improved the quality of life and probably the food security of consumers, its impact on economic growth has clearly been suboptimal. The results show that the juice manufacturers have not, even ten years after the intervention, become an integrated marketing channel for wholesalers and their suppliers. Instead they are regarded by the wholesalers as occasional customers, with no need for specific knowledge about their preferences. The wholesalers overlook opportunities for sorting and grading that could increase the satisfaction of both juice manufacturers and consumer-merchants. To their dissatisfaction, the juice manufacturers do not always receive pineapples from which they can produce a good juice quality. The study therefore shows that even at the aggregate level, the marketing system adapts to the intervention at best at a very slow pace.

Transaction cost theory is unlikely to explain the lack of adaptation in the marketing system fully. Sorting and grading entails some specific investment for the wholesalers. Sorting pineapples to meet the preferences of the juice manufacturers comes at the risk of behavioural uncertainty (i.e., opportunistic behaviour of juice manufacturers); if the demands of the juice manufacturers are not explicitly communicated to the wholesalers, it also creates some volume uncertainty. To govern such transactions, transaction cost theory would prescribe a hybrid form of governance, such as a strong social relationship, finding a balance between vertical integration (hierarchy) and the current arm's-length transactions (Geyskens et al., 2006). The transaction costs associated with trade flows offer insufficient explanation for the lack of adaptation; instead, we need to turn to the other elements of the marketing system.

The marketing system analysis has revealed substantial differences in the characteristics of the two buyer groups, rooted in the social matrix. The juice manufacturers are generally well-educated, middle-class entrepreneurs with access to sufficient capital to start their business. The consumer-merchants are more typical subsistence entrepreneurs. The exchange logics, contexts, flows, roles, and networks among the consumer-merchants in Benin resemble the descriptions of marketing systems surrounding subsistence entrepreneurs in India (Viswanathan, Sridharan, & Ritchie, 2010; Viswanathan, Sridharan, Ritchie, Venugopal, & Jung, 2012): They are mostly oriented toward survival, engage in oral agreements, create custom-made offerings, and purchase on credit. To improve assortments for juice manufacturers thus would require profound changes to elements of the marketing system. In terms of networks, governance, and exchange logics, stronger relationships would need to express trust and commitment not through credit and other favors but rather as chain coordination processes, such as planning and order fulfillment. In their roles, wholesalers would need to lead the channel coordination by undertaking more structural sorting and grading for both channels.

Thus we find an institutional gap between the traditional marketing channel and the new customer group. This term usually refers to institutional differences between a seller and a buyer in an export market that is substantially different in socioeconomic, regulative, and cultural terms than the home market (Yang, Su, & Fam, 2012), but a similar gap may arise within a country, especially when nations exhibit substantial heterogeneity in the social matrix, as is often the case for developing and emerging markets (Burgess and Steenkamp 2006). Speece (1990) used the term "ethnodomination" to indicate the penetration of a new group of actors in a traditional system. He further suggests that the traditional system goes through a process of cultural assimilation in order to adapt. Because the process is cultural, such adaptation may be slow. Accounts from cognitive psychology (Weick, 1979) further suggest that ignorance may stem from routine behaviour, such that wholesalers may have fallen prone to routinely serving their traditional market, leading them to ignore the new juice-maker market. In that respect, wholesalers have fallen into a competence trap that prevents them from responding effectively to new opportunities (Danneels, 2007). As newcomers learn the trade from older generations, the same competences get passed from one generation to another, making it unlikely that the system will adapt in the future, just as it has not adapted in the past decade, at least without further interventions.

Yet the ignorance explanation also falls short when we deal with aggregate marketing systems, because the large numbers of actors active at an aggregate level increase the likelihood that at least one of them will respond to the opportunity. Our study identified one juice-maker that sourced pineapples directly from growers and thereby avoided wholesalers, as well as two others that spent considerably more time at the market. Noting these exceptions, we cannot claim there was no adaptation at all in the marketing system; rather, the adaptation process appears very slow. Factors in the social matrix in which the system is embedded also appear to have contributed to this lack of adaptation. Layton (2011) proposes that the development from emergent to purposeful, structured systems hinges on the emergence of corporate entities. No such entities have appeared among the wholesalers in our study. The social embeddedness of their businesses grants these actors significant shared resources, beyond their individual resources (Viswanathan, Seth, Gau, & Chaturvedi, 2009). With limited schooling opportunities and the sheer absence of business training opportunities, knowledge is mostly a shared resource, disseminated mainly by copying others' successful behaviours (Harris-White, 2010). Because such essential resources are shared rather than owned, they do not create any competitive advantage. The search for new markets or market segments and the development of competences that establish a position of competitive advantage is therefore not necessarily part of the process (Hunt, 2000). This situation constrains the development of marketing systems in developing countries, and with it, their adaptability to interventions.

CONCLUSION AND IMPLICATIONS

The results imply that the adaptation of marketing systems to interventions in development contexts needs to be managed and effects of interventions need to be considered beyond the primary target group. To stimulate other actors in the system to adapt, complementary marketing interventions may be required. Such complementary interventions should focus on not just the primary beneficiaries of the technical intervention but also other actors in the marketing system. In our study, the central group of wholesalers appeared upstream of the group toward which the technical intervention was targeted (juice manufacturers). In this sense, the marketing system perspective offers richer insights into the adaptability of the system than an approach restricted to transaction costs, such that the marketing system analysis makes a valuable, complementary contribution to development economics and technological disciplines, which are far more prevalent in development debates than marketing is.

Implications for policy makers

Although bottom-up insights are needed to design development interventions (Viswanathan et al., 2012), a theoretical understanding of how marketing contributes to development, as captured in marketing systems theory (Layton, 2011), also can lead to more effective interventions (see also Ingenbleek, 2014). In that respect, policy makers should first ask which effect they hope to achieve, such as greater standardization by harmonizing fragmented markets or increased specialization by segmenting markets and developing differentiated products and services for them (Tedlow, 1996). Standardization may lead to scale efficiencies and require interventions in terms of infrastructure and logistics to enable market access (Dadzie et al., 2013). Specialization instead may lead to better exploitations of the differences in willingness (and ability) to pay or a more optimal use of input material with natural quality variations. The study presented here offers an example of the latter effort, in that introducing pasteurisation techniques to establish a new customer group (juice manufacturers) should enable the system as a whole to make more effective use of the natural variation in harvested pineapples.

Policy makers also should consider which actors take central positions in the system to define the necessary changes. These actors require further investigation to determine if they are likely to respond. Insights into any barriers to their responsiveness in turn could generate ideas for complementary interventions. For example, if a technological intervention requires actors in the marketing system to bear financial risks, which in turn requires assistance from their communities or families, micro-lending to pursue the specific opportunity, created in parallel with the intervention, may reduce or eliminate that barrier.

Financial barriers seem relatively easy to address, but the removal of social and cultural barriers is likely more complex. Development workers therefore emphasize on the importance of education in general (e.g., United Nations 2005). A more specific way is by training to individual or groups of entrepreneurs, to raise their awareness of the possible tensions between pursuing market opportunities and their social networks. One example is the film *Shakti Rising*, developed with the participation of the micro-finance organization Madura and input from subsistence market researchers, reveals how an Indian woman living with her family in subsistence conditions makes her way out of poverty through the market and overcomes several barriers; Madura in turn uses the movie for instructional purposes (Madura Microfinance, 2013) and is part of a larger educational program (see www.marketliteracy.org).

In the specific case of the Beninese pineapple system, a possible intervention might focus on training that increases wholesalers' understanding of the juice-making process, helping them learn to appreciate the needs and wants of this customer group, potentially leading to a higher level of specialization.

Among new customer group, interventions could seek to increase understanding of the potential gains of providing feedback and loyalty to their suppliers. Sheth (2011) argues that market development is a process of raising expectations. If juice manufacturers, for example, come to expect that they can obtain affordable pineapples that are suitable for juice-making without much risk, they likely would increase their feedback to wholesalers and gradually contribute to the development of a more specialized marketing channel within the system, targeted explicitly at their preferences, which should become increasingly pronounced through this process. Finally, new customer groups can organize their own supply by "cutting out middlemen". This solution might be implemented not only individually but also collectively, through associations.

Implications for market research and marketing system analysis

By taking the specific characteristics of these markets into account (Ingenbleek et al., 2013), this study applied conjoint techniques in a development context. In that respect, this study increases the toolbox available to marketing system analysts and market researchers in developing countries (Kramer & Belz, 2008; Viswanathan, Sridharan, & Ritchie, 2008). The application of conjoint methods, which are common in North America and Europe (Wittink & Cattin, 1989; Wittink, Vriens, & Burhenne, 1994), requires specific adjustments to match the development context though. For example, using pictographic stimuli helps align with the prevalence of pictographic thinking (Gau, Jae, & Viswanathan, 2012). A sorting task, before grading the stimuli, also appeared helpful in our data collection process. These practices are recommended for future applications of complex conjoint designs in development contexts.

Second, measuring preferences of different groups of actors in the marketing system generates new insights that can improve the functioning of that system. At a practical level, our results from the Beninese pineapple system indicate the dislike of the use of ethephon, shared among all actors. This finding implies an opportunity to increase customer trust in pineapple supplies by eliminating ethephon from the production process. Likewise, the results indicate a common dislike for pineapples with pests or fungus. Valuable transportation costs could be saved if such pineapples were removed from the assortment at the earliest stages possible. Pineapples that are particularly large or have physical damage are disliked by the consumer-merchants but not necessarily by juice manufacturers. If such pineapples were sorted out for juice-making, the perceived quality of pineapple supplies would likely increase among consumer-merchants. The conjoint study thus reveals concrete opportunities for making the pineapple system more efficient and effective.

Limitations and directions for further research

This paper offers empirical evidence from one case, the adaptation of a supply system to a new customer group, for a fresh and perishable agricultural product, in one specific country in West Africa. To draw generalizable conclusions on the conditions in which marketing systems respond to development interventions, more research is therefore necessary. As our study focuses on an agricultural product, thus pertaining to suppliers from rural areas in a developing country, future research may explore urban areas, where it could possibly test effects of interventions in systems for less-perishable products and services, like manufactured goods and communication services. Our findings may also not generalize to settings that are even more rural than the context studied here, like, for example, the marketing system of East African pastoralists (Ingenbleek et al., 2013). Our study also focused on the creation of a new customer group from a socioeconomic middle class. While the emerging middle classes are found in many developing and emerging markets, future research could examine whether suppliers would respond differently to customers from socioeconomic upper classes (because the difference in purchasing power makes the opportunity easily recognizable) or from the base of the pyramid (because differences in the marketing system are smaller).

With respect to the design of development interventions, further research should specify the effectiveness of technical development interventions, such as marketing components targeted at central players in the marketing system that seek to effect marketing's potential contribution to development. Such studies should provide deeper insights into the type of development interventions that can remove potential barriers to development and enable subsistence entrepreneurs to seize opportunities, without threatening their role in their social networks, their safety net, or their prior investments.

Appendix

Combining all attributes with all levels according to a full-factorial design would yield 768 profiles (2 varieties × 3 sizes × 4 skin colours × 2 levels of translucence × 2 levels of fungus presence × 2 levels of ethephon presence × 2 levels of insect presence × 2 levels of physical damage). Because such a large number of profiles cannot be reliably assessed by respondents, we used a fractional-factorial main-effects design to obtain a subset of 16 calibration profiles that were selected with the help of SPSS software. We added another 6 holdout profiles (presented in three pairs) for validation purposes. Then each respondent evaluated 22 profiles in total.

To present these profiles to the respondents, we chose a pictorial approach (Figure 2.4). Less literate respondents tend to engage in pictographic thinking (Gau et al., 2012); as a result, experiments and conjoint studies conducted in subsistence contexts benefit from including pictographic stimuli (Ingenbleek et al., 2013). Each respondent first carried out a sorting task, grouping the 16 calibration profiles into three piles: one with pineapples they would consider buying, one with pineapples they would maybe consider buying, and one with pineapples they would not consider buying. For each pineapple in each pile, respondents subsequently rated how likely they were to buy it. We used a 10-point scale that appeared on the right-hand side of the picture frame; a value of 1 indicated the lowest likelihood to buy (sad face), and a value of 10 represented the highest likelihood to buy (smiling face). The faces helped respondents who had received little formal education. We used the ratings for the calibration profiles to estimate attribute-level partworths, using an ordinary least squares regression for each respondent.

After rating the 16 calibration profiles, respondents received three sets of two holdout profiles and were to pick from each set the pineapple they liked the best. Their choices were thus compared with the predicted scores, according to the first-choice hit criterion (Huber et al., 1993). If the predicted buying likelihood (calculated from the estimated partworths) for the chosen pineapple was higher than the one for the non-chosen pineapple, the choice supported the (internal) predictive validity of the partworth estimates. To allow for some margin of error, we also considered a choice to be supportive of (internal) predictive validity if the difference in predicted buying likelihood between the chosen and the non-chosen pineapple was not lower than – 0.5.

Each respondent saw three choice pairs. With a cut-off value of – 0.5, only one respondent had less than two consistent choices (see Figure 2.5). For this respondent, the mean of the differences between chosen and non-chosen profiles was – 0.92. We excluded the respondent from further analyses.

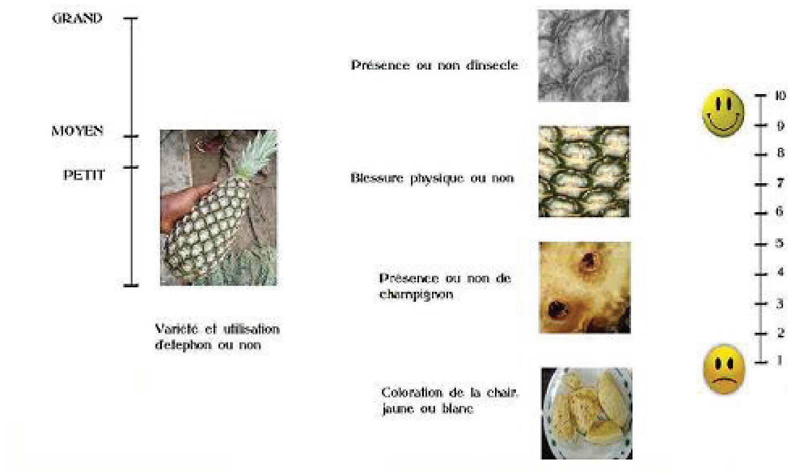


Figure 2.4

Example of one profile (extracted from the questionnaire)

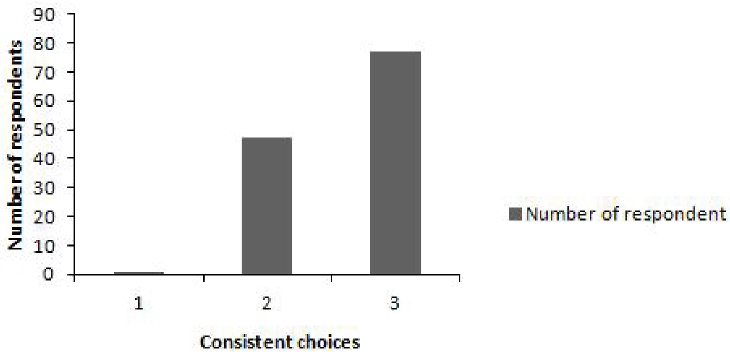


Figure 2.5

Distribution of number of consistent choices

Footnotes

[1] Fit indices are not available of the measurement model because the model is saturated as it contains only one latent variable.

[2] We also controlled for relevant trading variables, but they had no impact on the results.

[3] The cluster analysis revealed that the ratio of the agglomeration coefficients after the second step did not come close to exceeding 1.3, indicating no evidence of clusters of wholesalers with preferences that differed considerably from the mainstream.

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3

EFFECT OF PHYSICAL DAMAGE AND STORAGE OF PINEAPPLE FRUITS ON THEIR SUITABILITY FOR JUICE PRODUCTION

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ABSTRACT

This study evaluated the suitability of physically damaged pineapples, variety 'MD2', that were stored for up to nine days at 20 °C for the production of fresh pineapple juice. Fresh pineapples were bruised and cut in different ways. The study showed an interaction effect of the physical damage treatments and storage duration on juice pH, TSS and sucrose content. However, bruising and cutting treatments did not affect the physicochemical qualities and vitamin C content of the fresh juice. Furthermore, storage of pineapple fruits for up to nine days was accompanied by an increase of glucose and fructose.

Keywords: Ananas comosus, variety 'MD2', variety 'Kona Sugarloaf', vitamin C

INTRODUCTION

Pineapple (*Ananas comosus*) is a well appreciated fruit all over the world. World production quadrupled between 1960 and 2005, reaching over 16 million tons (Vagneron, Faure, & Loeillet, 2009). Pineapple is a good source of vitamin C, fibres and minerals (Montero - Calderon, Rojas - Graü, & Martin - Belloso, 2009) and can be consumed fresh or processed into products such as pasteurised pineapple juice, pineapple syrup or dried pineapple.

Benin is a West African country at the coast of Atlantic Ocean, which has a tropical climate that is suitable for growing tropical fruits such as pineapple. The coastal zone of the country accounts for more than 90 % of the domestic annual pineapple production (220,800 tons in 2010) (FAOSTAT, 2012). Two pineapple cultivars are produced: 'Smooth Cayenne', which was originally produced for the European export market, and 'Kona Sugarloaf', highly appreciated for its aroma and sweet taste and consumed fresh or processed into juice. Due to the strict standard regulations for pineapple in Europe, only about 2 % of the Beninese production was exported to European countries in 2010. Domestic markets and other West African markets account for about 80 % of the traded pineapple. The remaining part (about 18 %) is lost as a result of physical damage (Helvetas, 2007). Physical damage can occur during harvest and post-harvest handling steps such as during transport, at destination markets and at retail, including consumer handling. Physical damage is extremely common during fruit handling, and is defined as plastic deformation, superficial rupture and destruction of vegetable tissue due to external forces (Sanches, Durigan, & Durigan, 2008). It includes surface injuries such as scuffing, abrasions, cuts and punctures, and internal bruising due to impact, vibration, or compression (Kader, 2002; Kasmire & Kader, 1978). Bruising, for instance, can be caused by impact against other surfaces and/or by vibration during transport. According to Vigneault et al. (2002), impacts are transitory movements caused by sudden acceleration or deceleration causing great dissipation of energy and consequent damage to the fruit. Some of the consequences of physical damage are internal quality loss with flavour and nutritional changes (Durigan, Mattiuz, & Durigan, 2005). For fruits such as guava, mango and peach, research shows, among others, loss of acid content due to mechanical impact (Durigan et al., 2005; Kasat et al., 2007; Mattiuz & Durigan, 2001; Moretti, Sargent, Huber, Calbo, & Puschmann, 1998). Loss of vitamin C has also been reported for tomato (Moretti, Sargent, Huber, Puschmann, & Fontes, 1999). Research also showed that bruising significantly reduced total soluble solids of Tahiti limes (Durigan et al., 2005). The objective of this research is to evaluate the effect of using stored pineapple with physical damage on the physicochemical and nutritional qualities (vitamin C) of the fresh pineapple juice.

MATERIALS AND METHODS

The effect of using physically damaged pineapples that were stored for a period of up to nine days was studied in 2 independent experiments. To reduce the effect of natural variation in the fruits, variety 'MD2' from Costa Rica was used in experiment 1. In experiment 2, variety 'Kona Sugarloaf' from Benin was used.

Experiment 1 was carried out using 80 pineapple fruits of variety 'MD2' from Costa Rica. Experiment 2 was carried out with 5 fruits of variety 'Kona Sugarloaf' from Benin and 5 fruits of 'MD2' from Costa Rica.

The 80 pineapple fruits were treated by cutting to cause external damage and by bruising for internal damage. Two cuttings treatments were applied: a mild cutting treatment consisting of two vertical cuts, from the top of the fruit to the bottom, with a depth of 1.0 cm, and a severe cutting treatment, consisting of 8 evenly distributed vertical cuts from the top to the bottom of the fruit, with a depth of 2.0 cm. Similarly, two bruising treatments were applied; an Instron 5565 Universal Testing Machine (Instron Ltd, High Wycombe, Great Britain) with a 19.6 cm^2 cylindrical metal probe was used to cause bruising: the mildly bruised treatment by pressing the pineapple with a force of 5.1 N/cm^2 and the severely bruised treatment by pressing the fruit with 17.8 N/cm^2. The cylinder was put in the middle of the pineapple fruit. The severeness of the bruising treatments was based on the shell integrity tests, performed with this machine. The tests consisted of finding the maximum force that the pineapple fruit could sustain before breaking the shell. For a pineapple, at the end of its shelf life, the shell bursted when the force was around 12 N/cm^2, whereas for a relatively fresh pineapple, this was around 20 N/cm^2. After the different treatments, the 80 pineapple fruits were stored at 20 °C. Twenty pineapples were used for chemical analysis at day 2, 4, 7 and day 9, namely four for each of the 5 treatments.

During experiment 2, chemical characteristics of the juice of undamaged 'Kona Sugarloaf' fruits were determined and compared with those of the juice of undamaged 'MD2', stored at 30 °C for 7 days. This experiment aimed at determining the chemical changes in juice from 'MD2' at an ambient temperature similar to that of a tropical zone, as an indication of what might happen to physically damaged pineapples of another variety, in particular variety 'Kona Sugarloaf' from Benin.

Juice preparation

First the crown leaves and first 1.5 cm of flesh of the pineapple were sliced off with a knife. A pineapple slicer was put on top of the flesh that was made accessible. The slicer was turned till it reached the bottom of the pineapple. The slicer was pulled out. The flesh was weighted, collected in cheesecloth and pressed with a hydraulic press (IKA Werke GmbH & Co.KG, Staufen, Germany). The 'MD2' variety used in the experiment 1 gave a juice yield of about 58 %. The 'MD2' variety used in the experiment 2 gave a juice yield of about 64 % and the 'Kona Sugarloaf' variety gave a juice yield of 62 %. The juice samples were collected in tubes, immediately frozen with liquid nitrogen and stored in a freezer at -25 °C. They were defrosted on the day of the analysis by putting the tubes into tap water at room temperature.

pH and total soluble solids

The pH value was measured using a pH meter (PHM standard 82 pH meters, Radiometers, Copenhagen, Denmark). The total soluble solids (TSS) of juice were determined using a refractometer (Eclipse 45-08, Bellingham + Stanley, Tunbridge Wells, UK). All measurements were carried out according to AOAC procedures (Horwitz, 2000).

Sugar determinations

Glucose, fructose and sucrose contents in juice were determined by the method described by Matsuura-Endo et al. (2004). Pineapple juice was diluted 100 and 400 times with milli-Q water. These solutions were filtered using a 0.45 μm cellulose acetate (CA) filter. The filtrate's contents of glucose, fructose and sucrose were determined using an HPLC system (Ultimate 3000, Thermo Scientific, Dreieich, Germany) equipped with an Alltech Prevail Carbohydrates ES 5μm column 250 x 4.60 mm (Alltech, Lexington, Kentucky, USA) and an Evaporative Light Scatter Detector

(ELSD). The eluents were acetonitrile (75 %) and milli-Q water (25 %). Total sugar was calculated from the sum of the molar concentration of glucose, fructose and sucrose.

