Controlling Post-Harvest Losses of Yam (*Dioscorea spp.*) by Application of Gibberellic Acid

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Table of contents

Acknowledgements i
Table of contents iii
Abstract vii
Résumé viii
Zusammenfassung x

1 Introduction and Aim of Project .................................................. 1

2 Literature Review ........................................................................... 3

2 - 1 Yam as an economically important food crop 3
   Taxonomy and plant characteristics 3
   Consumption 4
   Economic yam network 5

2 - 2 Storage behaviour of yam 5
   Physiology - respiration and evaporation 6
   Physiology - dormancy and sprouting 7
   Non-physiological losses 12

2 - 3 Control of post-harvest losses in yam 14
   Modification of storage environment 14
   Direct interventions on the tuber 16
   Interventions during growth and harvest 19

3 Environment and Methodology ...................................................... 21

3 - 1 Location 21
3 - 2 Climate 23

3 - 3 Yam tubers 26
   Choice of yam genotypes and origin of tubers 26
   Tuber segment terminology 27

3 - 4 Post-harvest treatments 28
   Phytosanitary conditioning 28
   Storage structure 28
   Post-harvest treatments 29

3 - 5 Storage and planting of seed yam tubers 30
   Field preparation and planting 31
   Crop management and harvest 31

3 - 6 Experimental trials 32

3 - 7 Measurements and statistical analysis 34
   Weighing and recording of sprouting 34
   Dry matter analysis and calculation of respiration 34
   Field measurements 35
   Statistics 36
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td><strong>Functionality of Gibberellins in Yam</strong></td>
<td>39</td>
</tr>
<tr>
<td>4 - 1</td>
<td>Chapter summary</td>
<td>39</td>
</tr>
<tr>
<td>4 - 2</td>
<td>Introduction</td>
<td>40</td>
</tr>
<tr>
<td>4 - 3</td>
<td>Results</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Effect of GA$_3$ on yam tuber respiration and evaporation</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Spatial distribution of sprouts and apical dominance</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Effect of PNC removal</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Effect of the application of GA$_3$ to different tuber parts</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Influence of the time of GA$_3$-application on post-harvest parameters of yam</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>Genotypic variability of GA$_3$ treatment</td>
<td>49</td>
</tr>
<tr>
<td>4 - 4</td>
<td>Discussion</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Effect of GA$_3$ on respiration and evaporation of yam tubers</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Sprout localisation as affected by GA$_3$.</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Site of GA$_3$ application.</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>Time of GA$_3$ application</td>
<td>54</td>
</tr>
<tr>
<td>4 - 5</td>
<td>Conclusion and outlook</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td><strong>Effect of Post-Harvest Treatments on the Performance of Seed Yam</strong></td>
<td>57</td>
</tr>
<tr>
<td>5 - 1</td>
<td>Chapter summary</td>
<td>57</td>
</tr>
<tr>
<td>5 - 2</td>
<td>Introduction</td>
<td>58</td>
</tr>
<tr>
<td>5 - 3</td>
<td>Results</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Post-harvest losses of seed yam tubers</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Characteristics of setts</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>General growth characteristics.</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Correlation of covariates and yield</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Refined analysis of yield</td>
<td>64</td>
</tr>
<tr>
<td>5 - 4</td>
<td>Discussion</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Post-harvest treatment of seed tubers</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Influence of sett characteristics on yield</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Importance of seed dressing</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Photometric evaluation of leaf apparatus</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Economic aspects</td>
<td>74</td>
</tr>
<tr>
<td>5 - 5</td>
<td>Conclusion and Outlook</td>
<td>74</td>
</tr>
<tr>
<td>6</td>
<td><strong>Improving the Application of GA$_3$ to Prolong Dormancy of Ware Yam Tubers</strong></td>
<td>77</td>
</tr>
<tr>
<td>6 - 1</td>
<td>Chapter summary</td>
<td>77</td>
</tr>
<tr>
<td>6 - 1</td>
<td>Introduction</td>
<td>78</td>
</tr>
<tr>
<td>6 - 2</td>
<td>Results</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Application of substrates</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Effect of GA$_3$ concentration</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Comparison of GA$_3$ application methods</td>
<td>79</td>
</tr>
<tr>
<td>Chapter</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>6 - 3</td>
<td><strong>Discussion</strong></td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>Improved application of GA3</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>Advantages of GA3 treatment</td>
<td>83</td>
</tr>
<tr>
<td>6 - 4</td>
<td><strong>Conclusion and outlook</strong></td>
<td>84</td>
</tr>
<tr>
<td>7</td>
<td><strong>Feasibility of GA3 Application in Farm Conditions</strong></td>
<td>87</td>
</tr>
<tr>
<td>7 - 1</td>
<td><strong>Chapter summary</strong></td>
<td>87</td>
</tr>
<tr>
<td>7 - 2</td>
<td><strong>Introduction</strong></td>
<td>88</td>
</tr>
<tr>
<td>7 - 3</td>
<td><strong>Results</strong></td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Storage characteristics</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Technical parameters of the post-harvest treatments</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Economic parameters of the post-harvest treatments</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Partial budgets</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>Characteristics of farmers</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>On-farm storage in Nigeria</td>
<td>96</td>
</tr>
<tr>
<td>7 - 1</td>
<td><strong>Discussion</strong></td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Post-harvest losses at farm level</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Economic evaluation of GA3 application in the Ivory Coast</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>Economics of storage in Nigeria</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>Risk assessment</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>Contribution of farmers to improved storage</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>Perception of improved storage by farmers</td>
<td>103</td>
</tr>
<tr>
<td>7 - 2</td>
<td><strong>Conclusion and recommendations</strong></td>
<td>103</td>
</tr>
<tr>
<td>8</td>
<td><strong>References</strong></td>
<td>107</td>
</tr>
<tr>
<td>9</td>
<td><strong>Curriculum Vitae</strong></td>
<td>121</td>
</tr>
</tbody>
</table>
Abstract

Yam (Dioscorea spp.) plays a central role in the daily diet and the agricultural system of roughly 200 million people in West Africa. In spite of decreasing yields and competition from cheaper staples, a year round supply in urban markets is highly desirable and profitable for producers and traders, because yam is deeply rooted in the consumers' culture. This implies long storage periods, because the yam is an annual crop which can only be harvested during approximately seven months of the year. Losses due to physiological processes, rots and pests can be considerable and constitute a major threat to the economic viability of yam storage and the food security of the population concerned.

Yam tubers are dormant after harvest and few losses occur. However, once sprouting begins, reserves are rapidly depleted as respiration increases and a large, inedible sprout is formed. Quality changes may also occur for both major species of the Ivory Coast, i.e. positively for D. alata and negatively for D. cayenensis-rotundata. The application of Gibberellic Acid (GA3) to yam tubers of D. alata and D. cayenensis-rotundata has been shown to efficiently reduce post-harvest losses due to a prolongation of dormancy. This technique is not yet in use, possibly due to the limited feasibility and economic viability of the current application method, the dipping of yam tuber heads in a solution of GA3.

In order to improve the application of GA3 to yam, storage experiments were carried out on-station and on-farm in the Ivory Coast from 1999 to 2001. The two late harvest genotypes Krenglé (D. cayenensis-rotundata) and Bètè bètè (D. alata) were used.

GA3 decreases losses in a threefold way: Firstly, due to the prolongation of dormancy nutrients and water are transferred into the sprout later. Secondly, the respiration is decreased during the sprouting phase from 0.4g kg⁻¹ d⁻¹ for untreated tubers to 0.2g kg⁻¹ d⁻¹. Thirdly, the evaporation of water is reduced from 1.5 to 1.1g kg⁻¹ d⁻¹.

For D. alata, an application of GA3 is only efficient immediately after harvesting. A late treatment does not efficiently reduce storage losses. For D. cayenensis-rotundata, a treatment at harvest time is most efficient, however, also a single treatment later on during dormancy reduces post-harvest losses considerably.

GA3 acts systemically. Although applied only to the tuber part where sprouting naturally begins, i.e. at the tuber head, it changes the timing and localisation of sprouting of the entire tuber. Specifically, it leads to the formation of multiple sprouts on the whole tuber of D. cayenensis-rotundata in contrast to untreated tubers which sprout preferentially at the tuber head.

For planting, yam seed tubers are cut into segments, called setts, of the desired size along the apical-basal tuber axis. Plants produced by GA3-treated seed tubers had a more homogeneous emergence and yield as shown in a two year field trial. It was established that, generally, setts which carried a sprout at planting emerged quicker and had a higher yield. Furthermore, a general yield gradient along the longitudinal tuber axis was confirmed, leading to highest yields from apical setts. Setts cut from middle
Résumé

L’igname (*Dioscorea spp.*) est une denrée importante et joue un rôle central dans le système agricole d’environ 200 millions de gens en Afrique de l’Ouest. Malgré une productivité en baisse et une concurrence d’autres aliments, l’approvisionnement des marchés urbains pendant toute l’année est hautement désirable autant pour les producteurs que les commerçants. Cela serait lié au fait que l’igname soit profondément enracinée dans les habitudes alimentaires de certains consommateurs. L’approvisionnement annuel nécessite une durée de stockage longue, parce que l’igname ne peut être récoltée que pendant sept mois. Les pertes occasionnées par les phénomènes physiologiques, les pourritures et les ravageurs peuvent être importantes...
et constituent un risque majeur pour la rentabilité économique du stockage d'igname et pour la sécurité alimentaire des populations concernées.

Les tubercules d'igname sont dormants après la récolte et peu de pertes sont observées. Cependant, quand la germination apparaît, les réserves sont rapidement épuisées à cause de la respiration élevée et de la formation de germes non comestible. Des changements de qualité sont aussi observés pour les deux principaux espèces de la Côte d'Ivoire. Pendant que la qualité culinaire de *D. cayenensis-rotundata* s'abaisse après la levée de la dormance, celle de *D. alata* s'améliore. L'application de l'acide gibbérellique (GA3) aux tubercules d'igname diminue efficacement les pertes post-récolte grâce au prolongement de la dormance provoqué par ce phytohormone. Jusqu'à présent, cette technique n'est pas encore utilisée, probablement parce que la méthode actuelle qui consiste à tremper la partie apicale des tubercules dans une solution de GA3, est difficilement faisable et économiquement peu rentable.


Le GA3 diminue les pertes à trois niveaux: Premièrement, en provoquant la prolongation de la dormance, les éléments nutritifs et l'eau sont transférés plus tard des tubercules au germe. Deuxièmement, la respiration pendant la phase de germination est diminuée de 0.4 à 0,2g kg⁻¹ j⁻¹. Troisièmement, l'évaporation de l'eau est diminué de 1.5 à 1.1g kg⁻¹ j⁻¹.

Pour *D. alata*, l'application du GA3 doit se faire immédiatement à la récolte. Une application plus tard ne diminue plus les pertes post-récoltes. Par contre, *D. cayenensis-rotundata* peut être traité pendant toute la phase dormante, même si un traitement à la récolte est le plus efficace.

Le GA3 agit systémiquement chez l'igname. Une application du GA3 à la partie apicale (la "tête" de l'igname), où commence normalement la germination, apporte un changement de la période et du lieu d'apparition des germes sur le tubercule entier. Spécifiquement, le GA3 provoque la formation de plusieurs germes sur tout le tubercule contrairement aux tubercules non-traités qui germent préférentiellement sur la tête.

Pour la plantation, l'igname est coupé dans des morceaux, appelés boutures. Les plantes produits par des tubercules traités au GA3 ont montré une levée et un rendement plus homogène au cours de deux années d'essais. Il a été établi que des boutures ayant déjà un germe à la date de plantation levaien plus rapidement et avaient un rendement plus élevé. En plus, un gradient de rendement était confirmé à l'intérieur du tubercule. Les boutures des parties apicales avaient un plus haut rendement que ceux des parties inférieures. Compte tenu du fait que le GA3 augmentait le nombre de germes sur les parties basses du tubercule, mais en limitait sur les parties apicales, les boutures issue des semencaux traités avaient des rendements plus homogènes. Cet effet pourrait réduire l'impact négatif de la levée asynchrone bien connue dans les champs
d’igname. Le traitement au GA3 des semenceaux réduisait légèrement le nombre des tubercules par plante, et par conséquent, le poids moyen des tubercules était plus élevé.

En ce qui concerne le stockage des gros tubercules destinés à la consommation, des nouvelles méthodes d’application du GA3 étaient développées. Elles visaient à améliorer et remplacer le trempage déjà connu. Trois nouvelles méthodes étaient testées pendant 3 ans de recherche sur station et des concentrations optimales étaient déterminées. Du GA3 dissous dans la terre (25mg kg⁻¹) ou dans l’amidon gélatinisé (860mg kg⁻¹) et appliqué sur la partie apicale du tubercule montraient des effets comparables à ceux observés avec le trempage (150mg kg⁻¹ pour 1 heure). La pâte à terre, l’amidon gélatinisé et le trempage diminuaient de façon significative les pertes post-récoltes de 9 à 15% pour D. cayenensis-rotundata. Même si le trempage réduisait les pertes plus efficacement, les deux autres méthodes utilisaient moins de GA3. En plus, ils étaient préparées et appliquées facilement. La pâte à terre était plus efficace si le traitement était répété avant la levée de la dormance. La troisième méthode, la pulvérisation des tubercules au GA3 (150mg kg⁻¹) n’était pas efficace. De même, le GA3 était sensiblement moins efficace sur D. alata. A cause de cette faible efficacité et la tendance à maintenir une qualité alimentaire peu appréciée pour cette espèce, le traitement de D. alata au GA3 n’est pas à recommander.

Afin d’obtenir des informations précises sur l’économie et la faisabilité des nouvelles méthodes d’application en milieu paysan, un essai on-farm était fait avec le Krengl chez 18 producteurs. Le GA3 dans la pâte à terre et dans l’amidon gélatinisé étaient aussi supérieur au trempage dans les conditions paysannes grâce à plusieurs facteurs. Ces applications étaient plus rapides (7 à 8h t⁻¹ contre 14h t⁻¹) et utilisaient 50 à 80% moins de GA3. En même temps, une diminution des pertes d’environ 10% était maintenue. Le dégermage manuel était inclus dans l’essai. Même s’il diminuait des pertes seulement de 4%, ce traitement constituait une alternative économiquement viable au traitement chimique. Le stockage prolongé des tubercules d’igname était financièrement profitable et encore plus, en utilisant les méthodes améliorées.

Zusammenfassung


GA₃ vermindert den Nach绩teverlust in dreifacher Weise: Erstens werden Nährstoffe und Wasser später in den Spross verlagert, da die Dormanz verlängert wird. Zweitens ist die Atmungsaktivität während der Keimphase reduziert. Statt 0.4g werden nur 0.2g kg⁻¹ Trockenmasse pro Tag veratmet. Drittens wird die Verdampfung von Wasser von 1.5g auf 1.1g kg⁻¹ pro Tag vermindert.


GA₃ wirkt systemisch. Auch wenn GA₃ nur apikal angewendet wird, wo die Knolle normalerweise austreibt, wird die zeitliche Abstimmung sowie der Keimort auf der ganzen Knolle verändert. Im Speziellen führt die GA₃-Behandlung dazu, dass basale Knollenteile deutlich mehr Keime bilden.

Um das bestehende Tauchverfahren zu verbessern und zu ersetzen wurden neue Anwendungsmethoden entwickelt. Während 3 Jahren wurden drei Verfahren zur Behandlung von grösseren Yamsknollen, die dem Verzehr dienen, getestet und die optimalen Konzentrationen bestimmt. GA$_3$ in feuchter Obererde (25mg kg$^{-1}$) sowie in gelatinisierter Maniokstärke (860mg kg$^{-1}$) waren vergleichbar mit dem Tauchverfahren (150mg kg$^{-1}$ für 1h). Alle drei Behandlungen reduzierten konsequent die Nachernteverluste um 9 bis 15% in *D. cayenensis-rotundata*. Obwohl das Tauchverfahren effizienter war, konnten die beiden Alternativen mit weniger GA$_3$ und schneller angewandt werden. Die Anwendung von GA$_3$-haltiger feuchter Erde verminderte die Nachernteverluste am besten, wenn sie vor Ende der Dormanz wiederholt wurde. Die dritte neue Anwendungsweise, das Besprühen der Knollen mit einer GA$_3$-Lösung (150mg kg$^{-1}$) war nicht wirksam. Auch bei *D. alata* reduzierte die GA$_3$-Behandlung allgemein weniger die Nachernteverluste. Da mit der Behandlung bei dieser Sorte ein Qualitätsverlust einhergeht, wird die Verwendung von GA$_3$ bei *D. alata* nicht empfohlen.

Um die Wirtschaftlichkeit und Durchführbarkeit der GA$_3$-Behandlung unter bäuerlichen Verhältnissen zu testen, wurde ein on-farm Versuch mit 9t Krenglè bei 18 Bauern durchgeführt. Die Behandlungen, die feuchte Erde oder gelatinisierte Stärke verwenden, waren dem Tauchverfahren überlegen, schneller behandelt (7 bis 8h t$^{-1}$ vs. 14h t$^{-1}$) und 50 bis 80% weniger GA$_3$ verwendet wurde. Gleichzeitig wurde eine Verminderung der Nachernteverluste um 10% erzielt. Die manuelle Entkeimung der Knollen wurde ebenfalls in den Versuch einbezogen. Obwohl die Verluste nur um 4% gesenkt werden konnten, ist diese Behandlung eine wirtschaftlich interessante Alternative zu einer chemischen Behandlung. Die Lagerung von Yams von Januar bis Anfang Juni war gewinnbringend. Finanziell am vorteilhaftesten waren die verbesserten Behandlungen mit GA$_3$. 
In yam (*Dioscorea spp.*), the lack of adoption of improved techniques is not restricted to the diverse array of improved storage methods, but extends to cultivation techniques, genetically improved material, and system management. The yields of all African food crops are stable, if at best slightly rising. This explains to some extent the sadly unchanging state of the African food crisis. It is said to have arisen due to unfavourable environments (drought and political instability) as well as neglect by governments (lacking research and extension) (Okoli & Onwueme 1987). Other, more ethnological reasons may be found in Signer's book (1999). It is not within the scope of this thesis to offer ready-made solutions for problems related to the African food crisis, but the settings must be respected. Yam is a major food crop and its availability has an impact on the quality of life and livelihood of most people in West Africa. Storage drastically influences the availability of yam in the period from January to August. Improved storage is believed to alleviate the scarcity of yam during this period, increasing food security and the revenue of the farmers.

It has been shown on the example of GA\textsubscript{3} application to yam tubers that the rate of adoption of improved post-harvest techniques is positively influenced by their performance, and negatively by the resources needed to implement them (Daouda *et al.* 2002). The technique of GA\textsubscript{3} application significantly reduces post-harvest losses, and yet adoption has not happened. Since food is scarce at the times concerned by extended yam storage, and since yam is valuable and frequently plays the role of a cash-crop, the need for such improved storage methods can be assumed. It appears, therefore, that the cost-effectiveness is still insufficient to foster adoption.

Another reason behind the low adoption rate of improved storage techniques may be the lack of awareness. Although farmers are aware of the problem of post-harvest losses,
they do not know the existence of, let alone the technical details and economic benefits of an improved storage technique. In the case of GA3 application to yam tubers, the unavailability of GA3 on African markets further complicates matters. Without the resolution of these key elements, i.e. the availability of an economically viable technique and of GA3 as well as the farmers' knowledge about this technology, widespread adoption will not occur.

From this research the following input may be offered: the technology can be improved and shown to be economically viable and, within limits, it may be shown to be acceptable for farmers to use.

Therefore, this thesis will aim as a first step to understand more about the technical and biological parameters that influence the effect of GA3 application to yam tubers. It must be known which factors affect its efficiency, its reliability and its feasibility. Where are the biological limits? With this knowledge, improved methods for the application of GA3 will be designed. When their reliability and efficiency has been proven and their precise formulation is known, their economic viability must be forecasted. To do this, and in order to assess feasibility, it will be aimed to test-run these methods using real quantities, the farmers' tubers and storage structures, and the real economy of yam sale. Such a simulation of the transfer of technology where the researcher reduces his role to an observer is the final step in development as far as agronomic engineering is concerned.

Yam tubers are a common product for consumption, at the same time they serve as seed for the next generation. The cost of seed yam is a major constraint of yam production, and seed tuber quality is perceived as highly determinant for the yield. Little precise information is, however, available. It was aimed to gain more insight into the way the biological parameters of the seed yam influence the performance of the yam plant. The effect of a GA3 treatment of seed tubers on the growth parameters and yield issue of these tubers was also studied.

This thesis may be considered as one in a group of three that concentrate on different aspects of yam storage with the help of GA3 in the Ivory Coast. The evolution of quality during the yam's storage life, specifically as affected by GA3 application, is the topic of Nindjin's thesis (2002). An economic model of the yam sale over time and market dynamics of yam are treated in Dao's thesis (2003). Furthermore, this project is embedded in an INCO-DEV project dealing uniquely with yam post-harvest aspects in West Africa.
2 Literature Review

Yam has earned little attention from scientific research compared to other food crops. Nevertheless, a plethora of information is available on agriculture, storage, nutrition, economics and ethnology of yam. For reviews on the cultivation of yam, the reader is referred to the excellent books by Degras (1993) or Miège and Lyonga (1982). Yam storage has been reviewed by Osagie (1992). Recent revelations and prospects for yam research may be found in Orkwor et al. (1998) and Berthaud et al. (1997).

2 - 1 Yam as an economically important food crop

Taxonomy and plant characteristics. Yam is a tuber forming and liana type plant that is generally classified in the order of Dioscoreales, fam. Dioscoreaceae. Although generally attributed to the Monocotyledons, it shows features of some dicotyledonous plants. The 200 odd species of the genus Dioscorea are distributed mainly in the tropics with a few representatives in the warmer temperate zones (taxonomy in Ayensu 1972). Only few species are cultivated, the most widespread being Dioscorea alata (L.), Dioscorea rotundata, (Poir.) and Dioscorea cayenensis (Lam.). The latter two are often referred to as the Dioscorea cayenensis-rotundata complex, because the species separation could not be upheld with the molecular and morphological data at hand (Terauchi et al. 1993). This species complex contains D. rotundata nomen nudum and D. rotundata var. x 'cayenensis'. Throughout this thesis, D. cayenensis-rotundata will be used to designate either species.

The leafed and sometimes spiny vine of the yam plant climbs 6 to 12m high in order to penetrate the canopy of a forest. It branches there to form its main aerial apparatus and flowers. Under the ground, yam possess a shallow (<1m) fibrous root system which is
concentrated within the top 30cm of the soil (Onwueme 1978). When the plant is
grown from a true seed, one or several tubers are incepted, which originate from the
hypocotyl and which generally penetrate deep into the soil (Lawton & Lawton 1969). A
meristematic and vascular continuity between stem, roots and tuber is given by a
structure termed "primary nodal complex" (PNC) (Wickham et al. 1981, Wilson et al.
1998). Preformed buds are generally found on the PNC of a mature tuber, however,
the periderm of the whole tuber surface is capable of the neoformation of a bud.

Consumption. The yam tuber is rich in starch and serves as a staple food. 90% of the
approximately 30 million metric tons of yam produced annually are grown in the yam
belt in West Africa (FAO 2002). It stretches from the Cameroon mountains to the
Bandama river in the Ivory Coast, and over wide areas, especially in the East, the
D. rotundata is by far the most common species encountered. In the Ivory Coast,
however, the Asiatic species D. alata makes up two thirds of the production (Dumont
1998). This species encompasses the common, late harvest genotypes Florido and Bètè
bètè. Within D. cayenensis-rotundata, the term "Lokpa" is often used for the large group
of genotypes that are harvested twice (mainly Kponan, Assawa, etc.), while the Krenglè
group (cv. Krenglè, Gnan, Djaté) are generally harvested once. When a double harvest
is performed, non mature tubers are dug out at approximately 5 months after planting.
Since the rest of the plant is left unharmed, a second tuber is formed subsequently,
normally with a different, more lobed shape. It is harvested at the same time as single
harvest genotypes and serves almost exclusively as planting material. Most farmers
grow a multitude of genotypes to satisfy both culinary preferences and seasonal needs.
A thorough classification of Ivorian yam genotypes can be found in Miège (1952)
and Hamon & Toure (1990).

Per capita consumption in the yam belt is estimated between half and one kilogram of
yam daily (Ayensu & Coursey 1972). For the Ivory Coast, about 200kg head\(^{-1}\) year\(^{-1}\) is
produced (FAO 2002). One should, however, bear in mind that roughly 50% of the
yam is not consumed but serves as seed yam, or is lost. About 300g seems available per
Ivorian per day, and considerably more if the non yam-eating ethnic groups are
excluded from the calculation. At these daily intakes, yam contributes to the
consumers' needs of proteins and vitamin C (Coursey & Aidoo 1966, Osuji et al. 1986).
The increased role for yams in supplying needed carbohydrates to alleviate the African
food crisis has been strained (Okoli & Onwueme 1987). The ethnocentric attachment
to the yam cultivation has been mentioned repeatedly (Coursey & Coursey 1971,
Onwueme 1978, Cooke et al. 1988). This is not surprising, because yam is believed to
have been domesticated in 3 000 B.C. (in Orkwor et al. (1998), p1). The cultural
importance may explain the variety of yam based foods and festivals, but it mainly says
that yam is important for the society.

In the Ivory Coast, yam is consumed in many different forms. Pounded after cooking,
"foutou" is practically a national meal. But also simply cooked, or cooked in sauce,
roasted, and fried in oil are widespread preparations of yam. Ivorians have a good sense
of culinary quality of yam, a fact that renders the introduction of new genotypes, new
cultivation or storage methods difficult (Dumont et al. 1997a, Nindjin 2002).
Economic yam network. The low percentage of *D. alata* commercialised in the Ivory Coast (Touré *et al.* 2002) suggests that most of the yam is consumed near the production site. Nevertheless, the supply of urban markets leads to a noticeable long distance transport and sale of yam. According to the availability of yam the year through, the price fluctuates strongly, depending on the genotype. From July until January, double harvest genotypes of high quality are sold at high prices in all major towns. From January to May, the primary genotype Krenglè of *D. cayenensis-rotundata* is prominent on the markets, together with *D. alata*, which fills the gap until the new season in July (Touré *et al.* 2002). Yam marketing is highly stratified. Buyers, wholesalers, semi wholesalers and retail sellers are specialised and tend to protect their market (source: board of economists, INCO-YAM annual meeting 2001, Ibadan, Nigeria).

The risk of storage remains mainly in the hands of the farmer, as sellers tend to make a profit from high turnover rates rather than long term speculations on price development (Dao 2003). Research has, however, shown, that traders experience heavier marketing losses (17% in Oyo State, Nigeria) compared to farmers (9%) (Singh & Aromolaran 1985). Presumably, the farmer has to put up with the physiological and phytosanitary risk of storage, while traders absorb the risk during transport and handling. The latter two have been shown to drastically lower the number of saleable tubers (Thompson 1972, Bancroft *et al.* 1998).

In Nigeria, the overall expenditure elasticity of demand for yam was greater than one. Therefore, increased urban income is likely to boost the sale of yam without affecting the prices. Also, yam offer was shown to have a positive price elasticity. Improved production or storage methods which increase the supply of yam will lower the price and increase quantities at low expenditure levels (Nweke *et al.* 1992). This behaviour of consumers is likely to be linked to the cultural attachment: yam is a prestigious and first-class staple food.

2 - 2 Storage behaviour of yam

The vegetation period of yam is generally shorter than 12 months. Although harvesting may be staggered, today no off-season production is possible, which could supply yam when it is scarcest. The production of yam is, therefore, accompanied by short and long term yam storage. Whereas tubers would naturally stay in the soil to overcome periods when growth is impossible, man uproots the tubers and stores them in air. Furthermore, man stores yam beyond the „natural storage time“, i.e. beyond the time when the yam plant would enter a new vegetative reproduction cycle. This has consequences for the storage of yam.