Total vitamin C

Fresh fruit juice (10 mL) was centrifuged for 10 min at 4 °C, after which the supernatant was collected in 2.0 mL Greiner tubes and again centrifuged for 10 min at 10,500 rpm at 4 °C. The juice was filtered using 0.2 μm CA filters.

The total vitamin C (total ascorbic acid) concentration was determined by measuring both the Ascorbic Acid (AA) and Dehydroascorbic Acid (DHA) using a HPLC system equipped with a C18 column (Hernandez, Lobo, & Gonzalez, 2006). AA was measured directly. Then, DHA was reduced back to AA; for that purpose, 1.5 mL of filtered fruit juice was mixed with 15 μL 1M Tris-2-carboxyethylphosphine (TCEP) solution in amber HPLC vials and stored in the dark for at least 20 minutes in ice.

Statistical analysis

Experiment 1

Data were analysed by SPSS software (version 16.0). Two way-anova was used to look for interaction between the two independent variables: duration of storage and physical damage. When the interaction appeared to be significant, the mean value of the combined effect of both independent variables was compared using one way anova. In case the interaction was not significant, we looked at the main effect of the duration of storage and the physical damage treatments separately. In this case, the Tukey test was performed to compare the mean within each independent variable. A correlation test was also performed to check if there was any association between the different quality parameters (Field, 2005). Experiment 1 was replicated four times independently with different pineapples.

Experiment 2

T-student test was performed to compare the chemical characteristics of the juices prepared from varieties 'MD2' and "Kona Sugarloaf". Experiment 2 was replicated four times independently with different pineapples.

RESULTS

The interaction of the physical damage treatment and storage duration was found to be significant for the pH ($F_{12,79}$ = 2.31, $P < 0.05$), TSS ($F_{12,79}$ = 1.98, $P < 0.05$), sucrose content ($F_{12,79}$ = 2.27, $P < 0.05$) and the total vitamin C content ($F_{12,79}$ = 3.40, $P < 0.01$) of pineapple juice whereas the interaction was not significant for the fructose ($F_{12,79}$ = 1.07, $P > 0.05$) and the glucose ($F_{12,79}$ = 1.85, $P > 0.05$) content.

This effect depended on the duration of storage after the fruit was physically damaged (Table 3.1). Considering the juice pH, no difference among treatments was found until day 7; we observed that mild bruising at day 9 showed a low pH value (3.5) that was significantly different when compared to the pH resulting from the other physical damage performed at that day (Table 3.1). Considering the TSS, physical damage, mainly the heavy cutting strongly reduced the degrees Brix of the pineapple juice at day 4. The degrees Brix was the lowest (13.2) at that day for this treatment. As far as the sucrose content of the juice was concerned, it was found to be greatly reduced when the pineapple was heavily cut and stored until day 9; in fact the sucrose content was the lowest at that day under this treatment of physical damage. The total vitamin C content of the juice was reduced at an earlier stage of the storage of the pineapple, i.e., at day 2 with mildly cut pineapple, showing the lowest amount of total vitamin C (581.7 μg/mL) and the undamaged pineapple showing the highest amount of total vitamin C (724 μg/mL).

Table 3.1

Combined effect of storage duration and physical damage on quality parameters of pineapple juice from MD2 variety (Experiment 1)

		pH	Degrees Brix	Total vitamin C (μg/mL)	Sucrose (mg/mL)
Day 2	Regular	3.3 ± 0.1[a]	14.2 ± 0.8[a]	724.50 ± 93.2[a]	49 ± 10.2a
	Mild bruising	3.3 ± 0.1[a]	13.4 ± 2.1[a]	648 ± 19[a]	46.7 ± 9.2[a]
	Heavy bruising	3.3 ± 0.1[a]	14.0 ± 0.7[a]	605.2 ± 56.9[ad]	46.0 ± 2.4[a]
	Mild cutting	3.3 ± 0.0[a]	14.0 ± 0.1[a]	581.75± 29[d]	43.7 ± 7.5[a]
	Heavy cutting	3.2 ± 0.1[a]	14.8 ± 1.1[a]	685 ± 52.7[a]	47.7 ± 7.4[a]
Day 4	Regular	3.4 ± 0.1[a]	14.3 ± 0.4[ab]	-	54.5 ± 9.1[a]
	Mild bruising	3.4 ± 0.0[a]	14.5 ± 0.6[ab]	-	49.2 ± 2.6[a]
	Heavy bruising	3.4 ± 0.1[a]	15.3 ± 0.5[a]	-	54.7 ± 2.5[a]
	Mild cutting	3.4 ± 0.1[a]	15.6 ± 0.6[a]	-	55.5 ± 3.9[a]
	Heavy cutting	3.4 ± 0.1[a]	13.2 ± 0.1[b]	-	43.7 ± 6.4[a]
Day 7	Regular	3.5 ± 0.1[a]	14.2 ± 1[a]	727.0 ± 17.56[a]	76.7 ± 12.9[a]
	Mild bruising	3.5 ± 0.1[a]	13.8 ± 1.29[a]	676.2 ± 37.9[a]	51.0 ± 9.9[a]
	Heavy bruising	3.4 ± 0.1[a]	14.5 ± 0.5[a]	764.0 ± 52.3[a]	63.0 ± 5.5[a]
	Mild cutting	3.5 ± 0.1[a]	14.6 ± 0.4[a]	697.5 ± 40.6[a]	61.0 ± 5.6[a]
	Heavy cutting	3.5 ± 0.1[a]	15.1 ± 1.1[a]	685.1 ± 24.2[a]	58.0 ± 7.4[a]
Day 9	Regular	3.7 ± 0.1[a]	12.2 ± 0.1[a]	699.5 ± 60.9[a]	42.5 ± 15.8[a]
	Mild bruising	3.4 ± 0.1[b]	14.0 ± 1.3[a]	693.5 ± 28.7[a]	34.2 ± 6.9[a]
	Heavy bruising	3.6 ± 0.1[a]	13.2 ± 1.3[a]	725.0 ± 58.85[a]	32.5 ± 8.2[a]
	Mild cutting	3.7 ± 0.1a	13.6 ± 1.4[a]	692.0 ± 65.9[a]	62.2 ± 23.1[ab]
	Heavy cutting	3.6 ± 0.1a	13.3 ± 1.2[a]	631.50 ± 44.2[a]	29.5 ± 10.3[ac]

(-) data not available

Data with different superscript letters in the same column for the same day are significantly different at $P < 0.05$.

The interaction of the damage treatment and storage duration did not have a significant effect on the fructose and glucose contents. It was shown that only storage duration affected fructose and glucose contents.

Figure 3.1 shows the glucose, fructose, sucrose and total sugars content expressed in moles from day 2 to day 9.

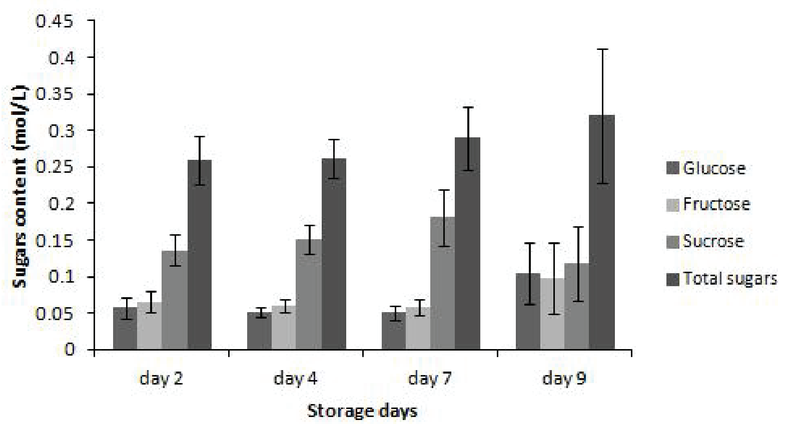

Figure 3.1

Glucose, fructose, sucrose and total sugars contents of pineapple juice made from physically damaged and stored pineapples from 'MD2' variety (Experiment 1)

Fructose and glucose contents of juice of the pineapples increased significantly ($p < 0.01$) from day 7 to day 9. No significant difference was noticed between the juice of the pineapples that were stored till day 2, day 4 and day 7 ($p > 0.05$) (Figure 3.1). The total sugars did not significantly ($p < 0.05$) change during the storage period.
Table 3.2 presents the comparison of physico-chemical characteristics of juice made from varieties 'MD2' and 'Kona Sugarloaf".

Table 3.2

Characteristics of juice of 'MD2' variety and 'Kona Sugarloaf' pineapple variety stored during 7 days at 30 °C (Experiment 2)

	MD2	Kona Sugarloaf
pH	3.9 ± 0.1a[z]	3.9 ± 0.1a
TSS (° Brix)	14.2 ± 0.4a	14.2 ± 0.4a
Total vitamin C (µg/ml)	636 ± 14.1a	171 ± 28.04b
Fructose (mg/ml)	22.8 ± 2.2a	11 ± 1.5b
Glucose (mg/ml)	23.6 ± 2.6a	11.4 ± 1.3b
Sucrose (mg/ml)	57 ± 7.5a	60.8 ± 3a

([Z] Means ± (standard error) within each parameter row with different letters are significantly different at $p < 0.05$; n = 5 for each variety)

There was no significant ($P > 0.05$) difference in pH, TSS and sucrose content between the two pineapple varieties 'MD2' and 'Kona Sugarloaf'. 'MD2' pineapples showed the highest total vitamin C, fructose and glucose contents (Table 3.2). 'MD2' contained almost 4 times more vitamin C than 'Kona Sugarloaf' with 2 times more fructose and glucose at a similar content of sucrose.

DISCUSSION

Physical damage and storage time combined had an effect on the pH, TSS, the total vitamin C and the sucrose content of the 'MD2' pineapple juice . However, the mean differences observed at day 9 for pH, day 4 for the TSS, day 2 for total ascorbic acid (TAA) and day 9 for sucrose (see Table 3.1) were in accordance with the natural variation found in pineapple fruit (Shamsudin, Daud, Takriff, & Hassan, 2007). In bruised tomato fruits, the total vitamin C content was about 15 % lower than in unbruised fruits (Moretti et al., 1998). This was not the case in our study. There was no significant difference in the total vitamin C content between bruised and undamaged pineapples (see Table 3.1). The pineapple samples used in the present study were mature but firm and green-yellow. It is therefore possible that the impact of bruising was not sufficient to cause a significant degradation in the total vitamin C content.

Furthermore, duration of storage in this study did not affect the total vitamin C content. This result was not expected because generally fruits and vegetables show a gradual decrease in the total vitamin C content as the storage temperature or duration increases (Adisa, 1986; Klimczak, Małecka, Szlachta, & Gliszczyńska-Świgło, 2007; Lee & Kader, 2000; Polydera, Stoforos, & Taoukis, 2003). Achinewhu and Hart (1994) reported a strong decrease in total vitamin C due to aging in pineapple, which is in contradiction with our finding. This might have been due to the difference in the storage temperatures (30 to 32 °C) used by these authors, compared to the 20 °C in our research. Other authors found that the total vitamin C initially increased and then decreased during storage at 8 °C and increased when held at 22 °C (Chen & Paull, 1995; Teisson, Martinprevel, & Marchal, 1979). However, Izumi et al. (1984) studied the effect of chilling temperatures on changes of total vitamin C content of some chilling-sensitive crops and found that total vitamin C content in cucumber, for instance, decreased continuously at 5 °C, whereas no decrease was observed at 20 °C.

Physical damage and storage duration together did not have a significant ($P > 0.05$) effect on fructose and glucose. However, storage duration significantly ($P < 0.05$) affected the fructose and glucose content.

The major sugars in pineapple are fructose, glucose and sucrose (Karkacier, Erbas, Uslu, & Aksu, 2003; Ramallo & Mascheroni, 2005; Sanz, Villamiel, & Martınez-Castro, 2004; Shamsudin et al., 2007). The amount of fructose and glucose did not change till day 7, but increased from day 7 to day 9 (Figure 3.1). The data in Table 3.1 show that the sucrose content did not really change. The peak of the sucrose concentration was attained at full ripeness and then declined; fructose and glucose continued to increase (Singleton & Gortner, 1965; Tay, 1977). The decrease of sucrose with a simultaneous increase of fructose and glucose could be explained by the inversion of sucrose (Fuleki, Pelayo, & Palabay, 1994).

The comparison between the varieties 'MD2' and 'Kona Sugarloaf' aimed at determining the validity of the results of experiment 1. 'MD2' had the highest total vitamin C content. If vitamin C would be the most important factor for the quality of juice, this would imply that 'Kona Sugarloaf' would not be a good choice for juice production according to the results of this study. However, Wardy et al. (2009) found a much higher value in 'Kona Sugarloaf' from Ghana, namely 421 μg/mL, against 171 μg/mL found in this research. This suggests a large variation between different batches of 'Kona Sugarloaf'. A similar high variation in the total vitamin C content within the same variety of pineapple was also mentioned by Miller et al. (1951).

As far as physical damage is concerned, when pineapple was stored at 20 °C, physical damage did not affect the quality parameters measured in this study. However, storage contributed to a substantial increase of fructose and glucose at day 9. Actually, the sweetness of pineapple fruit is attributed to the combination of sucrose and its component sugars, fructose and glucose (Inglett, 1981). Our findings are corroborated by Pongjanta et al. (2011), who also reported an increased sweetness of pineapple juice during storage due to an increase of fructose and glucose while the sucrose content decreased.

CONCLUSION AND RECOMMENDATIONS

The study showed that the pH, total soluble solids, total vitamin C and sugar contents of pineapple juice produced from physically damaged fruits does not differ significantly from juice made from undamaged fruits. Regarding storage, the content and composition of the sugar fraction were the most important changes observed. Storage till 9 days in this study contributed to a change in the sugar composition of the pineapple and would contribute certainly to improve the taste through enhanced sweetness. This effect needs to be studied further to understand its physiological background and its impact on the sensorial quality. However, to fully benefit from these pineapples, adequate sorting and storage facilities need to be implemented upstream to avoid fast degradation. These damaged pineapples can therefore be used for pasteurised pineapple juice production. Pasteurisation is another important factor that impacts the nutritional and sensorial quality of pineapple juice. Its parameters (time and temperature) need to be studied in more detail to enable optimisation of this part of the pineapple juice production chain.

4

EFFECT OF PROCESSING ON THE QUALITY OF PINEAPPLE JUICE

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ABSTRACT

Pineapple processing plays an important role in juice preservation. Because the quality of the pineapple juice is affected by the processing technology applied, the effects of pasteurisation and other preservation methods on the overall juice quality was discussed. During juice processing, microorganisms are destroyed and chemical changes occur. To optimize processing conditions, knowledge of the kinetics of these reactions is needed, but as yet, data on the degradation of the amino acids, vitamin C, and the change in sugar contents during pineapple juice pasteurisation are scanty. Furthermore, the kinetics of hydroxymethylfurfural production should be investigated by a precise technique such as high-performance liquid chromatography.

Keywords: HPLC, Kinetics, Pasteurisation, Vitamin C

INTRODUCTION

Pineapple, *Ananas comosus*, is a commercially important fruit that represents a major export product for many tropical countries. Like other fruits, pineapple is important in the human diet as a source of micronutrients, especially vitamins and minerals. According to Purseglove (1972), the edible part of the pineapple fruit (60 % of the fresh fruit) has a moisture content of 85 %. This high water content makes the fruit susceptible to physicochemical and microbiological degradation; therefore, pineapple is processed. Fresh pineapple can be processed into several products such as canned pineapple slices, pineapple juice concentrate, pineapple pulp, dried pineapple and pasteurised pineapple juice. Among these products, pasteurised pineapple juice is one of the most important pineapple commodities. However, processing may affect the nutritional and the organoleptic values of processed pineapple.

Some studies have focused on the safety of pineapple juice (Badge & Tumane, 2011; Bermudez-Aguirre & Barbosa-Canovas, 2012; Carneiro et al., 2002; Ewaidah, 1992; Ferreira et al., 2009; Maresca et al., 2011; Obeta & Ugwanyi, 1997b; Obeta & Ugwuanyi, 1997a; Rosenthal et al., 2002; Salomao et al., 2007; Slongo & de Aragao, 2008; Tchango Tchango et al., 1997; Zimmermann et al., 2011; Zimmermann et al., 2011), as well as on its nutritional (Al-Jedah & Robinson, 2002; Camara et al., 1995; de Carvalho et al., 2008; Gawler, 1962; Uckiah et al., 2009; Zheng & Lu, 2011) and sensorial quality (Chan et al., 1973; de Carvalho & da Silva, 2010; de Carvalho et al., 1998; Gassaye et al., 1991; A. Laorko, Li, & Tongchitpakdee, 2011; Ohta, 1987; Pereira et al., 2005; Rattanathanalerk, Chiewchan, & Srichumpoung, 2005; Wen & Wrolstad, 2002). The sensorial and nutritional quality of the juices produced around the world and especially in developing countries are a relevant topic. Some problems encountered are loss of vitamin C during heat treatment (Achinewhu & Hart, 1994; Akinyele, Keshinro, & Akinnawo, 1990; Uckiah et al., 2009), and nonenzymatic browning, the Maillard reaction, after processing (Rattanathanalerk et al., 2005).

In the framework of studies on the quality of pasteurised or sterilized pineapple juice, it appeared necessary to find out what is already done in this respect. This review aims at identifying the juice quality issues as far as safety and nutritional and sensorial quality are concerned. The unit operations, new technologies used, and gaps in the knowledge concerning nutritional and sensorial quality of canned/bottled pineapple juice are discussed.

EFFECT OF PROCESSING ON THE NUTRITIONAL QUALITY OF PINEAPPLE JUICE

Minerals

The major mineral elements in fresh pineapple juice are potassium (K) (124 ± 9.6 mg/100 mL), magnesium (Mg) (15.4 ± 5.1 mg/100 mL), phosphorus (P) (3.1 ± 0.3 mg/100 mL), iron (Fe) (0.2 ± 0.02 mg/100 mL) and manganese (Mn) (0.3 ± 0.1 mg/100 mL) (Camara et al., 1995). The potassium content is corroborated by Krueger et al. (1992), who found 110 mg/100 mL (with a range from 83 to 141 mg/100 mL). In general, the variation observed in fruits could be associated with variation in cultural practices (Zúñiga-Arias, Ruben, & van Boekel, 2009).

Akinyele et al. (1990) reported that a thermal treatment at 99 °C during 17 min reduced the calcium (Ca) and potassium contents of pineapple juice by 50 %. The mechanism of this reduction was not explained and is unexpected because these minerals cannot disappear just like that. Perhaps they are locked up in precipitates; this needs further investigation.

Vitamin C

According to Kabasakalis et al. (2000), vitamin C is a sensitive substance that can easily be lost in many conditions such as exposure to light, high temperature and oxygen access. The vitamin C content of fresh pineapple juice is reported to range from 9.2 mg/100 mL to 93.8 mg/100 mL (Achinewhu & Hart, 1994; Camara et al., 1995; Miller & Schaal, 1951). This suggests a large variation of vitamin C in pineapple fruit. Camara et al. (1995) found the vitamin C content of fresh pineapple juice to be 84.2 ± 9.6 mg/100 mL while the value for commercial pineapple juice made from concentrate varied between 8.5 ± 1.4 and 58 ± 4.9 mg/100 mL.

Akinyele et al. (1990) found that pasteurisation of pineapple juice at 99 °C for 17 min caused a loss of 94 % of the vitamin C content. This decrease in vitamin C could be the result of its oxidation into dehydroascorbic acid or diketogulonic acid during heat treatment (Mills, Damron, & Roe, 1949). Pasteurisation at 90 °C for 3 min caused a decrease of vitamin C content from 33.5 ± 1.9 mg/100 mL to 12.8 ± 1.1 mg/100 mL, leading to 38 % of vitamin C loss (Achinewhu & Hart, 1994).

Uckiah et al. (2009) studied vitamin C loss of juice from fresh peeled 'Queen Victoria' variety of pineapple after different process unit operations, namely peeling, blending, filtering, exhausting and pasteurisation. Exhausting is the process of removal of air from cans. It is an important step in the processing of the juice as it removes dissolved air and thus makes oxygen unavailable for reaction during storage (Evenden & Marsh, 1948). Results show that, while the fresh juice contained an average vitamin C content of 24.8 mg/100 mL, peeling led to the highest percentage loss of vitamin C (41.8 %) followed by exhausting performed at 90 °C for 10 min (23.7 %). Next to that, pasteurisation that was also performed at 90 °C for 10 min, did not lead to an important loss (9.5 %) of vitamin C (Uckiah et al., 2009). So, heat treatment of juice at 90 °C for 10 min in an open pan for exhausting generated more vitamin C loss than heat treatment for pasteurisation in a sealed bottle at 90 °C for 10 min. According to the authors, this could be explained by the fact that, in the process described, the juice was in direct contact with the heated air generated by the water bath during exhausting. The pasteurisation was implemented after the sealing of bottles. Thus, in the presence of atmospheric oxygen, heat had a more destructive effect on ascorbic acid (Licciardello, Esselen, & Fellers, 1952). However, the temperature and time applied for exhausting could be reduced.

Goh et al. (2012) studied the effect of thermal and ultraviolet treatments on the stability of ascorbic acid in pineapple juice. Ultraviolet treatment was performed with an average power of 2.3 mW/cm^2, exposure duration of 3.3 s, and at a dosage of 7.5 mJ/cm^2, whereas thermal pasteurisation was performed by heating the pineapple juice at 97 °C for 5 min. The initial value of the ascorbic acid was 16.4 mg/100 g. They found that an ultraviolet treatment showed a higher ascorbic acid content (12.6 ± 1.1 mg/100 g) than a thermal pasteurisation treatment (10.1 ± 0.8 mg/100 g). This suggests that UV treatment is a better processing method to retain the heat-sensitive ascorbic acid than a thermal treatment. However, the study did not compare the equivalent microbial destruction among both technologies. Further studies are recommended in order to know more about the effect of UV and thermal treatment on the microbial destruction in pineapple juice. Other temperatures and times should be investigated to minimize the loss of the ascorbic acid.

As few studies have been done on pineapple juice, we refer here to other fruit juices to get some idea of stability of vitamin C. Vikram et al. (2005) studied the effect of ohmic, infrared, conventional, and microwave heating methods on the destruction of vitamin C in orange juice. Ohmic heating, which is defined as a process wherein electric current is passed through materials with the primary purpose of heating them (Knirsch, do Santos, Martins de, Vicente, & Penna, 2010), resulted in higher nutrient retention at all temperatures (50, 60, 75 and 90 °C) compared to infrared and conventional heating. A comparison of electromagnetic and conventional methods of heating showed that the degradation of vitamin C for all methods of heating followed first-order kinetics. The authors report that, when the temperature increased from 50 to 90 °C for conventional, ohmic, infrared and microwave heating methods, the rate constant k (min^{-1}) increased from 0.0351 to 0.1784, 0.0240 to 0.1571, 0.0444 to 0.2284, and 0.0504 to 0.1944, respectively. The authors state that the activation energy values varied with the method of heating: 64.8 ± 2.6 kJ/mol for microwave, 47.3 ± 0.8 kJ/mol for ohmic, 39.8 ± 0.6 kJ/mol for conventional, and 37.1 ± 1.7 kJ/mol for infrared heating. Recalculation based on the k values given by the authors, however, gives standard deviations of 16.2, 34.0, 3.9 and 6.2 min^{-1}, respectively. These are much higher standard deviations than the authors reported, so in our view their conclusion that the heating method has a significant effect on activation energies is not justified.

Other studies report that ascorbic acid thermal degradation kinetics in citrus juices under pasteurisation followed a first-order reaction model (Johnson, Braddock, & Chen, 1995; Knirsch et al., 2010; Saguy, Kopelman, & Mizrahi, 1978). However, there is no kinetic study on vitamin C degradation during pineapple juice pasteurisation. Studying the kinetics of such degradation during pasteurisation is crucial to enable optimization of the process.

Polyphenols

Polyphenols are secondary metabolites present in all vegetable tissues, including flowers and fruits. As antioxidants, polyphenols may protect cell constituents against oxidative damage and therefore limit the risk of various degenerative diseases associated with oxidative stress (Bazinet, Lamarche, & Ippersiel, 1998).

Mahdavi et al. (2010) determined and compared the total polyphenols in natural fresh and commercial packaged fruit juice. Total polyphenol contents of fruit juices were reported as mg gallic acid equivalent (GAE)/100 mL. The study showed that the total polyphenol content in natural fresh pineapple juice was 36.2 ± 0.5 versus 35.7 ± 0.3 mg GAE/100 mL in commercial pineapple juice, indicating no significant difference. Comparison of this total polyphenol contents of commercial pineapple juice with the results of Lugasi and Hóvári

(2003) showed that the polyphenol content of pineapple juice from Mahdavi et al. (2010) was lower (35.7 ± 0.3 vs 67.4 mg GAE/100 mL). This might indicate a high variation of polyphenols in pineapple fruits, but no further data are available.
The findings of Mahdavi et al. (2010) suggest that processing does not have much effect on the polyphenol content of pineapple juice. However, the processing technology involved in the commercial pineapple juice production was not described in the study. The effect of different processing techniques on polyphenols of pineapple juice should be investigated in greater detail.

Amino acid and sugar contents

Amino acids are present in many foodstuffs, including beverages, and they are important for human nutrition (Massey, Blakeslee, & Pitkow, 1998). They also affect sensorial quality attributes, including taste, aroma, and colour (Ames, 1998; Kirimura, Shimizu, Kimizuka, Ninomiya, & Katsuya, 1969).

Gawler (1962) investigated the free amino acids of canned Malayan pineapple juice. Amino acids identified in the juice were: asparagine, proline, aspartic acid, serine, glutanic acid, alpha-alanine, aminobutyric acid, tyrosine, valine, and isoleucine. Wen and Wrolstad (2002) identified by HPLC that tyrosine and tryptophan are the two major aromatic amino acids of pineapple. The kinetics of reactions involving those amino acids in pineapple juice during heat treatments like pasteurisation need to be assessed because of their role in the Maillard reaction, which can be of importance for human nutrition.

Sugars in pineapple juice contribute to dietary energy. They play an important role in the taste characteristics and thus in the acceptability of the juice by consumers. Camara et al. (1996) determined sugars by HPLC in fresh pineapple and pineapple products like pineapple juice, pineapple juice concentrate, commercial pineapple juice and nectars. The dominant sugar in these products was sucrose (4.1 ± 0.7 g/100 mL) followed by fructose (2.5 ± 0.5 g/100 mL) and glucose (2.3 ± 0.4 g/100 mL), both of which were found in more or less similar concentrations. Recently, an interesting study was published by Wardy et al. (2009) on the sugar contents of three pineapple varieties namely, 'MD2', 'Smooth Cayenne' and 'Kona Sugarloaf'. It was found that the sugar content was highest for the 'MD2' variety followed by 'Kona Sugarloaf' and 'Smooth Cayenne'. However, 'Kona Sugarloaf' had the highest sweetness index (Brix/acid ratio), namely 15.4, followed by 'MD2' (12.7) and 'Smooth

Cayenne' (6.98). This indicates the potential of 'Kona Sugarloaf' for juice processing. To date, very few studies have been done on that variety; characterization of fresh and pasteurised 'Kona Sugarloaf' juice is needed.

Amino acids and reducing sugars play an important role in the Maillard reaction. In the early stage of the Maillard reaction, a reducing sugar, like glucose, condenses with a compound possessing a free amino group to give a condensation product N-substituted glycosilamine, which rearranges to form the Amadori rearrangement product. At pH 7 or below (as in the case of pineapple juice), the Amadori product undergoes mainly 1, 2-enolisation with the formation of hydroxymethylfurfural (HMF) (i.e., when hexoses are involved). HMF is highly reactive and takes part in further reactions. Carbonyl groups, for instance, can condense with free amino groups, which results in the incorporation of nitrogen into the reaction product. In an advanced stage, a range of reactions take place that lead to the formation of brown nitrogenous polymers and co-polymers, known as melanoidins (Hodge, 1953).

Ooghe and Dresselaerts (1995) investigated the amino acids, sugars and HMF contents of concentrated pineapple juice. The concentrates analyzed were divided into six groups depending on the origin and furthermore on the evaporation, the package and the storage techniques used. These groups were group 1 (N=12; Thailand, west side of the Gulf of Thailand, 7-step evaporator, aseptically packed); group 2 (N=7; Thailand, west side of the Gulf of Thailand, 3-step evaporator, deep-frozen); group 3 (N = 12; Thailand, east side of the Gulf of Thailand, 3-step evaporator, aseptic packed); group 4 (N=9; Thailand, east side of the Gulf of Thailand, 3-step evaporator, deep-frozen); group 5 (N=6; Indonesia, 5-step evaporator, aseptic packed); group 6 (N=11; Kenya, 5-step evaporator, aseptic packed). For the analysis, all the concentrates were diluted with demineralized water. The amino acids identified were asparagine, methionine, histidine and lysine as determined by cation exchange chromatography; HMF and sugars were determined by HPLC. Table 4.1 presents the average values of the sugars, amino acids and HMF content in the concentrated pineapple juice.

Table 4.1

Sugars, amino acids and hydroxymethylfurfural (HMF) content in concentrated pineapple juice from different regions

Parameter	Thailand (W) 7st. Gulf ev. aseptic p.	Thailand (W) 3 st. APV ev. deep frozen	Thailand (E) 3 st. APV ev. aseptic p.	Thailand (E) 3 st. APV ev. deep-frozen	Indonesia 5 st. APV ev. aseptic p.	Kenya 5 st. APV ev. aseptic p.
Glucose (mmol/L)	161.0 ± 16.6	133.2 ± 11.1	222.1 ± 22.2	149.8 ± 5.5	177.6 ± 5.5	255.3 ± 11.1
Fructose (mmol/L)	149.8 ± 22.2	116.5 ± 5.5	199.8 ± 27.7	144.3 ± 72.1	166.5 ± 10.5	260.9 ± 16.6
Sucrose (mmol/L)	166.5 ± 17.5	204.5 ± 5.8	113.9 ± 32.1	198.6 ± 58.4	151.9 ± 5.8	61.3 ± 17.5
Asparagine (mmol/L)	4.9 ± 0.7	5.3 ± 0.5	2.9 ± 0.4	3.4 ± 0.1	4.8 ± 0.6	1.8 ± 0.5
Methionine (mmol/L)	0.4 ± 0.1	0.6 ± 0.1	0.3 ± 0.1	0.4 ± 0.0	0.5 ± 0.0	0.2 ± 0.0
Histidine (mmol/L)	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.1 ± 0.0
Lysine (mmol/L)	0.2 ± 0.1	0.3 ± 0.0	0.1 ± 0.1	0.2 ± 0.0	0.2 ± 0.0	0.1 ± 0.0
HMF (mg/100 mL)	0.1 ± 0.1	1.3 ± 0.7	22.0 ± 14.1	1.2 ± 0.8	0.8 ± 0.4	8.4 ± 2.2

Adapted from Ooghe and Dresselaerts (1995)

First, tyrosine and tryptophan, which were previously identified by Wen and Wrolstad (2002) as the two major aromatic amino acids of pineapple, were not detected in the concentrated pineapple juice. Second, the sugar content was higher than the amino acid content in the concentrated pineapple juice, whatever the origin. Amino acids will therefore be the rate-limiting factor during the Maillard reaction. Concerning the pineapple juice origin, the asparagine values were significantly ($P < 0.01$) higher for pineapple juice from Indonesia and the west side of the Gulf of Thailand, than for juices from Kenya and the east side of the Gulf of Thailand. For Kenyan pineapple juice, significantly ($P < 0.01$) higher glucose and fructose values and significantly ($P < 0.01$) lower methionine were found. According to the authors, this was attributed to the technology and/or storage conditions applied in that country and may be the result of a faster and more complete hydrolysis of sucrose into glucose and fructose. However, these observed variations could also be related to the pineapple variety and agronomic factors such as soil type and cultural practices.

As far as technology and storage conditions were concerned, a significant ($P < 0.01$) increase was noticed for the glucose and fructose contents due to the hydrolysis of sucrose during processing and/or storage of the concentrates from the same origin. The HMF value also increased, but only for the concentrates obtained from the east side of the Gulf of Thailand. In addition, a significant ($P < 0.01$) decrease was reported for the sucrose due to hydrolysis, as well as a decrease of the methionine due to its oxidation into sulphoxide and sulphone. Another significant ($P < 0.01$) decrease was reported for the asparagine, lysine and histidine for the concentrates of the east side of the Gulf. The authors reported that this was due to the Maillard reaction of lysine and histidine with reducing sugars. The increase of HMF in the aseptically packed juice sample from the east of Thailand compared to the one from the west could be explained by the difference in technology applied and not to the storage conditions.

Therefore, the Maillard reaction is an important quality issue that needs to be understood in more detail in pineapple juice processing, especially in pasteurised pineapple juice. In pineapple juice, the Maillard reaction is the main reaction that affects juice quality (Rattanathanalerk et al., 2005). The study described by Ooghe and Dresselaerts (1995) gave a nice overview of the differences in quality between differently processed pineapple juice obtained from concentrates. However, they did not explore the effect of the processing and the effect of the storage on the pineapple quality change separately. Moreover, the variety of the pineapple used was not specified, which might also contribute to important variations among the juices.

Rattanathanalerk et al. (2005) evaluated the effect of thermal processing (55–95 °C) on the quality loss of pineapple juice. For this study, fresh pineapple of variety 'Smooth Cayenne' was obtained from a local market. The HMF, the nonenzymatic browning index and brown pigment formation were measured by a spectrophotometric method. The flesh was cut into small pieces and the juice was extracted using a hydraulic machine. It was shown that HMF, brown pigment formation and the nonenzymatic browning index increased linearly with heating time and therefore, followed zero order reaction kinetics. For HMF, the reaction rate constants increased from 3.8×10^{-3} to 12.3×10^{-3} $min^{-}1$ when the temperature increased from 55 to 95 °C. The activation energy was estimated at 29.4 kJ/mol. Rate constants for brown pigment formation increased from 0.10×10^{-3} to 0.56×10^{-3} min^{-1} when the temperature increased from 55 to 95 °C. This indicated that HMF was formed at a higher rate at elevated temperatures and subsequently affected brown pigment formation.

Due to the large natural variation of total soluble solids and sugar contents observed in pineapple varieties (Miller & Schaal, 1951; Wardy et al., 2009), it is necessary to always mention the variety used during experiments and to collect the pineapple directly from the field and not from the market where different lots may be mixed. This would help to minimize the variation observed. Also, a study of changes in sugars as affected by heat treatment is required. Furthermore, the HPLC technique is better to quantify HMF in pineapple juice because other compounds may interfere with spectrophotometric analysis; a HPLC technique can separate the compounds of interest from interfering compounds.

Organic acids

The organic acids present in juice originate from biochemical processes, from their addition as acidulants, stabilizers or preservatives, or from the activity of some microorganisms (particularly yeasts and bacteria). They contribute to taste and flavor of juice. For instance, malic and acetic acids bear a negative though significant correlation to sweet taste and scented flavors (Gomis & Alonso, 2004).
Chan et al. (1973) found citric (336 mg/100 g), malic (536 mg/100 g), succinic (5.9 mg/100 g), and volatile acids such as acetic acid (6 mg/100 g) as the main organic acids in

pineapple juice. The variation in content was not presented, which makes the results difficult to interpret.

Citric and malic acids have been reported as the main nonvolatile acids, whereas acetic acid has been reported as the main volatile acid of canned Malayan pineapple juice (Gawler, 1962). Ohta (1987) identified more volatile acids in canned pineapple juice. Acetic acid (3 mg/100 g), caproic acid (0.2 mg/100 g) and caprylic acid (0.1 mg/100 g) were found in canned pineapple juice produced in the Philippines with nine other acids including propionic acid, isobutyric acid, *n*-butyric acid, 2-methylbutyric acid, isovaleric acid, capronic acid, caprylic acid, capric acid and cinnamic acid. Krueger et al. (1992) identified isocitric acid as another organic acid of fresh pineapple juice (Table 4.2). Citric and malic acids provide the basic acid taste that characterizes pineapple juice, (de Vasconcelos Facundo, de Souza Neto, Maia Narendra Narain, & Dos Santos Garruti, 2010) but numerous other acids contribute to the overall sour sensation.

Cold sterilization is known to minimize the effect of heat treatment on the factors determining the sensorial quality of fruit juice. Carneiro et al. (2002) reported, for instance, that cold sterilization and clarification of pineapple juice by microfiltration did not affect the acidity of pineapple juice with an average value of 800 mg/100 g citric acid, which is the same as the one reported by Camara et al. (1995) and Krueger et al. (1992) (see Table 4.2). A practical problem of cold sterilization and clarification is that such processing methods are far more expensive than traditional processing technologies (Hendrickx, Knorr, Loey, & Heinz, 2005).

Laorko et al. (2010) reported that the use of commercial pectinase (0.03 % v/v) as clarifying agent before ultrafiltration did not affect the acidity of the pineapple juice as compared with the fresh juice. Therefore, the use of commercial pectinase seems to be interesting for the juice processing industry for as far as acidity is concerned.

Table 4.2

Organic acid contents of pineapple juice

Organic acid	Amount (mg/100 g)			Detection method	References
	Minimum	Average	Maximum		
Malic acid	300	400	536.3	HPLC, GLC	(Krueger et al., 1992) (Camara et al., 1995) (Chan et al., 1973)
Citric acid	400	800	1100	HPLC	(Krueger et al., 1992) (Camara et al., 1995)
Ascorbic acid	9.2	50.8	93.8	Titration, fluorometry	(Camara et al., 1995)
Isocitric acid	8	17.2	26.5	HPLC	(Krueger et al., 1992)

EFFECT OF PROCESSING ON THE MICROBIOLOGICAL QUALITY OF PINEAPPLE JUICE

Most fruit juices and drinks available in groceries, supermarkets, bars and cafes are pasteurised. Spoilage of juice is mostly due to contamination with aerobic acid-tolerant bacteria as well as yeasts and molds. Al-Jedah and Robinson (2002), after investigating the quality of fresh fruit juices in Qatar, reported that fresh pineapple juice contained 1.9 x 10^3 colony-forming units (CFU)/mL of coliforms and 3.2 x 10^4 CFU/mL of molds and yeasts. Bacteria that have been associated with spoilage in soft drinks include *Acetobacter*, *Bacillus*, *Clostridium*, *Gluconobacter*, *Lactobacillus*, *Leuconostoc*, *Saccharobacter*, *Zymobacter*, *Zymomonas* and *Escherichia coli*. Badge and Tumane (2011) reported that, in unpasteurised pineapple juice, bacterial counts were found between 1 x 10^5 and 15 x 10^5 CFU/mL. *Staphylococcus aureus* and *Escherichia coli* were detected in all unpasteurised pineapple juices. This presence of pathogenic as well as nonpathogenic microorganisms in fresh juice was attributed to contamination carried by insects on damaged fruits. Tchango Tchango (1997) identified *Candida pelliculosa*, *Candida holmii* and *Kloeckera apis* as the spoilage yeasts isolated from natural fermented pasteurised pineapple juice in Cameroon. These microorganisms were responsible for organoleptic changes in the pasteurised pineapple juice, making them unsuitable for consumption. Deak and Beuchat (1993) isolated four species of yeast from pineapple juice concentrate, namely *Candida tropicalis*, *Cryptococcus laurentii*, *Hanseniaspora guilliermondii* and *Saccharomyces cerevisiae*. Di Cagno et al. (2010) reported that *Pichia guilliermondii* was the only identified yeast in fresh pineapple juice, whereas *Lactobacillus plantarum* and *Lactobacillus rossiae* were the main identified species of lactic acid bacteria. Titarmare et al. (2009), after a bacteriological analysis of street-vended fresh fruit juices in Nagpur city, India, reported that collected fresh pineapple juices were contaminated with 1.4×10^2 to 4×10^3 CFU/mL of *Staphylococcus*. The same authors reported that the total coliforms ranged from 5.2×10^3 to 5.4×10^4 CFU/mL, whereas the recommended microbiological standards for any fruit juice in the Gulf region are 10 to 100 CFU/mL for coliforms. These findings show that fresh pineapple juice is generally not exempt from high levels of pathogenic as well spoilage microorganisms. Therefore, careful processing is needed to secure its safety and shelf life.

Pasteurisation

Pineapple juice spoilage microorganisms are bacteria, molds and yeasts since they are acid tolerant (Graumlich, Marcy, & Adams, 1986). According to these authors, lactic acid bacteria are not heat resistant; their D-value (i.e., the time required to destroy 90 % of the organism at a certain temperature) is $D_{60\ °C}$ = 0.1–0.3 min. Consequently, the normal thermal pasteurisation applied for juices easily destroys them. Traditional thermal treatments can be carried out using hot-fill pasteurisation processes. In the hot-filling process, juices are heated up to the target temperature (normally between 92 and 105 °C) for 15–30 s (Spinelli, Sant'Ana, Pacheco-Sanchez, & Massaguer, 2010).

As far as yeasts are concerned, they are able to grow under low pH conditions. Therefore they can easily grow in fresh pineapple juice, which is considered as a high-acid fruit because of its pH of < 4 (Camara et al., 1995). *Candida*, *Pichia*, *Rhodotorula*, *Torulopsis*, *Saccharomyces*, *Zysosaccharomyces*, *Hansenula* and *Trichosporon genera* have been associated with juice spoilage in juices (Renard, Gómez di Marco, Egea-Cortines, & Weiss, 2008). However, yeasts also are generally not heat resistant ($D_{60\ °C}$ < 1 min), although some strains such as *Saccharomyces cerevisiae* (Hocking & Jensen, 2001) are characterized by a $D_{60\ °C}$ = 7–22 min.

Table 4.3 presents the D-values of some microorganisms in different fruit juices after pasteurisation, including some data for pineapple juice.

Table 4.3

D- and Z-values of some microorganisms in different fruit juices

Microorganism	Product	D-value (min)	Z-value (°C)	References
Lactic acid bacteria	Pure citrus juice	$D_{55\,°C}$ = 16.5 $D_{65\,°C}$ = 4.2	46.3	(Sukasih & Setyadjit, 2008)
Candida pelliculum	Pineapple juice	$D_{65\,°C}$ = 3.2 $D_{75\,°C}$ = 1.5	17.2	(Tchango Tchango et al., 1997)
C. pelliculosa	Pineapple juice	$D_{75\,°C}$ = 13.5	31.8	
K. apis		$D_{70\,°C}$ = 27.8	21.9	
Neosartorya fisheri	Apple juice	$D_{80\,°C}$ = 208.3 $D_{85\,°C}$ = 30.1 $D_{90\,°C}$ = 2.0	5	(Salomao et al., 2007)
Neosartorya fisheri	Papaya juice	$D_{80\,°C}$ = 129.9 $D_{85\,°C}$ = 19.0 $D_{90\,°C}$ = 1.9	5.5	(Salomao et al., 2007)
Neosartorya fisheri	Pineapple juice	$D_{80\,°C}$ = 73.5 $D_{85\,°C}$ = 13.2 $D_{90\,°C}$ = 1.5	5.9	(Salomao et al., 2007)

Z-values describe the temperature increase that is required for the thermal destruction curve to move 1 log-cycle, or, in other words they indicate the resistance of an organism to heat. Molds are easily destroyed by pasteurisation (Lima Tribst, de Souza Sant'Ana, & de Massaguer, 2009). The D and Z values found for pineapple juice were lower than those reported by Sukasih and Setyadjit (2008) for citrus juice. This could be explained by the difference of temperature applied and the nature of the microorganisms considered in the different studies (see Table 4.3).

In the past, juice stability was assumed to be guaranteed by mild pasteurisation and thermal treatments used were, for instance, 74 °C/16 s or 85 °C/1 s (Graumlich et al., 1986). However, after the discovery of sporulating acidophilic bacteria, more attention is needed. Fortunately, pineapple juice has a low pH (< 4.6) (Camara et al., 1995) and no *Clostridium botulinum* germinates, grows, or produces toxin under these conditions (Chikweche &

Fletcher, 2010). Thus pineapple juice can receive a relatively mild heat treatment. This milder treatment preserves much of the colour and flavor of the juice that would be lost if the juice would receive the more severe heat treatment necessary to kill spores.

Some studies were reported on the influence of a heat treatment on the resistance of several pathogenic microorganisms in pineapple juice. Slongo and de Aragao (2008) reported that the thermal resistance of *Neosartorya fischeri* ascospores increased with an increase in the ratio between degrees Brix and acidity in the heating medium. According to Splittstoesser and Splittstoesser (1977), the nature of the heating media influences the rate of inactivation of ascopores. This can be explained by the protective effect that the presence of soluble solids has on the *Neosartorya fischeri* ascospores. The mechanism for the protective effect of soluble solids was not given by the authors.

Obeta and Ugwuanyi (1997a) reported that pineapple juice pasteurised at 80 °C for 30 min and stored at 4–5 °C as well as juice containing sodium benzoate and stored at room temperature were protected from spoilage by ascospores for 64 days. Moreover, according to Obeta and Ugwuanyi (1997b), addition of sucrose at a level of 30 % (which is actually very high for juice), significantly (P = 0.05) protected ascospores from inactivation during cold storage but addition of sucrose at a level of 50 % delayed colony formation by 3 days in pineapple juice agar. This solution does not seem realistic for pasteurised pineapple juice but could be interesting in pineapple jam production.

Salomao et al. (2007) studied the heat resistance of *Neosartorya fisheri* in three different juices (apple, pineapple and papaya). All experiments revealed a greater heat resistance of ascospores in apple juice, followed by papaya juice and finally pineapple juice (see Table 4.3). Of the three juices tested, apple juice exhibited maximum D-values. The D-values for papaya juice and pineapple juice decreased with acidity and the ratio between degrees Brix and acidity. The lowest D-values were observed for pineapple juice as far as *Neosartorya fisheri* is concerned. Citric acid, which is known to be the preponderant acid in pineapple and papaya juices, apparently has a smaller protective influence on the thermal resistance of ascospores of *Neosartorya fisheri* than malic acid in apple juice.