Post-harvest losses may be simply defined as ”loss of edible matter after the harvest“. This is simple to measure if whole parts of the tuber are rotten, or eaten by rats, or insects: everything is lost. Regarding physiological processes, the losses are less obvious and of a more subtle character. This will be accounted for in the relevant paragraphs.
Physiology - respiration and evaporation. The loss of dry matter (DM) and water, which is independent of pathology, has been recognised as an important factor influencing post-harvest losses of yam tubers. As any living organism the yam tuber respires and transpires. A few authors have measured respiration directly, and their results have shown that the evolution of CO₂ outlet follows a certain pattern, which is strongly related to the physiological age of the tuber. Before and right after harvest (maturity), the tubers exhibit a high respiration rate of 18 to 20mg CO₂ kg⁻¹ h⁻¹ corresponding to 0.2 - 0.58 g kg⁻¹ loss per day (Table 2 - 1). Daudet (1980) has shown that the respiration is far higher during the growth phase of the tuber (200mg CO₂ kg⁻¹ h⁻¹). The early post-harvest rates represent the general reduction of activity of the maturing tuber as growth ceases. This is also exhibited by the fact that apical tuber parts cease respiration before basal parts, where the growth is actually taking place (Passam & Noon 1977, Passam et al. 1978). A few days to weeks after harvest the respiration rate drops to a very low level of about 5mg CO₂ kg⁻¹ h⁻¹ for all tuber parts. Once sprouting has set in, high levels of 20 to 45mg CO₂ kg⁻¹ h⁻¹ were again measured, first in the apical tuber part. Passam et al. (1978) calculated the contribution of respiration to the total daily weight loss as follows: after harvest 26% (duration: 1 month), during dormancy 7% (five months), and during sprouting 35% (2 months)(see also Table 2 - 1). In combination with the total daily losses, the contribution of evaporation can be estimated. It appears constant across all periods at about 1.4 to 1.6g kg⁻¹. The loss of water seems, therefore, less affected by the physiological state of the yam tuber. It is, however, contributing far more to the daily weight loss of yam than the respiration.

Respiration and evaporation are influenced by temperature, relative humidity, ventilation, wounding, and infection by parasites. Lower temperature leads to lower respiration rates (Passam et al. 1978). At 15°C, respiration drops drastically and it even ceases at lower temperatures (Coursey et al. 1966). Wounded yam tubers lose DM and water quickly, a process which is counteracted by the suberisation of the wound (Passam et al. 1976a, Fawole & Evans 1989). Rot and nematode infection increase respiration manifoldly, either due to the respiration of the infectious organisms, or due to the defence reaction of the yam (Coursey & Russull 1969, Castognone-Sereno 1989).

**TABLE 2 - 1 Respiration rates of yam tubers after harvest, during dormancy and during sprouting.**

All values were converted to g kg⁻¹ d⁻¹ loss assuming starch as a sole substratum and the complete evaporation of the produced CO₂ and H₂O.

<table>
<thead>
<tr>
<th>Source</th>
<th>After harvest</th>
<th>Dormancy</th>
<th>Sprouting</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daudet 1980</td>
<td>0.25 - 0.57</td>
<td>0.08 - 0.16</td>
<td>0.25 - 0.33</td>
<td>D. trifida, 25°C</td>
</tr>
<tr>
<td>Passam et al. 1978</td>
<td>0.58</td>
<td>0.11</td>
<td>0.74</td>
<td>D. rotundata, 25°C</td>
</tr>
<tr>
<td>Coursey &amp; Russull 1969</td>
<td>0.20 - 0.49</td>
<td>0.13 - 0.18</td>
<td>0.20 - 0.69</td>
<td>D. rotundata, 25°C</td>
</tr>
<tr>
<td>Duration of phase</td>
<td>3 - 8 weeks</td>
<td>6 - 20 weeks</td>
<td>open</td>
<td></td>
</tr>
</tbody>
</table>
Tubers of *D. cayenensis-rotundata* which are harvested immature (first harvest) have higher losses (Olympio *et al.* 1983). They are more prone to rot and have higher evaporation than mature tubers, because the epidermis is not fully formed yet. For *D. alata*, the harvest date did not significantly influence the storage losses, except that a late harvest led to a better conservation of DM and a higher loss of water (Dumont 1994). Dumont *et al.* (1997b) recognised a complex relationship between mineral fertilisation and storability. Chemical fertilisation (75N, 54P₂O₅, 94K₂O h⁻¹) increased losses by 6% in *D. cayenensis-rotundata* and 1% in *D. alata* after six months of storage (Dumont 1997b). Other results suggested that N fertilisation inconsistently and only slightly shortened dormancy (by 1 week), while K fertilisation slightly prolonged it (Kpeglo *et al.* 1981). How fertilisation is linked to the yam tuber's physiology and associated post-harvest losses is, however, not known.

**Physiology - dormancy and sprouting.** The yam tuber has a distinct physiological evolution from its inception to its decay, characterised by a long phase of enlargement and tuber bulking, the detachment from the mother plant, a subsequent dormant phase and finally the sprouting phase leading to the senescence of the tuber. However, little is known about the different physiological control mechanisms that are dominant during these phases. With respect to storage, the dormant and the subsequent sprouting phase are critical and the current knowledge will be exposed below.

Apart from increased respiration, sprouting also leads to the growth of an inedible sprout. Its mass accounts for 8 to 12% of the initial tuber weight in *D. cayenensis-rotundata*, or 3 to 9% in *D. alata* after 6.5 months of storage (Girardin 1996). A green sprout, especially a thoroughly lignified one as in *D. cayenensis-rotundata*, has a quite different composition to the tuber. All its "ingredients" must, however, originate from the tuber. A sprouting tuber may not look decayed, but it must have lost much of its nutritional value. Over 6 months of storage, 15% of the protein N, and 50% of the non protein N was lost in *D. cayenensis-rotundata*. Similar values were attained by *D. alata* after 12 months of storage (Osuji & Ory 1986). However, the profile of the amino acids (and fatty acids) was found to vary little over storage time (Kouassi *et al.* 1988). It has also been shown that the starch content decreases drastically during storage. For *D. cayenensis-rotundata*, this drop was sharply related to the event of sprouting. The starch content dropped from 700g kg⁻¹ (dry base) to 450 to 500g kg⁻¹ once dormancy is broken (Hariprakash & Nambisan 1996). *D. alata* shows a more linear loss of starch, and the magnitude of loss was less pronounced. 8 to 13% of the starch was lost after 5 months of storage of *D. alata* (Ravindran & Wanasundera 1992, Girardin 1996). Some of the starch is found again in form of soluble sugars, mostly sucrose (Mozie 1987a, Kouassi *et al.* 1990, Girardin 1996), which is due to the increase glycolytic enzymes upon sprouting (Ikediobi & Oti 1983, Wellington & Ahmad 1993). Fructose appears only once sprouting has set in (Mozie 1986).

The sprouting process happens as follows. In *D. alata* the inner cortex and in *D. cayenensis-rotundata* the primary thickening meristem start cell division and form a radial layer of approximately 30 cells width. At apparently unspecified loci, increased
localised cell divisions lead to the organisation of shoot apical meristems. The first foliar primordia develops into the calyptrae prior to the formation of axillary buds in the axils of the calyptrae. Meristematic activity in the region of the first node of the developing adventitious bud results in the formation of a mass of parenchyma and meristematic cells at the base of the differentiating shoot apex. These cells represent the PNC initial. Numerous tannin cells and blocks of meristematic cells develop and add to the PNC initial. The resulting protuberance is at the base of the developing adventitious bud and encased in an extension of the tuber germination meristem. In between these two meristems and connected with them lies the PNC-meristem. Its continued activity leads to the vascularisation of the PNC. Eventually, root initials are formed around the circumference of the developing PNC (adapted from Wickham et al. 1981). This clearly shows that the PNC is a "toll gate" for all exchanges between the bud, the roots, and the mother tuber. Not surprisingly, it is thought that the PNC exerts some control over the sprouting process (Wilson et al. 1998). The daughter's PNC is, however, formed well after dormancy is already broken. If any, it must be the mother tuber's PNC which influences the physiological behaviour of the tuber. This seems to be the case, as in tubers where the PNC's preformed buds grow out, further sprouting is suppressed (Wickham et al. 1981). The description of the germination process also reveals another important fact: although the whole periderm is readied for sprouting, only few sites actually do so. The localisation of these sites seems not determined by morphological features.

There is strong evidence that the timing of visible sprouting is under almost pure endogenous control. Tubers of *D. cayenensis-rotundata* which were harvested at largely different times after planting all sprouted in the same period (Okoli 1980, Passam et al. 1982a, Biegot & Touré 1983). This period of programmed and reversible inability to sprout in spite of favourable conditions is generally termed dormancy. Using the definitions given by Lang et al. (1987), the periderm of yam is in an endodontant state, i.e. the dormancy is regulated by physiological factors inside the affected structure. Strictly speaking, endodormancy was defined as being regulated by photoperiodism or chilling responses of the affected tissue itself. In the case of a yam tuber, no other structure seems to qualify for imposing dormancy on the periderm except itself. However, except for temperate species' bulbils, neither chilling nor photoperiodism has been shown to impose or release dormancy in yam. Once meristematic activity of the periderm has resumed, a bud is formed about 7 to 15 days later (Onwueme 1973). An ecodormant state may be reached. The bud then regulates its growth in accordance with the environment. Temperature dependent growth of the shoot has been shown for *D. spiculiflora*, the optimum being between 26 and 32°C (Preston and Haun, in Craufurd et al. 2001). If several buds grow simultaneously, paradormancy is imposed upon all but one. This type of dormancy involves a biochemical signal from another structure (Lang et al. 1987), and the term is also used in the context of apical dominance. The processes regulating endo-, para, or ecodormancy in yam, and their relative importance, are poorly understood (Craufurd et al. 2001).
The length of dormancy is according to above information under strong genetic control, and it may have extremely varying lengths. Borrowed from potato literature, yam dormancy should be regarded as beginning at the time of tuber initiation and ending with the active bud growth (Craufurd et al. 2001). All references available, however, define the start of dormancy as a rather arbitrary point in time, e.g. the time of harvest, or senescence of the mother plant. Counting from harvest, *D. bulbifera* and *D. dumetorum* are long dormant species (14 to 20 weeks). *D. alata*'s dormancy is 8 to 16 weeks long. *D. cayenensis-rotundata* and *D. trifida* may have a rather shorter dormancy of 2 to 4 weeks, but it may last as long as 13 to 16 weeks (p.48 in Orkwor et al. 1998). To be precise, even the termination of dormancy is mostly ill perceived, since the actual resumption of meristematic growth precedes the visible sprouting by several days. It was suggested that the epidermal cracking should be used instead of the visible sprout to determine the end of the dormancy more precisely. Similar to the tuber initiation as the start of dormancy, the time of meristematic activity, or epidermal cracking, are difficult, if not to say impossible to measure if a statistically relevant number of tubers should be observed. The currently widespread definition - starting at harvest and ending at visible sprouting - is chosen for convenience and as a compromise between feasibility and biological precision. They allow a comparison within a group of tubers without much loss of information. This terminology will be assumed throughout this thesis.

The current knowledge on yam tuber physiology suggests that at a lower level dormancy might be controlled by a family of compounds called batatasins. These phenolics (stilbenoids) were first isolated as dormancy inducing substances by Hashimoto et al. (1972) from bulbils of *Dioscorea batatas*. The application of batatasins to *D. alata* prolonged the dormancy (Ireland & Passam 1985). Since then, five main types (I to V) have been isolated from different yam species. Ireland et al. (1984) described a sharp increase of batatasins upon maturing of the tubers and a steady decline after harvest. Furthermore, it was shown that batatasins are only found in the yam's cortex (also in Hasegawa & Hashimoto 1973). Batatasins have reversible, inhibitory effects on O2-uptake in chloroplasts and mitochondria and efficiently disrupted CO2-evolution in chloroplasts (Iino et al. 1978). Other stilbenoids are known to stress a range of membrane related processes such as ATPase activity and IAA-oxidation. It seems that batatasins affect the activity of a cell, and such it was speculated that they are a suitable candidate for a metabolic inhibitor during the control of dormancy (Ireland & Passam 1984).

However, it would be speculative to attribute the regulation of dormancy to a general suppression of respiration and related processes alone. Suttle (1996) stated that severe metabolic restrictions such as deficiency of primary metabolites, or DNA template, can be outruled as dormancy provoking, because even during dormancy tubers are metabolically active and reactive to different stimuli. Interestingly, Okagami (1978) found that various inhibitors of protein and nucleic acid synthesis promoted the sprouting of half-dormant bulbils of various *Dioscoreae spp.*. This confirmed Okagami and Tanno's hypothesis (1977) which proposed the presence of a twofold sprout-
regulating system in bud-bearing bulbils of several Asian *Dioscoreae*. Based on his experiences with bulbils of *Begonia evansiana* (Okagami 1972) he suggested a sprout-promoting and a dormancy-inducing system for yam bulbils. He considered the latter to be present in the tuber body and the former in the buds. Protein inhibitors would repress the formation of the dormancy inducing protein(s) and allow the sprout promoting protein(s) to supersede. The twofold sprout regulation was also observed by Wickham *et al.* (1984a). Both systems appear to be influenced by GA₃ as illustrated in Figure 2-1.

![Figure 2-1](image)

**FIGURE 2-1** Model of the relation between sprout-promoting and sprout-inhibiting (or dormancy inducing) system and its dependency on GA₃. The upper graph is obtained by performing a subtraction of the two curves in the lower graph. (adapted from Okagami & Tanno 1977).

GA₃ prolongs the dormancy of yam tubers and it has been suggested that it depresses the respiration. GA₃ leads to an increase of batatasins and other phenolic growth inhibitors. As shown by Ireland and Passam (1984), the batatasin level was approximately 20% higher in GA₃-treated compared to untreated tubers, and this higher level was maintained throughout the storage period. Even when 50% sprouting was reached for GA₃-treated tubers, their batatasin content was still 14% higher than in untreated tubers. This fact does not only illustrate that batatasins cannot be fully responsible for the termination of dormancy, but it may also explain lower respiration rates of GA₃-treated tubers, because batatasins decrease respiration rates of mitochondria by direct action (Iino *et al.* 1978).
Among the Asian species studied, Tanno et al. (1992a, 1994, 1995) found GA4, GA9, GA12 and GA24 for the non-13-hydroxylation pathway for GAs. GA19, GA20 and GA53 were found off the early-13-hydroxylation pathway. He considered the former pathway to exceed the latter with regard to dormancy control in Dioscoreacea (Tanno 1998). So far no reports are available on the presence of different gibberellins in D. cayenensis-rotundata or D. alata and GA3 and GA7 have never been discovered in Dioscoreacea. Tanno et al. (1992b) found that GA4 was more efficient than GA3 in bulbils of D. opposita Thunb. regarding inhibition of sprouting while the promotion of shoot growth was equally affected by both gibberellins. He suggested that GA4 was largely responsible for dormancy control.

Park et al. (2001) found that the concentration of GAs decreases in yam tubers over time as does the related phenolic compound, batatasin (Ireland & Passam 1984). The initial GA concentration at harvest decreases over time until the spraying promotion exceeds the dormancy inducing principle. Sprouting then occurs and dormancy is terminated. The interdependence of batatasins and GAs has been shown clearly: an application of GA3 resulted in an increase of batatasins (mostly of batatasin I) and a prolongation of dormancy in both yam tubers and bulbils (Hasegawa & Hashimoto 1974, Ireland & Passam 1984). Both chemicals are certainly not solely responsible for dormancy control. As an example, maleic hydrazide increased dormancy without an accompanied increase of batatasins, and GA3 and batatasins applied together were not more prolonging than GA3 alone (Ireland & Passam 1984). Batatasin I seems also related to one of the two antifungal compounds in the yam peel (Ogundana et al. 1984) (the other one resembling hircinols from orchids). This feature may have coevolved, as long dormancies require good protection from rots.

As would be suspected from the process of tuber formation (detailed in Trouslot 1983) many gradients, longitudinal and radial, are known within the tuber's components. Among them several have also a time-dependent evolution, and within this evolution the end of dormancy often marks an important change. Batatasins have been mentioned already, but also glutathione, phenol oxidases, and o-diphenolase, were found to correlate very well with the onset of sprouting (Ikediobi et al. 1989, Isamah et al. 2000). The search for true regulators of sprouting has so far not yielded a clear picture, and presently the governance of this process is still poorly understood. The fact that most of these studies have been carried out across several species of Dioscoreacea certainly does not facilitate the process of understanding.

This is in contrast with the clear phenotypic picture that now exists of the regulation of the sprouting process. A phenomenon mentioned repeatedly, and well known to yam growers, is apical dominance. Lawton and Lawton (1969) have already noted that growth of a new stem from a mature tuber always takes place near the point of attachment of the tuber to its parent stem. Passam (1977) measured 90 to 100% sprouting in the apical tuber part at the breakage of dormancy. Also bulbils of D. alata exhibit this polarity (Passam et al. 1982b) and tuber roots are thicker and more numerous at the head than at the tail (Ferguson & Gumbs 1976). For cultivated species of yam, single harvest tubers are cut into setts, which, thanks to the neobudding
capacity of the peridermis, give rise to new shoots. Many reports refer to the behaviour of planted setts with respect to their origin on the tuber they were cut from. Onwueme (1973) noted that regardless of the orientation of the (planting) sett, the head-ward (apical) part of the sett sprouts more readily (also in Rao et al. 1974, Passam et al. 1982b).

Another aspect observed by aforementioned authors is the apical dominance exerted by an already existing sprout upon the formation and growth of others on the same tuber (paradormancy). Onwueme (1973) noted a general inverse relationship between the diameter of the largest sprouting locus and the total number of sprout loci. If the dominant sprout was excised, others took the lead. If one sprout was dominating, other loci were formed but did not grow quickly. Only if tubers were stored for a prolonged period, did sprouts arise along the length of the tuber (Passam 1977). Trouslot (1983) brought up the hypothesis of the competition between sprouts in multiple sprouting setts, leading to a late tuberisation. This apical dominance may follow from the ecological role yam occupies in the forest. Sufficient tuber reserves and preferential growth of only one sprout have evolved in order to penetrate the shaded canopy each year (Wilson et al. 1998).

Four levels of apical dominance are, therefore, differentiated on a yam tuber:

1. The localisation of sprouts appears to be controlled by the point of attachment of the mother plant.
2. Once a first sprout is present the formation of subsequent sprouts is delayed.
3. The first sprout suppresses the elongation of subsequent sprouts.
4. Within one sprout, apical growth is preferred over the growth of lateral buds.

In each of these four situations, the organs present differ greatly, and it is likely that different control mechanisms dominate. It thus appears inappropriate to use an identical terminology for all phenomenon. It is a problem that classical botanical terminology and definitions do not fit simply to the peculiarity of yam sprouting, i.e. the lack of preformed buds. The following terms are suggested in order to separate the four different levels of apical dominance described above. The first phenomenon relates to the spatial distribution of sprouts on yam tubers and will be termed "polar sprouting". The second phenomenon will be differentiated as "apical control" from the third and fourth which represent to the author's mind classical apical dominance, because they are characterised by competition between true buds.

Non-physiological losses. For D. cayenensis-rotundata, so called "soft and wet rots" are a major threat during storage. Penicillium spp. have been identified as the fungi which cause most rot globally, but many other species are also found in yam rot (Noon 1978, Foua-Bi et al. 1979, Ikotun 1983). Optimal fungal development occurs between 25 and 30°C and at high relative humidity for most species (Ikotun 1983). Rots generally develop only if the yam tuber has been wounded, either through cultural manipulation, or by insects, rodents, or ruminants. This is not surprising because yam peel has antifungal properties (Ogundana et al. 1984, Aderiye et al. 1996). There seems to be no
relation between applied NPK and tuber rot in *D. cayenensis-rotundata* (Azih 1976). In real conditions the weight of rotten tubers ranged ranged from 0 to 15% in the Ivory Coast (Serpantie 1983). In Togo, 16% of the tuber weight was found rotten after five months of storage at farm level (N’Kpenu 1997). A market survey in Ghana revealed 38% of the tubers affected by rot (Bancroft *et al.* 1998). It is clear that yam rot poses a severe problem to storage and may be responsible for the majority of post-harvest losses.

For *D. alata*, insects are more important regarding post-harvest problems. An inventory of the entomofauna found on the two major yam species in the Ivory Coast was compiled by Ratnadass and Sauphanor (1983). Two lepidopterans are the main causal species, *Euzopherodes vapidella* (Mann) and an unidentified species of the Tineidae (Sauphanor & Ratnadass 1985, Sauphanor *et al.* 1987). These moths generally need a wound to lay their eggs, and the larvae subsequently feed on the tissue. Opportunistic rots and insects follow, and they may often be more damaging than the primary pests. *Araecerus fasciculatus* (Degeer) was shown to penetrate tubers of *D. cayenensis-rotundata* and *D. alata* even in the absence of a wound, but not as effectively (Emehute & Echendu 1992). Scale insects (*Aspidiella hartii* (Ckll) and *Planococcus dioscorea* (Will)) are often found on the skin of *D. alata* tubers. Although post-harvest losses are not greatly affected by this specific pest, heavy infection hampers the field emergence (Akinlosotu & Kogbe 1986). According to Sauphanor (1988), losses due to insects amount for 20 to 38% on *D. alata* in the Ivory Coast. 63% of the tubers were infested by insects in a survey in the North-East of the country (Sauphanor & Ratnadass 1985). During a large on-farm experiment, 4 to 34% of the tubers had to be discarded due to insect damage in Nigeria (Morse *et al.* 2000). The extent of the damage caused by insects certainly varies largely, but it may attain very high levels.

Both species are hosts for several nematodes, the causal agents of "dry rot" (*Scutellonema bradys*, *Meloidogyne* spp., and *Pratylenchus coffeae*). Although acquired during growth, nematodes continue to breed in the yam tuber during storage in the first few millimetres of the skin. During feeding they disrupt the tissue, opening it to opportunistic organisms (Jatala & Bridge 1990). *S. bradys* can multiply 9 to 14 fold in *D. cayenensis-rotundata* and 5 to 8 fold in *D. alata* during 6 months of storage (Bridge 1973, Adesiyan 1977). There is a yet unproven hypothesis that nematodes start to proliferate rapidly once the tuber enters a stage of metabolically low activity, i.e. a dormant state (Cadet & Queneherve 1994). On Ghanaian markets, 30% of the tubers were found infected by nematodes (Bancroft *et al.* 1998). Nematode infections increase post-harvest losses by 27% due to increased respiration (Castognone-Sereno 1989) and peeling losses were increased from 17 to 42% when *D. cayenensis-rotundata* was heavily infested with *M. incognita* (Adesiyan *et al.* 1975). Globally, it is estimated that the economic losses due to nematodes may be as high as 18% for yam (Queneherve 1997). Nematodes have clearly been identified as a major threat to yam cultivation and storage.

Among the several viruses that infect yam, only one is suspected to be related with post-harvest losses, i.e. the Internal Brown Spot (IBS). Whether it truly is a virus has not
been established clearly (Brunt et al. 1996). The brown concretions of considerable size brought about by this disease exclusively on D. alata render part of the tissue inedible. IBS does, however, not seem to increase storage losses in any other way (Mantell & Haque 1978).

A survey in Ghana revealed that 32% of the tubers had pre-harvest splits, 11.8% holes by stones in the soil, and 43.8% had holes from speargrass. Although these wounds generally heal well when the tuber is in the soil, these factors may offer entrances for rots and insects. 21.6% of the tubers showed signs of termite invasion, and approximately 10% of the volume was estimated inedible by this cause (Bancroft et al. 1998). In the Ivory Coast, termites were much less prominent (1.12% of 30 000 tubers) (Foua-Bi et al. 1979).

Rodents and birds are often cited by farmers to cause losses (own interviews). Surveys have not entirely confirmed this fear (0.15% rodent and 0.09% bird damage on-farm (Foua-Bi et al. 1979), 1.5% rodent damage on market (Bancroft et al. 1998). Modern storage structures generally try to fence off rodents (Nwankiti et al. 1988) and to prevent theft. The true impact of these factors has not been properly surveyed. It is likely that these factors are perceived as important by the farmers because they exhibit a direct competition for food by humans/rodents, in contrast to the other mentioned factors, which are considered inherent to yam storage.

2 - 3 Control of post-harvest losses in yam

Any attempt to generally attribute a magnitude to each factor affecting post-harvest losses must be imprecise. The interactions between time, genetic background, environment, and humans are too complex. At best, the knowledge of how these factors lead to post-harvest losses helps to devise control measures and reasonable storage strategies. All factors leading to post-harvest losses are to some extent dependent on the species and genotype looked at. This factor will not be taken into consideration in the overview below.

Modification of storage environment. The temperature is probably the most important factor influencing storage losses. During the dormant phase, Ezeike (1989) found the temperature to be predominantly influencing storage losses, and thus, a good linear fit was obtained when modelling storage life using the temperature. Cold storage at optimally 15°C has been proven to reduce respiration and to prolong the dormancy (Passam et al. 1978, Foua-Bi et al. 1979, Demeaux & Vivier 1984, Mozie 1988). Lower temperatures lead to tissue deterioration and to heavy losses when transferred to ambient temperature (Coursey 1968). Furthermore, cold storage increased rot and must therefore be combined with a fungicide treatment (Thompson et al. 1977, Demeaux & Vivier 1983). A controlled temperature regime offers a great potential to maintain losses at very low levels, however, the cost of this is too high. Since yam storage generally takes place at the farmer's level, the feasibility is highly questionable in today's Africa.
The direct effect of ventilation is not clear. At 16°C, continuous ventilation was better than intermittent ventilation (Mozie 1984), but another study found higher ventilation to be associated with higher losses (Ajayi & Madueke 1990). The structure of the yam barn suggests that light ventilation is positive. General knowledge on gaseous exchange argues that high ventilation increases transpiration (Ben-Yehoshua 1987). High humidity is acknowledged to slightly accelerate sprouting and the development of rots (Passam et al. 1982c, Ikotun 1983, Ezeike et al. 1989, Solano et al. 1996a).

Optimal storage humidity was said to range from 30 to 70% (Igbeka 1985). Controlled atmosphere has not been investigated very much but so far no positive effect has been found. High CO₂ content seems to favour the formation of roots (Demeaux & Vivier 1983).

A cheap and widespread method for healing wounds is curing, a short term storage environment. Using high temperatures (32 to 40°C) and high humidity (70 to 95%) for 4 days, the wound healing of the tubers is accelerated, which closes the door to pathogens and insects (Been et al. 1977, Noon 1978, Wilson 1980). These conditions are obtained by exposing a covered heap of tubers to the sun. Alternatively, "cool curing" in a pit at 26°C for two weeks was also efficient at reducing storage losses (Nnodu 1987). While deep wounds heal well, superficial abrasion and peeling do not suberise. The latter wounds lead to steady losses which do not decrease after several days (Passam et al. 1976a). In some cases, curing was not effectively reducing storage losses, in these cases presumably first harvest tubers have been used (Onayemi & Idowu 1988). Certain results indicate that curing may promote sprouting (Been et al. 1977).

Nevertheless, the cheapness and simplicity of the procedure advocate its spread.

The storage structures used in the yam belt, and the new ones proposed by researchers, search for a compromise between the different components of the environment influencing yam storage. As an example, improved storage pits decrease losses due to lower temperature (Ezeike 1987, 1989, Ezeike et al. 1989, Girardin 1996), but similar pits increased the damage by rats compared to other storage structures (Girardin 1996). Furthermore, pit storage increased the abundance of yam scale insects (Sauphanor 1986). Another example is the roofing of a yam barn, which delayed and decreased the incidence of rot, but hastened sprouting according to Nwankiti et al. (1988). A heavily fenced and cumbersomely locked yam house in the Northern Ivory Coast suggests clearly that the farmer's main concern are stray cows and theft. Neither rats, rots and insects, nor sprouting can be efficiently controlled in the heaps of yam piled inside. The typical yam barn offers beneficial climate (ventilation) and easy visual control of rots and theft, but the yam are often exposed to rain, birds, and rats. The yam barn has been repeatedly shown to increase physiological losses compared to pits, or sheds (Ezeike 1985, Sauphanor 1986, Girardin 1996). In general, yam storage structures minimally protect the yam from sun and excessive heat. Every other addition seems to be traded off against a disadvantage. Without a lot of investment, an ideal storage structure cannot be easily devised. For a short description and drawings of traditional yam storage structures in the Ivory Coast, refer to Girardin (Girardin 1996, p4 - 9).
Direct interventions on the tuber. The limitations imposed by the impact of storage structures on yam post-harvest hazards imply that certain risks must be controlled with direct interventions on the tubers. Rots, insects, and nematodes can be counteracted with pesticides. Unfortunately, interventions with fungicides have shown erratic responses at ambient temperatures (Thompson et al. 1977, Foua-Bi et al. 1979, Demeaux et al. 1982, Fiagan 1991). It is important that the treatment is applied before inoculation, or not more than 36 hours after (Ogundana 1972, Ricci et al. 1979, Ogundana & Dennis 1981). Generally, hefty concentrations are necessary to suppress rotting efficiently, i.e. 1000mg kg\(^{-1}\) for thiabendazole and benlate (Ogundana 1972), 2500mg kg\(^{-1}\) for thiabendazole in another study (Demeaux et al. 1982). Combined with the high cost and unavailability of fungicides, and a generally uneasy application (soaking for >10min), this may explain why fungicide treatments are rarely found in present on-farm storage (Ejechi & Souzey 1999). Biological control using *Trichoderma viride* (*Hypocreaceae*) efficiently suppressed the fungal pathogen population on yam (Okigbo & Ikediugwu 2000). A phenolic extract of *Acalypha hispida* (*Euphorbiaceae*) leaves efficiently halved the incidence of rots in a thorough study (Ejechi & Souzey 1999). Neither method for biological control of rot appears, however, ready for field use.