Ultrasound

Among the emerging technologies that have been tested in the last few years, ultrasound is one of the nonthermal novel technologies for juice processing. Ultrasound is based on the use of sound waves above the threshold of human hearing (> 14-16 kHz) that can travel and propagate into a material, providing information about composition and other characteristics depending on the frequency (Soria & Villamiel, 2010). Bermudez-Aguirre and Barbosa-Canovas (2012) studied the effect of ultrasound with temperature in a continuous and pulsed mode in the inactivation of *Saccharomyces cerevisiae* in pineapple juice. In the thermosonicated (ultrasound with temperature) treatment, in which the conditions were 24 kHz, a maximum amplitude 120 μm and a maximum temperature 60 °C, a 6.4-log reduction of *Saccharomyces cerevisiae* was achieved after 30 min of continuous thermosonication. Moreover, it was suggested that sonication caused the elimination of dissolved oxygen, resulting in lower oxidative degradation (Cheng, Soh, Liew, & The, 2007). However, the same study showed that sonication treatments were not effective in deactivating polyphenoloxidase (PPO), a key enzyme implicated in reduced nutritional and sensorial quality as a result of enzymatic browning. Furthermore, the treatment conditions used were only efficient for microbial inactivation. Therefore, even if ultrasound seems to be a viable technology for juice pasteurisation and to achieve a 5-log reduction, more research needs to be done on its effect on other quality parameters, including PPO and vitamin C content.

High pressure

Ascospores of *Byssochlamys fulva* are extremely heat resistant and frequently associated with the deterioration of thermally treated fruit products (Tournas, 1994). Ferreira et al. (2009) assessed the inactivation of *Byssochlamys nivea* ascospores in pineapple juice by combining pressure sequences involving high pressure cycles with relatively mild thermal processing. The results show that in pineapple juice an application of a sustained pressure of 600 MPa at 90 °C for 5 min induced a reduction of 6 log-cycles. Pressure cycles appeared to be more effective in inactivating *Byssochlamys nivea* ascospores in pineapple juice than the application of a sustained high pressure.

Maresca et al. (2011) evaluated the effects of a multiple-pass high-pressure homogenization treatment on the microbial inactivation of *Saccharomyces cerevisiae*, *Lactobacillus delbrueckii*, *Escherichia coli* inoculated into commercial fruit juices like pineapple, red orange,

orange juices and fresh Annurca apple juice. The results first show that the level of inactivation increased with the pressure level and the number of passes. For instance, at 100 MPa, after 5 passes, between 6 and 7 log-cycles of inactivation were reached. When the pressure level was increased to 150 MPa, the first passes caused a microbial inactivation of 4.5-5 log-cycles, whereas the following passes were significantly less effective on the residual high-pressure homogenization (HPH)-resistant microbial load. In particular, a 3-passes treatment at 150 MPa seemed to be sufficient to reach a microbial inactivation larger than 7 log-cycles. This study showed that a multiple-pass HPH treatment was efficient and could be used to preserve the quality of fruit juices like pineapple juice. A comparison of kinetic studies on inactivation of microorganisms under different processing methods would be helpful in designing a better process.

Rosenthal et al. (2002) studied the effect of ultrahigh pressure (300 MPa) on fruit juices contaminated by yeasts; the pressure resistance of a number of yeasts associated with the spoilage of fruit products was examined, namely *Zygosaccharomyces bailii*, *Saccharomyces cerevisiae, Pichia anomola, Candida magnoliae* and *Rhodotorula glutinis*. The outcome of this study was that a pressure treatment at 300 MPa for 10 min reduced viable numbers of a cocktail of *Zygosaccharomyces bailli* strains by 4 Log units in pineapple juices, thereby demonstrating that it is possible to greatly reduce the number of viable cells of the yeasts usually responsible for pineapple juice spoilage.

Ultraviolet radiation, pulsed light and pulsed electric fields

Ultraviolet (UV) radiation involves the use of radiation from the electromagnetic spectrum from 100 to 400 nm and is categorized as UV-A (320–400 nm), UV-B (280–320 nm) and UV-C (200–280 nm) (Guerrero-Beltr & Barbosa-C, 2004). Keyser et al. (2008) studied UV-C radiation as a nonthermal treatment for the inactivation of microorganisms in fruit juice. In a guava-pineapple juice, a 3.31 $\log_{10}$ aerobic plate count (APC) reduction and 4.48 $\log_{10}$ yeasts and molds reduction were achieved after a UV-C dose of 1377 J L^{-1} during 18 s. Since guava juice is turbid, a higher UV dosage was necessary for the guava-pineapple juice than was necessary for the apple juice, which needed only 230 J L^{-1} to get a 3.5 $\log_{10}$ reduction for the APC bacteria and a 3.0 $\log_{10}$ reduction for the yeasts and molds. This could be explained by the fact that clarified apple juice is a clear liquid and is therefore easily penetrated by the UV light (Guerrero-Beltran & Barbosa-Canovas, 2005).

Next to ultraviolet radiation, pulsed light (PL) is a method of food preservation that involves the use of intense and short duration pulses of broad-spectrum “white light” (Teai, Claude-Lafontaine, Schippa, & Cozzolino, 2001). Noranizan et al. (2011) compared pulsed light and ultraviolet treatment on microflora survival of pineapple juice. The dosage used for ultraviolet was 38.1 mJ/cm^2. For the pulsed light treatment, juice was treated with 0.52 J/cm^2 of energy per pulse (3 min for 9 pulses). Ultraviolet and pulsed light are able to totally inactivate yeasts and molds. However, in the total plate count, which measured the total viable bacteria, UV gave a 91 % of inactivation, which was higher than PL inactivation by 9.4 %. This was explained by the light spectrum that was used and the processing condition of treatments. In this study, UV treatment exhibited mainly a wavelength of 254 nm, which has been proven to be bactericidal. For PL, a wide spectrum of light was used, which made the dosage less concentrated. Additionally, treatment condition of pineapple juice in UV is nonstatic, resulting in a higher exposure of microorganisms to UV as compared to PL.

Jaya et al. (2004) studied the effect of pulsed electric fields on the inactivation of microorganisms in pineapple juice. The effective voltages and number of pulses for inactivating spoilage microorganisms were 100 and 150 kV when juice was stored at 4 °C for 30 days. When comparing different treatments in the processing of pineapple, a multiple-pass high pressure seems the best treatment, leading to a reduction of more than 7 log-cycles at a pressure of 150 MPa (3 passes). However, sensorial testing is needed to evaluate the effect of this treatment on the organoleptic qualities of the juice.

Traditional heat treatments, such as pasteurisation, remain of interest to preserve pineapple juice. However, the process needs to be investigated in more detail so as to be able to predict the microbiological quality of the juice under different pasteurisation temperature ranges.

EFFECT OF PROCESSING ON THE ORGANOLEPTIC QUALITY OF PINEAPPLE JUICE

A few studies have reported on the organoleptic quality of pineapple juice. One of these was on the organoleptic quality of juice from three varieties of pineapple, namely ‘MD2’, ‘Smooth Cayenne’ and ‘Kona Sugarloaf’ in Ghana (Wardy et al., 2009). The preferences for organoleptic characteristics were assessed in a trial with 30 panelists. Of the three varieties, ‘Kona Sugarloaf’ and ‘Smooth Cayenne’ received the highest scores (3.9) for juice colour and ‘Kona Sugarloaf’ also the highest score (4.2) for sweetness, whereas ‘MD2’ got a 2.2 for colour and a 3.8 for sweetness. The scale of the scores ranged from 1 (like extremely) to 7 (dislike extremely). According to the authors, 'Kona Sugarloaf' appeared to have more juice, less fiber and more sugar, presenting the best prospects and advantages for juice processing. Unfortunately, there is no study on the effect of pasteurisation on the quality of 'Kona Sugarloaf' juice in general and on the organoleptic quality of the pasteurised juice in particular.

Heating processes can affect the quality of a fruit juice leading to consumer dissatisfaction. Nonenzymatic browning reactions and pigment destruction have been found to be the major causes of such problems, and not enzymes causing browning because these are susceptible to heat, at temperatures of > 50 °C (Martinez & Whitaker, 1995). Rattanathanalerk et al. (2005) studied the effect of thermal processing on the Hunter colour parameters (L, a, b and ΔE) between 55 to 95 °C. They found that, with increasing temperature and time, the pineapple juice became darker, which corresponded to a decrease in L value. According to Avila and Silva (1999), the colour change was mainly due to the degradation of carotenoids and nonenzymatic browning (Maillard reaction).

Ewaidah (1992) studied the organoleptic quality of canned pineapple juice after storage at 5, 24, 33 and 42 °C for a 12-month period; the pineapple variety was not reported. The author observed a significant difference (P □ 0.05) between juice stored at 5 and 24 °C and that stored at 33 or 42 °C. Pineapple juice stored at 5 °C rated the highest score (8.3) in colour, while the juice stored at 42 °C rated the lowest score (1.8). As far as flavor is concerned, there was significant difference (p □ 0.05) between pineapple juice stored at 33 and 42 °C and that stored at 5 and 24 °C. However, there was no significant difference between juice stored at 33 or 42 °C. Pineapple juice stored at 5 °C received the highest score (7.9) for flavor while juice stored at 33 and 42 °C got the lowest scores, respectively, 5.0 and 2.3. Storage temperature therefore appeared critical for maintaining the organoleptic quality of the pineapple juice. It is known that esters are among the important components of natural flavors and fragrances (Rodriguez-Nogales, Roura, & Contreras, 2005). In recent studies, Teai et al. (2001) mentioned that esters, lactones, furanoids, and sulfur compounds act as very potent odor components of Polynesian pineapple. So, the kinetics of change (degradation) in ester content should be investigated to gain insight in the degradation of the pineapple juice flavor during processing and storage.

The exotic flavor and aroma of pineapple are important and attractive quality attributes. Maintaining these characteristics as close as possible to the natural fresh juice, is a challenge to fruit juice industries.

The volatile compounds that produce the characteristic aroma of pineapple depend on the fruit varieties (van Boekel, 2000; Zúñiga-Arias et al., 2009), the area where the pineapple crop is grown (Teai et al., 2001), the season (Graumlich et al., 1986), the stage of ripening (Renard et al., 2008), the development of the fruit (Hocking & Jensen, 2001; Lima Tribst et al., 2009), storage conditions (Keller, 2006; Tribst et al., 2009) and the position of the flesh on the fruit (Keller, 2006; Sapers, 2006). The volatile compounds in fresh pineapple include a variety of esters, lactones, acids, hydrocarbons, sulfur-containing compounds and carbonyl compounds (Mills et al., 1949).

De Vasconcelos Facundo (2010) studied the changes in flavor quality of pineapple juice during processing. The juice samples were collected at five processing steps (raw material, extraction, finishing, centrifugation and concentration) from two different batches: batch 1, processed in the morning, and batch 2, processed in the afternoon. The samples were stored at -18 °C till sensorial analysis by a panel. The study revealed that processing significantly influenced the perception of flavor and aroma in both batches, except for pineapple flavor in batch 1. The sensorial panel could not perceive a reduction in pineapple aroma and flavor for concentrated juice from batch 1 as it did for the same sample from batch 2. To understand this result, there is a need for studying the flavor chemistry of these samples. The study did not give any information about the condition in which batch 2 was kept before processing. Then, it becomes impossible to grasp how the storage conditions could have caused the different sensorial assessments of juice from the two batches.

There is no further research on the effects of heat treatments on the taste and flavor components of pineapple juice. Therefore, the effect of pasteurisation on the quality loss of pineapple juice regarding esters, lactones, acids, hydrocarbons, sulfur-containing compounds and carbonyl compounds awaits further investigation.

EFFECT OF EXTRACTION METHOD ON PINEAPPLE JUICE QUALITY

With respect to the extraction methods for pineapple juice, particular attention has been given to the improvement of recovery rates. Pineapple juice can be obtained with an extraction machine only, or, in addition, enzymes can be used to increase the yield and the juice recovery from the pineapple pulp or residue. Sreenath et al. (1994) studied the improvement of juice recovery from pineapple pulp/residue using cellulases and pectinases. Pectinex Ultra SP-L, a pectinase preparation from *Aspergillus niger*, and celluclast, a cellulase preparation from *Trichoderma viridae*, were used. The use of the commercial cellulase, the pectinase or their mixture at an enzyme concentration of 0.02 % at 27-30 °C for 30 min, increased juice recovery to 81–86 % against 72 % in the untreated samples. Turbidity recorded at 650 nm gave a high absorbance of 1.2 against 0.8 after addition of pectinex and/or celluclast. The juice prepared with celluclast or pectinex was acceptable on a 5-point hedonic scale and scored similar to the untreated samples. However, the sensorial panel indicated that pectinex-treated juice tasted more like the untreated samples than the celluclast-treated juice. Moreover, when the enzyme mixture (celluclast + pectinex) had been used, the juice was not acceptable and got a low sensorial score. According to the authors, juice recovery remained almost the same after the addition of celluclast or pectinex. The lack of statistical evidence of the differences between treatments and information about the variety used in this study make other studies necessary to clarify the effect of cellulase and pectinase on pineapple juice recovery and sensorial consequences.

Dzogbefia et al. (2001) studied the production and the use of pectolytic enzymes from yeast to aid pineapple juice extraction. The enzymes were obtained by culturing *Saccharomyces cerevisiae* in pineapple juice. Fresh pineapple juice from variety 'Smooth Cayenne' was sterilized at 1.1 kg/cm^2 for 15 min and used as medium for yeast culturing. Then, 100-mL portions of the sterile juice were inoculated with 4 mL of malt extract containing 4.2 x 10^6 cells per mL of *Saccharomyces cerevisiae* suspension. Growth of yeast cells was monitored for 8 days. At the end of the culturing, the medium was centrifuged at 3600 X *g* for 10 min and the supernatant was used for the analysis. The addition of this enzyme extract to crushed pineapple mash at 0.02 % resulted in a significant increase of 6.1 ± 0.2 % in juice yield. A 0.02 % enzyme treatment of the mash for 30 min was found to be the most effective dosage in reducing the processing time. Since the enzyme was active at room temperature, it could be added directly to the mash at ambient temperature and this is useful for juice manufacturers to adopt the use of the enzyme without any alteration of their processing parameters. Comparison of the use of the yeast enzyme and a commercial pectolytic enzyme proved that, on average, the increase in yield of juice was 6.1 ± 0.2 % and 9.9 ± 0.2 %, respectively. Therefore, pectolytic enzymes from the yeast did not perform as well as the commercial enzyme. However, for the application of the technology on an industrial scale, parameters for the scale-up production of the enzyme and the improvement of the performance of the enzyme obtained from the yeast will have to be carefully studied. This is so because other issues such as controlling clarity with such enzymes, sweetness and shelf life are all important factors for juice manufacturers.

Pal and Khanum (2011) studied the efficacy of xylanase purified from *Aspergillus niger* DFR-5 alone and in combination with pectinase and cellulase to improve the yield and clarity of pineapple juice. The juice clarity was measured by transmittance (% T) of juice at 650 nm. The single use of xylanase provided maximum yield (71.3 %) and clarity (64.7 %) as compared to the control (61.8 % yield and 57.8 % clarity). This result was explained by the fact that hemicelluloses are the most abundant constituents of pineapple fruit cell walls and xylan is a major fraction of it (Grassin & Fauquembergue, 1996). When used together, a synergistic effect of xylanase, pectinase and cellulase on process responses was observed, indicating the necessity of a cocktail of hydrolytic enzymes for complete cell degradation. Overall, an increase in juice yield by 52.9 % was observed. This could be explained by a synergistic effect on juice yield. As a result, the cells collapse at a fast rate resulting in a high yield (Qin, Xu, & Zhang, 2005). These findings demonstrated that the biotechnological potential of xylanase purified from *Aspergillus niger* DFR-5 could be of great importance to the juice clarification industry. Tochi et al. (2009) studied the influence of a pectinase and a pectinase/hemicellulases enzyme preparation on pineapple juice recovery. The results show that the highest juice recovery was recorded as 95 % when a mixture of the two enzymes was used at an extraction temperature of 40 °C against a control value of 70 %.

During the last decades, ultrasound has been used in the food industry (Patist & Bates, 2008). It was found that the application of ultrasound for juice extraction from plant materials considerably enhanced yield and shortened process time (Toma, Vinatoru, Paniwnyk, & Mason, 2001). For instance, combined ultrasound and enzyme extraction of grape was recently reported. Simultaneous treatment of grape mash by ultrasound and pectinase increased the extraction yield by 2.0 % (very low) and reduced the treatment time by over 4 times in comparison with a conventional enzymatic treatment (Achuonjei et al., 2003).

Tran and Le (2011) studied the impact of ultrasound on the catalytic activity of a pectinase preparation. Sonication of Pectinex Ultra SP-L solution with an enzyme concentration of 63.3 polygalaturonase units (PGU)/mL and subsequent use in pineapple mash enhanced the extraction yield by 5.6 % in comparison with the application of the same pectolytic preparation without ultrasonic treatment. The maximum extraction yield reached 83.4 % when the sonication time was 60 s. The authors deduced that sonication with a power of 225 W for 60 s had a positive effect on the catalytic activity of the enzyme. This was explained by the fact that ultrasound causes acoustic cavitation, which includes the formation, growth and violent collapse of small bubbles or voids in liquids as a result of pressure fluctuation (Suslick, 1988). According to Vargas et al. (2004), ultrasonic energy may act on the three-dimensional structure of the enzyme, which can lead to an increase in enzyme activity. However, ultrasound can cause inactivation of many enzymes due to the mechanical and chemical effects of cavitation (Mawson, Gamage, & Terefe, 2011). This needs to be taken into account if the application of the technology in pineapple juice processing would be considered. Furthermore, the levels of sugars, organic acids, phenolics and vitamin C in the sample treated by sonicated pectinase were significantly higher than in the control sample. However, the types of the sugars studied were not mentioned and need to be determined.

Table 4.4 presents the physicochemical characteristics of pineapple juice after sonication of the enzyme solution.

Table 4.4

Physicochemical characteristics of pineapple juice after a sonication treatment of a Pectinex Ultra SP-L solution

Characteristics	Sample treated by unsonicated Pectinex Ultra SP-L	Sample treated by sonicated Pectinex Ultra SP-L
Sugar (g/100 mL)	5.94[a]	6.36[b]
Total acidity (g of citric acid/100 mL)	0.0068[a]	0.734[b]
Total phenolics (g/100 mL)	0.0089[a]	0.0098[b]
Vitamin C (mg/100 mL)	24.1[a]	25.3[b]

Note. Values with different letters in each row represent statistically significant differences at the level of $P = 0.05$.

Adapted from Tran and Le (2011)

In developing countries, small-scale processing units are still using a juice extractor machine and muslin cloth for pineapple juice extraction due to the unavailability of the enzymes. Olukunle et al. (2007) developed a system that consists of a washing unit, a juice extraction unit, a juice filtration unit, a conditioning unit and a dispensary unit. The system was developed in such a way to make juice available in fresh form. The system provides fresh juice for quick processing at affordable prices. This method is relatively cheap for small-scale juice manufacturers and contributes to reduce the labor input for most of the small-scale juice manufacturers. The system has been introduced to some schools, villages, establishments and corporate organizations in Nigeria. The initial cost of the system was estimated at US$1500. Unfortunately, the price of the juice coming from the equipment is not mentioned. A cost-benefit analysis of the use of that equipment is required to enable the comparison of its performance to that of other methods. Moreover, the quality of the juice obtained from this type of equipment needs to be investigated. Another study was done on the extraction of juice from pineapple using a small-scale multi-fruit juice extractor (Oyeleke & Olaniyan, 2007). The result was that fruit slices of 2 cm^2 gave maximum yields of 71.4 %. The authors also report that juice yield and extraction efficiency decreased while extraction loss increased with an increase in the size of the fruit slice. This is in agreement with findings of Ishiwu and Oluka (2004), who evaluated the performance of a millet thresher and a juice extractor. Actually, the size of the fruit slice reflects the surface area of the fruit and juice cells exposed to maceration and pressing. A pH value of 4.1 was obtained and the ascorbic acid content was 11.5 mg/100 mL, which was lower than 24.8 mg/100 mL in the fresh pineapple juice (Uckiah et al., 2009). The variation in the ascorbic acid content is not reported in the study. As far as the extraction machine is concerned, the equipment presented quite interesting results for small processing units located in developing countries.

From an economic point of view, a juice extractor is still the best choice for small-scale processing units. However, the effect of extraction methods on the nutritional and sensorial quality of pineapple juice needs to be investigated by comparing the quality parameters such as vitamin C and the ratio of solids to acids content, the titratable acidity, and the recovery of volatile aroma components between hand-squeezed juice and commercial juice extractors (pasteurised or not).

EFFECT OF FILTRATION TECHNOLOGY ON PINEAPPLE JUICE QUALITY

Membrane technology is an alternative to conventional juice clarification and concentration processes that has been widely applied in the dairy and beverage industries since the discovery of asymmetric membranes by Loeb and Souriragin in the early 1960s (D'souza, 2005). Gassaye et al. (1991) studied the use of membrane techniques in the production of clarified pineapple juice. His study demonstrated that cross–filtration removed juice cloudiness (from 2000 to 0.36 Nephelometric Turbidity Units [NTU]) in a relatively short time and maintained the degree Brix. The authors also found that the techniques of tangential microfiltration did not significantly affect the acidity characteristics of the fresh juice. This was due to the very low retention of the organic acids on the membrane. However, the possibilities to use this expensive, sophisticated technology in the commercial juice industry are questionable.

De Carvalho et al. (1998) studied the clarification of pineapple juice by ultrafiltration and microfiltration. They found that juice clarified with the 0.22-μm ceramic membrane was better with respect to soluble solids, sugars and acidity than the 50-kDa polysulfone membrane. However, the best volume recovery was obtained by 50-kDa polysulfone membranes in comparison with the 0.22-μm ceramic membranes. The 50-kDa polysulfone membrane was more efficient than the 0.22-μm ceramic membrane in removing tannins and pectins. De

Carvalho et al. (2008) also studied the retention of sugars in the process of clarification of pineapple juice by micro- and ultrafiltration. The authors found that sucrose, glucose and fructose contents in permeates from ultrafiltration and microfiltration processes differed significantly. This is probably due to the use of enzymes (pectinase & cellulases) and pore size difference between membranes. The 100- and 50-kDa polysulfone membrane processes gave higher total sugar recoveries than those in which tubular membranes were used consisting of 30-80 kDa (69.5 %). The best total sugar recoveries were obtained with a 50-kDa membrane at 7.5 bar (90.7 %). Although the best total sugar recoveries were obtained in juice clarified with polysulfone membranes (50 kDa, 7.5 bar), the authors considered that the use of 0.3-μm polyethersulfone is more attractive and appropriate because of its tubular configuration and module geometry. Yet, this could be disputed because the tubular module design has a low surface area and is very expensive. So it would not be economical to adopt this technology for juice processing in general and in particular not for small-scale processing units.

De Barros et al. (2003) examined the flux behaviour of ceramic and polysulfone membranes during cross-flow ultrafiltration. The use of a ceramic tubular membrane gave an increased permeate flux with temperature. This could be explained by the decrease in viscosity of the juice during the process. From this study, the best operation conditions, which combine the best permeate quality and highest permeate flux, are 50 °C and 4.0×10^5 Pa (4.0 bar). However, when using the polysulfone hollow fiber membrane, the condition that provided the highest sugar recovery, soluble solids and ascorbic acid was 40 °C and 0.8×10^5 Pa (0.8 bar). These conditions resulted in the retention of 62 % of galacturonic acid, which according to Capannelli et al. (1994), corresponds to 99 % in soluble pectins, maintaining a turbidity of 2.0 NTU and an absorbance close to the value obtained by de Carvalho et al. (1998) using a ceramic membrane of 50 kDa. However, the flow rate of the clarified juice was highest in the juice obtained using the 0.22-μm ceramic membrane (52 L m^{-2} h^{-1}). According to Jiraratananon et al. (1997), the corresponding value for ultrafiltration by monolith alumina 0.1-μm and 0.01-μm membranes was, respectively, 6.3 L m^{-2} h^{-1} and 15.8 L m^{-2} h^{-1}. De Carvalho and da Silva (2010) also studied the clarification of pineapple juice. The highest flux (57.7 L m^{-2} h^{-1}) was obtained with a tubular polyethersulfone membrane with an average cut-off of 0.3 μm under a pressure of 150 kPa. When comparing the membranes, the use of a ceramic tubular 0.01-μm membrane gave the best performance with a flux of 124.0 L $m^{-2}h^{-1}$ (de Barros et al., 2003). This finding is interesting for research, but its effective implementation in pineapple juice production should be evaluated. The positive effect of filtration on the intrinsic quality of pineapple juice quality is still small. The main advantage of membrane technology is the fact that it works without the addition of chemicals and with a relatively low energy use, but it is unfortunately, very expensive. Thus, they are not suitable for small-scale processing units.

CONCLUSION

Detailed descriptions of the variety and sampling method are required for any research on pineapple fruits to enable the proper interpretation of the findings. Moreover, due to the large variation in pineapple quality between fruits, it is advocated to only use fruits of a known origin, preferably from the same field, to increase the chance of obtaining meaningful significant differences in experimentation concerning the processing technology.

There is insufficient knowledge on the effect of pasteurisation on the nutritional and sensorial quality of the juice. Moreover, the new technologies studied for pineapple juice production need more investigation on their practicability in the pineapple juice industry. From the literature review, it appeared that the quality of pineapple juice is largely influenced by the technology used during processing. Given the nature of the acidic juice, with a pH between 3 and 4, microbial survival in the pineapple juice is relatively low. So far few studies have been performed on the effect of pasteurisation on the quality of pineapple juice parameters such as colour, sugar content, acidity and vitamin C. Studies were done separately and did not allow predicting the quality of the juice after a specific treatment. A structured and detailed kinetic study of the effect of pasteurisation on parameters such as colour, vitamin C, sugars and hydroxymethylfurfural, as an intermediate of the Maillard reaction, could be helpful to optimize the quality of pasteurised pineapple juice. Moreover, specific attention should be given to sensorial research on pineapple juice obtained from different varieties and by different processing techniques.

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5

EFFECT OF PASTEURISATION ON THE MICROBIOLOGICAL, PHYSICOCHEMICAL AND NUTRITIONAL QUALITY OF FRESH PINEAPPLE JUICE FROM THE 'KONA SUGARLOAF' VARIETY

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Submitted

ABSTRACT

The effect of heat treatment in the pasteurisation range was assessed on yeast inactivation, physicochemical and nutritional characteristics of fresh 'Kona Sugarloaf' pineapple juice. Yeast inactivation could be described by the Weibull model. The desired 6 log reduction was achieved at 63 and 65 °C at 8 and 2 min, respectively. The pH, degrees Brix and organic (malic & citric) acids did not change during heat treatments from 55 to 95 °C. A significant change in fructose and glucose contents started only to occur at 85 °C, while sucrose hydrolysis was only observed from 95 °C. Hydroxymethylfurfural, one of the intermediate products in the Maillard reaction, was also only detected at 95 °C. Very little degradation of ascorbic acid, the most important nutrient in pineapple juice, was observed. In general, a low heat treatment of 2 min at 65 °C was sufficient to inactivate yeasts and to preserve the nutritional and the physicochemical quality of the pineapple juice.

Keywords: Yeasts, Pineapple juice, Vitamin C, HMF, Sugars, Thermal treatment, Weibull model

INTRODUCTION

Pineapple is one of the most appreciated tropical fruits due to its aroma and flavour (Carneiro et al., 2002). The fruit can be consumed fresh or processed into, for instance, canned slices, juice concentrate, pulp, dried parts and pasteurised juice. The latter is the most popular product due to its pleasant sensorial attributes (Rattanathanalerk et al., 2005).

Thermal treatment is generally applied to extend the shelf life of fruit products. However, heat treatment can affect the nutritional and the sensorial quality attributes (Hardy, Parmentier, & Fanni, 1999). Vitamin C losses and nonenzymatic browning are reported as the main consequences of thermal treatment on pineapple juice (Achinewhu & Hart, 1994; Akinyele et al., 1990; Ooghe & Dresselaerts, 1995; Rattanathanalerk et al., 2005). Nowadays new technologies are being developed to avoid nutritional and sensorial losses, such as ultrasound (Bermudez-Aguirre & Barbosa-Canovas, 2012), high pressure (Ferreira et al., 2009; Maresca et al., 2011; Rosenthal et al., 2002), ultraviolet radiation, pulsed light and pulsed electric fields (Jaya et al., 2004; Keyser et al., 2008; Noranizan et al., 2011). However, thermal pasteurisation remains important because it is a simple and inexpensive technique for many small agro-industries. Therefore, it is relevant to assess how pineapple juice can be processed through pasteurisation to avoid spoilage while preserving its nutritional and physicochemical quality.

The effect of thermal treatment on hydroxymethylfurfural (HMF) and brown pigment accumulation in pineapple juice was investigated by Rattanathanalerk et al. (2005). However, the authors used a spectrophotometric method, which is not very specific and could have been disturbed by other compounds (Zappala, Fallico, Arena, & Verzera, 2005). As to the sensory properties of pineapple juice, organic acids such as citric and malic acid are known to provide the basic acid taste that characterizes the juice (de Vasconcelos Facundo et al., 2010). High concentrations of organic acids and low pH in most fruits are known to be critical for the preservation of fruit juice (Igual, García-Martínez, Camacho, & Martínez-Navarrete, 2010). They also help to stabilize ascorbic acid and anthocyanins (Wang, Chuang, & Ku, 2007).

Kinetic studies are helpful to predict quality loss resulting from different process conditions. For example, the application of the Weibull model to describe thermal inactivation of microbial vegetative cells has been investigated (Adekunte, Tiwari, Scannell, Cullen, &

O'donnell, 2010; H. Chen & Hoover, 2004; Dilek Avsaroglu, Buzrul, Alpas, Akcelik, & Bozoglu, 2006; van Boekel, 2002) and kinetic models have been used to evaluate vitamin C degradation in fruit products such as orange juice (Polydera et al., 2003; Vikram et al., 2005), strawberry juice (Odriozola-Serrano, Soliva-Fortuny, Gimeno-Añó, & Martín-Belloso, 2008) and citrus juice (Burdurlu, Koca, & Karadeniz, 2006).

Despite the multitude of research on fruit juice preservation (Aleman et al., 1996; Banerji, Madan, & Misra, 1997; Jain, Sankhla, Dashora, & Sankhla, 2003; Jin & Zhang, 1999; Lavinas, Miguel, Lopes, & Valente Mesquita, 2008; Linton, McClements, & Patterson, 1999; Maresca et al., 2011; Noci et al., 2008; Ogawa, Fukuhisa, Kubo, & Fukumoto, 1990; Zhang & Mittal, 2005), information regarding microbiological spoilage, kinetics of vitamin C degradation, the change of sugars, organic acids and HMF using a more specific method such as High Performance Liquid Chromatography (HPLC) is lacking for pasteurised pineapple juice. The aim of this work is to investigate the effect of heat treatment in the pasteurisation range on yeast inactivation, physicochemical and nutritional quality of pineapple juice.

MATERIAL AND METHODS

Yeast inactivation

Raw material

Three batches of fresh, mature pineapples, variety 'Kona Sugarloaf' variety, from different production areas in Benin, West Africa, were used to perform this experiment. The pineapples were processed immediately after purchase.

Juice preparation

After rinsing the fruits in tap water, the shell was removed using a stainless steel knife. The flesh was cut into small pieces and the juice was extracted using a hydraulic machine (Compact Health Stream Juice press, UK) at ambient room temperature (28 °C).

Heat treatment

A serie of glass tubes was filled with 15 mL of fresh pineapple juice and subjected to heat treatments in a heating block (Liebisch Labortechnik, the Netherlands) at 57, 59, 61, 63 and 65 °C, respectively, for different time periods. The juice was treated at 57 °C for 5, 10, 15, 20 and 25 min; at 59 °C for 1, 2, 4, 6, 8 and 10 min, at 61 °C for 1, 2, 3, 4 and 5 min, at 63 °C for 25, 40, 60 80, and 100 s and finally at 65 °C at 10, 20 and 30 s. After the treatment time the tubes were immediately cooled in an ice-water bath.

Yeast counts

Ten mL of fresh pineapple juice was transferred aseptically into 90 mL sterile peptone salt (5 g of peptone, 8.5 g of NaCl, 1000 mL of distilled water, pH = 7.2 ± 0.2) and homogenized for about one minute using a stomacher (Stomacher 400 circulator Seward, England). Microorganisms were enumerated by the pour plate method. Yeasts and moulds were grown on Malt Extract Agar (MEA) incubated at 25 °C for 72 hours (Heard & Fleet, 1985; Skaar & Stenwig, 1996).

Chemical changes in pasteurised juice

Juice preparation

Three batches of 'Kona Sugarloaf', purchased in Benin from three different pineapple farmers to perform this experiment in triplicate, were stored at a temperature between 12 °C and 16 °C. Batch A was processed into juice on the first day after the arrival in the Netherlands (day 1). On day 2, batch (B) was processed and on day 3, batch (C). After juice preparation, the samples were stored frozen at -20 °C, except for the samples in which vitamin C was determined.

Heat treatment

Triplicate experiments were conducted at five temperatures (55, 65, 75, 85, 95 °C) and 7 time periods (0, 10, 20, 30, 40, 50, 60 min), using the three batches of pineapple (A, B and C). A 5 x 7 factorial design was used in the scheduling of each experiment. For each experiment, five series of seven glass tubes were filled with 8 mL of fresh pineapple juice, sealed with tube caps and subjected to heat treatment in a heating block (Liebisch Labortechnik, the Netherlands) at 55, 65, 75, 85 and 95 °C, respectively, for 10 to 60 min. After treatment, the tubes were immediately cooled in an ice-water bath. Vitamin C, pH, degrees Brix, malic acid, citric acid, HMF, fructose, glucose and sucrose were measured.

Determination of pH, degrees Brix and organic acids (citric and malic acids)

The pH was measured using a pH meter (Inolab PH 720) at room temperature. The degrees Brix was measured with a refractometer (Eclipse 45-08, Bellingham + Stanley, Tunbridge Wells, UK). Organic acids (citric and malic acids) were determined by HPLC. The prepared pineapple juice samples were first centrifuged for 10 min at 1000 rpm and then supernatants were filtered with a 0.2 μm cellulose acetate (CA) filter. The solution was poured in a vial and analysed by HPLC equipped with a Prevail Organic Acids Column 250 x 4.6 mm Grace Alltech 88645 and a Dionex Ultimate 3000 RS Diode-Array Detector (DAD) that monitored at 210 nm. The analytical conditions were: flow 1 mL min^{-1}, isocratic mobile phase, a column temperature of 30 °C, eluent 0.1 M KH_2PO_4 in Milli-Q water of which the pH was adjusted to pH 2.5 using phosphoric acid.

Vitamin C determination

Vitamin C consists of ascorbic acid (AA) and its oxidized form, dehydroascorbic acid (DHA). Fresh pineapple juice (1 mL) was collected into 1.5 mL Greiner tube and then centrifuged for 10 min at 10,500 rpm at 4 °C. The supernatant was collected and filtered with a 0.2 μm CA filter; 0.5 mL of the filtered supernatant was transferred into a glass tube that contained 7.5 mL of 3 % metaphosphoric acid (MPA) and 1 mM of tert-Butylhydroquinone (THBQ). The vitamin C concentration was determined by measuring ascorbic acid (AA) using an HPLC system equipped with a C18a Polaris Column 150 x 4.6 mm and an UV detector that monitored at 245 nm. The analytical conditions were: flow 1 mL min^{-1}, isocratic mobile phase, eluent 0.2 % (v/v) orthophosphoric acid in Milli-Q water, and a column temperature of 20 °C.

Glucose, fructose and sucrose determinations

Pineapple juice was diluted 400 times with Milli-Q water. These solutions were filtered using a 0.2 μm CA filter. The filtrate's contents of glucose, fructose and sucrose were determined by HPLC using an Alltech Prevail Carbohydrates ES 5 μm 250 x 4.6 mm column equipped with an Evaporative Light Scattering Detector (ELSD). The temperature of the evaporator was set at 80 °C, the temperature nebulizer at 60 °C, and the carrier flow rate was 1.3 mL min^{-1}. The analytical conditions were: flow 1 mL min^{-1}, isocratic mobile phase, a column temperature of 25 °C, and an eluent 75 % (v/v) acetonitrile in demineralized water.

Hydroxymethylfurfural determination

The juice samples were centrifuged for 10 min at 1000 rpm; the supernatant was filtered with a 0.2 μm CA filter and transferred into HPLC vials. The HMF contents of the filtrates were determined by HPLC equipped with a Varian C18a Polaris Column 150 x 4.6 mm and UV/VIS detector that monitored at 284 nm. The analytical conditions were: flow 1 mL min^{-1}, isocratic mobile phase, eluent 5 % (v/v) acetonitrile in Milli-Q water, and a column temperature of 20 °C.

Kinetic modelling of yeast inactivation

The kinetics of yeast inactivation in the pineapple juice during heat treatment was described according to the Weibull model (van Boekel, 2009). The survival curves were obtained by plotting the log (N/No) (with N the number of survivors and No, the initial number) versus time (min) for each temperature. The parameters in the Weibull model were obtained via nonlinear least-square regression using the solver option in Excel (Microsoft). The error analysis on the parameters was done using the Excel macro solverAid (de Levie, 2004). The cumulative function of the survival curve used is:

$S(t) = \exp(-(\frac{t}{\alpha})^{\beta})$ (1) and

$\log S(t) = -\frac{1}{2.303}(\frac{t}{\alpha})^{\beta}$ (2)

The time needed to achieve a 6 log reduction was calculated according to equation 3 (van Boekel, 2009):

$t_d = \alpha(-\ln(10^{-d})^{1/\beta})$ (3)

in which d is the number of decimal reductions.

Statistical analysis

Results are given as mean ± SD of three independent determinations. A one-way Anova was used to test the effect of heat treatment on the different physicochemical and nutrional parameters of the pasteurised pineapple juice.

RESULTS AND DISCUSSION

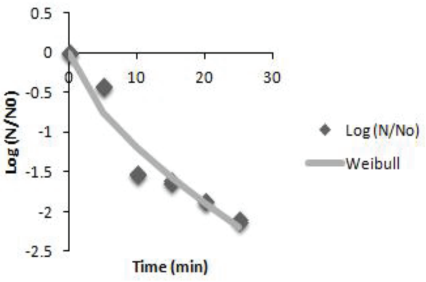
Effect of heat treatment on the inactivation of yeasts in pineapple juice

The Weibull model has been proposed to describe non-linear inactivation curves (Baranyi & Roberts, 1994; Buchanam, Golden, Whiting, Phillips, & Smith, 1994; R. Linton, Carter, Pierson, & Hackney, 1995; Peleg, 2000; Peleg & Cole, 2000; van Boekel, 2002). The model is sufficiently robust to describe a concave upward survival curve if $\beta < 1$ and a concave downward if $\beta > 1$ (van Boekel, 2002). Figure 5.1 shows the data and the fit of the Weibull model to yeast inactivation at 57, 59, 61, 63 and 65 °C. Two curves resulted in $\beta < 1$ and three in $\beta > 1$. At 57 and 59 °C, at which $\beta < 1$ (see Figure 5.1a-b), the results suggest that the remaining cells of the yeasts seem to resist the heat stress. However, at the higher temperatures 61, 63 and 65 °C, at which $\beta > 1$, the opposite is the case (see Figure 5.1c-2); the remaining cells seem to become increasingly damaged at increasing heating time. Visual inspection of the curves indicates that the fits obtained are very reasonable; the residuals are, by and large, randomly distributed. It is also obvious that first order kinetics does not apply for the data in Figure 5.1a-e. The calculated Weibull model parameters with corresponding correlation coefficients between the parameters are listed in Table 5.1.

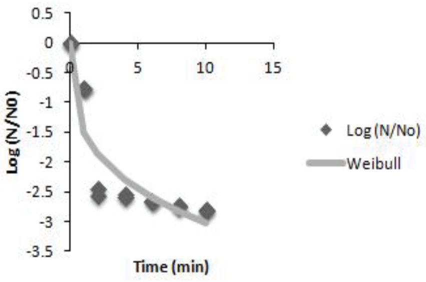
Table 5.1

Effect of temperature on the Weibull model parameters α and β and their standard deviations. r is the correlation coefficient between the parameters.

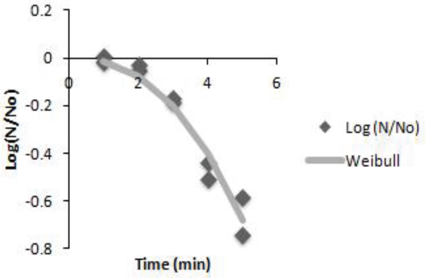
Temperature (°C)	α (min)	β	r
57	2.20 ± 0.75	0.66 ± 0.10	0.98
59	0.01 ± 0.02	0.30 ± 0.07	0.99
61	4.13 ± 0.10	2.39 ± 0.32	0.51
63	1.15 ± 0.04	1.84 ± 0.15	0.89
65	0.36 ± 0.02	2.42 ± 0.45	0.88



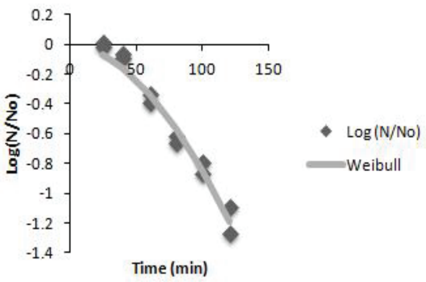
a.



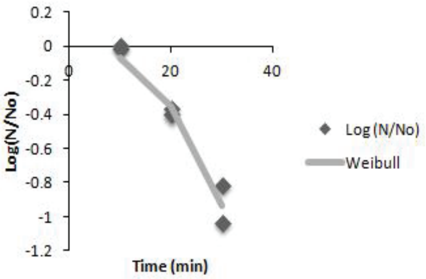
b.



c.



d.

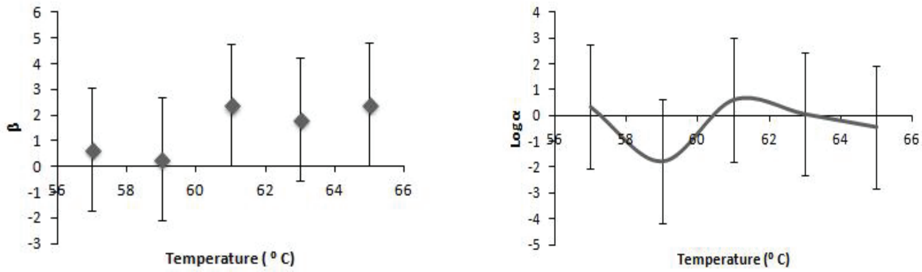


e.

Figure 5.1

Fit of the Weibull model to inactivation of yeasts at 57 (a), 59 (b), 61 (c), 63 (d) and 65 °C (e).

The results show a transition in heat resistance at 61 °C with a shift from $\beta < 1$ to $\beta > 1$. This is an interesting phenomenon because it shows that something critical happens to the cells at temperatures above 61 °C. Unfortunately, it makes the temperature dependence of the Weibull parameters complicated. The parameters α and β are correlated: if β changes, α changes as well. If the parameter β would remain constant, the temperature dependence of α can be modelled in a straightforward way: there is a logarithmic relation between α and temperature (van Boekel, 2002). However, because of the correlation between α and β and the fact that β is not constant, this relation is disturbed, as shown in Figure 5.2.



A. B.

Figure 5.2

Weibull shape parameter β (A) and scale parameter α (B) as a function of temperature for inactivation of yeasts in pineapple juice; error bars indicate 95 % confidence intervals.

The time needed to achieve a 6 log reduction of yeasts in the heated pineapple juice was 37 min at 57 °C, 8 min at 63 °C and 2 min at 65 °C. D-values from literature are $D_{60\,°C} < 1$ min for yeasts in general and $D_{60°C}$ = 7-22 min for the strain *Saccharomyces cerevisiae* (Hocking & Jensen, 2001). Despite the complications in kinetics, the results suggest that a heat treatment of 65 °C for 2 min is sufficient to inactivate yeasts in pineapple juice and therefore to give juice a proper microbial shelf life by pasteurisation. The remaining question is what happens to the non-microbial characteristics of the juice. This is discussed in the next sections.

Effect of thermal treatment on the physicochemical characteristics of pineapple juice

pH, degrees Brix, citric and malic acid

The initial pH of the juice was 3.86 ± 0.05 and the degrees Brix was 11.0 ± 1.5. The pH and the degrees Brix did not change significantly ($P > 0.05$) due to the heat treatments of the pineapple juice, which is in line with other studies (Kim, Tadini, & Singh, 1999; Yeom, Streaker, Zhang, & Min, 2000). These quality parameters are important as they are closely related to the stability of bioactive compounds in fruit products (Sánchez-Moreno, Plaza, de Ancos, & Cano, 2006). There were no changes in the malic and citric acid content after the heat treatments; on average these were 0.02 ± 0.002 M and 0.031 ± 0.005 M, respectively.

Vitamin C

Figure 5.3 shows the change in the AA concentration during heat treatments at 55, 65, 75, 85 and 95 °C in pineapple juice. AA significantly ($P < 0.05$) decreased from 0.91 ± 0.32 mM at 55 °C to 0.73 ± 0.26 mM at 95 °C. In addition, a significant difference ($P < 0.05$) was observed in the AA content when juice was heated at 65 °C, 75 °C and 85 °C (see Fig. 3.). This result suggests that the increase in temperature affects the AA in pineapple juice to some extent. AA is thermolabile and several studies have reported the effect of temperature on AA content (Cruz, Vieira, & Silva, 2008; Tiwari, O'Donnell, Muthukumarappan, & Cullen, 2009; Vikram et al., 2005). Even though the total loss in vitamin C between the highest and the lowest temperature studied was around 20 %, the losses in AA among each temperature studied were very low (< 8 %). The low degradation rates made it impossible to do proper kinetic modelling; generally, degradation must be at least 30-40 % before a model can be applied (van Boekel, 2008). A very rough calculation of activation energy from our data shows this to be < 20 $kJ.mol^{-1}$. However, this only indicates that the temperature sensitivity of AA degradation in pineapple juice is very small; because of the low degradation rates a precise calculation of the activation energy is not possible. This is a remarkable result because AA is usually susceptible to thermal degradation. Probably, the low pH conditions, as is the case in pineapple juice (3.86 ± 0.05), might stabilize it. A similar behaviour of ascorbic acid was reported in orange juice (Plaza et al., 2006) and amarula juice (Hiwilepo-van Hal, Bosschaart, van Twisk, Verkerk, & Dekker, 2012). Dhuique-Mayer et al. (2007) also reported that the degradation of vitamin C to be very low in citrus juice, in contrast to their expectation. Perhaps, it is time to reconsider the general perception that vitamin C is always very thermolabile.