Studies confirm that several insecticides effectively protect against damage from insects, if they are applied immediately after harvest (Sauphanor & Ratnadass 1985, Atu 1986). Furthermore, the protection from insects conferred by an insecticide decreased the incidence of rot (Morse et al. 2000). A combination of insecticide and fungicide (Koufla at 2.5kg t\(^{-1}\), 15g kg\(^{-1}\) Permethrine, 20g kg\(^{-1}\) Malathion, 20g kg\(^{-1}\) Thiabendazole) on 30t of yam, storage losses were reduced by 10 to 20% with *D. cayenensis-rotundata* in the Ivory Coast (Fiagan 1991). Such large scale experiments demonstrate clearly the potential of pesticide treatments. Because insects are mainly a problem for *D. alata*, which is rare except in the Ivory Coast and which is of low value, it is not surprising that few farmers practice such treatments.

Nematodes are efficiently controlled by seed tuber or post-harvest treatments with nematicides (Atu et al. 1983, Roman et al. 1984, Atu 1986, Onyenobi 1987, Cadet & Daly 1996). Due to their toxicity and high cost, their use cannot be recommended for ware yam. A hot water treatment has been developed with an optimal temperature of 53°C for 25min. It efficiently reduces nematode population without damaging the sprouting ability (IITA 2002). As with nematicides, a treatment of ware yam appears difficult, and the best way to control nematode damage in storage must be to prevent infestation on the field.

γ-irradiation of yam tubers has been shown to be effective at 5 to 15kRad (Demeaux et al. 1982). Suppressing sprouting very efficiently, it had no adverse effect on the measured parameters of quality of *D. alata* (Rivera et al. 1974). The cost was estimated to be very low compared to cold storage (Demeaux & Vivier 1984), however, the necessary equipment and the diffuse storage of yam in the producing countries seem to prohibit the spread of such a technology.
The application of waxes delayed sprouting by 3 weeks in *D. alata* and decreased storage losses by 6% (Martin 1977) but it was not efficient in reducing rot and sprouting in *D. trifida* (Solano *et al.* 1996a). The high cost and the comparatively small advantage do not recommend waxing of yam tubers. A rather surprising approach was chosen by Afolabi *et al.* (1997) when they coated tubers with termitaria slurry. After 11 months of storage, losses were reduced from 40% to 10 to 20%, in some cases due to a drastic reduction in rots. Quite obviously, this technique, using 0.17 kg of slurry to coat one tuber, cannot be reasonably recommended. It seems to rather illustrate the effect of modifying the microbial flora on the yam tuber's skin during yam storage, a new field of controlling rot.

In view of the importance of yam physiology on post-harvest losses, the plentiful attempts to prolong dormancy are not surprising. A review may be found in Craufurd *et al.* (2001). In brief, most chemicals, i.e. the whole range of known plant hormones, some growth regulators, and other easily available chemicals have influenced yam dormancy erratically. In Passam's words, "to date, gibberellic acid would appear to offer the most promise as a practical chemical means of prolonging and extending storage life." (Passam 1982a). This is not only related to its quite reliable effect on dormancy, but also due to its global availability, non-toxicity, and its price. GA₃ is widely used in agriculture and the brewing industry. It generally induces germination of dormant seeds, and modifies flowering and growth of plants. To give some examples, it is used on seedless grapes to increase yield, in oranges and other fruit to raise shell quality, on coffee to obtain simultaneous flowering, and on flowers to accelerate flowering and increase the size of the inflorescence (Stuart & Cathey 1971). It also breaks dormancy in potato (*Solanum tuberosum*), which is quite contrary to its effect in yam. It is generally thought that the (near-) absence of preformed buds in yam as opposed to potato tubers, is the main characteristic explaining this different reaction (Passam 1982a). It is notable that so far no foolproof chemical to break yam dormancy has been discovered. Such a chemical would be useful in breeding and for off-season production of yam. CCC as an inhibitor of GA synthesis appears to have sprout promotive capabilities (Okagami & Tanno 1977, Shiwachi *et al.* 2001a), but according to the IITA, its effects are as yet unconvincing for application (R. Asiedu, pers. comm.a)

In view of the practical scope of GA₃ application, some researchers have concentrated on how to improve its benefit on yam storage rather than to understand how it works. Okagami and Nagao (1971) first described the dormancy prolonging effect of GA₃ on bulbils of *Dioscorea*. Since the first measurement of GA₃'s impact on post-harvest losses by Martin (1977), the application with this aim has remained the same. Tubers were soaked in solutions of varying concentrations for different lengths of time. Within the tested range, the prolongation of dormancy and reduction of post-harvest losses by GA₃ are positively correlated with the concentration of GA₃ used and the time of immersion. 150 mg kg⁻¹ is so far the lowest effective concentrations for *D. cayenensis*-

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rotundata (Igwilo et al. 1988), and 75mg kg⁻¹ for D. alata (Girardin et al. 1998). For D. cayenensis-rotundata it has been shown that the duration of immersion can be as low as 2h (at 150mg kg⁻¹), and for D. alata the shortest efficient immersion time was 0.5h at 150mg kg⁻¹ (Girardin et al. 1998). These studies clearly aimed to reduce the used amount of GA₃, although it was not actually tried to estimate the use of GA₃ in a comparable manner. It is proposed that the consumption of GA₃ should be given as g of GA₃ used to treat one (1) t of yam. According to Nnodu et al. (1992), using an immersion of whole tubers, a very high consumption of 300g t⁻¹ can be calculated. The immersion of tuber heads only, lower concentrations, and shorter durations, has lead to a significantly lower use of GA₃. Using Girardin's findings, i.e. repeated use of the solution over max. 3 days, the use may be reduced to 2 to 4g t⁻¹. Using even lower concentrations for soaking seems possible (O.Girardin, pers. comm.), thus this figure could be further reduced. In an isolated case, GA₃ has significantly prolonged the dormancy of D. alata, but not reduced the storage losses (Rao & George 1990). Furthermore, very low concentrations of GA₃ seem rather to promote sprouting of yam (Okagami & Tanno 1977).


In contrast to other chemicals applied to edible organs of plants, there has been no attempt to trace the whereabouts of GA₃ in the yam tuber. This lacking evidence is easily explained: the analytical procedure to detect and quantify GA₃, even at the (high) concentrations expected in yam tissue after a GA₃-application, are complicated and expensive, thus outside the physiological or practical scope of the concerned studies. Moreover, GA₃ is non-toxic (LD₅₀ (oral) > 15 000mg kg⁻¹ for rats (Tomlin 1994)) and residues are unproblematic, so there is limited interest in proving its absence in the yam tuber. The quality of D. alata has been shown to suffer from an application of GA₃ in the Ivory Coast. Whereas untreated tubers increase in quality over time, GA₃-treated tubers stay physiologically younger and attain a high level of quality only at a later stage. This statement does not hold for the investigated genotype of D. cayenensis-rotundata. Its quality basically decreases slowly over the storage period, dropping drastically upon sprouting. GA₃ in this sense prolongs the period of higher quality (Nindjin 2002).

At present, the only alternative to GA₃ with respect to reduced storage losses induced by sprouting, is the mechanical removal of sprouts (desprouting). The frequency of removal has been thoroughly tested on seed yam and over a storage period of 70d, higher frequencies generally lead to lower losses (Nwankiti 1988). According to Girardin (1996), who has extensively studied the technique, a monthly sprout removal
may be the optimal compromise between labour and efficiency. For *D. cayenensis-rotundata*, post-harvest losses can be reduced by 7% and for *D. alata* by 9% after 6.5 months if storage. For *D. alata* it has been shown that a combination of GA$_3$ and desprouting was more efficient than either of the techniques alone (Nindjin 2002). According to Serpantie (1983), desprouting is sometimes practised on Krenglè (*D. cayenensis-rotundata*) in the Ivory Coast in order to maintain pounding quality. In Sri Lanka, desprouting seems to be common practice (Wanasundera & Ravindran 1992).

**Interventions during growth and harvest.** It has been attempted to influence post-harvest behaviour of yam tuber, especially the dormancy, during the growth period of the yam plants. Pre-harvest spraying has been often unsuccessful using different chemicals (Campbell *et al.* 1962a, Wickham *et al.* 1984b, Solano *et al.* 1996b). Only the foliar application of GA$_3$ has prolonged dormancy of *Dioscorea esculenta* and of *D. alata* by 70 days (Wickham *et al.* 1984b, Onjo *et al.* 1999). Such a treatment would be easier to carry out than a post-harvest application, as all tubers of one plant are treated simultaneously and leaves are routinely treated with other chemicals. The drawback is the inefficient use of the chemical.

It is clear that during harvest, wounds must be avoided, as both rots and insects take advantage of these entrances, and losses may increase by up to 7% until healing is completed (Coursey 1967, Ogundana *et al.* 1970, Passam *et al.* 1976b, Emehute & Echendu 1992). It has been shown that high tuber moisture content (>700g kg$^{-1}$) exposes tubers to a higher risk of damage. As a consequence, tubers of *D. alata*, and early harvest tubers of *D. cayenensis-rotundata* are more prone to break and must be treated appropriately. A falling height of more than 3cm was hazardous enough to cause damage (Nwandikom 1990).
3 Environment and Methodology

3 - 1 Location

All on-station trials were carried out at the field station of the Centre Suisse de Recherches Scientifiques (CSRS, Abidjan, Ivory Coast) in Bringakro, Ivory Coast, about 180 km north-west of Abidjan (N 6.401 W 5.091, see Figure 3 - 1). The station is situated in the south of the region known as "V-Baoulé", a protrusion of the northern savannah into the tropical forest zone. Being at the edge between the forest and the savannah, the region offers a wide spectrum of soils and vegetation. Scientific research started there in 1989, and in 1995 the CSRS built a research station which provides accommodation and offers limited infrastructure. Research in Bringakro has focused on ethnology, veterinary medicine and agriculture. The village is relatively close to Abidjan, to the next town Toumodi (24km), and to the research station of Lamto (station écologique de Lamto, station géophysique de Lamto, 40km). Furthermore, the excellent relationship with the local inhabitants provides a smooth working environment, security, local knowledge and manpower, and access to land for experimental plots.

The inhabitants of Bringakro are mostly of the ethnic group Baoulé, which is a subgroup of the Akan tribe. Minorities are constituted by Djoula (a Malinke subgroup) and by Peul (nomadic pastoralists). The land is owned almost uniquely by the Baoulé which have, thus, the right to plant coffee and cocoa plantations (Coffea robusta, Theobroma cocoa) which form the economic cornerstone of the village. Food crops are grown mostly for consumption and partly for sale on the nearby market. The basis of agriculture is always yam. It is the first crop grown after the fallow, and it is generally associated with various vegetables and relay intercropped with cassava (Manihot esculenta), plantain (Musa spp.), sometimes taro (Colocasia esculenta), coffee, cocoa, and...
oil palm (*Elaeis guineensis*). Increasingly more land area, especially that which is prone to waterlogging, is dedicated to the cultivation of rice (*Oryza sativa*), which is a relatively new development (K. Müller-Durmus, pers. comm.\(^a\)).

![Map of the yam belt in equatorial West Africa](image)

**FIGURE 3 - 1 Map the yam belt in of equatorial West Africa.** Shape of yam belt according to Orkwor et al (1998).

While only thirty years ago, fields were prepared both in the forest and the savannah, nowadays it is almost uniquely the forest zone which is used. This is due to the introduction of cattle into the savannah, and the increasing cultivation of coffee and cocoa, the latter being uniquely done in the forest zone. Farming of the savannah has become hazardous because regulations and laws do not efficiently protect crops. Fencing is mandatory and at the same time financially prohibitive. The forest is becoming scarce as most of the land is now cropped either perennially or, according to the perception of the farmers, is of decreasing fertility. The savannah might in the future again become the land of the yam (source: own interviews). More details on farming and crops in Bringakro may be found in Girardin (1996), and Müller-Durmus (2003). For much of the major yam growing zone, lying further North, the savannah is the primary ecosystem used for the cultivation of yam. Therefore, the field trials were also conducted in the savannah of Bringakro.

Three major regions were selected within the Ivory Coast's production basin for *D. cayenensis-rotundata* cv. Krenglé: Bouaké, Dabakala and Korhogo (between 7°27'

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and 8°53' latitude North and 4°19' and 5°54' longitude West). As shown in Figure 3 - 2, the three selected sites represent the major centres that supply the wholesale market in Bouaké with Krenglè (Jespers 1995, Touré et al. 2002).

![Map of the situation of the on-farm trials.](image)

**FIGURE 3 - 2** Map of the situation of the on-farm trials. The major production basins of Krenglè and its commercial flow within the country are shown.

### 3 - 2 Climate

The climate is characteristic for the main yam production area in West Africa. It is of the type transitional equatorian and in Bringkakro it was characterised by a mean temperature of 27°C (monthly min. 20.4°C to max. 35.8°C), a relative humidity of 70% (monthly min. 50% to max. 95.6%), and rainfall of 900 to 1300mm (1999 to 2001).

Temperature and relative humidity were measured using two automated dataloggers (Ecolog TH1, Elpro, CH-9471 Buchs, Switzerland). The detailed course of outside temperature and relative humidity are given in Figure 3 - 3. For this purpose, the datalogger was positioned in a birdhouse painted white (30 x 18 x 20cm) on a stake (1.8m) which stood free of any vegetation and shade. The measurements were also collected inside the shed which served the storage of yam (Figure 3 - 4).

Inside the shed, minimum temperature was raised by 0.1 to 2.1°C and the maximum temperature was reduced by 0.2 to 5°C during the storage period. The minimum relative air humidity was generally raised inside the shed by 0 to 15%, while its
Climate

maximum remained unchanged. But the mean temperature and relative humidity inside the shed were mostly identical to the outside. These findings are in agreement with Girardin (1996).

Rainfall was measured using two rain gauges. One was pierced and fitted to a bottle to allow the measurement of heavy tropical rains (>45mm). The rainfall is characterised by a long and a short rainy season, which last from March to July and from September to November respectively (Figure 3 - 5). The year 2000 was marked by an unusual dryness (942mm), specifically in June. The year 2001 was wetter, but the short rainy season was dryer.

*FIGURE 3 - 3 Monthly mean temperature and relative humidity in Bringakro (outside the storage sheds) in 2000 and 2001.*
The monthly mean maxima and minima (columns) and the vegetation period of yam in the field experiment (arrow) are shown.
Environment and Methodology

FIGURE 3 - 4 Monthly mean temperature and relative humidity in Bringakro (inside the storage sheds) in 2000 and 2001.
The monthly mean maxima and minima are shown. The data is limited to the duration of storage.

FIGURE 3 - 5 Monthly rainfall in the savannah of Bringakro. Sum of rainfall: 1226mm (2001), 942mm (2000). The vegetation period of yam in the field experiment is shown (arrow).
● 2000; ■ 2001
3 - 3 Yam tubers

Choice of yam genotypes and origin of tubers. A representative variety type of each of the two main species *D. cayenensis-rotundata* and *D. alata*, Krenglé and Bètè bêtè respectively, were investigated in the present study. Both are late harvest types, which are estimated to make up 70% of the yams produced in the Ivory Coast (Serpantie 1983, Fiagan 1991). Also, both have been used previously in storage experiments and sensorial trials which supply abundant information specifically about these cultivars (Miège 1957, Girardin 1996, Nindjin 2002).

Krenglé is dormant for a short period of time, susceptible to rot and therefore difficult to store (Sauphanor 1988). It is a high quality, so called "noble yam" (Serpantie 1983) requiring labour-intensive cultivation, thus fetching high prices on the market (Guessan Bi 1997, Touré et al. 2002). Consequently, it plays an important role in the economics of the farm and market flows during the early months of the year. It was also chosen to represent the other countries of the yam belt, in which *D. cayenensis-rotundata* is grown by the majority.

Bètè bêtè is a classical staple food yam and is easily grown and stored, the latter because of its naturally long dormancy (Girardin et al. 1998); it is however susceptible to attack by insects (Sauphanor 1988). It fetches low prices at harvest, but as its quality improves and as other cultivars disappear from the market, its economic importance increases later in the storage season (Touré et al. 2002). Its main roles are therefore provision for subsistence and to supply the market when little other yam is available (Serpantie 1983).

Krenglé refers to a group of genotypes which are similar, at whose base there lies, however, a broad genetic diversity. A similar statement applies for Bètè bêtè. Bètè bêtè was only bought from farmers around Bringakro, thus guaranteeing a certain genetic homogeneity throughout the years. The type of Bètè bêtè used conforms to the groups Suigié and Sépié according to the classification of Miège (1952) (Figure 3 - 6 A).

As for Krenglé, it was not possible to maintain continuous sources throughout the study. In 1999 tubers were bought from one village near Toumodi which produces Krenglé in large quantities. In 2000, the need was considerably higher, thus, Krenglé was bought in wholesale market in Bouaké. They were of uncertain origin and harvest date, but their appearance suggested that they had been harvested maximum 1 month before the purchase. It is, however, known, that farmers differentiate several Krenglès with different storage qualities, which could not be respected here. In 2001, tubers originated mainly from my own production and from farmers around Bringakro. In 2000 the general shape was as in Figure 3 - 6 C, while in 1999 and 2001 the type was mostly as in Figure 3 - 6 B.

Tubers were bought in late December and early January, generally not more than 3 weeks after harvest. Only healthy and unbruised tubers were used and the calibre had to be between 500g and 4kg. A light infestation by yam scale insects (*Aspidiella hartii* and *Planococcus* spp.) was tolerated. Tubers grown at the CSRS in Bringakro were
cured for 2 to 4 days on the field in a straw-covered heap in the sun. Over the whole experimentation period, mean tuber weights were 1300 ± 570g (± standard deviation) for Krenglè and 1650 ± 700g for Bètè bètè.

Some experiments included further genotypes of *D. cayenensis-rotundata*, which were part of the CSRS's yam cultivar evaluation program. These genotypes were obtained from the IITA in 1998 and 2000 (courtesy of R.Asiedu, International Institute of Tropical Agriculture, Ibadan, Nigeria). Their tubers were grown on the Bringakro field station as described elsewhere (Ettien *et al.* 2002). Tubers between 500g and 1kg were chosen for the trials.

The maturity of a yam tuber has never been satisfactorily defined, although it is used to mark an important physiological event. Shiwachi *et al.* (2001b) used a threshold of moisture content to describe maturity. Generally, maturity is defined as the senescence of the foliar apparatus of their mother plant. The complete suberisation of the tuber epidermis is another possible indicator. The experiments were limited to mature tubers in these terms in view of the practical perspective of the project.

**Tuber segment terminology.** In the literature, the terminoloy of yam tuber segments is generally used without further explaining how the tuber is divided. The terms are also used by farmers. Here, "apical" denotes the part of the tuber where the mother plant was attached and where the PNC sits (Figure 3 - 7). In the literature, "proximal" and "head" are often used to denominate this tuber part. Apical parts have (in Krenglè) a reddish flesh which is harder and dryer than the rest of the tuber. "Middle" tuber parts
were characterised by white flesh and more watery texture than the head. "Basal" describes the tip ("bottom", "lower tuber part", "distal") of the yam tuber, where the tuber growth takes place. It is characterised by an even more watery consistency than the middle part. In order to attribute measurements to tuber parts, the following rule was adopted: Short and compact tubers were divided into three equal parts; longer and leaner tubers had apical and basal parts of equal size, but the middle could be up to half the tuber length.

3 - 4 Post-harvest treatments

**Phytosanitary conditioning**. Using a pesticide pump, all the tubers were sprayed on all sides with 200mg kg\(^{-1}\) Thiabendazole (2-(4-thiazolyl) benzimidazole, Tecto Flowable SC, Syngenta AG, CH-4002 Basel, Switzerland) to prevent fungal rot and in the case of Bètè bêtè also with 80mg kg\(^{-1}\) of the insecticide Deltamethrine (Décis®, Agrevo, Paris, France). After the treatment, the tubers were allowed to dry before other post-harvest operations were carried out. In 2000 and 2001, the storage structures were sprayed in April with Detamethrine to prevent a massive proliferation of insects at the onset of the rainy season.

**Storage structure**. For ease of handling and observation, tubers were stored on shelves (wooden grids) in two shady, thatched, mud-walled shed. The sheds were 14m long, 5m wide and 4m high. There were three shelves at 0.5, 1 and 1.5m height above the ground. They ran along the inside wall with a width of 1m. The mud wall reached only to a height of 1m, and above the wall was a mesh of bamboo which facilitated aeration. Blocks were, when necessary, arranged so that each block was exposed to a similar light intensity.
Preparation of tubers. The treatments occurred in January or February, not more than 3 to 5 weeks after the harvest of the tubers. The Primary Nodal Complex (PNC), i.e. the bud-bearing organ at the apical end of the tuber, was always removed except when otherwise stated. If the PNC was missing, a new, similarly sized wound was made with a knife at the original place.

Preparation of GA₃ solution. One effervescent pill of GA₃ (Berellex™, Zeneca Agrochemicals, Fernhurst, Haslemere, GU27 3JE, UK or FALGRO™, in 1999 and 2000; Fine Agrochemicals Ldt., Worcester, WR52RL, UK, in 2001), containing 1g of GA₃, was dissolved in an amount of fresh water dependent upon the desired concentration.

Post-harvest treatments. Table 3 - 1 summarises the different post-harvest treatments that were employed in the experiments. Where necessary, the treatments will be referred to as follows: Each treatment is followed by a number indicating the GA₃ concentration in the product employed (column "GA3 concentration [mg kg⁻¹]" in Table 3 - 1). The detailed description of the preparation and application of each treatment is given below.

Control. Tubers of this group did not undergo any further treatment. They served as witness for all other treatments.

Mechanical sprout removal:Despr. Sprouts were removed every two weeks. The sprouts were cut (D. cayenensis-rotundata cv. Krenglé) or broken (D. alata cv. Bètè bètè) at the tuber surface leaving a wound, which generally healed well without inducing rot. Sprouts of all sizes were removed.

Dipping: GaDip. The standard methods consisted of soaking the tuber heads in GA₃ solution (150mg kg⁻¹ for 1h). The procedure has been described precisely in Girardin et al. (Girardin 1996, Girardin et al. 1998). In brief, 6 litres of the GA₃ solution was prepared in a basin (Ø 1m). The heads of the yam tubers were then placed in the solution. When the basin was full of yam tubers, about 3cm of the apical end of the tubers were wettened. The solution was prepared just prior to use and used not more than twice except when otherwise stated.

Wet Soil: GaSoil. The GA₃ solution (300ml, different concentrations) was mixed with 1.4 to 1.5kg of air-dried, non-sterile topsoil (clay 51g kg⁻¹ silt 107g kg⁻¹ sand 832g kg⁻¹, pH 5.7, C 28g kg⁻¹ N 2.8g kg⁻¹). The amount of soil added was determined by the desired consistency, i.e. it was slightly viscous and adhered to the tubers. The wet soil was applied to the tubers so that it covered more than the previous scarring at the apical tuber end. The treated tubers were left to dry for 12h, before they were transferred to the shed. The quantity obtained was sufficient to treat 72 tubers, i.e. about 25g of wet soil was applied to each tuber. In the GaSoil/2x treatment, the application was repeated just before 50% of the tubers had sprouted. Existing sprouts were removed or a new wound was made before the wet soil was applied. In the "GaSoil+Despr" treatment, the tubers were treated with wet soil; once dormancy was broken, the sprouts were removed every two weeks.
Gelatinised starch: GaStarch. One part (w/w) of washed, sun-dried and ground (<200 µm particle size) cassava starch was dissolved in four parts (w/w) of water. The mixture was heated for 1 to 2 min while stirring continuously until the starch was fully gelatinised. It was left cool to room temperature after which two parts (w/w) of a solution of GA₃ (different concentrations) were vigorously mixed with the starch. A small amount of the resulting homogeneous mass was spread over the wound which was inflicted upon removal of the PNC. Starch (22g), water (88g) and a GA3 solution (44g) were used to treat 72 tubers, i.e. about 2.1g of gelatinised starch were used per tuber.

Spray: GaSpray. Tubers were arranged on the ground in rows and were sprayed with GA₃ solution (150mg kg⁻¹) in a pesticide pump so that the entity of each tuber was covered. The tubers were shaded and left to dry. When 50% of the tubers had sprouted, the sprouts were removed or a new wound was made and the treatment was repeated.

**TABLE 3 - 1 Mechanical and GA₃ treatments of yam using different concentrations and different products of GA₃ application.**

<table>
<thead>
<tr>
<th>Treatments, abbreviation</th>
<th>Product employed</th>
<th>GA₃ concentration [mg kg⁻¹]</th>
<th>Brief explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>None</td>
<td>0</td>
<td>Mechanical removal of sprout at 14d intervals</td>
</tr>
<tr>
<td>Despr</td>
<td>None</td>
<td>0</td>
<td>Dipping of tubers heads for 1h</td>
</tr>
<tr>
<td>GaDip</td>
<td>Water + GA₃</td>
<td>150</td>
<td>Dipping of tubers heads for 1h</td>
</tr>
<tr>
<td>GaStarch</td>
<td>Gelatinised starch + GA₃</td>
<td>175, 280, 860 and 1200 a</td>
<td>Approximately 2.1g were applied to each tuber head</td>
</tr>
<tr>
<td>GaSoil</td>
<td>Wet soil + GA₃</td>
<td>4, 12, 25, 50 and 100 a</td>
<td>Approximately 25g were applied to each tuber head</td>
</tr>
<tr>
<td>GaSoil+Despr</td>
<td>Wet soil + GA₃</td>
<td>25</td>
<td>GA treatment + mechanical removal of sprouts at 14d intervals</td>
</tr>
<tr>
<td>GaSoil/2x</td>
<td>Wet soil + GA₃</td>
<td>25</td>
<td>Treated twice (at harvest and at 50% sprouting after sprout removal</td>
</tr>
<tr>
<td>GaSpray</td>
<td>Water + GA₃</td>
<td>150</td>
<td>Treated twice (at harvest and at 50% sprouting after sprout removal</td>
</tr>
</tbody>
</table>

a. All concentrations used in different treatments are shown.

3 - 5 Storage and planting of seed yam tubers

Seed tubers of *D. cayenensis-rotundata* cv. Krenglè were smaller than the ware yam used for storage trials (2000: 710 ±14g; 2001: 687 ±10g). Storage began in January and ended in the beginning of May. At that time the sprouts were trimmed to a length of 10 to 20cm. The tubers were attributed to the field blocks in a way that the initially stored weight was equal for all treatments. That is, the sum of the tuber’s weight in January were equal among the treatments within one field block. At planting time (10th to 15th May), the planted weight differed by the magnitude of storage losses.
Field preparation and planting. The trials were carried out near the village of Bringakro (see Figure 3-1). A sandy, poor ferrallitic soil type was used that showed concretions of oxides and hydroxides. Trees and shrubs were uprooted. The terrain was superficially laboured and ridges (1m wide, 60cm high) or mounds (1m x 1m, 50cm high) were prepared. The subplot size was 4m x 7m and the block size was 8m x 14m. In 2000 two fields were set up each containing six blocks. One field was in the savannah and one in the forest zone. In 2001 one field with eight blocks was set up in the savannah only. For all fields, no crop had been grown at least for 12 years on the plot.

Before planting was carried out, the tubers were cut into setts of equal weight. A sett refers to a piece of yam tuber which may be used for planting; therefore it must be partially covered by skin. Furthermore, if there were several sprouts present on one tuber, it was cut in such a way that a maximum number of setts carrying a sprout were obtained. If a sett carried more than one sprout, all except the most vigorous one were removed. For all tubers, the basal tip (about 1cm) was removed according to local practice.

In 2000, the tubers were cut into setts on the field and planted. In 2001, the tubers were cut into individually numbered setts. Before planting, these setts were treated with 500mg kg⁻¹ Vydate®L (480g kg⁻¹ Oxamyl [Methyl N'N'-dimethyl-N-[(methylcarbomyl) oxy]-1-thiooxamirnidate], DuPont, Loon Plage, France) and 250mg kg⁻¹ Thiabendazole (Tecto® Flowable SC, Syngenta AG, CH-4002 Basel, Switzerland) using a commercial solvent-aiding wetting agent. In both years setts were distributed randomly within one subplot but for all stands, the identity of the mother tuber and the place from which the sett had been cut on the tuber was recorded (see Figure 3-7 for terminology). Additionally, it was noted for each sett whether it carried a sprout when planted.