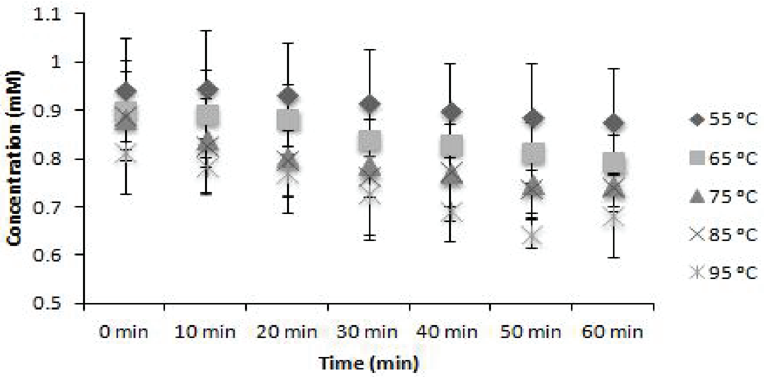


Figure 5.3

Thermal degradation of ascorbic acid (error bars indicate standard deviation for 3 replicates) in pineapple juice at different temperatures.

The AA content of the pineapple juice treated at 55 °C was initially 0.82 mM in batch A, 1.02 mM in batch B and 0.99 mM in batch C. The standard deviation appeared to be very large (± 0.10 mM), but this is not due to treatment or the analysis method but due to the natural variation in content. This high variation in the initial vitamin C was also found in the juice treated at 65, 75, 85 and 95 ° C. This supports that the variation between the three batches was due to the natural variation of the pineapple juice.

Hydroxymethylfurfural (HMF)

As nonenzymatic browning (Maillard reaction) is one of the major causes of colour change in fruit products, the effect of heating time on the accumulation of HMF was investigated. It was observed that only at 95 °C with a minimum time of 30 min HMF formation was initiated. According to Marcotte et al. (1998), HMF generation can only occur at temperatures above 95 °C in orange juice. However, this result deviates from the findings of (Rattanathanalerk et al., 2005), who detected, by spectrophotometry, HMF in pineapple juice treated at 55 °C. This could be due to the HMF detection method. Spectrophotometry may suffer from interferences from other compounds that absorb light at the same wavelength as HMF. Figure 5.4 shows the effect of heating at 95 °C on the HMF content (with standard deviation for 3 replicates) in pineapple juice.

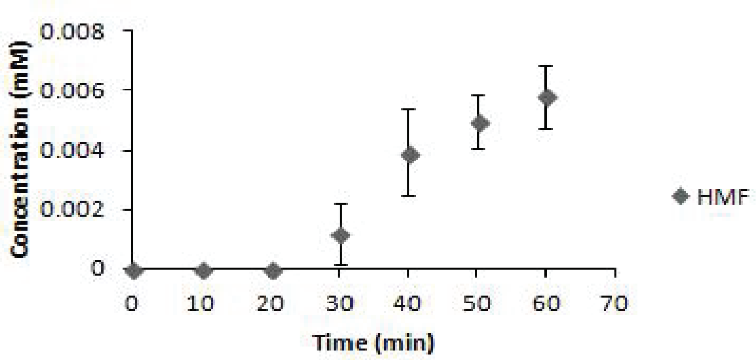


Figure 5.4

Effect of heating at 95 °C on the HMF content (error bars indicate standard deviation for 3 replicates) in pineapple juice.

Fructose, glucose and sucrose

Sucrose, glucose and fructose were studied as they are the major sugar components of pineapple juice (Bhandari, Datta, Crooks, Howes, & Rigby, 1997; Camara et al., 1996; Gawler, 1962; Wardy et al., 2009). The concentrations of fructose (123 ± 5.1 mM), glucose (100.5 ± 4.7 mM) and sucrose (320.8 ± 8.1 mM) in pineapple juice did not change after treatments at 55, 65 and 75 °C (see Figure 5.5). At 85 °C, sucrose showed a significant ($P < 0.05$) decrease from 320.8 mM to 292.4 mM. Overall, the glucose and fructose significantly increased at 95 °C (20, 30, 40, 50 and 60 min) (see Figure 5.5), whereas the sucrose content significantly decreased at 85 °C (30, 40 and 50 min) and 95 °C (20, 30, 40, 50 and 60 min) (see Figure 5.5). The decrease of sucrose with a simultaneous increase of fructose and glucose is explained by the hydrolysis of sucrose (Ooghe & Dresselaerts, 1995). Obviously, glucose and fructose are also subject to degradation as reducing sugars. However, our results show that this is very limited at the heat treatments applied here, in line with the fact that HMF formation is very limited. Since fructose is the sweetest of all naturally occurring carbohydrates (Hanover & White, 1993), pasteurisation of pineapple juice starting from 85 °C might affect the taste of the fresh pineapple juice, making it sweeter than its initial taste.

Figure 5.5 shows the changes in sugars in pineapple juice during heat treatment (with the standard deviation for three replicates).

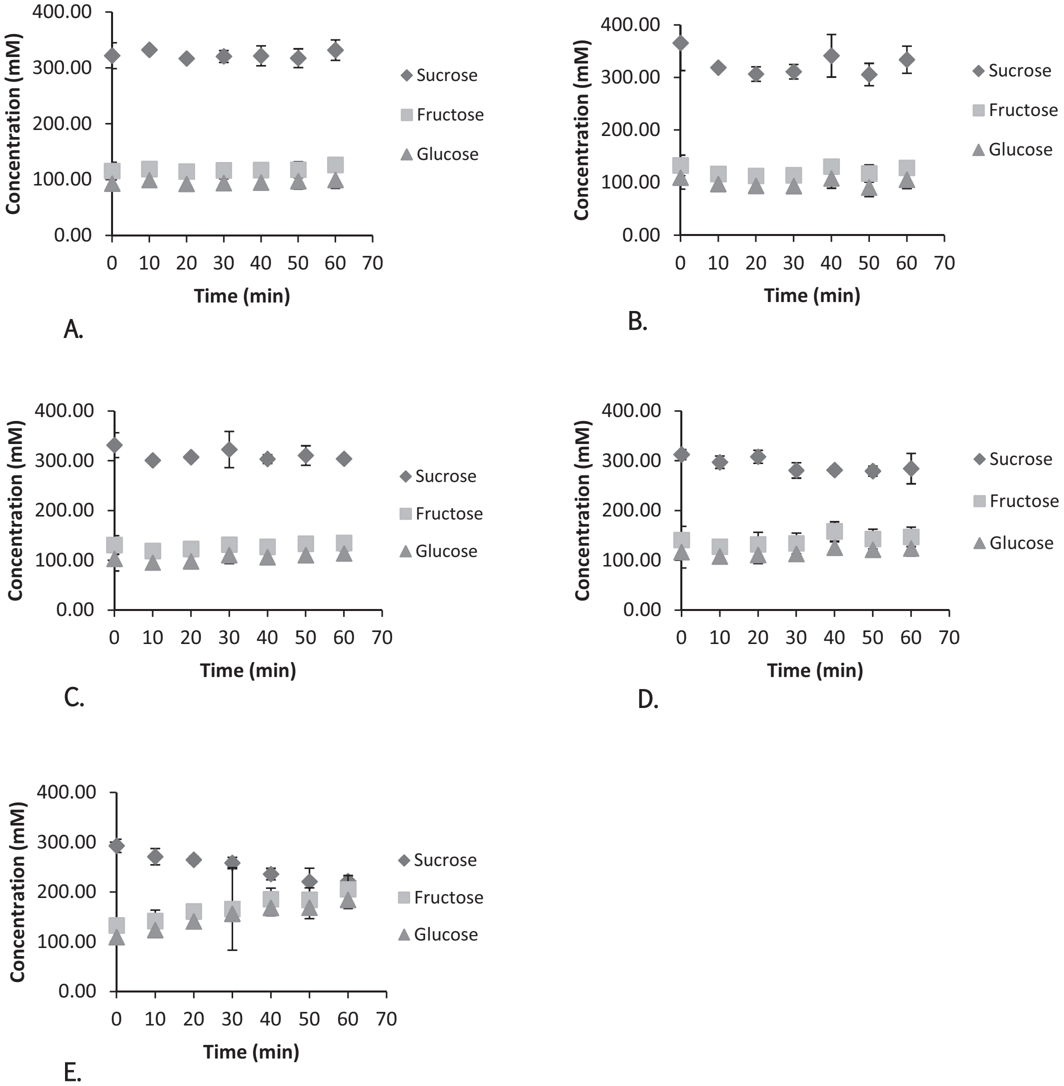


Figure 5.5

Changes in sugar composition in pineapple juice after heat treatments at 55 (A), 65 (B), 75 (C), 85 (D) and 95 ˚C (E) (error bars indicate standard deviations for 3 replicates).

CONCLUSION

A heat treatment of 65 °C for 2 min appeared to be sufficient to achieve a 6 log reduction of yeasts in pineapple juice. Chemical characteristics such as pH, degrees Brix, malic and citric acid concentrations were not affected by the heat treatments in the range studied. Hydrolysis of sucrose and formation of HMF were observed at 85 °C and 95 °C respectively, which could indicate the start of the Maillard reaction. The vitamin C content decreased with heating temperature but the effect of temperature on vitamin C degradation was low in the temperature range studied. Therefore, a pasteurisation treatment at a relatively low temperature could be used to prevent the pineapple juice from spoilage while preserving its nutritional and physicochemical quality.

These results are of importance for pineapple juice manufacturers in many small and large-scale juice industries. Most likely, pineapple juice is overprocessed. Our results show that pasteurisation needs not to be severe in order to obtain a reasonable shelf life. We did not study the organoleptic quality of the juice, but since pasteurisation can be done at a rather low temperature according to our results, we anticipate that damage to organoleptic quality will be limited.

ACKNOWLEDGEMENTS

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6

GENERAL DISCUSSION AND IMPLICATIONS

INTRODUCTION

This thesis is one of the outcomes of the Co-Innovation for Quality in African Food Chains (CoQA) programme implemented in three African countries, namely Benin, Ethiopia and South Africa. This programme aimed at designing integrated quality solutions combining approaches from different areas of expertise that can support smallholder pineapple growers and entrepreneurs to tailor the quality of their products to the demands of national and/or international markets, thus strengthening market access and competitiveness (www.coqa.nl). In Benin, the programme focused on quality management and quality improvement of the pineapple supply chain, with a special emphasis on pineapple juice. This thesis was conducted using an interdisciplinary approach by combining two disciplines: marketing and food technology. From this angle, the improvement of the pasteurised pineapple juice quality was investigated in the specific context of the Beninese pineapple marketing system. The marketing research analysed the pineapple marketing system while the food technological research investigated how pasteurised pineapple juice can be produced without compromising its quality. Within that framework, the following objectives were set:

i. evaluate the adaptation of Beninese pineapple marketing systems to the introduction of the pasteurised pineapple juice business;

ii. assess the extent to which pineapples with physical damage (i.e., of potential less quality) can be used for pineapple juice production;

iii. review the present state-of-the-art on the effect of processing on the quality of pineapple juice;

iv. evaluate the effect of pasteurisation on the microbiological, physicochemical and nutritional value of pineapple juice.

The relation of this thesis to the CoQA objectives and the extent to which these objectives were reached, are discussed in this chapter.

INTEGRATION OF FOOD TECHNOLOGY AND MARKETING RESEARCH

Food technology and marketing research have worked together before on consumer perceptions and preferences (Jongen & Meulenberg, 2005; Ruben, Tilburg, Trienekens, van Boekel, & Trienekes, 2007). The present thesis extends on this tradition to include marketing approaches to sourcing of pineapples, and a perspective on marketing system adjustments to the development of a new channel within the market, namely that of pasteurised pineapple juice production.

In general, marketing research in this thesis has helped to get a better insight in the marketing context; this was useful because in a developing country like Benin, the level of organization of the juice industry is low. The identification of fruit quality attributes needed by the juice industry is probably much less specified than it is in developed countries, where there is more interaction between the marketing board and research and development (R&D) team of food companies (e.g., Royal S.A.) (Francois-Haugrain et al., 1994). Such interactions are not ongoing in the Beninese juice making sector because the juice sector is still in its embryonic state. At this level, juice manufacturers are not familiar with any knowledge in product quality management and marketing that can help them to source their fruits according to the characteristic of the juice they are looking for.

Because we did a thorough analysis of the marketing system in which the juice manufacturers are embedded, we obtained better insight in important research questions for food technology when analyzing the preferences of the juice manufacturers.

The integration of food technology and marketing research was pivotal to the general objective of this thesis, which was to improve the quality of the pasteurised pineapple juice in the context of the Beninese pineapple marketing system. Actually, the system is characterized by a production system where two pineapples varieties are produced: 'Smooth Cayenne' and 'Kona Sugarloaf'. The analyses of the marketing system showed that variety 'Kona Sugarloaf' was preferred by juice manufacturers. This is because it is cheaper than variety 'Smooth Cayenne' (Kinkpe, Houessionon, Adégbola, & Biaou, 2013) and presents the best characteristics for juice production in Benin due to its higher juiciness and higher sweetness compared to the variety 'Smooth Cayenne' (Wardy et al., 2009). Based on this insight, we prioritized variety 'Kona Sugarloaf' for our research on the improvement of pasteurisation practices. This choice was relevant because variety can affect the quality of pasteurised pineapple juice (Chapter 4).

The marketing investigation helped also to find out what pineapple quality means for pineapple juice manufacturers while the technological research determined to which extent their preferences could be exploited without compromising the quality of the pineapple juice. Specifically, the marketing research showed that juice manufacturers are in favour of using pineapple with physical damage as input material for producing pasteurised pineapple juice. In principle, this is possible when pineapples are immediately processed after damage (within 24 hours at temperatures between 20-30 °C). However, in the Beninese context, pineapples with such damage are stored before being processed. Therefore, we designed an experiment that helped to understand in which condition such pineapples can be stored and used for juice production.

In summary, the approach of starting the project by a general investigation at the marketing system level has been successful in identifying market opportunities for juice manufacturers who are price sensitive. These opportunities would not have become obvious if the technological research would have been done without this information.

MAIN OUTCOMES OF THIS THESIS

The main outcomes of the present thesis are the following:

- The Beninese pineapple marketing system did not adapt to the introduction of pasteurised pineapple juice as a development intervention in the sense that juice manufacturers have not become an integrated channel of pineapple wholesalers (pertains to objective 1)

- Pineapples with physical damage can be used to produce juice without affecting the pH, the degree Brix, the organic acids and the vitamin C content of the pineapple juice. In addition, pineapple storage induced a change in the sugar profile, which led to an increase of the sweetness of the juice (pertains to objective 2).

- From the literature review, it appeared that the quality of pineapple juice is largely influenced by the preservation techniques used during processing. However, there is insufficient knowledge on the effect of pasteurisation on the microbiological, nutritional and sensorial quality of the juice (pertains to objective 3).

- Pasteurisation time and temperature can be considerably reduced as compared to the current practice. The effect of temperature in the pasteurisation range on vitamin C content in pineapple juice is low. Hydroxymethylfurfural (HMF), an important intermediate of the Maillard reaction, occurred only at 95 °C at a minimum holding time of 30 min which are conditions much above what is required for pasteurisation (pertains to objective 4).

In the following sections, the outcomes will be discussed from an integrative perspective.

RELATION BETWEEN FRESH PINEAPPLE AND PINEAPPLE JUICE QUALITY

Contribution from marketing research

Chapter 2 showed that ten years after the introduction of pasteurised pineapple juice, juice processing has not developed as an independent business with its own sourcing process. Actually, juice manufacturers are taking advantage of low priced pineapples to produce a pasteurised pineapple juice that has an added value. In fact, the marketing system itself provided enough information about the pineapple variety and quality attributes that are suitable for pasteurised pineapple juice production. In general, mature pineapples of the 'Kona Sugarloaf' variety without fungus that have not been treated with ethephon represent the ideal raw material that juice manufacturers are looking for in pineapple juice production. Perhaps unexpectedly, pineapples with physical damage appeared to be acceptable for juice production. So, a new marketing channel based on these pineapple characteristics can be promoted to maximize wholesalers' revenues because pineapples with physical damage were considered as waste on the fresh market.

The investigation of the Beninese pineapple marketing system (Chapter 2) gave relevant information about what juice manufacturers consider pineapples of good quality, and food technology as discipline helped to validate these preferences and to assess that pineapples with these characteristics are really suitable for juice production.

Contribution from technological research

The definition of pineapple quality refers to the sum of those fruit characteristics that make it most palatable and therefore desirable to consumers (Paull, 1993). As far as pineapple juice is concerned, quality is predominantly based on its taste through its sweetness index (i.e., total soluble solids/acids) and its nutritional value (notably vitamin C content).

Physical damage is known to decrease the total soluble solids (TSS) and the vitamin C content of fruits (Kaaya & Njoroge, 2004; Kader, 2002; Moretti et al., 1998). On the one hand, according to Durigan et al. (2005) the reduction of TSS reflects the effect of stress on the fruit and can be explained by the use of these elements as a source of energy (Sanches et al., 2008). On the other hand, the degradation of vitamin C in fruits after physical damage is attributed to vitamin C oxidation due to the reaction of ascorbic acid with oxygen (Montero et al., 2009).

The investigation of the Beninese pineapple marketing system showed that pineapples with physical damage are not rejected by juice manufacturers (Chapter 2). These pineapples are often used for juice production because of their low price compared to the undamaged pineapples. Indeed, our research (Chapter 3) showed that these damaged pineapples can be used to produce pasteurised juice, because they did not affect the nutritional (vitamin C) or the physicochemical (e.g., sugars, organic acids, TSS) characteristics of the fresh juice (Chapter 3). These findings were not expected. The pineapple fruits used in our study were mature but firm and apparently the impact of the physical damage was not such that it affected pineapple quality in a negative sense. In this context, it is important to emphasize that adhering to the right harvesting time is important because any fruit picked too late is more susceptible to effects of physical damage than fruit picked at the proper maturity. Pineapples with physical damage were stored at a relatively low temperature (20 °C) to increase shelf life up to 9 days. However, in the Beninese context, pineapples with such damage are stored at ambient temperature (around 30 °C) for 7 days because of the absence of storage facilities. Assuming a Q_{10} value of 2-3 for chemical reactions, the storage time of these pineapples at 30 °C would reduce from 9 days to 3-4 days. Consequently, storage temperature needs to be reduced to increase the shelf life of the fresh pineapples before processing.

FACTORS AFFECTING THE QUALITY OF PASTEURISED PINEAPPLE JUICE

Insights from the literature review

In chapter 4 we reported, based on an extensive literature review, that pasteurisation mainly affects the colour through nonenzymatic browning (Rattanathanalerk et al., 2005) and the vitamin C content (Akinyele et al., 1990; Uckiah et al., 2009) of fresh pineapple juice. Nevertheless, most of the variability observed in the literature cannot be explained. This is due to lack of information on the sample source (e.g., from the field or the market), sample homogeneity (i.e., whether the sample consists of fruits of the same variety, whether the sampled fruits were harvested at the same stage of maturity), and the storage conditions of the fresh juice which might affect certain compounds such as vitamin C. The various analytical methods applied might also have contributed to the variability in the reported data. In addition, the lack of information on statistical parameters such as standard deviations and means did not help to interpret the observed variability. For better interpretation of literature data, we suggest that in the future a clear description is given of the pineapple variety, its sampling method and the storage conditions of the fresh juice before any lab experiment. In addition, particular attention should be given to the precision of the parameters estimated from the data. In this perspective, it should also be mentioned how precision is reported: through standard deviation, standard error of the mean or confidence interval (van Boekel, 2009).

While pasteurisation is widely used to increase the shelf life of fruit juices in general and of pineapple juice in particular, few studies have questioned the effect of pasteurisation on the quality of pineapple juice (Chapter 4). It is reported that pasteurisation can negatively affect the nutritional and the sensorial quality of juice in general (Rattanathanalerk et al., 2005). However, literature showed insufficient proof that pasteurisation has indeed such a negative effect on pineapple juice quality (Chapter 4). Our findings suggest that pasteurisation should be optimized for each type of fruit juice individually because the resulting quality is related to the physicochemical and microbiological characteristics of each particular type of fruit. Fruits are in one of two groups on the basis of their pH: acid fruits such as pineapples and high-acid fruits such as berries. The more acid the fruit, the less heat is required for its preservation. Also, the more microbial cells naturally present in the fruit juice, the more severe the heat treatment necessary to kill them. The investigation of the pasteurisation on the quality of pineapple juice gave more insights on the factors that affect pineapple juice quality.

Insights from own food technology research

The challenge of any preservation technique is to increase shelf life while limiting nutritional and sensorial losses in quality. In the Beninese context, and in many other developing countries, pasteurisation appeared to be the most frequently applied technology for juice preservation. First, the temperatures used (in the range of 65 to 100 °C) are capable to inactivate yeasts, responsible for microbial spoilage of pineapple juice (Chapter 4 & 5). Second, it is an affordable technology for many small-scale juice industries throughout the world. Yet limited research has been done on the quality of pasteurised pineapple juice (Chapter 4). According to some authors (Knorr, Ade-Omowaye, & Heinz, 2002; Polydera et al., 2003; Rattanathanalerk et al., 2005; Rawson et al., 2011), thermal processes, such as blanching, pasteurisation or heat sterilization, induce various chemical reactions, leading to quality deterioration in foods by producing undesirable changes in nutritional and sensorial qualities. To clarify this issue for pineapple juice, chapter 5 of this thesis reports on the effect of pasteurisation on yeast inactivation, vitamin C and other chemical quality parameters (e.g., organic acids, hydroxymethylfurfural, sugars) of the pineapple juice. The objective was to monitor quality degradation of the juice through a kinetic study, knowing that heat treatments are the main factors that negatively affect the nutritional and the sensorial quality of fruit juice (Carneiro et al., 2002).

In general, the reactions in juice that might affect quality, are enzymatic browning, nonenzymatic browning, vitamin C loss and sugar hydrolysis (van Boekel, 2009). Polyphenol oxydase (PPO) is known as the catechol oxidase that catalyzes the oxidation of o-diphenol to o-diquinones as well as the o-hydroxylation of monophenols (Vaughn & Duke, 1984). It could be the main enzyme to cause enzymatic browning in pineapple fruit (Avallone, Guiraud, Brillouet, & Teisson, 2003). According to Stewart et al. (2001), however, pineapple has a low PPO activity, namely less than 100 mU/g fresh pineapple. In addition, Lozano-de-Gonzalez et al. (1993) reported browning inhibition abilities by pineapple juice. Das et al. (1997) reported that the activity of PPO can be inhibited by endogenous ascorbic acid and Supapvanich et al. (2012) determined that an extract made of the core of pineapples had the highest inhibitory effect on juice browning. Moreover, an investigation on the PPO content in the samples used for different experiments in our own research showed no PPO activity (results not shown). In addition, the enzymes causing browning in pineapple juice are susceptible to heat, at temperatures above 50 °C (Rattanathanalerk et al., 2005). Therefore PPO is not considered to be a critical quality issue in pasteurised pineapple juice.