The setts were planted according to local practice, i.e. they were enforced into the soil to a depth of 10 to 15cm at a density of 10 000 pl ha⁻¹. The area around the insertion point of the sett into the soil was subsequently mulched with straw to reduce the heat stress on setts, to improve water infiltration, and to reduce erosion.

Crop management and harvest. Two months after planting, a single dose of NPK 120:17:120 (kg units/ha) was applied between the plants on the ridges at a depth of approximately 5cm. Stakes (de-foliated, branching savannah trees of different species) were positioned to hold 4 or 6 plants in a regular pattern, i.e. each subplot had six stakes of about 2m height. Using a synthetic string or fibres of a local liana, shoots of more than 1m length were twined on the stakes. According to local practice, lateral branches were twined to the same support throughout the growth period. No phytosanitary measures were taken.

Anthracnose was the most wide-spread disease in both cropping years with one third of the plants mildly affected (score 2 to 3 out of 10). Virus-diseased plants were rare, i.e. less than 10% of the plants exhibited mosaic syndromes, vein banding, or otherwise misshaped leaves. Nematode infection of tubers at harvest was considerable in 2000.
Tubers harvested in 2000 showed signs of nematodes at 18.6 and 26.1% on the two fields respectively. In 2001, this figure has dropped sharply to 3.2%.

Harvesting was done in the last week of the year. The plants had reached full senescence by that period.

3 - 6 Experimental trials

A summary of all experiments is given in Table 3 - 2.

<table>
<thead>
<tr>
<th>No</th>
<th>Name</th>
<th>Year</th>
<th>Varieties</th>
<th>Factors (number of levels)</th>
<th>Blocks</th>
<th>Number of tubersa</th>
<th>Results on page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Improvement of GA3 application</td>
<td>1999</td>
<td>Krenglè &amp; Bètè bètè</td>
<td>treatments (10)</td>
<td>6</td>
<td>792 K &amp; 1008 B</td>
<td></td>
</tr>
<tr>
<td>1b</td>
<td>Improvement of GA3 application</td>
<td>2000</td>
<td>Krenglè &amp; Bètè bètè</td>
<td>treatments (13)</td>
<td>6</td>
<td>906 K &amp; 858 B</td>
<td>a) to c) on 77ff</td>
</tr>
<tr>
<td>1c</td>
<td>Improvement of GA3 application</td>
<td>2001</td>
<td>Krenglè</td>
<td>treatments (6)</td>
<td>6</td>
<td>432</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Effect of PNC removal</td>
<td>2001</td>
<td>Krenglè</td>
<td>treatments (2) x level of PNC removal (3)</td>
<td>3</td>
<td>120</td>
<td>46f</td>
</tr>
<tr>
<td>3</td>
<td>Respiration and Evaporation</td>
<td>2000</td>
<td>Krenglè</td>
<td>treatments (3) x time of sampling (4)</td>
<td>4</td>
<td>288</td>
<td>41ff</td>
</tr>
<tr>
<td>4</td>
<td>Time series</td>
<td>2000 + 2001</td>
<td>Krenglè &amp; Bètè bètè</td>
<td>treatments (2) x time of application (7)</td>
<td>3</td>
<td>384 &amp; 384 (per year)</td>
<td>47</td>
</tr>
<tr>
<td>5</td>
<td>Application of GA3 to different tuber parts</td>
<td>2001</td>
<td>Krenglè</td>
<td>treatments (2) x site of application (3)</td>
<td>-</td>
<td>160</td>
<td>47</td>
</tr>
<tr>
<td>6</td>
<td>Storage and planting of seed tubers</td>
<td>2000 + 2001</td>
<td>Krenglè</td>
<td>treatments (4)</td>
<td>4</td>
<td>548 &amp; 427 (per year)</td>
<td>57ff</td>
</tr>
<tr>
<td>7</td>
<td>GA3 application to other genotypes</td>
<td>2001</td>
<td>div.</td>
<td>treatments (2) x genotype (17)</td>
<td>-</td>
<td>227</td>
<td>49</td>
</tr>
<tr>
<td>8</td>
<td>On-farm storage Ivory Coast</td>
<td>2000</td>
<td>Krenglè</td>
<td>treatments (4)</td>
<td>3</td>
<td>8047</td>
<td>87ff</td>
</tr>
<tr>
<td>9</td>
<td>On-farm storage Nigeria</td>
<td>2001</td>
<td>div.</td>
<td>treatments (3)</td>
<td>6</td>
<td>1770</td>
<td>96f</td>
</tr>
</tbody>
</table>

a. K = Krenglè, B = Bètè bètè

1 Improvement of GA3 application. The tubers were subjected to all post-harvest treatments shown in Table 3 - 1. A range of concentrations was tested for the wet soil and the gelatinised starch products. Within a treatment there were 12 tubers per replication. Storage began in the first week of February in 1999 and 2000, and in the second week of January in 2001. Storage ended in June for Krenglè and in July/August for Bètè bètè.
2 Effect of PNC removal. PNC removal and GA₃ treatment were combined. The PNC was removed or not and the tubers were treated with GaSoil 25 or not. In the group of GA₃-treated tubers, tubers from which the PNC had been half removed were included. Storage started in the first week of February and ended in June. 8 tubers were used per replication and treatment.

3 Respiration and Evaporation. Tubers (24 tubers per replication and treatment) were stored with the following treatments: GaStarch 860, regular desprouting or untreated control. The trial started 7d after the harvest (17.1.2000). Towards the end of dormancy of untreated tubers (8 weeks after the start of the trial), just thereafter (at 11 weeks) and at two later stages of the conservation period (at 18 and 22 weeks), 24 tuber per treatment (i.e. 6 per replication) were analysed for dry matter (DM) contents of tuber and sprout.

4 Time series. At 1, 4, 6, 9, 12, 14 and 16 weeks after harvest, batches of stored tubers were treated with GaStarch 860. Every batch was only treated once. The control tubers served as a base line for the duration of dormancy and post-harvest losses. 8 tubers were used per replicate, per treatment, and per variety.

5 Application of GA₃ to different tuber parts. Tubers were treated with GA₃ apically, on the middle part, or basally. For the apical treatment, the PNC was removed and the wound created by this operation was treated with GaStarch 860. For the middle and basal treatment, the PNC was also removed. In addition, a wound was inflicted with a knife on the middle or basal part of the tuber, respectively. It was ensured that the yellowish periderm below the epidermis was wounded, because it is this layer from which sprouts originate (Onwueme 1973) and it was supposed to contain transport vessels. These wounds were then treated with GaStarch 860. 40 tubers were employed per treatment. The trial started in January and ended in June.

6 Storage and planting of seed tubers. Seed tubers were stored using four post-harvest treatments (control, desprouting, GaStarch 860, and GaStarch 300). Storage started in January and ended in May. The planting was performed as described above.

7 GA₃ application to other genotypes. GaStarch 860 was applied to a range of improved genotypes.

8 On-farm storage Ivory Coast. 18 farmers were chosen in three different regions of the Ivory Coast with the region treated as a factor (Figure 3 - 2). 30 to 50 tubers per farmer were used as a control. The remaining tubers were divided into four groups, each treated with Despr, GaDip 150, GaSoil 25, or GaStarch 860 respectively. Storage and treatments were carried out at the storage site of each farmer.

9 On-farm storage Nigeria. 59 farmers in six villages in Nassarawa State, Nigeria, stored 30 tubers each. Three treatments were tested, i.e. untreated tubers, GaSoil 25 treated with the PNC wounded but not removed, and GaSoil 25 treated with the PNC fully removed. Storage and treatments were carried out at the storage site of each farmer.
3 - 7 Measurements and statistical analysis

**Weighing and recording of sprouting.** For on-station trials, each tuber was weighed (precision 0.1g) and was randomly selected for the treatments and replication. Post-harvest losses, or total weight losses, were calculated as shown in Formula 3 - 1. The fresh weight and germ length (precision: 2cm) were recorded every one to two months during the storage period (4-7 months) depending on the year and the variety. The sprouts were removed from the tubers when their length hindered weighing (longer than 1.5m). It was then cut at about 20cm from the base and the weight of the sprout was recorded. After about 1 week a new sprout appeared at the node below the cut. In such a case, as well as for treatments demanding regular removal of vines, the sum of the sprout lengths and weights were used for comparison to other tubers. The sprouts were removed completely for all tubers at the end of the trial and their lengths and weights were recorded. The frequency of weighing was every one to two months for experiment 1. For the other experiments, weighing was done at the start and at the end of a trial. On-farm, tubers were weighed in groups per treatment and farmer using a cattle scale (0.5kg) or a hanging scale (precision: 0.3kg).

**FORMULA 3 - 1 Calculation of total (left) and daily post-harvest losses (right).**

$L :$ losses [% or g kg$^{-1}$], $L_d :$ daily losses (% d$^{-1}$ or g kg$^{-1}$ d$^{-1}$), $FM :$ fresh matter, $t_0, t_1 :$ two consecutive points in time with $(t_1 - t_0)$ as storage duration [d].

\[
L = \frac{FM_{t_0} - FM_{t_1}}{FM_{t_0}} \quad L_d = \frac{FM_{t_0} - FM_{t_1}}{FM_{t_0}} \times \frac{1}{t_1 - t_0}
\]

Sprouting was evaluated visually (presence or absence of sprouts) and monitored every 5 days until 95% of the tubers had sprouted. The duration of dormancy was defined as the mean number of days from the start of the trial, or from harvest, to the first visible sign of sprouting (Ireland & Passam 1985). This is a compromise as the yam post-harvest literature is quite imprecise regarding the definition of the length of dormancy (see page 15). Most measurements on sprouts (number, length, weight) were attributed to a tuber part (Figure 3 - 7).

**Dry matter analysis and calculation of respiration.** DM was determined as described by Girardin (1996). A longitudinal, thin slice (0.5 to 1cm) was taken per tuber. The slice was then cut into cubes (3 to 5mm to each side) of which two random samples (15 to 25g each) were placed in small trays (matchbox size) of aluminium and of known weight. The fresh weight was recorded. The samples were then dried at 105°C for 24h. The dry weight was then recorded and the DM content calculated. Using lyophilisation, Grange et al. (1980) found 5% increased desiccation in *D. opposita* compared to the method described here.
FORMULA 3 - 2 Calculation of the daily respiration rate (top) and of evaporation rate (bottom).

DM : dry matter [g kg\(^{-1}\) (wet base)], FM : fresh matter [g], \(t_0\) and \(t_1\) : two successive points in time [d], RR : respiration rate, [g kg\(^{-1}\) d\(^{-1}\) (wet base)], ER : evaporation rate [g kg\(^{-1}\) d\(^{-1}\) (wet base)].

\[
RR = \frac{DM_{t_0,\,\text{tuber}} - (DM_{t_1,\,\text{tuber}} - DM_{t_1,\,\text{sprout}})}{t_1 - t_0}
\]

\[
ER = \frac{FM_{t_0,\,\text{tuber}} - (FM_{t_1,\,\text{tuber}} - FM_{t_1,\,\text{sprout}})}{t_1 - t_0} - RR
\]

Using the DM content at harvest (Krenglè: 343g kg\(^{-1}\)) as a reference, the respiration of DM and evaporation of water was calculated as shown in Formula 3 - 2. Tubers exhibiting any kind of rot or nematode infection were excluded from calculations as these are known to generally increase respiration dramatically (Coursey & Russull 1969, Fawole & Evans 1989). This calculation of a DM and water balance sheet was also used by Igwilo (1988). It is based on the assumption that neither DM nor water is produced or taken up by the yam tuber after harvest. Therefore, all unaccounted for loss of DM and water must be respired or evaporated respectively. The calculation method is however biased by the fact that yam tubers, even of the same species and cultivar, exhibit a varying DM content at harvest. All calculations based on this reference, the initial DM content, contain intrinsically this error. At early stages of storage, negative respiration rates may, thus, be obtained for individual tubers. However, since the error is identical for all tubers, the statistical analysis is not biased.

Field measurements. Crop emergence was recorded as the number of days until the sprout penetrated the straw mulch at intervals of 3 to 5 days. At 3 months after planting, foliar diseases (anthracnose: *Colletotrichum gloeosporioides*, leaf spots, and *Yam Mosaic Virus* YMV *potyvirus*) as well as growth related traits (volume, branching, vigour) were measured on a scale from 1 to 10 (1 = low, absent). The vigour of the plant referred to its potential to produce a high yield and was matched visually from plant size, phytosanitary state and colour of leaves. It was carried out by the author and an experienced yam grower, separately.

In 2001, an additional, vegetative parameter was measured. It was termed "planar plant surface" and measured the surface of the (3-dimensional) plant projected on a virtual plane, i.e. a photograph. Photographs were taken of each stake 4 months after planting using a Topcon IC-1 auto camera with a 35mm lens (aperture: 5.6, 1/125s) against a white background. The distance from the stake of 2.5m and the angle to the ridges (30°) was maintained for all stakes. The photographs were digitised and the background, i.e. all non-yam parts, were removed digitally using features of colour
filtering and manual rendering in Adobe® Photoshop (Adobe Systems Inc., San Jose, California, USA). The remaining surface consisting of yam leaves and stems, was measured using WinRhizo™ (Régent Instruments Inc., Québec, Canada). Each stake supported 4 or 6 plants, and the value of the planar surface obtained was attributed to joint values (yield, days to emergence, etc.) of all 4 or 6 plants.

At harvest, yield was measured per stand (2000) or per stand and per tuber (2001). Nematode infection or rot was measured visually using a scale from 1 to 9 (1 = healthy). The outward plants of each subplot were guard plants and only the inner 10 plants were considered for the yield calculations.

**Statistics.** The experimental design was, except where otherwise stated, a randomised complete block design (RCB). The analysis of variance (ANOVA) was carried out using the GLM procedure of SAS (SAS Institute Inc., NC, USA) for one-year data. For multiple year data the MIXED procedure was used since generally the interaction between treatments and years was significant. This procedure is better for unbalanced designs and differentiates more conveniently between fixed and random effects. When necessary, comparisons of means were based on least significant means using the appropriate error terms (McIntosh 1983). The data could normally be fitted using a linear model of the type $y=\mu+\alpha x$. Generally, $\alpha$ was of interest, i.e. changes in fresh weight, sprout lengths, number of sprouts etc. depending on time, treatments, etc. If other models were used, the details are given in the appropriate places.

For storage experiments, the grouping of tubers to constitute treatment units within a block was done to buffer big inter tuber differences and to avoid abnormal distribution of residual errors. For the field experiment, the effect field (savannah, forest) was
nested within the effect year and the effect block was nested within years and fields. In certain cases, it was necessary to mathematically transform the measured value in order to obtain homogeneity of variances or normal distribution of residuals.

To verify the assumptions of ANOVA, the residuals were plotted against the predicted values to check for structured distributions (independence of factors). Residuals were also analyzed for normal distribution using the UNIVARIATE procedure. Homogeneity of variance was checked using inbuilt options of SAS procedures or simply by making an ANOVA on the residuals.

Covariate analysis was done using the CORR and REG procedures of SAS. For this purpose, scatter plots were generated first and the relation between the two variables of interest was checked. If a correlation appeared likely, the Pearson correlation coefficient was calculated after mathematical transformation and selection of observations where necessary. Furthermore, a single factor regression of a covariate on the yield was carried out. For field measurements, means per stake were used, because certain measures (vegetative parameters) had been taken per stake. The frequency of observations was used for weighing.

Values for all DM and water contents were calculated for each tuber individually. Means per bloc were then used in an analysis of variance using a linear model (Formula 3 - 3). The analysis was done using the GLM procedure of SAS and the following model: \( y = \text{treatment, time, treatment*time} \). The treatment-term corresponds to the overall mean in the model (\( \mu \)), the time-term to the general linear component (\( b \)), and the interaction corresponds to the term \( b_i \) in Formula 3 - 3. The latter term was of interest to answer whether there were differences between treatments over time. (courtesy to H.-R.Roth, ETH Zürich, Switzerland)

**FORMULA 3 - 3 Linear model used for modelling dry matter and water evolution during storage yam tubers.**

Formula A expands into B by expanding the term \( b_i \) into a general component \( b \) and a treatment specific component \( b_i \). \( b \): general linear component, \( b_i \): interaction component, \( \mu \): overall mean, \( \varepsilon_{ij} \): residual error term, \( i \): treatment, \( j \): repetition (block), \( t \): time.

\[
y_{ijt} = \mu + b_i \times t + \varepsilon_{ji} \quad (A)
\]

\[
y_{ijt} = \mu + (b + b_i) \times t + \varepsilon_{ij} \quad (B)
\]
4 Functionality of Gibberellins in Yam

4 - 1 Chapter summary

It was aimed to obtain insight into the interaction between exogenously applied GAs and the yam tuber physiology. The following results were obtained by monitoring the evolution of fresh weight, DM content, and sprouting of stored yam tubers.

A GA$_3$ application to yam tubers reduced the respiration and evaporation. Furthermore, the transfer of tuber reserves to the sprout was curtailed. The latter process reduced losses in case of manual desprouting. Thus, both post-harvest treatments retarded the DM rise during storage. Possibly, a good pounding quality was maintained in consequence. GA$_3$ also changed the sprouting pattern in $D. cayenensis$-$rotundata$ but less so in $D. alata$. Tubers of $D. cayenensis$-$rotundata$ formed multiple sprouts in the middle and basal tuber part besides the normal apical tuber part. The other levels of apical dominance, i.e. the delay of the formation and elongation of the second and subsequent sprouts and the sprout branching are not affected by a post-harvest GA$_3$ application.

The primary nodal complex (PNC) had no direct effect on the length of dormancy in untreated tubers. GA$_3$ applied to the PNC did not prolong dormancy except when the PNC was wounded. When the PNC was removed, a treatment at an apical or middle tuber part prolonged dormancy. However, only an apical treatment also reduced post-harvest losses. An application of GA$_3$ more than 4 weeks after harvest was less efficient compared to at harvest. For $D. cayenensis$-$rotundata$ the later treatment still significantly reduced post-harvest losses. GA$_3$ should be applied on an apical wound at harvest for maximum reduction of post-harvest losses. Since the response to GA$_3$ was shown to be largely genotype dependent, a treatment must be finetuned first for new genotypes.
4 - 2 Introduction

The optimisation of the application of GA3 to yam tubers has been focusing on the reduction of post-harvest losses rather than on its impact on yam tuber physiology. For example, it is only recently that GA3 application to yam tubers has been shown to affect negatively the culinary quality of *D. alata* (Nindjin 2002). It is obvious that this change is provoked by the physiological changes that GA3 imposes upon the yam tuber's tissues. With the current, poor knowledge on GA3 functionality in the yam tuber, it is difficult to speculate about which mechanism lies behind this change of quality.

The sprouting of yam seems to be regulated mainly by interior factors. Most noticeable is the observation that sprouting happens preferentially at the apical end, and that the one sprout exerts an apical dominance over the subsequent ones (Craufurd *et al.* 2001). The impact of GA3 on these sprouting-regulating mechanisms has never been addressed.

On the other hand, the characteristics of the yam tuber may have a repercussion on the effect that GA3 has on tubers. An overview of the yam GA3 literature, rapidly gives the impression that the common ground is the consistently longer dormancy and the generally lower losses obtained by a GA3 treatment. These reports offer no congruent picture on the impact of GA3 on the absolute values of prolongation of dormancy and the reduction in post-harvest losses (Table 4 - 1).

<table>
<thead>
<tr>
<th>Source</th>
<th>Species</th>
<th>Prolongation of dormancy</th>
<th>Reduction of post-harvest losses</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Igwilo <em>et al.</em> (1988)</td>
<td><em>D. alata</em></td>
<td>2/3month</td>
<td>3%</td>
<td>150mg kg(^{-1})</td>
</tr>
<tr>
<td>Girardin <em>et al.</em> (1998)</td>
<td><em>D. alata</em></td>
<td>2months</td>
<td>27%</td>
<td>150mg kg(^{-1})</td>
</tr>
<tr>
<td>Martin (1977)</td>
<td><em>D. alata</em></td>
<td>1month</td>
<td>5%</td>
<td>?</td>
</tr>
<tr>
<td>Passam (1982b)</td>
<td><em>D. alata</em></td>
<td>3.5months</td>
<td>35%</td>
<td>150mg kg(^{-1})</td>
</tr>
<tr>
<td>Rao <em>et al.</em> (1990)</td>
<td><em>D. alata</em></td>
<td>4 months</td>
<td>0%</td>
<td>1000mg kg(^{-1})</td>
</tr>
<tr>
<td>Wickham <em>et al.</em> (1984a)</td>
<td><em>D. alata</em></td>
<td>2.5months</td>
<td>?</td>
<td>150mg kg(^{-1})</td>
</tr>
<tr>
<td>Igwilo <em>et al.</em> (1988)</td>
<td><em>D. cayenensis-rotundata</em></td>
<td>1month</td>
<td>9%</td>
<td>150mg kg(^{-1})</td>
</tr>
<tr>
<td>Girardin <em>et al.</em> (1998)</td>
<td><em>D. cayenensis-rotundata</em></td>
<td>2/3month</td>
<td>16%</td>
<td>150mg kg(^{-1})</td>
</tr>
<tr>
<td>Nnodu and Alozie (1992)</td>
<td><em>D. cayenensis-rotundata</em></td>
<td>1month</td>
<td>27%</td>
<td>150mg kg(^{-1})</td>
</tr>
</tbody>
</table>

Figures vary largely. Why does this variation arise? May there be other sources of variation than just the obvious ones, such as the genotype of the treated yam, and the concentration of GA3 applied? It seems possible that other factors, such as tuber age, presence of preformed sprouts, physiological gradients inside the tuber, affect the efficiency of a GA3 treatment.
Functionality of Gibberellins in Yam

The first aim of this chapter is to shed light on the effect of GA₃ on yam tuber physiology. Regarding the physiology, two topics will be addressed: the respiration rate and the sprouting localisation on yam tubers. Furthermore, different application methods modulate the effect of GA₃ on yam tuber physiology, and the impact of this has to be analysed. The focus will lie on the site of GA₃ application and the time of GA₃ application. This will eventually serve to define its practical use more clearly and, hopefully, to improve its usefulness as post-harvest practice for yam.

4 - 3 Results

Effect of GA₃ on yam tuber respiration and evaporation. Based on the dry matter (DM) content at different times after harvest, the respiration and evaporation was estimated using a DM balance sheet (trial no. 3, calculations and statistical model: page 32ff). As shown in Figure 4 - 1, fresh matter dropped quickly once sprouting had set in for untreated tubers and simultaneously the DM content rose. For regularly desprouted tubers both tendencies were slowed. GA₃-treated tubers showed a delayed sprouting which resulted in a delayed drop of fresh matter and a later increase of DM. At the end of the conservation period GA₃-treated tubers had a significantly lower DM content than desprouted or untreated tubers.

The evolution of DM and water of tuber and sprout, respiration and evaporation over time are shown in Figure 4 - 2. It is observed that tuber water content drops more quickly than tuber DM, which explains the rising DM content of tubers shown in Figure 4 - 1. GA₃-treated or desprouted tubers have significantly lower DM-losses. For desprouted tubers this is mainly due to the lower DM loss to sprouts, whereas for GA₃-treated tubers the respiration is also curtailed. The same holds for water loss. GA₃-treated tubers appear to evaporate less water than untreated tubers.

The linear regression comprised only the four true measurements over time, i.e. it excluded the initial measurement at time 0d which had no variation. The analysis of tuber DM and tuber water content, respiration and evaporation was straightforward using a linear model. Residuals were distributed normally and for all three variables a goodness of fit of 64 to 94% was obtained. Since the time-treatment interactions were moderately to highly significant model components, it may be assumed that there are true differences between the slopes of different treatments (see page 36 for explanations). The analysis of sprout DM and water was statistically difficult. Intrinsically GA₃-treated tubers have no sprouts at early stages which leaves all values at zero with zero variation. Furthermore, as the sprouts grew larger over time, so did the error of measurement. Both facts led to residuals which grew larger proportionally with an increasing predicted value. The variance was therefore not homogenous and analysis impossible.

In order to examine the relationship of evaporation and respiration rate as well as sprout length, tubers that had sprouted were analysed. For untreated tubers both respiration and sprout length are highly correlated with evaporation (Table 4 - 2). For
Results

For desprouted tubers only the respiration is correlated significantly with evaporation, while for GA3-treated tubers, all three variables appear largely independent.

The regression of respiration and sprout length on evaporation differed similarly among the treatments. For untreated tubers only the respiration was a significant linear component and a goodness of fit of 74% was obtained (Table 4 - 3). For desprouted tubers, respiration and sprout length were significant components. For GA3-treated tubers, the p-value of the entire model was insignificant. The intercept was smallest for untreated tubers.

FIGURE 4 - 1 Evolution of the relative post-harvest losses (top) and dry matter percentage (bottom) of tubers from D. cayenensis-rotundata cv. Krenglè during 5 months of storage. The means and standard errors of GA3-treated (◆), desprouted (●) and untreated (□) tubers, and the end of dormancy of control tubers (left arrow) and GA3-treated tubers (right arrow) are shown. Means followed by different letters at the same time are significantly different based on LS-Means.
Spatial distribution of sprouts and apical dominance. The sprouting behaviour of several hundred tubers was monitored closely during experiment numbers 1 and 6 (page 32). The results from these experiments will be presented later with regard to the optimisation of the GA₃ application (page 77ff). Here, the resulting sprouting pattern of on the tubers will be discussed. Whenever possible the results of two different application methods for GA₃ will be given. This should allow the verification and clarification of the observed effect with respect to the action of GA₃.

The sprout location is clearly influenced by a post-harvest application of GA₃ in D. cayenensis-rotundata (Table 4 - 4). Irrespective of the method used, GA₃-treated tubers sprouted more on middle and basal parts and less on apical parts than untreated tubers. Regular desprouting always increased the number of tubers bearing sprouts on middle parts.

### Table 4-2 Pearson correlation coefficients of evaporation, respiration and sprout length of D. cayenensis-rotundata cv. Krenglè.

<table>
<thead>
<tr>
<th>Treatmentᵃ</th>
<th>Evaporation rateᵇ,c</th>
<th>Respiration rateᵇ,c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.85 **</td>
<td>0.74 **</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.81 **</td>
</tr>
<tr>
<td>Desprouting</td>
<td>0.87 **</td>
<td>0.38 †</td>
</tr>
<tr>
<td></td>
<td>0.16 ns.</td>
<td>0.16 ns.</td>
</tr>
<tr>
<td>GA₃-treated</td>
<td>0.46 *</td>
<td>0.54 *</td>
</tr>
<tr>
<td></td>
<td>0.32 ns.</td>
<td>0.32 ns.</td>
</tr>
</tbody>
</table>

ᵃ. Means per bloc and time of measurement were used. Non-sprouting tubers were excluded from calculations.
ᵇ. Values for respiration and evaporation were calculated as % of initial tuber fresh matter.
ᶜ. Probability for the Pearson correlation coefficient to be 0 (F-test): not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*) or 1% level (**)
FIGURE 4-2 Evolution of dry matter (A, B), respiration (C), water content (D, E), and evaporation (F) of yam as affected by post-harvest treatment with GA₃ or desprouting. 13 to 20 tubers of D. cayenensis-rotundata Krenglé were used for each mean. Data is shown as part of the initially stored tuber mass. For a 1000g tuber at the start of storage, any given value represents the weight [g] of the item A to F at the indicated time of storage. Standard error of means are included.

GA₃-treated tubers ● desprouted tubers ○ untreated tubers □
In *D. alata* sprouts were formed to 80% apically as well, but 20% of the tubers had sprouts in middle parts - mostly in the upper middle part - too, while none of the tubers had basal sprouts. Post-harvest treatments had no impact on these ratios within this species (Table 4-4). About 15 to 20% of *D. alata* tubers formed multiple sprouts from the start without differences between post-harvest treatments (data not shown). At later stages, multiple sprouts were formed by more tubers, but 30% of all tubers remained single-sprouted. Desprouting significantly increased the number of sprouts per tuber from approximately 3 to 4.5 per tuber, while GA3 appeared to reduce this number to 2.

From two storage trials tubers of *D. cayenensis-rotundata* were classified in groups of tubers which a) formed one single sprout first or which b) formed multiple sprouts from the beginning. As shown in Table 4-5 the proportion of tubers forming single or multiple sprouts was not significantly influenced by any post-harvest treatment. About one third of *D. cayenensis-rotundata* tubers formed one sprout first while the rest started off more or less simultaneously with several sprouts. Desprouted tubers having multiple sprouts from the start formed approximately 8 sprouts per tubers until the end of the storage period as compared to approximately 5 for GA3-treated or untreated tubers.

---

**TABLE 4-4 Spatial distribution of sprouting loci depending on different post-harvest treatments of *D. cayenensis-rotundata* and *D. alata***

<table>
<thead>
<tr>
<th>Treatment</th>
<th><em>D. cayenensis-rotundata</em></th>
<th><em>D. alata</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% tubers bearing sprouts on</td>
<td>Total number of sprouts per tuber</td>
</tr>
<tr>
<td></td>
<td>Apical part</td>
<td>Middle part</td>
</tr>
<tr>
<td>Untreated</td>
<td>90 a</td>
<td>10 a</td>
</tr>
<tr>
<td>Desprouted</td>
<td>91 a</td>
<td>17 a</td>
</tr>
<tr>
<td>GaDip 150</td>
<td>45 b</td>
<td>30 b</td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>50 b</td>
<td>28 b</td>
</tr>
</tbody>
</table>

**Treatment**

- ns.
- **

**SEM**

- 3.1
- 3.5
- 2.4
- 0.26

**N**

- 1136
- 1136
- 1136
- 1136
- 216
- 216
- 216
- 216

**R-Square**

- 0.91
- 0.59
- 0.64
- 0.66
- 0.1
- 0.03
- -
- 0.81

---

a. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*) or 1% level (**). Means followed by different letters are significantly different based on Least Square Means.

In *D. alata* sprouts were formed to 80% apically as well, but 20% of the tubers had sprouts in middle parts - mostly in the upper middle part - too, while none of the tubers had basal sprouts. Post-harvest treatments had no impact on these ratios within this species (Table 4-4). About 15 to 20% of *D. alata* tubers formed multiple sprouts from the start without differences between post-harvest treatments (data not shown). At later stages, multiple sprouts were formed by more tubers, but 30% of all tubers remained single-sprouted. Desprouting significantly increased the number of sprouts per tuber from approximately 3 to 4.5 per tuber, while GA3 appeared to reduce this number to 2.
Results

Effect of PNC removal. The following results come from experiment 2 (page 32). As shown in Table 4-6, the removal of the PNC (without a GA3 application) does not significantly alter the duration of dormancy or post-harvest losses. If GA3 is applied to PNC-bearing tubers, dormancy is not prolonged and the reduction of post-harvest losses is only minimal. Dormancy is significantly prolonged only if half or all of the PNC is removed. If the PNC is present and the tuber is not treated with GA3, then the first shoots of 50% of the tubers will emerge from the pre-formed buds of the PNC. After a GA3 treatment of PNC-bearing tubers, the ratio decreases, and sprouts tend to emerge from the tuber sensu strictu.

<table>
<thead>
<tr>
<th>Post-harvest Treatment</th>
<th>Single sprout (%</th>
<th>Multiple sprouts (%</th>
<th>Single sprout: number of sprouts</th>
<th>Multiple sprouts: number of sprouts</th>
<th>Number of tubers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>34 66</td>
<td>1 → 4.0</td>
<td>4.3 ab → 5.2 a</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>Desprouted</td>
<td>19 81</td>
<td>1 → 3.4</td>
<td>5.4 a → 8.7 b</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>GaDip 150</td>
<td>38 62</td>
<td>1 → 2.1</td>
<td>4.2 b → 5.7 a</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>34 66</td>
<td>1 → 3.6</td>
<td>3.4 b → 5.7 a</td>
<td>128</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 4-5 Proportion of tubers forming single or multiple sprouts at the end of dormancy and final sprout number after 5 months of storage in *D. cayenensis-rotundata* Krenglè.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>ns.</th>
<th>ns.</th>
<th>**</th>
<th>†</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEM</td>
<td>15</td>
<td>0.27</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>476</td>
<td>153</td>
<td>323</td>
<td>323</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.01</td>
<td>0.50</td>
<td>0.49</td>
<td></td>
</tr>
</tbody>
</table>

Effect of PNC removal. The following results come from experiment 2 (page 32). As shown in Table 4-6, the removal of the PNC (without a GA3 application) does not significantly alter the duration of dormancy or post-harvest losses. If GA3 is applied to PNC-bearing tubers, dormancy is not prolonged and the reduction of post-harvest losses is only minimal. Dormancy is significantly prolonged only if half or all of the PNC is removed. If the PNC is present and the tuber is not treated with GA3, then the first shoots of 50% of the tubers will emerge from the pre-formed buds of the PNC. After a GA3 treatment of PNC-bearing tubers, the ratio decreases, and sprouts tend to emerge from the tuber sensu strictu.

TABLE 4-6 Effect of the removal of the primary nodal complex (PNC) as a function of GA3 application on duration of dormancy, sprouting and post-harvest losses of *D. cayenensis-rotundata* cv. Krenglè.

GA3 was applied as GaSoil 25. Each mean is based on 20-24 tubers.

<table>
<thead>
<tr>
<th>Post-harvest Treatment</th>
<th>Dormancy [d]</th>
<th>Sprouts originating on PNC [%]</th>
<th>Post-harvest losses after 5 months [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNC intact</td>
<td>82</td>
<td>53</td>
<td>49.3</td>
</tr>
<tr>
<td>PNC removed</td>
<td>84</td>
<td>(0)</td>
<td>47.5</td>
</tr>
<tr>
<td>PNC intact + GA3</td>
<td>84</td>
<td>35</td>
<td>45.2</td>
</tr>
<tr>
<td>PNC ½ removed + GA3</td>
<td>94</td>
<td>11</td>
<td>39.5</td>
</tr>
<tr>
<td>PNC removed + GA3</td>
<td>97</td>
<td>(0)</td>
<td>39.2</td>
</tr>
</tbody>
</table>

LSD0.05  7.6  29  6.97
SEM  2.4  10.1  2.2

** Treatment

a. Sources of variation were either not significant (ns.), or significant at the 5% level (*), or 1% level (**).
Effect of the application of GA3 to different tuber parts. Trial number 5 (page 32) had the following tuber characteristics after 6 months of storage. A GA3 treatment apically or in the middle tuber part led to a significantly prolonged dormancy while a basal treatment did not (Table 4 - 7). When treated apically, the tubers formed more of their sprouts on lower tuber parts. With all other treatments about 80% of the tubers sprouted apically. Post-harvest losses were only reduced by an apical GA3 treatment.

**TABLE 4 - 7 Effect of GA3 applied to different tuber parts on post-harvest parameters of D. cayenensis-rotundata Krenglè after 6 months of storage.**

<table>
<thead>
<tr>
<th>Tuber part treated with GA3</th>
<th>% tubers bearing sprouts on</th>
<th>Post-harvest losses [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dormancy [d]</td>
<td>Apical part</td>
</tr>
<tr>
<td>Apical</td>
<td>114 a</td>
<td>48 a</td>
</tr>
<tr>
<td>Middle</td>
<td>113 a</td>
<td>87 b</td>
</tr>
<tr>
<td>Basal</td>
<td>97 b</td>
<td>82 b</td>
</tr>
<tr>
<td>Untreated</td>
<td>90 b</td>
<td>79 b</td>
</tr>
</tbody>
</table>

Treatment
- **,** *,** †,**

Standard error of mean 2.79 8.8 7.0 3.5 1.30

N 160 136 136 136 138

R-Square 0.77 0.42 0.50 0.36 0.66

a. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*) or 1% level (**). Means followed by different letters are significantly different based on Least Square Means.

Influence of the time of GA3-application on post-harvest parameters of yam. GA3 was applied at different times after harvest to *D. cayenensis-rotundata* cv. Krenglè and *D. alata* cv. Bètè bètè. Untreated tubers were included as a baseline. Details are given on page 32 (experiment number 4). For both species, a treatment at harvest time prolongs dormancy longest (Figure 4 - 3). With a treatment at this period, losses are reduced from 27% (control) to 20% for *D. alata* after 5 months of storage. A treatment 4-12 weeks post harvest (PH) is not effective in reducing storage losses, although the dormant period may be significantly prolonged. Only towards the end of dormancy (50% sprouting, at 15 weeks after harvest) was the GA3 treatment effectively reducing losses again to 20%.

The sensitivity of Krenglè towards GA3 is also highest close to the harvest time. Post-harvest losses are reduced from 47% (control) to 34% with a treatment at harvest time. The prolongation of dormancy through GA3 then decreases linearly over time, still reducing storage losses to about 40%. As for *D. alata*, the length of dormancy was not necessarily well correlated with the degree of post-harvest losses.
RESULTS

FIGURE 4-3 Length of dormancy (left) and post-harvest losses after 5 months of storage (right) depending on the time of application of GA₃. The experiment ended when 50% sprouting was reached for each species. Each mean is based on 144 tubers and two experimental years. The standard errors of means, Least Significant Differences (LSD), and values for untreated tubers (un-linked dots and dotted lines) are shown.

- D. alata cv. ‘Bètè bètè’
- D. cayenensis-rotundata cv. Krenglè

FIGURE 4-4 Relationship between length of dormancy and post-harvest losses for 17 genotypes of D. cayenensis-rotundata as affected by a GA₃ post-harvest treatment. For each line, untreated tubers (left symbol) and the GA₃-treated tubers (right symbol) are shown. 4 to 11 tubers were used per genotype and treatment.
Genotypic variability of GA₃ treatment. In experiment No. 7 (page 32) the reaction of different genotypes of *D. cayenensis-rotundata* towards a treatment with GA₃ was tested. Figure 4 - 4 shows that untreated tubers experienced losses from 18 to 63% depending on the genotype. Most genotypes lost 33 to 45% during three months of storage. The dormancies were short compared to Krenglè, i.e. 40 to 60d. For most cultivars, the application of GA₃ prolonged dormancy and led to a decrease of post-harvest losses, which can be seen on the general upper-left to lower-right trend in Figure 4 - 4. For extreme genotypes, dormancy may have been prolonged significantly but the storage losses not reduced, and vice versa.

4 - 4 Discussion

**Effect of GA₃ on respiration and evaporation of yam tubers.** Although the sprout is the only visible factor of loss in sound tubers, both respiration and evaporation are more important regarding daily losses (Figure 4 - 2, Table 4 - 8). Since the loss of water is more attenuated than the loss of DM, the DM content of tubers rises over time. Similar findings were described for *D. rotundata* by Treche (1979), where DM rose slowly from 36 to 38% and reached 46% after the termination of dormancy.

**TABLE 4 - 8 Daily post-harvest losses, respiration and evaporation of *D. cayenensis-rotundata* Krenglè during sprouting.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Overall losses</th>
<th>Respiration g kg⁻¹ d⁻¹</th>
<th>Evaporation %</th>
<th>Sprout g kg⁻¹ d⁻¹</th>
<th>Loss of dry matter g kg⁻¹ d⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA₃</td>
<td>1.9</td>
<td>0.2</td>
<td>1.1</td>
<td>0.6</td>
<td>11</td>
</tr>
<tr>
<td>Desprouted</td>
<td>2.1</td>
<td>0.4</td>
<td>1.5</td>
<td>0.2</td>
<td>19</td>
</tr>
<tr>
<td>Control</td>
<td>2.7</td>
<td>0.4</td>
<td>1.5</td>
<td>0.8</td>
<td>15</td>
</tr>
</tbody>
</table>

a. Composed of the respiration rate and the DM-component of the sprout (calculated at a DM content of 200g kg⁻¹).

The respiration rates obtained with the DM balance sheet method compare well to directly measured ones from other researchers summarised in Figure 2 - 1 on page 6. The data obtained in the current experiment is presented in a comparable way in Table 4 - 8. The temperature and humidity in the present experiment were not controlled, but the mean temperature of 26°C and 80% RH in the storage sheds indicate that no major divergence should originate from these external factors. Temperature has been shown to influence respiration rates (Coursey *et al.* 1966, Passam *et al.* 1978).

Among the components of overall post-harvest losses, evaporation contributes most to the daily loss. Second in importance was sprout development. For untreated and GA₃-treated tubers, one third of the daily losses were due to the dislocation of reserves into the sprout. For GA₃-treated but especially for desprouted tubers, the absolute values
were much decreased. Respiration was least important, especially for GA3-treatment. The respiration rate and the DM-loss to the sprout essentially constitute the loss of edible dry matter, a term coined by Girardin (1996) regarding yam storage (he also included the peeling losses). Since the DM content of the sprout is approximately 200g kg\(^{-1}\), the respiration contributes 60% to the loss of DM for untreated and GA3-treated tubers. For desprouted tubers, the contribution of respiration to the edible DM loss rises above 90%.

GA3-treated tubers also exhibited a lower evaporation rate than untreated tubers (Figure 4 - 2, Table 4 - 8). This indicates that GA3 has an effect beyond the prolongation of dormancy. Transpiration is generally modelled using Fick's Law (Ben-Yehoshua 1987). Using the water potential deficit, surface area : volume ratio and crop-specific correction factors which express the resistance to water movement, the gaseous exchange can be adequately described. In the present case, temperature and RH were stable across the conservation period, although daily oscillations were substantial (see page 24). Therefore, the strict linear trend observed while modelling the evaporation (with a goodness of fit of 94%) was not surprising: the loss of water was constant over the whole period. Linear loss of water was also found for *D. alata* and *D. esculenta* (Ravindran & Wanasundera 1992). But why did GA3-treated tubers have a lower evaporation rate than untreated tubers? This fact was statistically highly significant and, as shown in Table 4 - 8, was responsible for 50% of the reduction in daily losses observed between untreated and GA3-treated tubers.

Among the variables of Fick's Law, it seems unlikely that the water potential deficit is influenced by GA3. Rising DM-content, leading to increased osmotic pressure, would decrease evaporation for untreated tubers, which is the opposite of the trend observed here.

Three hypotheses can be put forward: either GA3, or other secondary messengers, affect membrane properties such that the crop-specific correction factors for Fick's law are modified. Or, the surplus surface of sprouts formed by untreated tubers increases the transpirationally active surface and therefore the evaporation increases. As a third option, the increased respiration rate observed in untreated tubers leads to the production of more energy from the dissimilation process. This energy is generally dissipated through direct heat transfer to the environment and through evaporation of water.

Modification of membrane properties regarding water transport have never been described for the primary second messenger, batatasin, and shall therefore be disregarded here. That the increased surface through longer sprout length may play a role could be shown using linear regression. The sprout length was the best measurement of sprout surface available. A statistically significant linear relationship between evaporation and sprout length was found for untreated tubers (Table 4 - 2). Because both desprouted and GA3-treated tubers had artificially modified sprouting behaviour, the lower significance of the sprout length for the evaporation rate may be
explained. The increased sprout surface appears as a possible candidate to explain the increased evaporation of untreated tubers.

If it is assumed that all dissimilated matter is transformed into energy (at 18kJ g⁻¹) and that all energy is discharged as water vapour (at the expense of 2.43kJ g⁻¹ at 30°C), it can be calculated that untreated tubers should loose 3g water kg⁻¹ d⁻¹ and GA₃-treated tubers 1.5g kg⁻¹ d⁻¹ if isothermy should be maintaineda. These figures are greater than the values actually measured. Therefore, the higher respiration rate could also be held responsible for increased evaporation rates. The statistical analysis showed a clear correlation between the evaporation rate and the respiration rate (Table 4 - 2). Tubers that respire more apparently evaporate more. When sprout length and respiration rate were used together as regressors for the evaporation rate, only the respiration remained a significant factor for untreated tubers (Table 4 - 3). This is not surprising, because sprout length and respiration rate are correlated for these tubers, too (Table 4 - 2). For untreated tubers the respiration rate appears to be a major driving force for the evaporation according to the explanation given above. For desprouted tubers, the respiration rate is a similarly important factor. For GA₃-treated tubers, however, having a small respiration rate, neither component contributes significantly to the linear model for the evaporation. Their evaporation is mainly dominated by the basic parameters, such as the tuber surface and temperature. These two parameters also apply for untreated and desprouted tubers, but they are less determining.

Since the relation of water and DM loss are modified in GA₃-treated tubers, a different DM content is observed during storage. This DM content might be directly responsible for the quality changes that Nindjin (2002) has observed during storage. Serpantie (1983) has already claimed that below 250g kg⁻¹ and above 350g kg⁻¹ DM, a good pounding quality cannot be obtained. *D. cayenensis-rotundata* starts off with a relatively high DM content (350g kg⁻¹, Figure 4 - 1) and a good pounding quality. The DM rises for untreated tubers up to 480g kg⁻¹, and the quality deteriorates. Because of the GA₃ treatment the rise in DM-content is retarded, and consequently the pounding quality decreases more slowly. Compared to untreated tubers, GA₃-treated tubers appear to conserve a better pounding quality, which is what Nindjin had observed. This theory fits to the fact, that for *D. alata* the pounding quality (of untreated tubers) improves over time. This more watery species needs a rising DM content in order to yield good pounded yam. GA₃ application hinders this rise of DM content (Girardin 1996), and consequently leads to a lower quality after storage. This, too, was observed by Nindjin (2002).

**Sprout localisation as affected by GA₃.** The application of GA₃ to different tuber parts has shown that, when applied apically, GA₃ brings about a distortion of the sprouting localisation. This raises the question of how GA₃ modifies the four levels of apical dominance, which adequately describe the sprouting of yam (page 18).

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a. The formation of water during the oxidation of starch is neglected here. 1g of starch releases 0.6g of water upon dissimilation. The energy released, 18kJ g⁻¹, allows 7.7g of water to evaporate at 30°C.
The control of polar sprouting, i.e. where on the tuber sprouts are formed, is probably exerted well before the end of dormancy. This process, which may also be termed determination of sprouting loci, is not understood in yam (Suttle 1996). If preformed buds are present on the PNC, sprouting seems to mostly start there (Table 4 - 6). If the PNC is absent, and consequently no preformed buds are available, sprouting appears to take place preferentially on the apical tuber part, close to the abscission of the mother plant, i.e. of the PNC (Table 4 - 7 and Table 4 - 4). This is also true for bisected tubers (Passam 1977). It was suggested that this gradient of polar sprouting relates to the maturity of the concerned tissue, the oldest cells being found at the apical end (Craufurd et al. 2001). The application of GA$_3$ on a wounded or unwounded PNC suggests the capability of this phytohormone to modify sprouting pattern. It then increases the chance for a sprout growing on the tuber body instead of on the PNC (Table 4 - 6). But more so when the PNC is absent, and GA$_3$ is applied as done conventionally on its abscission place, the sprouting localisation is distorted. This can be observed by the higher number of tubers forming sprouts at middle and basal tuber parts (Table 4 - 4). It is only on this level of apical dominance, termed polar sprouting, that GA$_3$ had an appreciable releasing effect, and even then only for $D$. cayenensis-rotundata. As for $D$. alata, the application of GA$_3$ had no influence on polar sprouting. Regardless of the treatment, sprouts rarely emerge in this species at middle tuber parts and never at basal parts of the tuber.

The strong polar sprouting was also described by Passam et al. (1982b) in bulbils of $D$. alata. Whereas bulbils of $D$. bulbifera sprouted upon a humidity stimulus at any place of the bulbils's skin, $D$. alata bulbils sprouted invariably near the site of abscission. These bulbils also reacted differently towards a sprout inhibiting chemical (GA$_3$), in such a way that polar sprouting had a stronger positive correlation with a larger extension of dormancy by GA$_3$. When $D$. alata is compared to $D$. cayenensis-rotundata in the present study, this correlation cannot be upheld. $D$. alata as a strong polar sprouter has a weaker response to GA$_3$ than $D$. cayenensis-rotundata. Even at ideal time of application, GA$_3$ prolongs dormancy more in $D$. cayenensis-rotundata than in $D$. alata (Figure 4 - 3). Quite possibly, the number or size of the roots on the tuber surface during growth might indicate the extent of polarity shown during sprouting, as it was suggested by Ferguson and Gumbs (1976). Unfortunately, no quantitative studies are available on this topic. Ireland and Passam (1984) examined the longitudinal distribution of phenolic plant growth inhibitors on $D$. alata. Unidentified substances as well as batatasins were concentrated in the apical part at harvest, then declined steadily over time, until upon sprouting no more differences were found between apical and basal parts. In view of the phenotype observed here, these phenolic growth regulators are unsuitable candidates to explain polar sprouting.

Apical control, i.e. the delayed formation of subsequent sprouts once the first has emerged, is weak in $D$. cayenensis-rotundata as two thirds of the tubers end dormancy with the formation of several sprout loci (Table 4 - 5). This is in agreement with Passam (1977) who counted 2.15 sprouts per tuber when dormancy ended. Apical control is also weaker in $D$. cayenensis-rotundata than in $D$. alata because in the former
more sprouts are formed over the whole post-dormant period. For *D. cayenensis-rotundata*, GA$_3$ leads to a slight release of apical control (Table 4 - 5). For *D. alata*, GA$_3$ decreases the number of sprouts (Table 4 - 4) and thus seems to increase the apical control. Desprouting leads to an efficient release of apical control of both species. According to Serpantie (1983), this might be less so if desprouting happens when the first sprout is longer (>50cm).

Even though several sprouts may be formed at the end of dormancy, one of these sprouts is always dominant and efficiently suppresses or retards the growth of the others. This effect was referred to as tuber apical dominance. For *D. cayenensis-rotundata* the tuber apical dominance could be measured directly on tubers which formed multiple sprouts from the start. At a subsequent measurement, the multiple sprouts had varying length, indicating the preferential growth of one and the curtailed growth of the other sprouts (data not shown). GA$_3$ or desprouting as post-harvest treatments had no impact on these mechanisms. Qualitative observations on the branching of sprouts as an indicator for the sprout apical dominance, suggested that GA$_3$ has no effect on this mechanism either.

Table 4 - 9 summarises the classification of apical dominance as presented on page 18 for both species. Only polar sprouting is affected by GA$_3$. All other levels of apical dominance, i.e. apical control and apical dominance *per se*, appear to be only a little or not at all affected by GA$_3$. It must be concluded that once dormancy is lifted, the previously applied GA$_3$ has no more effect on the sprouting behaviour of yam tubers.

**TABLE 4 - 9 Summary of apical dominance in *D. cayenensis-rotundata* and *D. alata*.
Explanation of terminology of apical dominance on page 18.**

<table>
<thead>
<tr>
<th>Type of apical Dominance</th>
<th>Visible sign</th>
<th>Hypothetical time of installation of the apical dominance</th>
<th>Visible time of release</th>
<th>Effect of post-harvest application of GA$_3$ on dominance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar sprouting</td>
<td>Sprouts originate preferentially on apical tuber end</td>
<td>Inception of dormancy (soon after tuberisation)$^a$</td>
<td>intermediate stage of sprouting</td>
<td>2b efficient release</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apical control</td>
<td>Subsequent sprouts are formed after the 1st is installed</td>
<td>Formation of 1st sprout</td>
<td>for 2/3 of the tubers at sprouting, else late stage of sprouting</td>
<td>1 slight release$^c$ slightly increased$^c$</td>
</tr>
<tr>
<td>Tuber apical dominance</td>
<td>Elongation of subsequent sprouts is curtailed</td>
<td>Elongation of 1st sprout</td>
<td>late stage of sprouting</td>
<td>3 none (none)</td>
</tr>
<tr>
<td>Sprout apical dominance</td>
<td>Branching of sprout is inhibited</td>
<td>Formation/elongation of 1st sprout</td>
<td>very late stage of sprouting</td>
<td>4 (none) (none)</td>
</tr>
</tbody>
</table>

$^a$ Crafurd et al. 2001
$^b$ Not applicable for *D. alata* since its tubers hardly ever sprout basally.
$^c$ Efficient release through desprouting.
Site of GA$_3$ application. The PNC is the only organ bearing pre-formed buds at harvest (Onwueme 1973). Wickham et al. (1981) noted that the PNC is the organ of renewed growth and that its germination suppresses further shoot development in the tuber. The PNC, or rather the preformed buds present on it, also seem to control the site of sprouting in the present experiment. An application of GA$_3$ leads to a shift in the location of the sprouts from the PNC to the rest of the tuber body. The PNC, however, does not seem to control tuber dormancy to a large extent as was suggested by Wickham et al. (1981). Table 4 - 6 shows that the removal of the PNC does not have a major impact on the duration of dormancy. The same was shown for D. alata by Rao and George (1990). It is suggested that, although dormancy may well be partially controlled by the PNC, a mature tuber that does not have a PNC is dormant for the same length of time. The dormancy control is not localised in a given structure, but appears to be present all over the tuber.

When the tubers have their PNC removed, the site of application of GA$_3$ also matters. Only an apical treatment, i.e. close to the natural sprouting locus, reduces the sprouting there (Table 4 - 7). Furthermore, it increases sprouting at lower tuber parts. An application at middle or basal parts could delay sprouting of the entire tuber, but not very efficiently. The high number of tubers bearing sprouts medially with an apical treatment suggests the sprout-suppressing agent works systemically. Although GA$_3$ is only applied on the apical end, a visible effect on the localisation of sprouts is observed. Therefore a sprouting-regulating agent must be transported to lower tuber parts. This is supported by the effect of the application of GA$_3$ to middle parts, which significantly prolonged dormancy. Such an action may be termed "systemic".

It appears, however, that only when GA$_3$ is applied apically, are post-harvest losses reduced. GA$_3$ should, therefore, be applied there. Most importantly, it was shown that a wound is mandatory if GA$_3$ is to be effective. Where the removal of the entire PNC is not desired, a small wound must nevertheless be inflicted on the PNC. The PNC is considered an integral part of the tuber and its presence is necessary for commercialisation in Nigeria (G.C. Orkwor, pers. comm.\textsuperscript{b}, own interviews in Zaki Biam, Nigeria). In this case removal of a small part of the PNC is recommended, or infliction of a wound on the apical tuber part and treatment of these wounds with GA$_3$.

Time of GA$_3$ application. There is a general agreement that a GA$_3$ should be applied to D. alata as soon as possible after harvest (Martin 1977, Passam 1982b, Wickham et al. 1984a), which is supported here. A treatment with GA$_3$ more than 4 weeks after harvest did not reduce storage losses (Figure 4 - 3 on page 48). Only a treatment at 50% sprouting (12 weeks after harvest) led again to a reduction of post-harvest losses. Hypothetically, the general metabolic resting period of the yam tuber, as observed by respiration rates soon after harvest, leads to inefficient uptake, dislocation or activation of GA$_3$. With a GA$_3$-treatment during this "deep-dormant" period, the phytohormon seemingly does not reach its site of action, or not in an active form. It is suggested here

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54
that with the initiation of sprout formation (which happens well before the visible appearance of sprouts (Onwueme 1973)), a general activation occurs which enhances the receptivity of yam tubers to GA3.

The time-reaction pattern of \textit{D. cayenensis-rotundata} is distinctly different from \textit{D. alata}. A treatment with GA3 at the harvest time is best but not mandatory in order to reduce post-harvest losses. During the whole "deep-dormant" period, GA3 may also be applied with the expected effect of dormancy prolongation and the reduction of post-harvest losses. It seems that the tuber of \textit{D. cayenensis-rotundata} maintains a high enough metabolic activity to allow efficient uptake and activation of GA3 during the entire dormant period. This difference of metabolic rates between the two species is also observed in the daily losses (see Table 6 - 1 and Table 6 - 3 on page 90f).

Not surprisingly, when different genotypes are treated with the same GA and the same method, a wide range of response is encountered. Although the prolongation of dormancy may be termed generally applicable for all genotypes employed, the absolute value thereof, as well as the reduction of post-harvest losses, are highly variable (Figure 4 - 4). This provides a good perspectives from which to discriminate new varieties for storage requirement as well as to choose adequate germplasm for selection goals.

\textbf{4 - 5 Conclusion and outlook}

\textit{GA3} decreases losses in a threefold way: Firstly, as a direct implication of the prolongation of dormancy, DM and water is translocated into sprouts later, and therefore less DM and water is lost compared to untreated tubers. Secondly, the respiration is decreased in GA3-treated tubers because non-sprouting tubers respire less, but presumably also due to a deepening of the dormancy, and an increased batatasin content leading directly to curtailed respiration. Thirdly, the evaporation of GA3-treated tubers is decreased, because less transpirationally active surface is formed on sprouts and because the lower respiration implies, or allows, a lower evaporation.

Exogenously applied GA3 might at least have two different roles in the yam tuber: first it increases the level of growth inhibitors (batatasins according to Ireland and Passam 1984) and so suppresses sprouting in general, and prolongs dormancy. Secondly, GA3 also appears to influence the localisation of sprouts in relation to the apical tuber end. Onwueme (1973, 1982a) described the apical dominance exerted by a sprout as suppressing other sprouts within a certain radius. This zone of inhibition must be signalled by a molecule, upon which, hypothetically, GA3 has an influence. The agent regulating the spatial localisation of yam sprouts has not been discovered so far, but with the present knowledge, it may be deduced that it is unlikely to be the batatasins. In view of their biochemical properties (see page 15), batatasins may be effectors. They are regulated by GA3 but are not the initiators of dormancy. GA3 is most effective right
after harvest. This lets us suppose that dormancy is induced on the tuber by its mother plant, as it is only right after harvest that the tuber is still sensitive to hormonal inputs from the mother plant.