In chapter 5 we found that a pasteurisation treatment of about 65 °C for 2 min proved to be sufficient to achieve a 6 log reduction of yeasts in pineapple juice. In addition, the formation of hydroxymethylfurfural (HMF), an intermediate of the Maillard reaction, occurred only at temperatures of 95 °C after 30 min. Furthermore, vitamin C was quite stable at elevated temperatures.

In Benin, fresh pineapple juice is bottled and pasteurised at temperatures $T \geq 85$ °C. The use of such high temperatures for pineapple juice pasteurisation in Benin is to prevent any spoilage of the juice due to microorganisms. However, the necessary conditions of a pasteurisation treatment depends on the characteristics of the spoilage microorganisms and/or enzymes involved. Their inactivation requirements may vary with the product and need to be established first (Chapter 4). Often, the most heat resistant spoilage enzyme or microorganism is used as a target, or simply the most common spoilage organisms (Silva &

Gibbs, 2004). Based on our findings, pasteurisation of fruit juices should be designed according to the characteristics of the juice (namely pH, heat resistance of the target microorganisms, initial microbial load, heating medium characteristics) in order to optimize the process to save energy as well as preserve the nutritional and the sensorial quality of the juice.

In Benin, some pineapple juices heated at high temperature (T > 85 °C) darken strongly during storage at ambient temperature (30 °C), most likely due to the Maillard reaction. Since temperature and time present the most significant processing factors influencing the Maillard reaction, the reduction of the thermal load to which pineapple juice is exposed is a key factor to control the extent of this reaction. Our findings suggest that pineapple juice can be pasteurised at 65 °C for 2 min to preserve its nutritional (vitamin C) and sensorial (colour) quality while preventing spoilage by yeasts. This reduced heat load is also beneficial for subsequent storage of the juice.

IMPLICATIONS

Marketing

The analysis of the Beninese pineapple marketing system illustrates that the adaptation of marketing systems in developing countries to development interventions should not be taken for granted and that technical interventions may need support from additional marketing interventions. Wholesalers are at a strategic position in the system where pineapples are graded, sorted and possibly refused, before they are offered to specific buyers. Wholesalers are therefore best-situated to improve the adaptation of the system. An intervention could consist of a training that increases wholesalers' understanding of the juice-making process, helping them to align to the wants and needs of juice manufacturers. It is also possible to develop a group of specialized traders who collect the pineapples that are suitable for juice making from wholesalers and possibly the left-overs from merchants.

On the side of the juice manufacturers, a potential intervention may focus on raising the understanding of the potential gains of giving feedback and eventually being loyal to their suppliers. The relatively unarticulated preferences of juice manufacturers suggest that their relatively low level of satisfaction (Chapter 2) may not only be caused by the low performance levels of the pineapples that they purchase, but also possibly by low expectations. Sheth (2011) sees market development as a process of raising expectations. When juice manufacturers realize that they can receive affordable pineapples that are suitable for juice-making without much losses, then they will increase their feedback to wholesalers. This may gradually contribute to the development of a more specialized marketing channel within the system, targeted at their preferences that probably become more explicit during this process.

Food technology

Food quality is a complex concept, which is frequently measured using objective indices related to the nutritional, microbiological, or physicochemical characteristics. However, food quality is also a consumer-based perceptual construct, which is relative to a person or a place (Cardello, 1995). In Benin, the sweet taste of pineapple juice is the most important quality attribute for consumers (Kinkpe et al., 2013). Our findings showed that the variety 'Kona Sugarloaf' has a higher sugar content than the other variety that is also common in Benin, namely ‘Smooth Cayenne’. This finding was also reported by Wardy et al. (2009). We also noticed a partial hydrolysis of sucrose into fructose and glucose during storage of the pineapple, which would increase the sweetness of the juice. Thus, the storage of fresh pineapples emerges as a possible strategy to increase the sweet perception of the fresh juice. Therefore, when a sweeter taste is desired, our results suggest that harvested mature pineapple be stored up to seven days at 20 °C before being processed into juice. However, this may also support the occurrence of the Maillard reaction because of the increase in reducing sugars. Therefore, a study should be done to find a compromise between the increased sweetness on the one hand and juice discolouration on the other hand.

Pasteurisation is the most frequently used technology to preserve the quality of fresh pineapple juice and increase its shelf life. During pasteurisation, we noticed three phenomena. First, a pasteurisation treatment of 65 °C for 2 min was sufficient to inactivate the yeasts responsible juice spoilage. Second, the effect of temperature on vitamin C degradation is low. Finally, pasteurisation at 95 °C for 20 min induced an increase of the juice sweetness. Because pasteurisation at 95 °C - 20 min will reduce the shelf life of the juice through Maillard reaction, juice manufacturers can pasteurize their pineapple juice at 65 °C for 2 min and get a microbiologically safe juice while preserving its overall physicochemical characteristics and its vitamin C content.

Integration

The discussion of this section is based on the picture that emerges when the different insights are taken together. The Beninese pineapple juice production is heterogeneous in quality and quantity. The juice manufacturers differ in knowledge about juice processing technology and financial capabilities. The customers' demands pertaining to juice quality differ according to juice manufacturers. For instance, some customers want a pasteurised pineapple juice that has the same characteristics as fresh juice as far as taste, aroma, and colour are concerned, while other customers are satisfied with a pasteurised pineapple juice that is sweet and safe for human consumption. In order to satisfy the different types of customers, the pineapple juice industry in Benin is characterized by two main categories of juice manufacturers. The first category of juice manufacturers (less important in numbers) recognizes a clear relation between the input materials and the quality of the fresh juice obtained; they pay particular attention to the pineapple variety and maturity. The second category of juice manufacturers (most important in numbers) pays less attention to these attributes and sometimes adds water and sugar (sucrose) to increase the yield and the sweetness of the fresh juice, respectively.

The pasteurisation process is more or less similar for the two groups of juice manufacturers. The first category of juice manufacturers pasteurizes their pineapple juice in bottles of 0.33 L or 0.25 L at around 85 °C for at least 20 min while the second category of juice manufacturers pasteurizes at higher temperature of about 95 °C for a minimum time of 30 min.

The findings of our research can help the juice manufacturers to readjust their pasteurisation according to the expectation of their customers. For instance, for customers who are satisfied with a safe and sweet pineapple juice, pasteurisation should be implemented to avoid fermentation during storage. In addition, we showed that pasteurisation at 95 °C for 20 min would increase the sweetness of the pineapple juice as desired by these customers but the risk that the juice turns brown during storage is high. The pineapple juice can be pasteurised at this temperature but the shelf life of this juice would be short and this should be take into account.

For customers who are more demanding in terms of quality, such as hotels, restaurants and hospitals, juice manufacturers should pay attention to the pineapple sourcing and the pasteurisation process. Mature 'Kona Sugarloaf' fruits without damage by fungi, pests or insects should be used. Next, the pasteurisation treatment should be reduced to 65 °C for 2 min to preserve the sensorial (taste, colour) and the nutritional value (vitamin C) of the pineapple juice. In addition to what juice manufacturers would gain in quality, having to use less energy for the pasteurisation would be economically profitable for them because of the energy shortage and increasing costs of energy (Karekezi, 2002).

Apart from these suggestions to improve the quality of the pasteurised pineapple juice for different customers, there is a need to train juice manufacturers in the most effective way to pasteurize pineapple juice. Actually, the fresh pineapple juice is extracted from fresh pineapple, bottled, sealed and pasteurised in heated water. Juice manufacturers usually measure the temperature in the water and assume that the temperature is the same in the juice itself. This way of doing is not always effective because the heating up time might be longer than expected. Moreover, sometimes the temperature inside the juice is quite different from the temperature in the water because of the inappropriate heating system. Therefore, a project should be initiated to improve juice manufacturers' skills in measuring pasteurisation temperatures inside the juice during the heating treatment. During our research, the pasteurisation temperature has been monitored with an electronic device called i-button. The device was introduced in the juice and was able to record the temperature in the juice during the heat treatment. The same device can be used by juice manufacturers to control the pasteurisation temperature at a small scale level.

In the current context of Benin, where the pineapple juice market is still fragmented, there is a possibility for a company to build a pasteurised pineapple juice production plant with fresh pineapple storage facilities to increase the pasteurised pineapple juice production and distribute it to neighbouring countries such as Nigeria, Togo and Burkina-Faso. For example, this company can source mature (degree Brix = 14) 'Kona Sugarloaf' pineapples (with and without physical damage) at the field or market level, collect and store them in appropriate storage facilities (T = 20 °C) for less than 9 days. Pineapples with fungus or pests/insects damages should be avoided. The extracted pineapple juice can be pasteurised at 65 °C for 2 min.

With regards to what we discussed in this section, the development of the pineapple juice industry in Benin depends on the target market and of the financial capabilities of juice manufacturers. Whatever the target market, pineapple sourcing and pasteurisation are the most important factors that can affect the quality of the pasteurised pineapple juice. Because juice manufacturers differ in many respects (e.g. location, education, culture, financial capabilities), it would be difficult to make them work together as one industry. However, there is a possibility to train them on how to improve the quality of the juice they produce through appropriate pineapple sourcing and the right pasteurisation treatment. This will help them in producing a pineapple juice of constant quality. In addition, government institutions or NGO's might help juice manufacturers in identifying and accessing markets at regional or international level. They could even produce a pineapple juice of similar quality to be packaged under the same brand without extra costs because they can use their own equipment. Juice manufacturers, who are not interested in such collaboration can continue their juice business taking into account the recommendations described in the previous sections. Yet another possible scenario is that when juice manufacturers are trained, they can decide to professionalize by developing a strategic alliance with a packaging company. While this is a viable scenario, it is not easy to predict the effect that this new company would have on the existing pineapple juice industry.

FURTHER STUDIES

In this thesis the influence of the variety and the maturity stage of pineapple fruits on fresh juice characteristics was not investigated. These factors are controlled at production level. The quality of pineapple at maturity, for example, depends on the cultural practices. In Benin, pineapple varieties 'Smooth Cayenne' and 'Kona Sugarloaf' are cultivated. Variety 'Kona Sugarloaf' contains more juice, less fibre and more sugar presenting the best prospects for commercial pineapple juice manufacture (Wardy et al., 2009). However, as stated by Fassinou Hotegni et al. (2010), the current pineapple production practices affect the quality of the pineapple at maturity. The planting density of 'Kona Sugarloaf' was found to be higher (4-17 plants/m^2) than that of 'Smooth Cayenne' (4-11 plants/m^2), which led to a growth reduction (Zhang & Bartholomew, 1992), increased the total acids concentration and reduced the total soluble solids (Bartholomew, Malezieux, Sanewski, & Sinclair, 2003; Chadha, Melanta, & Shikhamany, 1974; Mustaffa, 1988). These characteristics will increase the acidity and reduce the sweetness of the fresh juice. A sweetness index (TSS/acidity) from 20 to 40 is recommended as a good maturity indicator (Duane P Bartholomew et al., 2003). We advocate to analyse and to adapt farming practices to agro-climatic conditions in order to improve the quality of the pineapple at maturity. This is important, because at the right maturity level, the pineapple is succulent (Bartholomew, Paull, & Rohrbach, 2003) and will be ideal for juice production in the Beninese context where sweet juice is demanded. Therefore, the quality of the fresh pineapple juice is more related to the maturity than to physical aspects.

We learnt from chapter 2 and chapter 3 that the external quality of the pineapple plays a minor role in the quality of the fresh juice as long as spoilage is avoided and the fruit is sufficiently mature. Further, it is clear that the quality of the pasteurised juice will mostly depend on the pineapple variety and the technology applied for juice production. Yet existing literature falls short on the varietal characterization of pineapple. The variation in the physicochemical and nutritional characteristics of pineapples from the same variety is important (Chapter 4 & Chapter 5), and the variation between the different varieties is expected to be high. In order to decide which variety is most likely to provide juice of the best nutritional and sensorial quality or other pineapple products, such as dried pineapples or marmalades, detailed varietal characterization is of utmost importance.

In this research, pasteurisation has been the only technology investigated to improve the quality of the juice. Other preservation technologies such as high pressure and pulsed electric field also deserve further investigation. Specifically, the effect of these technologies on the microbiological, physicochemical and nutritional quality of pineapple juice should be studied in greater detail to allow comparisons with the pasteurisation technology as far as pineapple juice is concerned. However, in the current context of Benin, like in the majority of developing countries, many hurdles such as costs, energy and water supply need to be overcome in order to implement these modern preservation techniques in the juice industry. In the end, these modern technologies can be considered only when they give a better pineapple juice quality (microbiological, nutritional and sensorial) than juice obtained from pasteurisation.

This thesis has not investigated the effect of storage on the quality of pasteurised pineapple juice. While some results could help to anticipate what could happen during storage, further research needs to be done on the fate of pineapple juice quality during storage.

First, we showed that a pasteurisation treatment of 20 min at about 95 °C has an ambiguous effect on juice quality as it increases the sweetness of the juice on the one hand but probably enhances the Maillard reaction during storage on the other hand.

Therefore, it is important to investigate the shelf life of pineapple juice pasteurised at 95 °C for 20 min. Second, the most important quality attributes that need to be maintained during storage of pasteurised pineapple juice are its nutritional (mostly vitamin C) and its sensorial quality (mostly its fresh aroma, taste and colour). Adams and Brown (2007) reported that in pineapple juice, nonenzymatic browning is predominantly related to ascorbic acid and sugar degradation. This means that in pasteurised pineapple juice, a control of the ascorbic acid and sugar degradation is crucial to preserve the juice from nonenzymatic browning, which in the course of time would affect the colour of the juice. Oxygen is the most destructive ingredient in juice causing degradation of vitamin C (Ajibola, Babatunde, & Suleiman, 2009). Oxygen present in the spaces between the juice vesicles and the surroundings saturates the juice, leading to oxidation reactions that often result in browning, changes in aroma, and loss of nutritional value (García-Torres, Ponagandla, Rouseff, Goodrich-Schneider, & Reyes-De-Corcuera, 2009). Therefore, oxygen needs to be removed during processing to avoid both degradation of vitamin C and browning. García-Torres et al. (2009) proposed some methods of oxygen removal in different fresh juices such as from pineapple. These methods included vacuum – deaeration, which consists of reducing the pressure of the gas above the juice before pasteurisation, or gas sparging, which consists of displacing the oxygen with another gas like nitrogen or carbon dioxide, and finally the use of membrane deaerators, which are put as a barrier between the liquid and the gas phase. Although these methods look interesting in a modern juice industry, their application is a challenge in the context of developing countries such as Benin, where processing is still implemented at a small scale with basic or semi industrial equipment. There is a need for research to investigate how oxygen can be removed during the juice processing with methods that can be used in the context of those countries. Moreover, it is known that dissolved oxygen may affect the flavour of fruit juices by formation of precursors such as dehydroascorbic acid, a precursor of aldehydes formed during the Strecker degradation (Pérez, Sanz, Brückner, & Wyllie, 2008). To what extent oxygen affects pineapple juice aroma is unknown and should be investigated.

Light exposure was found to promote browning in pineapple juice (Ajibola et al., 2009). Therefore, packaging plays an important role in the preservation of juice quality. The browning effect is expected to be lower in canned juices, for instance, than in bottled juices. In developing countries like Benin, emptied beer bottles (with a dark green colour) are commonly used as packaging material for pasteurised pineapple juice and this would diminish the possible effect of light. The impact of different types of packaging on the browning effect merits further research.

CONLUSION

The objective of this thesis was to investigate how quality of pasteurised pineapple juice can be improved when the marketing system has been taking into account. While the marketing system provides interesting answers on the ideal pineapple characteristics for juice production, we noticed that the Beninese pineapple marketing system did not adapt to this new juice business and the pineapple marketing channel for juice production is still absent. We conclude that a development intervention should not be limited to the target group but should include related actors, in this case in the marketing system. The analysis of the marketing system as developed in this thesis helped to identify the other actors who might need to be involved. In the specific case of the agro industry in developing countries, this would contribute to improve the adaptation of the marketing system and further will provide insights on the directions that any product development or improvement should take.

As far as the improvement of pineapple juice is concerned, our research demonstrated that the quality of pineapple juice is quite stable under different heat treatments. Nevertheless, pineapple juice does not need to be pasteurised at a high temperature (> 85 °C); it can be pasteurised at a temperature of 65 °C without any risk of spoilage due to yeast activity and deterioration of its nutritional quality (vitamin C) and sensorial quality (taste, colour).

The severe pasteurisation treatments generally applied in pineapple juice production are not justified. Moreover, the general understanding that heat treatments seriously affect the vitamin C content of fruit juices is not adequaly proven and should be reconsidered.

The analysis of the agricultural marketing system before embarking on food technological research can be used as a valuable approach to focus on the most important food technological issues in many developing countries.

7

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8

SUMMARY IN ENGLISH, DUTCH AND FRENCH

SUMMARY

This study is a result of the interdisciplinary project Co-Innovation for Quality in African Food Chains (CoQA). The objective of the research was to improve the quality of pasteurised pineapple juice taking the characteristics of the Beninese pineapple marketing system into account. To achieve this goal, a combination of marketing and food technology research has been used to capture the functioning of the system, to evaluate the market possibilities that can improve the system's performance and to improve the pasteurisation technology. The specific objectives were to: (i) evaluate the adaptation of Beninese pineapple marketing system to the introduction of the pasteurised pineapple juice business; (ii) assess the extent to which pineapples with physical damage (i.e., of potential less quality) can be used for pineapple juice production; (iii) review the present state-of-the-art on the effect of processing on pineapple juice quality and (iv) evaluate the effect of pasteurisation on the microbiological, physicochemical and nutritional quality of pineapple juice.

Chapter 2 of this thesis describes the adaptation of the Beninese pineapple marketing system to the pasteurised pineapple juice business. A conjoint experiment was designed and implemented to assess the preferences of pineapple wholesalers, pineapple consumer-merchants and pineapple juice manufacturers. The study measured and compared the preferences of these actors and investigated whether the preferences of the juice manufacturers have been taken into account by the wholesalers in their everyday business.

Our findings revealed that wholesalers are the main suppliers to both consumer-merchants and juice manufacturers. However, juice manufacturers' preferences are different from those of consumer-merchants. More specifically, juice manufacturers prefer large pineapples from 'Kona Sugarloaf' variety and believe that pineapples with physical damage can be used to produce pasteurised pineapple juice. This offers wholesalers the opportunity to sell pineapples that are not demanded by consumer-merchants, but it was found that wholesalers are not engaged in any specific sorting and grading activities to fulfill the wants of the pineapple juice manufacturers.

The marketing system approach used in this chapter goes beyond the transaction costs, a perspective that is frequently used in the development literature, in that it considers other factors such as cognition, and cultural norms and habits, that influence the perception of market opportunities and the willingness and ability to seize opportunities. Based on that

approach, we learned that the reason for the lack of adaptation of the system is caused by the lack of responsiveness of wholesalers due to such factors. The results imply that, in the development context, the adaptation of the marketing system to a development intervention needs to be managed and the effects of interventions need to be considered beyond the primary target group. In other words, complementary marketing interventions should focus on the other actors of the marketing system.

As juice manufacturers considered pineapples with physical damage as a possible raw material for pineapple juice production, the possibility of using pineapples with physical damage for pineapple juice production was investigated in chapter 3. Experiments were designed to simulate different types of physical damage (cuts and bruises) and the damaged pineapples were stored for up to 9 days. Physically damaged pineapples stored for up to 9 days at 20 °C showed no adverse effects on the physicochemical characteristics (pH, total soluble solids, sugars) and vitamin C content of fresh pineapple juice (Chapter 3). This suggests that pineapples with those characteristics are suitable for the production of pasteurised juice and that the preference of juice manufacturers for pineapples with physical damage to produce pasteurised pineapple juice is justified. However, the storage temperature should be taken into account. In the specific context of Benin, with an average temperature of 30 °C, pineapples with physical damage would not last longer than 3-4 days. In addition to this main finding, it was shown that storage of pineapples at 20 °C contributed to a substantial increase of fructose and glucose at day 9 through an inversion of sucrose. This would probably improve the taste through enhanced sweetness, but the increase of glucose and fructose will also enhance the Maillard reaction during and after pasteurisation.

Pasteurisation is widely used in juice production. Yet, few studies have investigated the effect of pasteurisation on the quality of pineapple juice (Chapter 4). In literature, large variations in the composition of pineapple juice are described. For instance, the variation in vitamin C is reported to range from 9 mg/100 mL to 94 mg/100 mL. As far as heat treatment is concerned, high temperatures in the range of 90 °C for 3 min to 99 °C for 17 min caused a loss of vitamin C from 38 to 94 %, respectively. To date, only one study investigated the effect of pasteurisation on the nonenzymatic browning (Maillard reaction) of pineapple juice. Because the technique (spectrophotometric method) applied to measure hydroxymethylfurfural (HMF) in the pasteurised pineapple juice is not the most accurate one, the determination of HMF in the pasteurised pineapple juice has been investigated in chapter

5. In addition, due to insufficient proof that pasteurisation has a negative effect on the pineapple juice quality as demonstrated in other juices (Chapter 4), the effect of pasteurisation on the microbiological (mainly yeasts), physicochemical (pH, degree Brix, organic acids, sugars content) and nutritional (vitamin C) quality was investigated in the range of 55 °C to 95 °C. It was found that yeast inactivation in pineapple juice could be described by the Weibull model. The desired 6 log reduction was achieved at 65 °C for 2 min. This result proved that pineapple juice does not need to be pasteurised at a high temperature (85 °C - 20 min) as it is generally applied in Benin and other countries to ensure juice safety. While not expected, vitamin C, the most important nutritional compound in pineapple juice, proved to be stable under the heat treatments investigated in this research. Actually, the degradation rate of vitamin C was below 20 %. Because of this stability, it was not possible to do a kinetic analysis. The physicochemical attributes of pineapple juice, such as pH, degree Brix, organic acid content, were not affected by the pasteurisation treatment. However, at 95 °C, a decrease of sucrose and a simultaneous increase of fructose and glucose contents was noticed, which will probably increase the sweetness of the juice but at the same time favour the Maillard reaction. The fact that HMF was detected in pineapple juice after 30 min at 95 °C, illustrates that the Maillard reaction can affect pineapple juice quality at higher temperatures and longer heat treatments (Chapter 5). Ultimately, pineapple juice should be pasteurised for 2 min at 65 °C to preserve its nutritional (vitamin C) and sensorial quality (colour, taste).

Finally, all findings were integrated in chapter 6 and were discussed from an integrative perspective. The integration of food technology and marketing research in one thesis was highlighted. The thesis has implications for further developing the industry. Currently, the pineapple juice industry is segmented because juice manufacturers differ in many ways. They are living in different locations, have different financial capabilities, different knowledge about juice processing techniques and as a result, they produce pasteurised pineapple juice that is variable in quality. In order to improve their pineapple juice quality and to increase their market access, juice manufacturers can be trained on better pineapple sourcing and pasteurisation techniques. Working more closely together, they can produce products at comparable quality levels using their own equipment. This pineapple juice can be branded under the same name and be sold to different markets. Juice manufacturers who are not willing to collaborate that way can continue to produce and improve their pineapple juice quality by taking the recommendations from this thesis into account.