The effect of yam tuber physiology on the efficiency of GA application has been shown to vary upon the site of application, the time of application, the genotype treated and on which GA is used. This may lead to the conclusion that GA3 application is far too variable to be a suitable treatment. In view of the fact that the best values for these parameters are known, this knowledge serves also to finetune the application of GA3: the chemical should be applied apically as soon after harvest as possible. High genotypic variance is to be expected. Treatment of an untested genotype must be optimised using different application types, times and concentrations.

The genetic potential for prolonged dormancy has not yet been properly acknowledged and taken advantage of. It has been shown above that new genotypes from the IITA have shorter dormancies than local ones from the Ivory Coast. This may have arisen from the desire of yam breeders to have a short dormancy in order to fit two growing cycles into one year. Although it allows a considerably faster selection process, it clearly poses a problem for post-harvest behaviour. The alternative to a genetically short dormancy is a reliable method of prematurely breaking dormancy which might be used for fast breeding. Unfortunately, no such method is available yet, although preliminary results are encouraging (Shiwachi, pers.l comm.c). It is recommended that a long dormancy should be a selection criterion.

General knowledge on yam dormancy across the world suggests strong genotypic variance. In potatoes, several loci have been identified as responsible, and a complex inheritance pattern is observed (Suttle 1996). The identification of such loci would be desirable for yam. Mutants and genetic variability may also be used to better understand the basic biology of dormancy control in tuberous organs (Suttle 1996). Research in this direction should focus on the implication of dormancy in timing of field emergence, tuberisation and tuber maturity, as cross-selection of these traits is likely. If it can be made available, marker based selection seems a sensible path to follow.

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Yam tubers may be cut into segments for planting. The weight and quality of these so-called setts strongly influences tuber yield. In order to elucidate the effect of a post-harvest GA$_3$ treatment of seed tubers on the quality of setts, a combined storage and field experiment was carried out.

Seed tubers of *D. cayenensis-rotundata* cv. Krenglé showed slightly reduced post-harvest losses after 4 months of storage if desprouting or GA$_3$ application were used. Because absolute losses were small, the sett size did not vary much between the treatments.

Neither the time to emergence nor the tuber yield were influenced by the post-harvest treatments. The time of emergence was, however, significantly affected by the sett origin on the mother tuber and sprouting state. Setts cut from the apical tuber parts sprouted fastest. Setts with a sprout at planting emerged 10d earlier than not-sprouted setts. Yield was strongly and positively correlated with the time of emergence. Therefore, apical setts and sprouted setts had the highest yields. The yield increase by sprouting at planting was linearly related to the time of emergence. With regard to the tuber position of the sett, seemingly a true gradient for yield potential existed within the tuber, which was independent of the time to emergence. It is recommended that setts that have sprouted at planting time should be planted together and on preferred sites. This should alleviate the problems of timing of cultural measures and redirect resources to promising yam stands.

When GA$_3$-treated seed tubers were cut into setts, more basal and middle setts had sprouts at planting compared to the two other treatments. However, fewer apical setts had sprouts. Therefore, GA$_3$ treatment led to a more homogenous yield for setts of different origins. This effect could help to reduce the negative effects of asynchronous field emergence known in yam fields. The GA$_3$ treatment did slightly reduce the number of tubers per stand, and consequently, the mean tuber weight was higher for this treatment.
5 - 2 Introduction

The importance of yam to the population living in the yam belt of West Africa, but also in other producing regions, has been discussed in the general introduction. Here, it must be re-emphasised, that the field performance of yam lags behind the increasing population and supply has been increased mainly through an expansion of the cultivated area (Doumbia 1998, Orkwor et al. 1998, FAO 2002). The technological development of yam production has been slow and in many cases, has had little impact on farmers' production techniques (Hahn et al. 1997). The principal problems of yam production that have been identified are the high cost of seed yam, high labour requirement, diseases and pests as well as high post-harvest losses (Orkwor et al. 1998).

The high cost of seed yam is easily explained since there is a positive correlation between the size of the sett planted and yield (Miège 1957, Onwueme 1982a, Ahoussou et al. 1983). Planting a large sett is expensive, but is rewarded with a more secure and generally higher yield. Larger setts emerge more rapidly (Onwueme 1978, Ahoussou et al. 1983, Nwoke et al. 1984), form a greater number of sprouts, and have a higher rate of emergence (Onwueme 1973). Large setts also lead to a higher mean tuber weight (Enyi 1972). Because the new yam plant draws on the material of the mother tubers until the 8th week (Njoku et al. 1984) and large setts provide more reserves, larger setts produce more vigorous plants. Other growth characteristics such as relative growth rate, net assimilation rate and leaf area ratio do not appear to be influenced by sett size (Nwoke et al. 1984). Ivorian farmers also tend to believe that a large sett can compensate for a nematode infection or rot of a tuber piece. Both diseases lead to a yield depression (Adesiyan et al. 1975, Atu et al. 1983, Mignucci et al. 1984).

Farmers tend to prefer small, whole tubers or setts cut from the apical end of a larger yam tuber (Onwueme 1982a). Whole tubers produce higher yields than fragmented ones (Dumont & Jeanteur 1988), possibly due to the larger coverage with periderm (Akoroda 1986) (D. floribunda seems an exception to this rule, as it was shown that whole tubers took longer to emerge than fragmented ones in this species (Rao et al. 1974)). Setts cut from apical tuber parts yield better than setts cut from lower lying parts of the tuber (Miège 1957, Goenaga et al. 1989). This explains the well known asynchronous emergence in yam fields. Trouslot (1983) suggested that the irregularity of emergence might be influenced from the mother tuber's physiological state, for example whether a bud was available at planting.

Both sett size and physiological characteristics may be influenced by the storage of yam. Although the period of storage may vary largely because of climatic and cultural conditions, modified by genotypic variability, the generally quoted vegetation period of 7 to 12 months for the cultivation of Dioscoreaceae suggests storage of seed tubers for 0 to 5 months. Biologically, this period corresponds to the natural dormant period which allows the yam to overcome periods of unfavourable growth conditions. In the cultivation of yam, this period may be longer than the natural dormancy, because of other constraints such as preparation of fields, rainfall, or the farmer's decision.
Whereas post-harvest losses would be low if the yam would develop its vegetative apparatus at the end of natural dormancy, the delay due to human decision leads to higher post-harvest losses if seed tubers are stored beyond the end of natural dormancy. Orkwor and Asadu (p. 123 in Orwor *et al.* 1998) collected information on the major planting times of yam in the Ivory Coast, Ghana and Nigeria. 34 to 100% of the yam is planted in the months March through May. In Nigeria, where 70% of the yam is produced (FAO 2002), 80% of it is planted in March and April. This indicates that a large portion of the seed yam is stored up to and beyond the end of natural dormancy, known to last from 2 to 4 months in West Africa (p.48 in Orkwor *et al.* 1998). Nwankiti *et al.* (1988) seemed to overestimate the duration of storage for seed yam in Nigeria, stating it to last 6 to 7 months. The losses in fresh and dry matter (DM) occurring during this post-dormant period may be substantial. Preformed, long sprouts are generally curtailed prior to planting because long sprouts are impractical for handling and risk breaking off. Some sprouts may be removed completely in order to reduce inter-sprout competition (own interviews).

The absence of uniform sprouting constitutes a major constraint on the implementation of cultivation practises such as weeding, herbicide and fertiliser application, as well as on synchronous maturity at the first harvest, etc. Therefore, farmers may wait for uniform sprouting of the seed tubers, i.e. up to the end of dormancy in all stored seed tubers, in order to obtain uniform sprouting in the field. Onwueme (1982b) suggested the use of aged tubers to overcome asynchronous emergence.

The only detailed publication available that deals directly with the effect of post-harvest parameters on yield is from Nwankiti (1988). Tubers from *D. cayenensis-rotundata* and *D. alata* were subjected to different sprout removal regimes. At 70d after harvest 32% post-harvest losses (mixed value for *D. cayenensis-rotundata* and *D. alata*) had been observed. Regular desprouting reduced the loss substantially to 13%. Planted as minisets (25g), there was no difference in emergence between the treatments, but a significant difference in Leaf Area Index 105 days after planting was noted, which disappeared 120 days after planting. Final yield was higher for plants originating from desprouted tubers (12t ha\(^{-1}\)) than from untreated tubers (9t ha\(^{-1}\)). The calibration of tubers was unaffected. Nwankiti (1988) explicitly discouraged using sprout suppressing agents on seed yam tubers. Without offering more details, another author, Igwilo *et al.* (1988), noted that GA\(_3\)-treated tubers sprouted and developed normally when planted after 12 months of storage.

The use of sprout suppressing agents on seed yam is thus controversial. The effect of reduced losses during storage of seed tubers appear, however, to be beneficial for subsequent cultivation. Therefore, the influence of methods that reduce post-harvest losses - GA\(_3\) application and desprouting - on the field performance of seed yam tubers was investigated. Furthermore, it was specifically aimed to study the effect of the GA\(_3\)-derived distortion of the sprouting localisation as described in the previous chapter on seed tuber performance. For this purpose, the results of experiment no. 6 (page 32) are presented and discussed in the following paragraphs.
5 - 3 Results

**Post-harvest losses of seed yam tubers.** The results of the two-year storage trial are summarised in Table 5 - 1. Dormancy was significantly prolonged for seed yam by 10d for both GA3 treatments. There was no difference between the two GA3-treatments. GA3 led to a lower total numbers of sprouts per tuber, because apical tuber parts had lower number of sprouts. Middle and basal tuber parts of GA3-treated tubers had higher numbers of sprouts than both control and desprouted tubers. Desprouted tubers had more apical sprouts than all other treatments. The post-harvest losses of all treatments were low, ranging from 13 to 20%. GA3 reduced storage losses best, followed by desprouted tubers and untreated tubers. The factor year had a significant effect on post-harvest losses but none on sprouting behaviour.

**TABLE 5 - 1 Effect of GA3 treatment on post-harvest parameters of seed tubers of D. cayenensis-rotundata cv. Krenglé after 4 months of storage.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dormancy [d]</th>
<th>Number of sprouts</th>
<th>Post-harvest losses [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>total</td>
<td>apical</td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>59 a</td>
<td>1.7 b</td>
<td>0.7 c</td>
</tr>
<tr>
<td>GaStarch 300</td>
<td>59 a</td>
<td>1.6 b</td>
<td>0.7 c</td>
</tr>
<tr>
<td>Desprouting</td>
<td>48 b</td>
<td>2.4 a</td>
<td>2.0 a</td>
</tr>
<tr>
<td>Control</td>
<td>50 b</td>
<td>2.0 b</td>
<td>1.6 b</td>
</tr>
<tr>
<td><strong>Treatment</strong></td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td><strong>Year</strong></td>
<td>**</td>
<td>ns.</td>
<td>ns.</td>
</tr>
<tr>
<td>SEM</td>
<td>2.6</td>
<td>0.14</td>
<td>0.07</td>
</tr>
<tr>
<td>N</td>
<td>303</td>
<td>842</td>
<td>842</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.71</td>
<td>0.67</td>
<td>0.94</td>
</tr>
</tbody>
</table>

a. not available, data of 2001 only
b. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*) or 1% level (**). Means in the same column followed by the same letter are not significantly different (P=0.05) based on Least Square Means.

**Characteristics of setts.** For each planted sett it was recorded whether it already had a sprout dating back to the storage period, and from which tuber part it originated. 80 to 90% of setts cut from apical tuber parts of control or desprouted tubers had sprouted at planting time whereas only 50% of GA3-treated tubers had only sprouted at that time (Table 5 - 2). However, two to four times the number of setts cut from middle and basal tuber parts had sprouted in GA3-treated tubers. Middle parts of control and desprouted tubers did not sprout at all, while only 10% of the basal setts from these groups had sprouted. Overall, setts from GA3-treated tubers had a significantly lower percentage of sprouting at planting time. Sett weight was calculated using the tuber weight obtained from the storage experiment divided by the number of sett cut from the tuber. Setts from GA3-treated and desprouted tubers were significantly heavier than those cut from control tubers but the absolute differences varied from just 7 to 10g.
Effect of Post-Harvest Treatments on the Performance of Seed Yam

General growth characteristics. Final emergence was higher in 2000 (97.5%) than in 2001 (92.7%). It was not influenced by the origin of the sett or the post-harvest treatment. The yield level was lower in 2001 (11.9t ha\(^{-1}\)) than in 2000 (18.4t ha\(^{-1}\)). The sett multiplication ratio (Akoroda 1985) was 11 in 2000 and 7 in 2001. If whole tubers were planted the time to emergence was reduced by about 7d compared to apical tuber parts for all treatments (data not shown). The yield was considerably higher for whole seed tubers (21.9t ha\(^{-1}\)) than for setts of fragmented seed tubers (15.3t ha\(^{-1}\)). Because this did not reflect the aim of the trial, only very few whole tubers were planted in 2001, and consequently results of whole tubers are excluded from the tables and figures. Likewise, guard plants and nematode infested plants were excluded from the following presentation of results. The disease scores and vegetative growth variables were not influenced by any fixed factor used in the experiment.

At first, all fixed factors occurring were analysed with a simple model, i.e. the factor alone plus the random factors (block, field). For the factor post-harvest treatment, Table 5 - 3 shows that few significant differences were observed. The number of tubers per plant were lower for GA\(^3\) treatments in both years, but the difference was only significant in 2000. Likewise, the mean tuber weight was only significantly different for treatments in 2001. The time to emergence and yield were not significantly affected by the post-harvest treatments.
TABLE 5-3 Yield and yield parameters of *D. cayenensis-rotundata* cv. *Krenglé* as affected by post-harvest treatment of seed tubers.
The ANOVA was carried out per year and took only the indicated factor plus blocks/fields as random factors into account. Nematode infested plants, guard plants, and plants grown from whole seed tubers were excluded.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Time to emergence [d]</th>
<th>Number of tubers per plant</th>
<th>Yield [t ha⁻¹]</th>
<th>Mean tuber weight per plant [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaStarch 860</td>
<td>28.6</td>
<td>41.2</td>
<td>2.07a</td>
<td>1.95</td>
</tr>
<tr>
<td>GaStarch 300</td>
<td>27.3</td>
<td>42.3</td>
<td>2.07a</td>
<td>1.94</td>
</tr>
<tr>
<td>Desprouting</td>
<td>26.1</td>
<td>40.7</td>
<td>2.68b</td>
<td>2.13</td>
</tr>
<tr>
<td>Control</td>
<td>28.2</td>
<td>39.2</td>
<td>2.46ab</td>
<td>2.11</td>
</tr>
</tbody>
</table>

| Treatment a     | ns. | ns. | ** | ns. | ns. | ns. | ns. | *   |
| SEM             | 1.71| 1.33| 0.15 | 0.19 | 4.44 | 3.98 | 275  | 117 |
| N               | 265 | 308 | 265 | 308 | 265  | 308  | 265  | 308 |

a. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*) or 1% level (**). Means in the same column followed by the same letter are not significantly different (P=0.05) based on Least Square Means.

TABLE 5-4 Yield and yield parameters of *D. cayenensis-rotundata* cv. *Krenglé* as affected by origin of the sett on the seed tubers.
The ANOVA was carried out per year and took only the indicated factor plus blocks/fields as random factors into account. Nematode infested plants, guard plants, and plants grown from whole seed tubers were excluded.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Days to emergence</th>
<th>Number of tubers per plant</th>
<th>Yield [t ha⁻¹]</th>
<th>Mean tuber weight per plant [g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apical sett</td>
<td>23.8 a</td>
<td>39.9 a</td>
<td>2.13 a</td>
<td>1.95</td>
</tr>
<tr>
<td>Middle sett</td>
<td>32.7 c</td>
<td>41.5 b</td>
<td>2.14 a</td>
<td>2.28</td>
</tr>
<tr>
<td>Basal sett</td>
<td>28.9 b</td>
<td>42.0 b</td>
<td>2.75 b</td>
<td>1.98</td>
</tr>
</tbody>
</table>

| Treatment a | ** | *   | ** | ns. | ** b | *   | ** b | † |
| Standard error of means | 1.0 | 1.06 | 0.27 | 0.11 | 2.37 | 0.75 | 82   | 64 |
| N           | 265 | 308 | 265 | 308 | 265  | 308  | 265  | 308 |

a. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*) or 1% level (**). Means in the same column followed by the same letter are not significantly different (P=0.05) based on Least Square Means.

b. For normalisation, square-root transformed values were used for the ANOVA.

The same analysis was used to describe the effect of the origin of the sett on plant characters (Table 5-4). Apical setts were consequently superior to lower based setts. In all years, they sprouted faster, had 2 to 4 t ha⁻¹ more yield and a higher mean tuber weight. The differences between middle and basal derived setts were erratic.

The state of sprouting of a sett especially strongly influenced most parameters (Table 5-5). Setts that had already sprouted at planting emerged quicker, had a higher yield (though not significantly in 2000) and produced heavier tubers. The number of tubers per plant was only significantly affected by sprouting state in 2000.
Correlation of covariates and yield. The results of the correlational analysis is presented in Table 5 - 6. Covariates were grouped according to the time when they had been measured. Within the covariates measured during the conservation period, only the weight of the sett was correlated slightly with the yield. In the range of sett size used here, the correlation between yield and sett size was positive and significant. However, only a little of the variation in yield could be attributed to the sett size as shown in the linear regression (Table 5 - 6). The dormancy was poorly correlated with the number of days to emergence (data not shown) and with the yield.

Covariates measured during the vegetation period generally had high correlation coefficients and regressors were highly significant. The number of days to emergence were negatively correlated with the yield (-0.47 t ha⁻¹ per day). The number of shoots, the vigour of the plant at 3 months after planting as well as the planar surface measured photographically, were all positively correlated with the yield. The three vegetative parameters (number of shoots, vigour, and planar surface) were all correlated to a varying degree with the number of days to emergence (data not shown). Disease scores were negatively correlated with yield. In particular, yam mosaic virus led to a yield decrease of 5 t ha⁻¹ per unit of virus score.

All four criteria chosen for the evaluation of the photosynthetic apparatus, i.e. volume, branching, vigour and plant planar surface, were highly intercorrelated. Both volume and branching were correlated to more than 80% with the vigour (data not shown). The photographic evaluation of the planar leaf surface as a quantitative measurement was highly correlated with all three qualitative criteria (> 80%). Therefore, the measurement of one criteria only was sufficient to obtain an estimate for yield. The photometric measurement was better correlated with yield than was the vigour (Table 5 - 6).
The two covariates measured at harvest in addition to the yield itself, i.e. the number of tubers and nematode infestation, were both highly and positively correlated with the yield. It is important to note that higher nematode scores led to higher yield. This applies foremost to infections with the rootknot nematode (*Meloidogyne* spp.). Heavily infested tubers form large bulbous protuberances on the tuber. This aberration may itself influence the sink capacity of the tuber and therefore the yield. Certainly, the higher quantity of soil that adheres to such tubers in the slots between the bulbs and on the misshaped roots artificially increases the weight.

### TABLE 5-6  Correlation and regression of covariates to the final tuber yield of three field trials with *D. cayenensis-rotundata* cv. Krenglè.

Stands which had no plant or no tuber were excluded from calculations.

<table>
<thead>
<tr>
<th>Group of covariate</th>
<th>Covariate</th>
<th>Unit and range</th>
<th>Pearson’s Correlation coefficient</th>
<th><em>P</em></th>
<th>Regression</th>
<th><em>P</em></th>
<th>R-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation period</td>
<td>ln(length of sprouts)</td>
<td>ln (cm) [0...5.4]</td>
<td>-0.02</td>
<td>ns.</td>
<td>-0.11</td>
<td>ns.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>weight of sprouts</td>
<td>g [0...75]</td>
<td>-0.004</td>
<td>ns.</td>
<td>-0.01</td>
<td>ns.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Post-harvest losses</td>
<td>% loss [2...38]</td>
<td>0.01</td>
<td>ns.</td>
<td>2.55</td>
<td>ns.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sett weight</td>
<td>g [111...287]</td>
<td>0.23</td>
<td>*</td>
<td>0.10</td>
<td>*</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Duration of dormancy</td>
<td>d [28...77]</td>
<td>0.16</td>
<td>ns.</td>
<td>3.05</td>
<td>ns.</td>
<td>0.02</td>
</tr>
<tr>
<td>Vegetation period</td>
<td>Days to emergence</td>
<td>d [9...83]</td>
<td>-0.62</td>
<td>**</td>
<td>-0.47</td>
<td>**</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Number of shoots per stand</td>
<td>number [1...9]</td>
<td>0.39</td>
<td>**</td>
<td>5.33</td>
<td>**</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Vigour</td>
<td>score [1...10]</td>
<td>0.60</td>
<td>**</td>
<td>1.63</td>
<td>**</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>Planar surface</td>
<td>number [1...83]</td>
<td>0.73</td>
<td>**</td>
<td>0.17</td>
<td>**</td>
<td>0.53</td>
</tr>
<tr>
<td>Foliar diseases</td>
<td>Anthracnose</td>
<td>score [1...5]</td>
<td>-0.27</td>
<td>*</td>
<td>-3.35</td>
<td>*</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>Yam mosaic virus</td>
<td>score [1...9]</td>
<td>-0.45</td>
<td>**</td>
<td>-5.08</td>
<td>**</td>
<td>0.20</td>
</tr>
<tr>
<td>at harvest</td>
<td>Nematode infestation</td>
<td>score [1...9]</td>
<td>0.43</td>
<td>**</td>
<td>3.23</td>
<td>**</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>Number of tubers</td>
<td>number [1...8]</td>
<td>0.52</td>
<td>**</td>
<td>8.21</td>
<td>**</td>
<td>0.28</td>
</tr>
</tbody>
</table>

a. Probability of the F-test: not significant (ns.), indicating a tendency (†, *p*<10%), or significant at the 5% level (*) or 1% level (**)  
b. Natural logarithm  
c. photographic measurement of planar surface of plant (data of 2001)

**Refined analysis of yield.** 3 fixed factors (post-harvest treatment of seed tubers, sett origin, sett sprouted at planting) and 2 random factors (blocks, year) were used to classify individual measurements. All factors were assembled in one statistical model. The results of this ANOVA using the number of days to emergence as a dependent variable are shown in Table 5 - 7. Of the fixed factors only sprouted at planting had a significant effect. Setts that had sprouted before planting took considerably less time to emerge. Treatment and the origins of sett were not significant. However, the interaction "treatment x sprouted at planting" and the interaction of all fixed factors were significant. This complex situation is clarified by the Figure 5 - 1. Emergence was delayed for GA3-treated setts of apical origin and sprouted at planting (Figure 5 - 1 A). Contrarily, emergence was prolonged for middle setts of untreated or desprouted...
tubers compared with GA$_3$-treated setts (Figure 5 - 1 B). For basal setts, the time to emergence was only prolonged for desprouted setts (Figure 5 - 1 C). For setts that had not sprouted at planting, the GA$_3$ treatment delayed the time of emergence in comparison to untreated or desprouted tubers (Figure 5 - 1 D). For middle and basal setts that had not sprouted at planting time, no variation was detected among the post-harvest treatments (Figure 5 - 1 E and F).

The same model was applied to the variable yield (Table 5 - 8). Only the two fixed factors sprouted at planting and origin of sett were significant. Neither the post-harvest treatment, nor any interactions were significant. In order to respect the fact that the percentage of sprouted setts varied among treatments, the means of the yields are graphically represented without the factor sprouted at planting (Figure 5 - 2). From this figure it is confirmed that the origin of the sett appeared to have an effect on the yield: Apical setts lead to higher yield than setts cut from middle and basal tuber parts regardless of the post-harvest treatment. However, whereas a GA$_3$ treatment led to a comparatively lower yield for apical setts, it increased the yield of middle and basal setts. As the size of the standard error bars suggest and the ANOVA has confirmed, the variability of the means is too high to show a significant difference.

The same full model was applied to the number of tubers formed per stand. The post-harvest treatment had a slight effect on the number of tubers (P<0.10). GA$_3$ treatment appeared to slightly, but not significantly, decrease the number of tubers from 2.4 per stand to 2 per plant (Table 5 - 3 on page 62). Setts cut from apical tuber parts formed significantly (P<0.05) fewer tubers than basal or middle setts. The sprouting state of setts at planting had a significant influence on the number of tubers (P<0.05). As a consequence, a derived value was computed that combined the number of tubers per plant and the yield: the mean tuber weight. The statistical model was applied to the mean tuber weight per stand (Table 5 - 9). The origin of the sett was the only fixed factor that was significant.

**TABLE 5 - 7 ANOVA of the dependent variable "Number of days to emergence".**
Nematode infested plants, guard plants, and plants grown from whole seed tubers were excluded. (N=573).

<table>
<thead>
<tr>
<th>Fixed factors</th>
<th>F-value</th>
<th>p</th>
<th>Random factors</th>
<th>Covariance parameter estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Treatment</td>
<td>1.6</td>
<td>0.19</td>
<td>Year</td>
<td>42.03</td>
</tr>
<tr>
<td>B Sprouted at planting</td>
<td>82.2</td>
<td>0.001</td>
<td>Block(year*field)</td>
<td>0.33</td>
</tr>
<tr>
<td>C Origin of sett</td>
<td>0.57</td>
<td>0.56</td>
<td>Residual</td>
<td>45.7</td>
</tr>
<tr>
<td>I1 A x B</td>
<td>0.37</td>
<td>0.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I2 A x C</td>
<td>2.37</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I3 B x C</td>
<td>0.15</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II A x B x C</td>
<td>2.79</td>
<td>0.012</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Results**

**FIGURE 5-1** Days to emergence of *D. cayennensis-rotundata* cv. Krenglè affected by post-harvest treatment and origin of sett.

Setts had sprouted at planting (A - C) or not (D - F). Values of apical setts (A, D), middle setts (B, E), basal setts (C, F), and standard error bars are shown (N=1948).

**TABLE 5-8** ANOVA of the dependent variable "Yield".

Nematode infested plants, guard plants, and plants grown from whole seed tubers were excluded. Square root transformed values of the yield [t ha⁻¹] were used (N=573).

<table>
<thead>
<tr>
<th>Fixed factors</th>
<th>F-value</th>
<th>p</th>
<th>Random factors</th>
<th>Covariance parameter estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Treatment</td>
<td>0.55</td>
<td>0.65</td>
<td>Year</td>
<td>0.055</td>
</tr>
<tr>
<td>B Sprouted at planting</td>
<td>5.54</td>
<td>0.019</td>
<td>Block(year*field)</td>
<td>0.0083</td>
</tr>
<tr>
<td>C Origin of sett</td>
<td>4.36</td>
<td>0.014</td>
<td>Residual</td>
<td>1.79</td>
</tr>
<tr>
<td>I1 A x B</td>
<td>0.06</td>
<td>0.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I2 A x C</td>
<td>0.21</td>
<td>0.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I3 B x C</td>
<td>0.22</td>
<td>0.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II A x B x C</td>
<td>0.42</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Although not statistically significant, a graphical representation of the means indicated the tendency of GA3 to increase tuber weight (Figure 5 - 3). Control tubers led to lower mean tuber weights compared to both GA3 and desprouted tubers. Whereas for all treatments apical setts lead to high mean tuber weights (1000g tuber\(^{-1}\)) middle and basal setts had much lower mean tuber weights for control tubers only. GA3-treated tubers led to higher mean tuber weights of both middle and basal setts.

**TABLE 5 - 9**  *ANOVA of the dependent variable "Mean tuber weight".*
Nematode infested plants, guard plants, and plants grown from whole seed tubers were excluded. Square root transformed values of the mean tuber weight [kg] were used (N=536).

<table>
<thead>
<tr>
<th>Fixed factors</th>
<th>F-value</th>
<th>p</th>
<th>Random factors</th>
<th>Covariance parameter estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Treatment</td>
<td>1.74</td>
<td>0.16</td>
<td>Year</td>
<td>0.0056</td>
</tr>
<tr>
<td>B  Sprouted at planting</td>
<td>0.52</td>
<td>0.47</td>
<td>Block(year*field)</td>
<td>0.00005</td>
</tr>
<tr>
<td>C  Origin of sett</td>
<td>9.31</td>
<td>0.001</td>
<td>Residual</td>
<td>0.121</td>
</tr>
<tr>
<td>I1 A x B</td>
<td>0.39</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I2 A x C</td>
<td>0.67</td>
<td>0.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I3 B x C</td>
<td>0.18</td>
<td>0.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II A x B x C</td>
<td>0.30</td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Although not statistically significant, a graphical representation of the means indicated the tendency of GA3 to increase tuber weight (Figure 5 - 3). Control tubers led to lower mean tuber weights compared to both GA3 and desprouted tubers. Whereas for all treatments apical setts lead to high mean tuber weights (1000g tuber\(^{-1}\)) middle and basal setts had much lower mean tuber weights for control tubers only. GA3-treated tubers led to higher mean tuber weights of both middle and basal setts.
Individual tuber weight was only directly measured in 2001. This data suggests that GA₃-treatment leads to a higher percentage of tubers being larger than 1kg. However, the relevance of the statistical analysis (R-square of 0.05) is so small that this statement must be taken with caution.