SAMENVATTING

Dit onderzoek is het resultaat van het interdisciplinaire project 'Co-Innovation for Quality in African Food Chains' (CoQA). Het doel van dit onderzoek was het verbeteren van de kwaliteit van gepasteuriseerd ananassap waarbij rekening gehouden wordt met de kenmerken van het huidige Beninese ananas marketingsysteem. Om dit doel te bereiken is er een combinatie van marketing en levensmiddelentechnologisch onderzoek uitgevoerd om het functioneren van het marketingsysteem te begrijpen, de mogelijkheden op de markt die de prestatie van dit systeem kunnen verbeteren te evalueren en de pasteurisatie-technologie van het ananassap te optimaliseren. Hiervoor werden de volgende doelstellingen opgesteld: (i) het evalueren van de reeds gemaakte aanpassingen in het Beninese ananas marketingsysteem voor de introductie van gepasteuriseerd ananassap; (ii) het beoordelen in hoeverre beschadigde ananassen (wat een lager kwaliteitsniveau kan betekenen) gebruikt kunnen worden voor het produceren van ananassap; (iii) een overzicht maken van de actuele technologie op het gebied van ananassap-productie en de effecten daarvan op de kwaliteit van het sap en (iv) het evalueren van het effect van pasteurisatie op de microbiologische en fysisch-chemische kwaliteit en de voedingswaarde van het ananassap.

In hoofdstuk 2 worden de aanpassingen van het marketingsysteem van de Beninese ananassen op de ananassap besproken. In hoofdstuk 2 worden aanpassingen besproken in het Beninese ananas marketingsysteem die een effect kunnen hebben op de kwaliteit van ananassap zoals gepercipieerd door ananassap producenten. Een conjoint analyse is ontworpen en uitgevoerd om vast te stellen wat de preferenties zijn van de groothandelaren van ananas (d.w.z. handelaren die niet direct aan de consument verkopen), de ananas-verkopers (handelaren die de ananassen wél direct aan de consument verkopen) en de producenten van het ananassap. In dit onderzoek werden de preferenties van de hiervoor genoemde partijen gemeten en vergeleken, en werd onderzocht of groothandelaren in hun werkzaamheden rekening hielden met de voorkeuren van de sapproducenten.

Onze bevindingen laten zien dat de groothandelaren de grootste leveranciers zijn aan zowel de ananas-verkopers als de sapproducenten. De preferenties van deze twee afnemers verschillen echter van elkaar. De sapproducenten willen namelijk grote ananassen van de variëteit 'Kona Sugarloaf en ze geloven dat mechanisch beschadigde ananassen alsnog gebruikt kunnen worden voor de productie van gepasteuriseerd sap. Dit levert de

groothandelaren de mogelijkheid om de ananassen die niet gewild zijn door de ananas-verkopers alsnog te kunnen verkopen. De resultaten geven echter aan dat de groothandelaren zich niet bezighouden met het specifiek sorteren en rangschikken van de ananassen om aan de voorkeuren van de sapproducenten tegemoet te komen.

In de betreffende literatuur kijkt men vaak alleen naar transactie kosten voor wat betreft de aanpak van het marketingsysteem. In dit hoofdstuk zijn ook andere factoren meegenomen, zoals kennis, culturele normen en gewoonten die invloed hebben op de perceptie van marktmogelijkheden en de bereid- en bekwaamheid om hiervan gebruik te maken. Deze factoren spelen een rol in het gebrek aan responsiviteit/reactie van de groothandelaren en dit veroorzaakt weer het gebrek van aanpassingen van het marketingsysteem. Uit de resultaten is gebleken dat, in een ontwikkelingscontext, de aanpassingen van het marketingsysteem aan een ontwikkelingsinterventie gemanaged moeten worden om deze interventies een bredere invloed te laten hebben dan alleen voor de de primaire doelgroepen. De resultaten laten zien dat het nuttig kan zijn om verder te kijken dan alleen naar de primaire doelgroepen in een bestaand marketingsysteem als men de bedoeling heeft een marketingsysteem zich verder te laten ontwikkelen. Met andere woorden: aanvullende interventies moeten zich ook richten op andere betrokken partijen in het marketingsysteem dan de primaire doelgroep.

Aangezien de sapproducenten mechanisch beschadigde ananassen bruikbaar beschouwden als grondstof voor ananassap, werd het gebruik van beschadigde ananassen voor sap onderzocht in hoofdstuk 3. Er werden experimenten opgezet om mechanische beschadigingen na te bootsen (d.m.v. inkepingen en kneuzingen). Mechanisch beschadigde ananassen die tot 9 dagen waren bewaard veroorzaakten geen nadelige effecten op de fysisch-chemische kenmerken (te weten pH, totaal gehalte aan vaste stof, suikers) en vitamine C gehalte van het verse ananassap (hoofdstuk 3). Dit suggereert dat ananassen met dergelijke mechanische beschadigingen geschikt zijn voor de productie van gepasteuriseerd ananassap en dat de voorkeur van de sapproducenten (die hoger was dan die van de groothandelaren en de ananas-verkopers) voor beschadigde ananassen terecht is. Er moet wel rekening gehouden worden met de opslagtemperatuur van de ananassen. In de huidige situatie in Benin, waar de gemiddelde buitentemperatuur 30 °C is, zullen ananassen met beschadigingen niet langer meegaan dan 3-4 dagen. Daarnaast werd er in het onderzoek gevonden dat een opslagtemperatuur van 20 °C bijdraagt aan een substantiële toename van fructose en glucose door inversie van sucrose na negen dagen opslag. Dit zou mogelijk de smaak verbeteren doordat het ananassap zoeter wordt, maar de toename in glucose en fructose kan ook leiden tot meer Maillard reacties tijdens en na de pasteurisatie met gevolgen voor smaak- en kleurafwijkingen.

Pasteurisatie wordt veel toegepast in de productie van ananassap. Toch zijn er maar weinig wetenschappelijke studies over het effect van pasteurisatie op ananassap . Ook verschilt de samenstelling van ananassap volgens de bestaande literatuur sterk, zoals bijvoorbeeld in het gehalte vitamine C, waarbij waardes van 9 mg/100 mL tot 94 mg/100 mL zijn gepubliceerd. Ten aanzien van pasteurisatie, veroorzaken behandelingen met hoge temperaturen zoals 90 °C gedurende 3 minuten en 99 °C gedurende 17 minuten een verlies aan vitamine C van 38 tot 94%, respectievelijk. Tot nu toe heeft slechts 1 studie het effect van pasteurisatie op de niet-enzymatische bruiningsreactie (de zogenaamde Maillard reactie) in ananassap onderzocht. Aangezien de spectrofotometrische methode die werd toegepast om hydroxymethylfurfural (HMF) te meten, niet de meest nauwkeurige is, werd de methode om HMF in gepasteuriseerd ananassap te meten nader onderzocht in hoofdstuk 5. Omdat er ontoereikend bewijs was voor nadelige gevolgen van pasteurisatie op de kwaliteit van het ananassap, zoals in de literatuur gerapporteerd voor andere sappen (hoofdstuk 4), werd het effect van pasteurisatie ook onderzocht op de microbiologische kwaliteit (vooral gisten), de fysisch-chemische kwaliteit (te weten pH, °Brix-waarde, organische zuren, suiker gehaltes) en de voedingswaarde (vitamine C). Zo werd gevonden dat de inactivatie van gistcellen in ananassap beschreven kan worden met het Weibull model. De gewenste log 6 reductie in gistcellen werd bereikt met het verhitten van het ananassap tot 65 °C gedurende 2 minuten. Dit toont aan dat het niet nodig is om het sap op hogere temperaturen te pasteuriseren, zoals dat nu in de praktijk wordt gedaan wordt in Benin (bij 85 °C gedurende 20 minuten) en andere landen om de veiligheid te garanderen. Tegen de verwachtingen in, bleef het gehalte vitamine C, de nutritioneel meest belangrijke component in ananassap, vrij stabiel tijdens de pasteurisatie behandelingen in dit onderzoek; de afbraak van vitamine C bleef onder de 20 %. Door deze geringe afbraak was een diepgaande kinetische analyse van de afbraak van vitamine C niet mogelijk. De fysisch-chemische kenmerken van het ananassap, zoals de pH, °Brix-waarde en het gehalte aan organische zuren, werden niet beïnvloed door de pasteurisatie stap. Bij pasteurisatie op 95 °C werd een afname van sacharose en een gelijktijdige toename van fructose en glucose geregistreerd. Dit zal waarschijnlijk leiden tot zoeter ananassap, maar mogelijk ook tot meer Maillard reacties. Aanggezien HMF alleen gevonden werd in ananassap na een behandeling van 30 minuten bij 95 °C, zal de Maillard reactie alleen effect hebben op sapkwaliteit na behandelingen met hogere temperaturen en langere tijden. Voor een optimaal behoud van de voedingswaarde (vitamine C) en de sensorische kwaliteit (kleur en smaak) verdient het aanbeveling om de pasteurisatie uit te voeren bij 65 °C gedurende 2 minuten.

Tot slot zijn alle bevindingen samengebracht in hoofdstuk 6. Hier wordt ook teruggekomen op de integratie van levensmiddelentechnologie en marketingonderzoek in éénproefschrift. De resultaten beschreven in dit proefschrift hebben implicaties voor de verdere ontwikkeling van de industrie. Op dit moment is de ananassap-industrie gefragmenteerd omdat de sapproducenten in vele opzichten verschillen. Per locatie zijn er verschillen van inzicht, verschillen in financiële mogelijkheden en verschilt ook de kennis over de verwerkingstechnieken van het sap. Dit leidt tot productie van gepasteuriseerd ananassap met een zeer variabele kwaliteit. Om de kwaliteit van het sap te verbeteren en de markttoegang van het gepasteuriseerde ananassap te vergroten, kunnen sapproducenten getraind worden in betere pasteurisatie-technieken en ananas-inkoop. Door beter samen te werken, kunnen ze producten produceren met vergelijkbare kwaliteit terwijl ze hun eigen apparatuur blijven gebruiken. Dit ananassap kan dan onder dezelfde merknaam op verschillende markten gebracht worden. Sapproducenten die liever niet op deze manier willen samenwerken, kunnen de kwaliteit van hun sap verbeteren met de technologische aanbevelingen van dit proefschrift.

RESUME

Cette étude est le résultat du projet interdisciplinaire ''Co-Innovation for Quality in African Food Chains" (CoQA). L'objectif de cette recherche était d'améliorer la qualité du jus d'ananas pasteurisé en tenant compte des caractéristiques du système de commercialisation de l'ananas Béninois. Pour atteindre cet objectif, une combinaison de discipline, marketing et science alimentaire a été utilisée pour capturer le fonctionnement du système, afin d'évaluer les possibilités au niveau marché qui peuvent améliorer les performances du système et contribuer à l'amélioration de la technologie de pasteurisation. Les objectifs spécifiques étaient les suivants: (i) évaluer l'adaptation des systèmes de commercialisation de l'ananas Béninois après l'introduction du jus d'ananas pasteurisé; (ii) évaluer dans quelle mesure les ananas avec des dommages physiques (c'est-à-dire, ayant un faible potentiel) peuvent être utilisés pour la production du jus d'ananas; (iii) examiner l'état de l'art de la transformation sur la qualité de jus d'ananas et (iv) évaluer l'effet de la pasteurisation sur la qualité microbiologique, physico-chimique et nutritionnelle du jus d'ananas.

Le chapitre 2 de cette thèse décrit l'adaptation du système de commercialisation de l'ananas Béninois après l'introduction du jus d'ananas pasteurisé. Une expérimentation d'analyse conjointe a été conçue et mise en œuvre pour évaluer les préférences des grossistes, des détaillants d'ananas frais et des producteurs de jus d'ananas pasteurisé. L'étude à évaluer et comparer les préférences en ananas frais de ces acteurs et à chercher à savoir si les préférences des producteurs de jus ont été prises en compte par les grossistes au cours de leur activité.

Nos résultats ont révélé que les grossistes sont les principaux fournisseurs des détaillants et des producteurs de jus. Cependant, les préférences des producteurs de jus sont différents de ceux des détaillants. Plus précisément, les producteurs de jus préfèrent les gros ananas de variété "Kona Sugarloaf" et estiment que les ananas avec des dommages physiques peuvent être utilisés dans la production de jus d'ananas pasteurisé. Ceci offre aux grossistes la possibilité de commercialiser des ananas qui ne sont pas exploitables par le marché de l'ananas frais, mais il a été constaté que ces grossistes ne sont pas engagés dans des activités spécifiques de triage pour répondre aux besoins des producteurs de jus d'ananas pasteurisé.

L'approche utilisée dans ce chapitre va au-delà de la théorie des coûts de transaction, une perspective qui est fréquemment utilisé dans la littérature de développement, en ce sens

qu'il tient compte d'autres facteurs tels que la cognition, les normes et les habitudes culturelles, qui influencent la perception, la volonté et la capacité à saisir les opportunités. Sur la base de cette approche, il apparaît que l'absence d'adaptation du système est causée par le manque de réactivité des grossistes en raison de ces facteurs. Les résultats indiquent que, dans un contexte de développement, l'adaptation du système de commercialisation à une intervention de développement doit être gérée en tenant compte des effets des interventions au-delà du groupe cible initial. En d'autres termes, des interventions marketing complémentaires devraient se concentrer sur les autres acteurs du système de commercialisation.

Toutefois, les producteurs du jus d'ananas pasteurisé ont considéré les ananas avec les dommages physiques comme une matière première adéquate pour la production de jus d'ananas, la possibilité d'utiliser les ananas avec des dommages physiques pour la production de jus d'ananas a été évaluer dans le chapitre 3. Les expériences ont été conçues pour simuler différents types de dommages physiques (coupures et abrasions), ainsi les ananas endommagés ont été stockés pendant 9 jours. Ces ananas endommagés physiquement et stockées pour une durée de 9 jours à 20 °C n'ont eu aucun effet défavorable sur les caractéristiques physico-chimiques (pH, matière solubles solides, sucres) et la teneur en vitamine C du jus d'ananas frais (chapitre 3). Ceci suggère que les ananas avec ces caractéristiques sont adaptés à la production de jus d'ananas pasteurisé et que la préférence des producteurs de jus d'ananas pour des ananas présentant des dommages physiques est justifiée. Cependant, la température de stockage doit être prise en compte. Dans le contexte spécifique du Bénin, avec une température moyenne de 30 °C, l'ananas avec des dommages physiques ne se conserverait pas plus de 3-4 jours. De plus, il a été démontré que le stockage d'ananas à 20 ° C a contribué à une augmentation importante de fructose et de glucose au jour 9 due à l'inversion du saccharose. Ceci améliorerait sans doute améliorer le goût sucré, mais l'augmentation de glucose et de fructose contribuera également à la réaction de Maillard pendant et après la pasteurisation.

La pasteurisation est largement utilisée dans la production de jus. Pourtant, peu d'études ont étudié l'effet de la pasteurisation sur la qualité du jus d'ananas (chapitre 4). Dans la littérature, des variations importantes dans la composition du jus d'ananas sont décrites. Par exemple, la teneur en vitamine C varie de 9 mg/100 ml à 94 mg/100 ml. En ce qui concerne les traitements thermiques appliqués au cours de la production de jus d'ananas pasteurisé, les températures élevées de l'ordre de 90 °C pendant 3 min à 99 °C pendant 17 min ont provoqué une perte en vitamine C de 38 à 94%, respectivement. À ce jour, une seule étude a examiné l'effet de la pasteurisation sur le brunissement non enzymatique (réaction de Maillard) du jus d'ananas. Parceque la technique (méthode spectrophotométrique) appliquée pour la mesure de l'hydroxyméthylfurfural (HMF) dans le jus d'ananas pasteurisé n'est pas la plus précise, la détermination du HMF dans le jus d'ananas pasteurisé a été étudiée dans le chapitre 5. Par ailleurs, pour preuve insuffisante que la pasteurisation a un effet négatif sur la qualité du jus d'ananas comme démontré dans d'autres jus de fruits (chapitre 4), l'effet de la pasteurisation sur la qualité microbiologique (principalement des levures), physico-chimiques (pH, le degré Brix, acides organiques, la teneur en sucres) et nutritionnelle (vitamine C) a été étudié dans l'intervalle de 55 °C à 95 ° C. Il est constaté que l'inactivation des levures dans le jus d'ananas peut être décrite par le modèle de Weibull. La réduction de 6 log souhaitée a été atteinte à 65 °C après 2 min. Ce résultat prouve que le jus d'ananas n'a pas besoin d'être pasteurisé à haute température (85 °C - 20 min) comme cela se fait généralement au Bénin et dans bien d'autres pays pour assurer la sécurité sanitaire du jus. Bien que inespéré, la vitamine C, le composé nutritionnel le plus important dans le jus d'ananas, s'est avéré être stable au cours des traitements thermiques étudiés dans cette recherche. En fait, le taux de vitamine C a présenté une diminution inférieure à 20%. En raison de cette stabilité, il n'était pas possible de faire une étude cinétique. Les caractéristiques physico-chimiques du jus d'ananas, tels que le pH, le degré Brix, la teneur en acide organique, ne sont pas affectés par le traitement de pasteurisation. Cependant, à 95 °C, une baisse de saccharose et une augmentation simultanée de fructose et en glucose a été remarquée, ce qui augmentera probablement le goût sucré du jus, mais en même temps favorisera la réaction de Maillard. Le fait que l'HMF ait été détecté dans le jus d'ananas, à 95 °C après 30 min, montre que la réaction de Maillard peut affecter la qualité du jus d'ananas, à des températures plus élevées et à des temps de traitements thermiques plus longs (chapitre 5). En définitive, le jus d'ananas devrait être pasteurisée à 65 °C pendant 2 min pour préserver sa valeur nutritionnelle (vitamine C) et sa qualité sensorielle (couleur, goût).

Enfin, tous les résultats ont été intégrés dans le chapitre 6 et ont été analysés dans une perspective d'intégration. L'intégration de la technologie alimentaire et de la recherche marketing dans une thèse a été soulignée. La thèse a des implications pour développer l'industrie. Actuellement, l'industrie du jus d'ananas est segmenté parce que les producteurs de jus diffèrent à bien des égards. Ils vivent à différents endroits, ont des capacités

financières, des connaissances différentes sur les techniques de transformation et, par conséquent, ils produisent des jus d’ananas pasteurisés de qualité variable. Afin d'améliorer la qualité du jus d'ananas et d'accroître leur accès au marché, les producteurs de jus d’ananas peuvent être formés sur les ananas adéquats à la transformation et de technique de pasteurisation. De ce fait, ils peuvent produire des jus de qualité comparables utilisant leur propre équipement sans avoir à se déplacer. Une telle production de jus d'ananas peut être labellisée sous le même nom et être vendue sur des marchés extérieurs. Les producteurs de jus d’ananas qui ne sont pas disposés à collaborer de cette manière peuvent continuer à produire et à améliorer la qualité de leur jus d'ananas en tenant compte des recommandations issues de cette thèse.

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ABOUT THE AUTHOR

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Menouwesso Harold Hounhouigan was born on November 10th, 1982 in Cotonou, Republic of Benin. He attended primary and secondary school in Benin and graduated from the secondary school in Benin in 2002. He started his training at the Faculty of Agronomic Science of the University of Abomey-Calavi (FSA/UAC) in Benin and graduated in December 2007 as "Ingénieur Agronome" with a specialisation in Nutrition and Food Science. In 2008, he followed a Master degree (Diplôme d'Etudes Approfondies) at the University of Abomey-Calavi. In August 2008, he was selected to join the INREF programme called CoQA as PhD fellow. He carried out the research presented in this thesis from October 2008 to November 2013. The current dissertation reports the results of this research, which has been published in peer-reviewed journals and presented at international scientific meetings.

Menouwesso Harold Hounhouigan is interested in improving food preservation technologies taking into account the specific context of developing countries.

PUBLICATIONS

Full papers

Hounhouigan, M.H., Linnemann, A.R., Soumanou, M.M., & van Boekel, M.A.J.S. (2014). Effect of Processing on the Quality of Pineapple Juice. *Food Reviews International, 30*(2), 112-133.

Hounhouigan, M.H., Ingenbleek, P.T.M., van der Lans, I.A., van Trijp, H.C.M., & Linnemann, A.R. (2014). The Adaptability of Marketing Systems to Interventions in Developing Countries: Evidence from the Pineapple System in Benin. *Journal of Public Policy & Marketing*, *http://dx.doi.org/10.1509/jppm.13.074.*

Hounhouigan, M.H., Linnemann, A.R., Ingenbleek, P.T.M., Soumanou, M.M., van Trijp, H.C.M., & van Boekel, M.A.J.S. (2014). Effect of physical damage and storage of pineapple fruits on their suitability for juice production. *Journal of Food Quality. doi: 10.1111/jfq.12094*

Submitted article

Hounhouigan, M.H., Linnemann, A.R., Soumanou, M.M., & van Boekel, M.A.J.S. Effect of pasteurisation on the microbiological, physicochemical and nutritional quality of pineapple juice from the ‘’Kona Sugarloaf” variety.

Conference abstract

Hounhouigan, M.H., Ingenbleek, P.T.M., van der Lans, I.A., van Trijp, H.C.M., & Linnemann, A.R. The responsiveness of the Beninese Pineapple Marketing System to a Development Intervention. Results from a Conjoint Field Study. The 2013 Annual Conference of the Emerging markets Conference Board, Port Elizabeth, South-Africa, 17-20 June 2013 (Oral Presentation).

OVERVIEW OF COMPLETED TRAINING ACTIVITIES

DISCIPLINE SPECIFIC ACTIVITIES		
Courses	Graduate School/Institute	Year
Marketing PhD Series	MCB, Wageningen	2009
Reaction Kinetics in food science	VLAG, Wageningen	2012
International workshop /conferences		
Workshop of Université d'Abomey-Calavi	UAC, Abomey-Calavi	2011
Oral presentation		
Inref conference	INREF, Wageningen	2012
Oral presentation		
Marketing conference	Nelson Mandela Metropolitan	2013
Oral presentation	University	
GVal conference	Institut de Recherche pour le	2013
Oral presentation	Developpement (IRD)	
CoQA annual workshops		
First workshop	CoQA, Wageningen	2008
Second workshop	CoQA, Addis-Abeba	2009
Third workshop	CoQA, Benin	2010
Fourth workshop	CoQA, Wageningen	2011
General courses		
Searching for science on the web	WUR library, Wageningen	2008
Working with endnote	WUR library, Wageningen	
Experimental methods in social science and interdisciplinary research	Mansholt graduate school, Wageningen	2009
Presentation skills	CENTA, Wageningen	2009
Techniques for writing and presenting a scientific paper	WGS, Wageningen	2009
PhD competence assessment	WGS, Wageningen	2010
Communication in interdisciplinary research	WGS, Wageningen	2010
Philosophy and Ethics of food science and technology	VLAG, Wageningen	2009
Reviewing a scientific paper	Wageningen graduate school, Wageningen	2012

Optional courses and activities		
Preparation, submission and approval of research proposals	VLAG, Wageningen	2008-2009
Participating in PhD excursion to Australia	FQD, Wageningen	2010
Participating in PhD excursion to England	FQD, Wageningen	2012

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