The statistical models used in the analysis above, showed that neither fixed nor random factors were very good at explaining the observed variation in the dependent variables. It was, therefore, attempted to identify other, more powerful covariates that explain the yield as well as the derived value, the mean tuber weight.

Because neither the number of "days to emergence", "number of shoots" per stand, nor diseases, were dependent on the post-harvest treatments but influenced significantly the yield (Table 5 - 6), these covariates were used in the full statistical model described above. The vegetative parameters could not be used despite their high correlation with the yield, because they were correlated with the number of days to emergence. In the special case of the "plant planar surface", its use as a covariate was not possible because it had only been assessed in 2001.

In an iterative process it was shown that the "days to emergence" and the "number of shoots" per stand alone were the best covariates. Any other covariate that was added did not further reduce the residual error. The results of this ANOVA on yield are given in Table 5 - 10. The only remaining, significant factor for the independent variable yield is
the origin of the sett. The effect of the post-harvest treatments remained insignificant. In comparison to Table 5 - 8, the residual error has decreased slightly. The most important difference seems to be that the factor sprouted at planting is no longer significant. Applying the statistical model with the two covariates to the mean tuber weight, the result was the ANOVA as shown in Table 5 - 11. The post-harvest treatment became a significant factor, as did the origin of the sett. Whether a sett had sprouted at planting was irrelevant, as were all interactions between the fixed factors.

**TABLE 5 - 10 ANOVA of the dependent variable "yield" using covariates.**
Nematode infested plants, guard plants, and plants grown from whole seed tubers were excluded. Square root transformed values of the yield [t ha⁻¹] were used to obtain normal distribution (N=573).

<table>
<thead>
<tr>
<th>Fixed factors</th>
<th>F-value</th>
<th>p</th>
<th>Random factors</th>
<th>Covariance parameter estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Treatment</td>
<td>0.40</td>
<td>0.75</td>
<td>Year</td>
<td>0</td>
</tr>
<tr>
<td>B Sprouted at planting</td>
<td>0.1</td>
<td>0.75</td>
<td>Block(year*field)</td>
<td>0.0068</td>
</tr>
<tr>
<td>C Origin of sett</td>
<td>3.4</td>
<td>0.03</td>
<td>Days to emergence</td>
<td>0.0037</td>
</tr>
<tr>
<td>I1 A x B</td>
<td>0.07</td>
<td>0.98</td>
<td>Number of shoots</td>
<td>0.0037</td>
</tr>
<tr>
<td>I2 A x C</td>
<td>0.45</td>
<td>0.84</td>
<td>Residual</td>
<td>1.52</td>
</tr>
<tr>
<td>I3 B x C</td>
<td>0.15</td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II A x B x C</td>
<td>0.31</td>
<td>0.93</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 5 - 11 ANOVA of the dependent variable "Mean tuber weight" using covariates.**
Nematode infested plants, guard plants, and plants grown from whole seed tubers were excluded. Square root transformed values of the mean tuber weight [kg] were used to obtain normal distribution (N=536).

<table>
<thead>
<tr>
<th>Fixed factors</th>
<th>F-value</th>
<th>p</th>
<th>Random factors</th>
<th>Covariance parameter estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Treatment</td>
<td>2.85</td>
<td>0.04</td>
<td>Year</td>
<td>0</td>
</tr>
<tr>
<td>B Sprouted at planting</td>
<td>2.41</td>
<td>0.12</td>
<td>Block(year*field)</td>
<td>0.0003</td>
</tr>
<tr>
<td>C Origin of sett</td>
<td>7.72</td>
<td>0.001</td>
<td>Days to emergence</td>
<td>0.0002</td>
</tr>
<tr>
<td>I1 A x B</td>
<td>0.44</td>
<td>0.72</td>
<td>Number of shoots</td>
<td>0.0007</td>
</tr>
<tr>
<td>I2 A x C</td>
<td>1.15</td>
<td>0.33</td>
<td>Residual</td>
<td>0.11</td>
</tr>
<tr>
<td>I3 B x C</td>
<td>0.09</td>
<td>0.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II A x B x C</td>
<td>0.53</td>
<td>0.78</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In summary, the relation between yield and the 3 fixed factors revealed that only the origin of the sett was a truly independent factor. The effect of the factor "sprouted at planting" was nilled when the number of days until emergence was used as a covariate. However, when the appropriate covariates were used in the statistical analysis, the mean tuber weight was significantly influenced by the post-harvest treatment.
5 - 4 Discussion

In the present study, storage losses were below 20% after 120d of storage, whereas in the only other comparable experiment, losses went up 32% for the control at 70d after harvest (Nwankiti 1988). It must be assumed, that the cultivars used here had a much longer dormancy as planting occurred only about half a month after the end of the dormancy of untreated tubers. The time of planting was chosen with respect to the timing of local farmers and the arrival of the rainy season. Post-harvest losses were therefore still minimal and the differences between the post-harvest treatments were small. Since both GA$_3$ treatments were equally effective, it can be concluded that for the small tubers used here, less GA$_3$ may be applied.

The cultivar Krengle is widely distributed in the Ivory Coast and constitutes, after double harvest cultivars, the major marketed genotype of *D. cayenensis-rotundata* (Touré et al. 2002). It was grown in a similar way by local farmers, with regard to planting density, sett size, and staking, with the noticeable differences of seed dressing and mineral fertiliser use. Generally, sett size was at the lower end of the range normally used (170g vs. 250 to 500g), which was traded off for a higher planting density (10 000pl ha$^{-1}$ vs. 6 000 to 8 000pl ha$^{-1}$). The use of seed dressing, homogenous staking and mineral fertiliser was intended to compensate for different growth conditions. Even then, yield per stand was observed to vary from 0 to 6.4kg m$^{-2}$ (corresponding to a yield up to 64t ha$^{-1}$!). It must be assumed that both localised soil conditions such as soil depth, availability of minerals, and genetic and physiological diversity, strongly affected tuber yield.

The large difference in yield from 2000 (18t ha$^{-1}$) to 2001 (12t ha$^{-1}$) may be explained by the difference in the amount and pattern of rain (Table 3 - 5 on page 25). Although less rain fell in 2000 (940mm vs. 1220 mm in 2001), it was more evenly distributed and especially the short rainy season was wetter in 2000 than in 2001. The dryness of June 2000 appeared to have been of lower importance. Yam plants had just sprouted then and the plants were still dependent on the mother sett for water uptake (Onwueme 1975, Njoku et al. 1984). In 2001 the abundant rains of the big rainy season could not be efficiently used due to the relatively late planting. The short rainy season offered only little rain, although it is during this period that yam plants bulk most of the tuber matter (Trouslot 1983) and are supposedly more susceptible to drought.

In view of the high variability in yield per stand and per year, the necessity to control all possible factors in a field trial must be highly stressed. Especially if small differences in yield are of interest, as might be expected from physiological differences of setts, the attempt to closely replicate on-farm conditions must be traded off against homogenous growth conditions. In the present case, artificial irrigation would have been justified. The pre-cision of the trial with respect a significant differences of yield was approximately 2t ha$^{-1}$.

**Post-harvest treatment of seed tubers.** This study aimed to analyse the effect of GA$_3$ on the yam tuber physiology in the field. Specifically, it was conceived that the distorted
sprout location found in storage experiments could affect the yield of setts of such tubers. However, the amount of variation in yield accounted for by sett position in the tuber was so high, that the positive effect of GA3 on sprout-bearing of setts was outweighed. In particular, apical tuber parts having a high yield potential were downgraded by GA3 suppression of sprouts on these setts. Middle and basal tuber parts were upgraded by GA3 because it increased the probability of them having a sprout at planting. Therefore, the application of GA3 seems not to be advisable under farmer's conditions, as the yield increasing effects are outweighed by yield-depressing effects.

GA3 treatment led to a tendencially lower number of tubers per plant, which was compensated for by a higher mean tuber weight. Using GA3 on seed tubers increased the mean tuber weight by 160 to 300g. Ethephon (2-chloroethylphosphonic acid) treatment of setts leads to an increase in the number of tubers per stand and a slight depression of mean tuber weight in *D. alata* (Goenaga et al. 1989). Whether this release of ethylene brought about by ethephon and the phenotypically contrary effect of GA3 relate to a similar physiological process of opposite force in the yam tuber, is unknown.

Both GA3 and desprouting increased sett size, but had no effect on yield. This was not surprising, as the absolute difference was only approximately 10g, which, in the range of 150 to 200g per sett, is unlikely to affect yield. Other cited reports had generally used doubling of sett size to obtain a significant difference in yield (Miège 1957, Ahoussou 1983).

Desprouting did not change the effect of sett origin on yield the way GA3 did. For both desprouted and GA3-treated tubers, the better conservation of reserves (Table 4 - 2 on page 44), had no impact on field behaviour and yield. It is assumed that, if other, short dormancy type genotypes were used, this benefit of the post-harvest treatment could become important. Nwankiti (1988) had used minisetts (25g) and so a possible weight difference between setts of different treatments was ruled out. Minisetts are fragile sprouters because much lower reserves and periderm are are available. Therefore, the effect of desprouting on yield may have been caused by the compositional difference between setts.

**Influence of sett characteristics on yield.** It is unanimously accepted that characteristics of the sett influence the subsequent plant and the final yield in yam. It was Miège (1957) who first speculated that "starch content, size of starch grains, time of tuber initiation, maturity of tuber, auxin content, date of planting are all factors of the mother tuber which influence the growth of the daughter yam plant". Little of his hypothesis has been verified. The abundance of studies exploring the effect of sett size and planting density were mentioned elsewhere. Few works have, however, explored in depth the physiological implications of the sett on the daughter plant.

Trouslot (1983) stated that the irregularity of emergence might be determined by the presence or absence of a sprout on a sett at planting. So far, no report is known that systematically measured the importance of whether a sett carries a sprout when planted or not (although it seems to be "common knowledge" to some extent). This difference
is, however, crucial for the resulting development and yield of a yam plant as it was shown in our study. Setts carrying sprouts at planting emerged 10d faster and led to a substantial increase in yield of 3t ha\(^{-1}\) (Table 5 - 5). When the time of emergence was used as a covariate in the statistical analysis, this effect disappeared (Table 5 - 8 vs. Table 5 - 10). Therefore, this increase in yield seems uniquely allocated to the earlier emergence. The number of tubers was slightly affected and the mean tuber weight of sprouted setts was higher than of non-sprouted setts. Furthermore, setts having sprouted at planting emerged to 100%, while for non-sprouted setts at planting the final emergence was 96% (data not shown).

It is astonishing that the time of emergence influences yield so drastically. Trouslot (1983) found that tuber initiation is dependent on a) the start of linear growth of the aerial axis and b) on a fixed number of main-stem nodes, the number being dependent on the genotype. An early emerging shoot would reach tuber initiation earlier. It would reach the bulking of the new tuber earlier and spend more time doing so, resulting in a higher yield. Studies by Shiwachi et al. (1995, 2000, 2001b) indicate that the bulking, i.e. the fast growth of the tuber, is triggered by increasing photoperiod. If setts of \(D.\ alata\) were planted in March, tuber initiation happened after 3 weeks, but tuber bulking only after the 21\(^{st}\) of June. Setts planted in July started bulking immediately after tuber initiation had taken place (Shiwachi, pers. comm.\(^{a}\)). Therefore it seems more appropriate to argue, that, although tuber initiation happens earlier for early emerging plants, the bulking of the tuber starts at the same time. The comparative advantage of an early emerging plant would therefor be the more massive aerial apparatus. When the competition between the tuber and the aerial apparatus for assimilates increases, the more massive plant has a higher assimilate production. During senescence a larger plant can also translocate more material from the aerial apparatus to the maturing tuber. In summary, the great sink capacity of the yam tuber rewards the greater photosynthetic capacity achieved with earlier sprouting (for a review on growth phases of yam see Zinsou 1997).

As outlined in the introduction, the position on the mother tuber from which a sett is cut has an impact on the performance of this sett. The most relevant study for this purpose was conducted by Miège (1957) using the same genotype forty five years ago. He found that the emergence of Krenglé occurred sooner if apical parts were used (29d) compared to all lower parts (about 36d). Yield was likewise affected, with apical setts yielding highest (14.5t ha\(^{-1}\)) compared to lower lying setts (about 12.5t ha\(^{-1}\)). Similar results were found for \(D.\ alata\). The other study directly measuring the effect of the origin of the sett was carried out by Rao et al. (1974) using \(D.\ floribunda\), a species planted in India for the sake of diosgenin production. This species has strong polar sprouting. Setts cut from apical tuber parts sprouted after 30d compared to 60d for lower lying setts. Yield was 50 to 300% higher for apical setts compared to middle and basal setts.

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In the present study, control tubers showed a similar gradient in emergence and yield. In fact, the origin of the sett was the only factor that consequently remained significant irrespective of other fixed factors and covariates used to model yield. Setts cut from middle tuber parts were especially delayed in emergence and depressed in yield. This also applied to a lesser extent to basal tuber parts (see Table 5 - 4 and Figure 5 - 1). In contrast to the occurrence of sprouts at planting, the effect of the origin of the sett is independent of the time of emergence. This was observed when the number of days before emergence were used as a covariate in the statistical analysis; the origin of the sett remained a significant factor (Table 5 - 8 vs. Table 5 - 10). Since the interaction of sprout-bearing and origin of the sett was also an insignificant factor, the gradient in yield observed from apical to basal setts was not due to the sprouting state.

My studies suggest, therefore, that the variation in yield due to position of the sett on the mother tuber, is not a result of earlier emergence, nor of the higher chance that apical setts bear sprouts, but of an intrinsic, physiological disposition present in the mother tuber.

**Importance of seed dressing.** Emergence is known to be lower without a fungicide seed dressing (Mignucci *et al.* 1984). When setts are cut from whole tubers, the inner tissue is exposed to fungal attack. Some setts may rot before the shoot has been fully formed and before the plant becomes independent of the mother sett. In the field trials, the emergence varied slightly within the years. Use of seed dressing tended to have a negative impact on emergence (98% in 2000 without seed dressing vs. 92% in 2001 with seed dressing). It is possible that the nematicide used in 2001 was partly toxic. However, it allowed the nematode score to drop from 1.85 to 1.22 and the number of infected tubers from 22% to 3%.

**Photometric evaluation of leaf apparatus.** The measurement of the planar plant surface as described here for the first time (page 35) is a simplification of the Leaf Area Index (LAI) measurement. LAI and Leaf Area Duration (LAD) have been identified as strong determinants for yield in yam and many other crops (for yam see Zinsou 1997). Both parameters set in relation the ground occupied by a plant and the respective foliar surface, combined with timely duration in the case of LAD. Their measurement is either destructive, or demands sophisticated equipment.

The volume occupied by a plant is a close estimate for LAI if leaf density is supposed fixed. Leaf density was assumed to be fixed if yams are growing on stakes and have abundant space. The volume of simple geometric shapes can be adequately described by the projected surface. Several yam vines were twining up one central stake, leading to a pyramidal shape. The planar surface of the foliage occupying one stake was, therefore, regarded as a simple but sufficient estimate for the volume occupied by the leaves. Ideally, the photographs should have been taken from more than one angle.

The method used here does not destroy any plants, and it demands relatively low tech equipment (camera, scanner, adequate software) but it does only measure the planar surface of a plant (on a stake) from one given angle. In spite of some errors intrinsic to
Conclusion and Outlook

this procedure, it proved sufficient to obtain a high correlation (R-square of 0.73) and strong enough to explain variation in yield (see Table 5 - 6). The biggest advantage of the planar surface is the speed of the procedure. To establish the values for 192 yam stakes representing 896 yam plants took 1d of photographing, and approximately 3d of evaluation. A destructive method would take several times this time.

For yam plants on comparable stakes, this method seems to allow a good estimation of the volume a plant has occupied with its foliar apparatus, and consequently the LAI it has reached. It is clear that a standardisation of the procedure is difficult and that results are, thus, not comparable across different fields and genotypes. For a cheap solution in one field with standardised field practice, this procedure seems, however, a satisfactory substitute for the precise but laborious determination of the LAI. Allowing the substitution of volume by total biomass, the strong correlation with the tuber yield produced is confirmed. Chowdhury (1998) deduced from more precise measurements, that the tubers of *D. cayenensis-rotundata* constitute strong sinks, which respond positively to high biomass production.

**Economic aspects.** The price of seed yam is known to be considerably higher than for ware yam, especially during the planting season (M.Touré, pers. comm\(^b\)). Roughly, double the price can be expected for healthy seed yam than for ware yam of *D. cayenensis-rotundata* cv. Krenglé in April (400CFA kg\(^{-1}\) vs. 200CFA kg\(^{-1}\))\(^c\). At present, most farmers produce their own seed yam in Nigeria (Aighewi *et al.* 2001), and this is probably true for the entire yam belt. It can be expected that the market for seed yam will be growing in the future, especially if improved techniques of seed yam production, such as the minisett technique, prove economically profitable. Furthermore, the growing market for yam will allow a diversification of production, as has been the case with the Irish potato. This is already becoming a reality in Nigeria (G.C. Orkwor, pers. comm\(^d\)).

The difference in weight after storage of seed yam only differed slightly in the experiments. The economic model presented later (page 92ff) indicates that GA\(_3\) application to seed tubers is already economically viable with the presented figures. For varieties with high post-harvest losses due to short dormancy, the benefit can become substantial.

### 5 - 5 Conclusion and Outlook

In contrast to fears expressed by Nwankiti (1988), a sprout suppressing agent as GA\(_3\) used for seed tuber treatment does not adversely affect the yield. From the present experiments it can be concluded that the effect of GA\(_3\) ends with the onset of sprouting

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\(c\). in 2002, 1 € corresponded to 650CFA
\(d\). Orkwor, G.C., National Root Crop Research Institute NRCRI, Umudike, PMD 7006 Umühaia, Nigeria.
nrcri@infoweb.abs.net
and tubers behave subsequently as untreated tubers. Thus, emergence and other parameters during the vegetation period remain only slightly affected by the post-harvest treatment. However, the results show that both the application of GA$_3$ and desprouting can have positive effects on the yield components. The mean tuber weight is increased if setts come from GA$_3$-treated tubers.

GA$_3$ treatment of yam tubers can be encouraged if late planting is likely, a high tuber weight and homogenous yield are assets for the farmer. All results have been acquired using a genotype of *D. cayenensis-rotundata* which is widely used in the Ivory Coast. Given the variability within and among genotypes (Table 4 - 4 on page 48), our conclusions need to be confirmed using different genetic backgrounds. Furthermore, the effect of GA$_3$ treatment on setts of *D. alata* should be investigated.

Sprouted setts emerge more rapidly, and as a direct consequence have higher yields. This information is valuable in several ways: first, the constraints imposed by the lack of homogeneity of emergence could be partially overcome if sprouted and non-sprouted setts were planted on separate plots. The yam grower would have to execute all measures at two points in time, i.e. when the plot from sprouted setts is ready and when the plot from non-sprouted setts is ready. The timing and efficiency of measures which are dependent on the stage of the plant’s development, would be improved. The fields with sprouted setts should get preferential attention by the farmer and justify more inputs as the yield potential is considerably higher.

Second, any technique which increases the number of setts carrying sprouts at planting time has an intrinsic, high potential to increase yield. This idea has been put into action by the minisett technique, in which setts are pre-sprouted in a moist sawdust bed and only sprouted setts are gradually transplanted to the field (Akoroda 1986, Igwilo & Okoli 1988, Kalu 1989, George 1990, Sreekantan *et al.* 1995, Segnou 1999). Pre-sprouting is laborious and any technique that increases the chance of setts, or minisetts, carrying sprouts at planting time with less effort should have a high potential of adoption. Further research is needed on how post-harvest treatments affect the presence and distribution of sprouts on whole tubers. Okezie (1984) used IBA (Indole butyric acid, a synthetic auxin) to promote sprouting of quiescent buds on stem cuttings. His suggestion of using IBA to break dormancy and/or induce sprouting in setts to obtain uniform development on the field has, however, never been tested on seed tubers. Passam *et al.* (1982b) found no effect of auxins on the sprouting of bulbils of *D. alata* and *D. bulbifera*. Mozie (1987b) found only a little promotion of sprouting by IBA and 2-4 D ((2,4-dichlorophenoxy)acetic acid, a synthetic auxin). Ethylene chlorhydrin has been shown to promote rapid sprouting (Campbell *et al.* 1962b, Passam *et al.* 1982b), however its toxicity forbids a widespread use.

It is recommended that setts that have sprouted at planting time should be planted together and on preferred sites. This should alleviate the problems of timing of cultural measures and redirect resources to promising yam stands.
Improving the Application of GA₃ to Prolong Dormancy of Ware Yam Tubers

6 - 1 Chapter summary

Aiming to reduce the cost and time needed to treat yam tubers with gibberellic acid (GA₃), this study compared several new methods of application to the established dipping procedure (150mg kg⁻¹ for 1h). Both GA₃ containing soil paste (25mg kg⁻¹) and gelatinised starch (860mg kg⁻¹) were applied to tuber heads of Dioscorea alata and D. cayenensis-rotundata in the Ivory Coast. Soil paste, gelatinised starch and dipping consistently prolonged the dormancy and reduced the post-harvest losses by 9 to 15% in D. cayenensis-rotundata (three year means). Although dipping reduced storage losses most efficiently, soil paste and gelatinised starch used considerably less GA₃. Both new treatments were easily prepared and quickly applied. Soil paste was most effective when the treatment was repeated before the end of dormancy. The third new method, spraying the tubers with a GA₃ solution (150mg kg⁻¹), was not effective.

For extended storage periods of healthy tubers of D. cayenensis-rotundata GA₃ application may be recommended as post-harvest practice.
6 - 1 Introduction

Since the dormancy-prolonging effect of GA3 on yam dormancy has been discovered, researchers have repeatedly attempted to improve the efficiency of the treatment. The efforts were aimed at the reduction of the amount of GA3 used, either by decreasing the concentration of the solution used for dipping, or by shortening the immersion time. This has led to an optimised dipping procedure in which the first centimetres of the yam tuber head are dipped in a solution of 150mg kg⁻¹ GA₃ for 0.5h (Girardin et al. 1998). The repeated use of the same solution up to six times and for three consecutive days did not hamper efficiency (Nnodu & Alozie 1992, Girardin et al. 1998). Nevertheless, it seems that the application is still too costly, time-consuming and tiresome for the farmers to carry out (Daouda et al. 2002).

It was attempted to study the possibilities of reducing the amount of GA3 and time used to treat yam in comparison to the dipping procedure.

6 - 2 Results

Application of substrates. During three years different substrates (page 30) were tested on both Krenglè and Bètè bètè (experiments 1a to 1c, page 32). The application of GA3 in wet soil to the tubers took about 5 to 8min for 72 tubers and it adhered well to the tubers. The wet soil took 6 to 12h to dry and once dried usually fell off when touched, leaving the tuber in the same condition as when it was removed from the field. The application of GA3 in gelatinised starch took about 5 to 10min for 72 tubers. The starch stuck very well to the wound and the necessary handling of the tubers was possible immediately after treatment. After about 12 to 24h the glue had dried completely, forming a very hard surface, and protecting the wound. In 2000 the cassava starch and a ground tablet of GA3 were mixed. The resulting powder was dissolved in the appropriate amount of water and heated. This product was easy to prepare and to apply to the yam tubers as described above. Spraying the yam tubers with a GA3 solution was carried out with ease but a large amount of substance (2.2l of 150mg kg⁻¹ GA3 for 72 tubers) was required. Dipping the tubers was time-consuming (35min to treat 72 tubers in two immersion basins). Once the immersion period was over, the tubers were transferred immediately to the store shed. Removing the sprouts was done quickly especially for D. alata from which the sprouts were broken off by hand.

Effect of GA3 concentration. Using gelatinised starch as a GA3-carrier, two overlapping concentration series were used in 1999 and 2000 with Krenglè and Bètè bètè (Figure 6 - 1 A and C). The optimal concentration was 860mg kg⁻¹. Lower concentrations did not effectively reduce storage losses; higher concentrations did not significantly improve performance. These findings apply to both species investigated.

Wet soil induced a similar pattern of decrease in fresh weight (Figure 6 - 1 B and D). Although there was a large difference between the years, the trend over the two years was conclusive for Krenglè: a low concentration of 25mg kg⁻¹ GA3 (GaSoil 25) was
most efficient. Lower concentrations (6.25 or 12.5mg kg⁻¹) did not effectively reduce storage losses, and higher concentrations (50 or even 100mg kg⁻¹) did not further decrease storage losses. Similar results were obtained for *D. alata* cv. Bètè bètè, although the effect of GA₃ in 2000 was not pronounced. Possibly, 100mg kg⁻¹ is a safer concentration for this species.

**Comparison of GA₃ application methods.** The treatments which gave the best results were used to compare the methods of application with the standard method of application (GaDip), to the alternative of mechanical desprouting (Despr), and to control tubers, for two or three years. The best treatments selected were GaSoil 25 and GaStarch 860. With the former, on average 625µg GA₃ in 25g wet soil were used per tuber, and with GaStarch 860 on average 1800µg GA₃ in 2.1g gelatinised starch were applied to each tuber. The amount of GA₃ used per tuber in the dipping procedure must be calculated in relation to the potential of re-using of the solution for 24h maximum (Girardin *et al.* 1998). Between 2000 to 4000µg GA₃ were probably used per tuber.

**FIGURE 6.1** Effect of GA₃ applied in wet soil or gelatinised starch on post-harvest losses of tubers of *D. cayenensis-rotundata* cv. Krenglè and *D. alata* cv. Bètè bètè. Losses are expressed as % fresh weight lost after 4 months of storage in 1999 (●, ■) and 2000 (○, ○). Each mean is based on 72 tubers and the standard errors of mean are shown as error bars.

A: GA₃ in gelatinised starch, GaStarch, on *D. cayenensis-rotundata* cv. Krenglè.
B: GA₃ in wet soil, GaSoil, on *D. cayenensis-rotundata* cv. Krenglè.
C: GA₃ in gelatinised starch, GaStarch, on *D. alata* cv. Bètè bètè.
D: GA₃ in wet soil, GaSoil, on *D. alata* cv. Bètè bètè.
Table 6 - 1 lists the effects of the treatments on the post-harvest performance of *D. cayenensis-rotundata* cv. Krenglè. All the GA3 treatments prolonged dormancy. During the dormant phase, i.e. from the start of the trial to 50% sprouting of the control tubers, daily losses were slightly lower for the treated tubers. Once the tubers started to sprout, post-harvest losses increased drastically for all treatments.

### TABLE 6 - 1 Effect of selected GA3 treatments on post-harvest parameters of *D. cayenensis-rotundata* cv. Krenglè during storage for 4 to 5 months (3 year means).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of GA3 used per tuber [µg]</th>
<th>Post-harvest losses [%]</th>
<th>Dormancy [d]</th>
<th>Daily losses [%]</th>
<th>Dormancy</th>
<th>Sprouting</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaDip 150</td>
<td>2000-4000</td>
<td>22.9 a</td>
<td>103 a</td>
<td>0.114 a</td>
<td>0.267 a</td>
<td></td>
</tr>
<tr>
<td>GaStarch</td>
<td>1800</td>
<td>26.1 ab</td>
<td>93 ab</td>
<td>0.124 a</td>
<td>0.310 ab</td>
<td></td>
</tr>
<tr>
<td>GaSoil 25</td>
<td>625</td>
<td>29.0 b</td>
<td>85 ab</td>
<td>0.120 a</td>
<td>0.361 bc</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>37.7 c</td>
<td>69 c</td>
<td>0.150 b</td>
<td>0.418 c</td>
<td></td>
</tr>
</tbody>
</table>

**Treatment**
- **ns.**
- † p<10%
- * 5%
- ** 1%

**Standard error of means**

<table>
<thead>
<tr>
<th>Post-harvest losses</th>
<th>Dormancy</th>
<th>Daily losses</th>
</tr>
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<td>4.73</td>
<td>11.6</td>
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</tr>
</tbody>
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<table>
<thead>
<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>848</td>
<td>576</td>
<td>557</td>
</tr>
</tbody>
</table>

GaDip 150 led to the lowest storage losses (22.9%), followed by GaStarch 860 (26.1%). Tubers treated with GaSoil 25 showed a 29% loss, which was significantly different to the loss of untreated tubers (37.7%), and of dipped tubers. A slight but insignificant improvement was observed when desprouting was combined with a GaSoil 25 treatment (GaSoil+Despr, data not shown). In 2000, GA3 sprayed Krenglè had lost 36.9% fresh weight after 4 months of storage whereas the control tubers had lost 42.3% (data not shown).

The best results were obtained by splitting the amount of GaSoil applied into two applications (GaSoil/2x). In 2000 and 2001 the GaSoil/2x treated tubers lost 24.9% fresh weight after 5 months of storage, while the control tubers had lost 39.5% (Table 6 - 2). The interaction between treatments and years was mainly the result of this treatment (GaSoil/2x). It was similarly effective in both years, whereas all the other treatments, with or without GA3, led to higher losses in 2001 than in 2000.
Improving the Application of GA₃ to Prolong Dormancy of Ware Yam Tubers

The GA₃ treatment was generally less efficient with *D. alata* cv. Bètè bètè (Table 6 - 3). Dormancy was significantly prolonged by 14d when the tubers were treated with GaDip 150. The other GA₃ treatments prolonged dormancy only slightly (GaStarch 860) or not at all (GaSoil 25, GaSpray 150). Likewise, a significant reduction in post-harvest losses was only obtained by GaDip 150, Despr, and GaStarch 860. Daily losses varied little during dormancy, and they were about half as high as for Krenglè. During sprouting, i.e. after three months of storage, daily losses were quadrupled but were still considerably lower than for Krenglè. During this last phase, the lowest daily losses were obtained by Despr.

**TABLE 6 - 2** Effects of selected GA₃ treatments on post-harvest losses of *D. cayenensis-rotundata* cv. Krenglè over a period of 4 to 5 months (2 year means).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Post-harvest losses [%] 2000</th>
<th>Post-harvest losses [%] 2001</th>
<th>Abs. difference between years [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaDip 150</td>
<td>21.3 a</td>
<td>31.4 a</td>
<td>10.1</td>
</tr>
<tr>
<td>GaSoil/2x 25</td>
<td>24.7 b</td>
<td>25.1 b</td>
<td>0.4</td>
</tr>
<tr>
<td>Despr</td>
<td>30.2 c</td>
<td>38.1 c</td>
<td>7.9</td>
</tr>
<tr>
<td>Control</td>
<td>34.2 d</td>
<td>44.7 d</td>
<td>10.5</td>
</tr>
</tbody>
</table>

* Treatment a
  - **
  - **
  - -

* Standard error of means: 1.14 2.1 -

* N: 256 252 -

a. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*), or 1% level (**). Means followed by different letters are significantly different based on Least Square Means.

**TABLE 6 - 3** Effect of selected GA₃ treatments on post-harvest parameters of *D. alata* cv. Bètè bètè during 7 months of storage (2 year means).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dormancy [d] a</th>
<th>Post-harvest losses [%]</th>
<th>Daily losses [%] a</th>
<th>Dormancy</th>
<th>Sprouting</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaDip 150</td>
<td>115 a</td>
<td>25.3 a</td>
<td>0.050 a</td>
<td>0.229 ab</td>
<td></td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>101 b</td>
<td>29.0 b</td>
<td>0.066 b</td>
<td>0.259 bcd</td>
<td></td>
</tr>
<tr>
<td>GaSoil 25</td>
<td>94 bc</td>
<td>31.4 bc</td>
<td>0.069 b</td>
<td>0.291 d</td>
<td></td>
</tr>
<tr>
<td>GaSpray 150</td>
<td>99 bc</td>
<td>29.4 bc</td>
<td>0.066 b</td>
<td>0.250 bc</td>
<td></td>
</tr>
<tr>
<td>Despr</td>
<td>95 bc</td>
<td>25.4 ab</td>
<td>0.063 b</td>
<td>0.196 a</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>92 c</td>
<td>33.2 c</td>
<td>0.069 b</td>
<td>0.274 cd</td>
<td></td>
</tr>
</tbody>
</table>

* Treatment b
  - **
  - †
  - *
  - **

* Standard error of means: 3.19 1.97 0.0037 0.031

* N: 404 694 404 404

a. Data of 2000 only
b. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*), or 1% level (**). Means followed by different letters are significantly different based on Least Square Means.
6 - 3 Discussion

The post-harvest behaviour of the cultivars or species in these trials is similar to that reported by other authors. Girardin et al. (1998) and Serpanție (1983) reported daily losses of fresh matter during dormancy of 1g kg\(^{-1}\)d\(^{-1}\) and of 2 - 3g kg\(^{-1}\)d\(^{-1}\) during sprouting. Passam et al. (1978) found that losses where twice as high during dormancy. Sauphanor (1988) observed slightly lower losses after similar periods of storage of the same genotypes. Although dormancy is considered to be controlled largely by endogenous factors (Craufurd et al. 2001), storage losses might also be influenced by genotype and environmental conditions, which would explain some of the large differences that have been reported. Because the tubers used in the trials had different origins (i.e. were bought on the market), the variability within the genotype could explain some of the difference in post-harvest losses between years in the experiments.

Improved application of GA\(_3\). The benefits of applying GA\(_3\) to yam tubers have been known for about 35 years (Martin 1977), and the method of application method has hardly changed. For *D. cayenensis-rotundata*, Igwilo et al. (1988) reported a prolongation of dormancy of 56d and a 12% reduction in post-harvest losses; Girardin et al. (1998) reported a 14% reduction of post-harvest losses and a 20d prolongation of dormancy. In general, the present data support those results; a major difference was found in the daily loss of fresh matter, which was considerably higher here. This can be explained as follows: about three months after the end of dormancy the daily losses decreased again (data not shown), due to a loss of the initial vigour of sprouting and a subsequent senescence of the tuber. As only the period directly after sprouting was covered, in which considerable amounts of fresh matter were lost, higher values for daily loss were obtained in comparison to other studies.

The wet soil product operates at lower concentrations than hitherto reported for GA\(_3\) (i.e. 25mg kg\(^{-1}\)). Furthermore, wet soil and gelatinised starch affect only the small area of the inflicted wound, whereas dipping the tubers heads means that large surface areas of presumably non-permeable epidermis are treated. Regarding GaDip, after several rounds of soaking, too little liquid is left to efficiently wet the tubers; the remains have to be discarded. These reasons explain the fact that less GA\(_3\) is used by the new methods, although it is unknown why such different concentrations GA\(_3\) (860 and 25mg kg\(^{-1}\) respectively) are effective in the gelatinised starch and wet soil. The soil used in the former treatment seems to transfer the GA\(_3\) to the tuber more efficiently than the gelatinised starch. At present it is unknown how the composition of the soil affects the efficiency of this transfer. In order to correctly assess the transfer efficiency, a method to measure the amount of GA\(_3\) in the tuber should be used. The quantification of GA\(_3\) involves rather complex purification and detection procedures, which were not attempted here (Nishijima & Katsura 1989, Yamaguchi & Weiler 1989, Bounaix & Doumas 1995).

The repeated treatment with wet soil (GaSoil/2x) led to a more consistent effect than the other applications of GA\(_3\) (Table 6 - 2). Wickham et al. (1984a) had already found that additional treatment of the sprouted tubers led to renewed dormancy. Although
this renewed dormancy lasted only for about two weeks in the present experiment, tubers have accelerated losses during the germination phase and hence the comparative advantage of a repeated application. Ireland and Passam (1985) found that the shoots of re-treated tubers grew faster. The complete removal of the sprouts is therefore necessary if the tubers are to be re-treated with GA3.

With the exception of spraying, the alternative methods for applying GA3 compare well to the standard method of dipping the tuber in a GA3 solution which was included here, but also with the results of other researchers. The only other method for applying GA3 that has been reported thus far is the pre-harvest foliar spray on D. esculenta and D. alata (Wickham et al. 1984b, Onjo et al. 1999). The drawback of the foliar application is the inefficient use of GA3 (225g GA3 ha⁻¹, calculated according to Wickham et al. 1984b), because all tubers are treated and not only those that require a treatment; additionally, a large amount of GA3 is lost during application. The latter is also true of the spraying of tubers in my experiments, and this was why it was rejected during the evaluation. The gain in fresh matter was extremely small compared to the amount of GA3 used (roughly 4000µg GA3 per tuber) and compared to the performance of other treatments.

Using GA3, a prolongation of dormancy of 1 to 1.5 months has been frequently attained for D. alata (Martin 1977, Ireland & Passam 1985, Girardin et al. 1998). The reduction of post-harvest losses was mostly in the order of 10 to 15%. D. alata reacted less favourably to the GA3 application here, probably due to the lateness of application (up to 5 weeks after harvest). The best treatment (GaDip 150) reduced losses by 8% over a period of 7 months (Table 6 - 3). This seems to be a small benefit compared to the already low level of losses (33% for control tubers after 7 months). Furthermore, the new techniques did not result in a comparable reduction of losses and, thus, cannot be recommended for this species of yam.

Our explorative trial using a wider range of genetic variability has shown that GA3 application has a fair likelihood of being efficient throughout the yam belt on D. cayenensis-rotundata.

**Advantages of GA3 treatment.** The sprouting of a yam tuber marks an important point in its life cycle and leads to the activation of meristematic tissues, and subsequently reserves and newly synthesised products are transferred to the sprout. Several nutritional factors are affected by this. D. rotundata tubers had lost 15% of their protein-nitrogen and 50% of non-protein-nitrogen after 6 months of storage (Osuji & Ory 1986). Mozie (1983) and Osuji et al. (1986) reported that, upon sprouting, nitrogen loss was accelerated and that soon thereafter the nitrogen was depleted. Ravindran and Wanasundera (1992) went as far as to claim that the storage period should, therefore, not include the end of dormancy, except when sprouting has been prevented. Although the protein content in the yam tuber is small, the importance of yam to nitrogen contribution of diet increases when large quantities are consumed and other sources of nitrogen are lacking (Osuji et al. 1986). While no data is available on
the nitrogen content of GA3-treated tubers, it is assumed that delayed sprouting leads to a curtailing of the N loss and, thus, to a slightly improved availability of nitrogen in a yam based diet.

It has been shown that the starch content decreases drastically from 700 to 500g kg\(^{-1}\)d\(^{-1}\) (dry base) during storage (Hariprakash & Nambisan 1996), although some of the starch is found again in the form of soluble sugars (Mozie 1987a). Both GA3 treatment and desprouting slows the loss of starch (Girardin 1996, Nindjin 2002). Furthermore the conservation of tissue water through the prolongation of dormancy means that the tubers shrivel to a lesser extent. The shrivelled appearance is often cited by authors as a negative asset for the marketing of old tubers (Mozie 1984). These findings clearly show that a spread of the post-harvest treatment with GA3 for yam would be advantageous.

6 - 4 Conclusion and outlook

Although GA3 was slightly less effective when applied using the alternative methods reported here, these methods offer other advantages. Firstly, the time spent applying GA3 to the tubers is remarkably shorter compared to the dipping method. While this was not tested on a large batch of tubers, the results suggest that the use of soil or gelatinised starch reduces the time needed for treatment by a factor of 5 to 6. Secondly, the amount of GA3 needed is about four times smaller. Martin (1983) stated that "[...] the treatment applies grams of GA3 where nanograms are needed." This certainly applies here. The methods of application proposed here seem to enhance the delivery of GA3 to the site of action.

With respect to \textit{D. alata} the following question must be posed: to what extent would an improved storage technique be beneficial in the Ivory Coast? Despite the nutritional benefits that may arise, the economic and sensorial parameters of a GA3 treatment of this species are less advantageous. Its naturally long dormancy and small daily losses mean that a reduction in post-harvest losses through modification of tuber physiology is always small though not insignificant. Given the role played by this species for farmers, society and the economy, there will probably be little motivation for investing money and labour as long as the risk of losing all tubers during storage and the expected gain remain small. This statement was verified by Dao \textit{et al.} (2002), who concluded that the adoption of a new method of storage depends to a large extent on the gain in fresh matter that it achieves. In a model approach this was confirmed: the gross benefits of storage using GA3 and desprouting on \textit{D. alata} were considerably smaller than for \textit{D. cayenensis-rotundata} (Guessan Bi 1997). The most striking argument against modifying the physiology of \textit{D. alata} was, however, forwarded by Nindjin (2002). He showed that the sprouting and subsequent modification of the tuber characteristics of \textit{D. alata}, e.g. the loss of water and the increase of DM content, is a necessary prerequisite for good pounding quality. A water preserving technique, such as the application of GA3 (Igwilo \textit{et al.} 1988), therefore, extends the period of lower quality. The advantages of GA3 with regard to the preservation of nutritional quality and fresh
weight are outweighed by the need to develop a good sensorial quality of the product. The application of GA$_3$ to _D. alata_ is, therefore, questionable for the settings of the Ivory Coast. A method of increasing the number of saleable tubers, e.g. by a protection from insect attack, seems to be more promising.

For _D. cayenensis-rotundata_, nutritional, economic and sensorial parameters of the GA$_3$ treatment are consistently advantageous. Its pounding quality improves during storage (Nindjin 2002), its commercial value and its role as a cash crop are important (Daouda _et al._ 2002) and the reduction in weight loss achieved with the method is considerable.

However, these advantages for GA$_3$-treated tubers are noticeable only when tubers are stored for a prolonged period of time. I, therefore, recommend that farmers treat the tubers with GA$_3$, as reported here, only if they intend to stock their tubers well beyond the period of dormancy. Healthy, intact tubers should be selected and the GA$_3$ should be applied as soon as possible after harvest. Before 50% of the tubers have sprouted, healthy tubers should be treated again. Thus, the post-harvest losses can be further reduced and the treatment becomes very reliable.

Tubers should be checked on a regular basis for rots and sprouting. Rotten tubers should be removed from the storage structure and, if the workforce permits, manual desprouting is recommended even for GA$_3$-treated tubers.

In 1999 there were 26 tubers of the treatments GaDip, GaStarch and GaSoil that had not sprouted at all at the end of the storage period in June. Their post-harvest losses amounted to 11.2% compared to 38.2% for control tubers! This certainly underlines the tremendous potential of sprout suppressing agents. However, the proposed techniques are still far away from this ideal situation with respect to efficiency. Furthermore, the time to treat the tubers and the amount of active substance used may still be further reduced. The paragraph below explores some ideas of how this might be achieved, and in which directions engineering research should employ in the future.

Further simplification of GA$_3$ application can be envisaged. For example, auto-adhesive strips containing GA$_3$ in the glue which would be stuck to the wound created by the removal of the PNC. This technique has been employed in Japan to deliver inhibitors of GA-synthesis to yam during scientific experiments (H. Shiwachi, pers. comm.). Likewise, an injection that penetrates only 2-3mm into the tuber could deliver GA$_3$ in small quantities at almost any point of the tuber, though preferably at the apical section, and lead to a prolongation of dormancy. Both methods would have a high potential of success in the author's view, but would require a even higher technicality (special syringe) or a special form of GA$_3$. Both are unlikely to be developed by the "market" at present prices of yam and with the absence of a clientele buying new technologies.

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To use GA$_3$ in foam has been suggested, but the poor response of *D. cayenensis-rotundata* to application of GA$_3$ to the skin without a wound discourages this. The most practical solution would be a fumigation of the tubers. This, if GA$_3$ is to be used, should be difficult to do given the properties of the chemical. Paper strips, confetti, or coconut fibre evaporating the methyl ester of $\alpha$-naphtalene acid have been used by Campbell *et al.* (1962a). In *D. alata*, losses were reduced by 12% by August, however, the author did not recommend the treatment due to the limited economic benefit obtained.

For the moment it seems that GA$_3$ remains the only promising chemical to be used to prolong dormancy, and that the developed methods to apply are the most feasible under current conditions. Commercially available$^b$ GA$_{4/7}$ was also tested (data not shown) and proved to be equally effective as GA$_3$. Unless specific physiological information becomes available, the quest for new sprout suppressing, non-GA chemicals appears unyielding.

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$^b$ 100mg kg$^{-1}$ of GA$_{4/7}$ using the dipping procedure for $^{1/2}$h (NOVAGIB$^\text{TM}$, 1% w/w GA$_{4/7}$, Fine Agrochemicals Limited, Worcester, WR52RL, UK).
7 - 1 Chapter summary

Alternative methods have been developed on-station beforehand which can enhance the overall performance of GA$_3$ application to yam. The efficiency of the most promising ones was tested under rural conditions.

An on-farm storage trial was conducted with Krenglé ($D. \text{cayenensis-rotundata}$) in the Ivory Coast (2001) which included 18 farmers. Untreated tubers lost on average 35% of the initial weight after 4 months of storage. The three studied regions had significantly different levels of loss, possibly due to general storage practice and genotypic variability within Krenglé. GA$_3$ dissolved in both wet soil (GaSoil), gelatinised starch (GaStarch) and the known dipping procedure (GaDi) significantly reduced storage losses by approximately 10%. GaSoil and GaStarch could be applied in 7 to 8h t$^{-1}$ compared to 14h t$^{-1}$ for GaDip. Furthermore, GaSoil only used 0.7g t$^{-1}$ GA$_3$ compared to a use of 1.6g t$^{-1}$ for GaStarch and 3g t$^{-1}$ for GaDip. Desprouting was less efficient than GaStarch and GaDip.

The economic evaluation showed that prolonged storage is highly profitable because prices rise to more than compensate for the tubers' lost weight. Using any improved post-harvest application, the net added benefit was increased. Desprouting was most profitable if high prices for inputs were assumed. The scope of profitability was shown by the best farmer who doubled his profit through improved yam storage.

A prospective trial in Nigeria with 59 farmers showed that GA$_3$ prolonged dormancy in most of the 12 used genotypes. For the widely used genotype "Pepa", the post-harvest losses were reduced by 11%. Whether the Primary Nodal Complex was removed or just wounded did not influence the efficiency of GA$_3$.

The supply of yam during critical periods and the farmer's revenue of yam cultivation can be enhanced using the proposed storage methods. Therefore, the legalisation and marketing of GA$_3$ as well as the dissemination of these improved methods is encouraged.
New methods to apply GA$_3$ to yam tubers were developed and tested on-station as described in the previous chapters. This was done with the aim of reducing the cost of the treatment in order to achieve a better economic viability. Principally, this subject could be addressed with an economic model, as formulated by Dao (2003), and using the information acquired on-station. However, GA$_3$ application under less controlled circumstances might be less efficient. The varying reaction of different genotypes has been mentioned and examined earlier (Figure 4 - 4 on page 48), and it is well documented in the literature (page 40). More factors that affect the storage behaviour of yam in general were presented in the general introduction (page 19ff), amongst which the storage structure may be the most important on farm. The storage structure's impact on the internal climate and biosphere, and its indirect influence on yam storage have been the topic of many research projects (page 21f). Yam growers use different structures and genotypes, and whether an interaction exists between post-harvest treatments with GA$_3$ and the remaining post-harvest system has not been properly resolved.

Another, very important parameter cannot be satisfactorily explained with economic models and on-station research: the feasibility of a technique in the eyes of the farmer. Without doubt this question is the hardest to answer, the developer and the final user being two different persons. Because the feasibility was assumed to be a major barrier to adoption (page 7), the work presented thus far could not be concluded without addressing the point of view of the farmer on the application of GA$_3$ to yam.

It appears to be unanimously accepted that storage losses are high in yam- as it was assumed prior to this study - yet, very little information about the extent of losses under farm's storage conditions are published. Serpantie (1983) had measured for a mixture of genotypes losses in the order of 10 to 35% in the central Ivory Coast. N'Kpenu (1997) studied the effect of curing in five villages in Togo and described on-farm losses precisely. For untreated tubers an overall loss of 58% was measured. With curing the losses due to rots were lowered to 8% of the initial tuber weight after five months of storage (vs. 16.2% for untreated tubers). Using another genotype, the same author noted losses due to rots decreased to 2%. This example illustrates the necessity to confirm on-station results in a varied setting. Furthermore, it raises the question of the magnitude of losses under on-farm conditions.

In the current research it was aimed to extend the knowledge on yam post-harvest behaviour under on-farm conditions. Specifically, the performance of different GA$_3$ treatments was assessed in these settings and the economic viability of an improved storage system was examined.
7 - 3 Results

Storage characteristics. The following data was obtained from experiment no. 8 (page 32). Each farmer used between 195 and 1320kg of tubers (D. cayenensis-rotundata cv. Krenglé), harvested in general 1 to 2 weeks before the trial started, except in Bouaké, where the tubers were about 2 months old at the time of the treatment. Heavily bruised and nematode infected tubers, as well as tubers of less than approximately 0.7kg were rejected. Tubers were stored in the locally available storage structures. The core data of the trial is summarized in Table 7 - 1. In Dabakala and

TABLE 7 - 1 Core data of the on-farm trial in 2000.

Storage start: end of January/beginning of February, yam price at 80,000CFA t\(^{-1}\)a
Storage end: beginning of June, yam price at 180,000CFA t\(^{-1}\).

<table>
<thead>
<tr>
<th>Zone</th>
<th>No. of farmers</th>
<th>Tuber weight [t]</th>
<th>Mean tuber weight [kg]</th>
<th>Storage structure</th>
<th>Time of treatment: days post harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bouaké</td>
<td>6</td>
<td>1.66</td>
<td>1.058</td>
<td>Traditional yam barn (French: “claie”)</td>
<td>50</td>
</tr>
<tr>
<td>Dabakala</td>
<td>5</td>
<td>1.76</td>
<td>1.933</td>
<td>Heap on wooden grid covered with straw or vines</td>
<td>13</td>
</tr>
<tr>
<td>Korhogo</td>
<td>7</td>
<td>5.88</td>
<td>1.108</td>
<td>Conical straw barn on wooden grid</td>
<td>6</td>
</tr>
</tbody>
</table>

a. 1€ corresponds to 656 CFA (fixed rate, 2001).

Korhogo, the traditional method of storage (control) consisted of cutting the sprouts 1 to 2 times during storage period with a cutlass. This was done when the sprouts were longer than 2m. The sprouts were cut in such a manner that 0.5 to 1m of the sprout remained on the tuber. In Bouaké, apart from attaching the tubers to the yam barn, no treatment was executed by the farmers. However, all farmers were in the habit of examining the stock every 1-2 months to eliminate rotten tubers.

The trials were set up from the 22nd of January to the 17th of February 2001 respecting the itineraries of the farmers regarding harvesting and other works. Tuber dormancy was well established as no tubers had sprouted at the time of treatment.

The evolution of sprouting during the trial was only assessed in Dabakala where a technician was closely following the trial. There, 50% of the control tubers had sprouted after 87d. GaSoil treated tubers reached this level 12 days later and GaStarch or GaDip treated tubers 19d later (Figure 7 - 1). In the two other regions, casual surveys in the middle of April confirmed the slight delay of sprouting of GA\(_3\)-treated tubers (data not shown). At the final weighing (23rd of May), just a few GaDip-tubers had sprouted.

During the storage period of 100-120 days, a few tubers were discarded due to rots. In certain isolated cases, theft or damage from astray cows lead to high number of tubers lost (0-5%). Towards middle/end of May, several farmers, especially in Dabakala and Korhogo, complained about the level of rot and the increasing losses. They were eager to sell because they thought that the losses of conservation were getting too high. Other
farmers, especially in Bouaké, observed a lower level of rot and were less eager to sell the stock. The term "tuber health" was regularly measured by a technician in Dabakala as his subjective opinion of the state of the tubers. Its evolution is shown in Figure 7 - 1. After an initial drop, a steady level is reached for three months. The subsequent drop, in the second half of May, reflects the perceptions of the farmers: the "tuber health" started to deteriorate.

**FIGURE 7 - 1** Evolution of tuber health and sprouting of tubers stored at 6 farmers in the region of Dabakala, Ivory Coast, for 4 months.

- Tuber health
- Relative sprouting intensity of:
  - Control
  - GaSoil 25
  - GaStarch 860
  - GaDip 150.

**Technical parameters of the post-harvest treatments.** While treating the tubers, the time to treat was measured, the amount of GA₃ utilised was estimated and remarks from the farmers were noted (Table 7 - 2). To soak the tubers for half an hour was most time consuming. The "dead" time, i.e. waiting for the half hour to elapse, could be used to remove the PNC. Nevertheless, 14h t⁻¹ were needed to apply GaDip. To apply gelatinised starch or the wet soil was considerably faster (7 - 8h t⁻¹). The time to prepare the solutions, the gelatinised starch, or to mix the soil was not taken into consideration, as it was estimated insignificant compared to the time needed to apply the GA₃ in any suggested form if large quantities are to be treated. The time needed for desprouting can only be estimated. Based on the time used to remove the PNC, 10h t⁻¹ were assessed for desprouting (once per month for 4 months). This is slightly higher than the 6h t⁻¹ proposed by Girardin (1996). Although one sprout removal event is sufficient to reduce storage losses (Nwankiti 1988), Girardin et al. (1997) suggested once per month as a feasible frequency with better control of storage losses.
The farmers were asked to evaluate the difficulty they experienced in applying the different treatments. GaDip was regarded most straightforward, easy to prepare and carry out. The difficulty was judged to be knowing how long to soak the tubers for, because few farmers had watches, and that it took a long time to do the treatment. To prepare the gelatinised starch was cumbersome, a recipe had to be followed and such it was less appreciated with respect to simplicity. To prepare the wet soil was easy, but - like the gel - to stick the paste to every tuber was considered tiresome. A negative asset was that the soil fell off the tubers and one farmer thought it a "dirty job". For both wet soil and the gelatinised starch, the short time needed to apply the treatment was highly valued. Desprouting was judged very easy and some farmers already knew the procedure. The main drawback of desprouting was the need for constant attention during the conservation period and the time needed to undo the heap and cut the sprouts every month. Nevertheless, 90% of the farmers were ready to execute dipping, wet soil or desprouting on their own, and 70% still thought themselves capable of preparing and applying the gelatinised starch.

Economic parameters of the post-harvest treatments. At the beginning of June, four months after the start of the conservation, the storage period ended. Differences between the zones were significant for post-harvest losses and rots, but the interaction between the post-harvest treatments and the zone was not. The treatment also had no influence on the level of rots. Because of missing interactions, the means across zones are presented. Control tubers had lost 35.2% of their initial weight (Table 7 - 3). Desprouting decreased the losses by 4%. GaSoil treated tubers lost 29.7%, and GaDip and GaStarch treated tubers 24.9 and 25.9% respectively. When the means per zone were used and the level of rots as a covariate, 93% of the variation was explained by the

### TABLE 7 - 2 Technical variables measured for three different GA₃-applications and the desprouting treatment.
Zones (3) were considered as blocks and farmers (18) as repetitions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Man hours to treat [hrs t⁻¹] a</th>
<th>Quantity of GA₃ used [g t⁻¹]</th>
<th>Difficulty [1...4] b</th>
<th>Acceptability [%] c</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaDip 150</td>
<td>14.1 a</td>
<td>2.98 a</td>
<td>1.8</td>
<td>92</td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>7.9 b</td>
<td>1.62 b</td>
<td>2.7</td>
<td>71</td>
</tr>
<tr>
<td>GaSoil 25</td>
<td>7.1 b</td>
<td>0.67 b</td>
<td>2.6</td>
<td>90</td>
</tr>
<tr>
<td>Despr</td>
<td>10d</td>
<td>0</td>
<td>2.1</td>
<td>92</td>
</tr>
<tr>
<td>Treatment e</td>
<td>**</td>
<td>*</td>
<td>ns.</td>
<td>ns.</td>
</tr>
<tr>
<td>Standard error of means</td>
<td>0.754</td>
<td>0.318</td>
<td>0.386</td>
<td>15.6</td>
</tr>
<tr>
<td>N</td>
<td>72</td>
<td>72</td>
<td>48</td>
<td>47</td>
</tr>
</tbody>
</table>

- a. Excluding the time to prepare the product but including approximately 2.5h t⁻¹ for the removal of the PNC.
- b. Score from 1 to 4, 1 = easiest treatment.
- c. Percent of the farmers agreeing to perform the treatment on their own.
- d. One desprouting assumed per month, i.e. approximately 2.5h t⁻¹ x 4 = 10h t⁻¹.
- e. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*), or 1% level (**). Means in columns followed by different letters are significantly different based on Least Square Means.
different factors of the statistical model (in brackets: % variation): treatment (72%), block (15%) and rot (6%). The farmers globally ranked the treatments in accordance with the post-harvest losses. This ranking was performed by the farmers ignoring the measured loss of weight, nor the financial benefit, but including the difficulty experienced during the setup and the conservation period.

**TABLE 7-3 Post-harvest losses, ranking by farmers, and gross benefits of storage of Krenglé for 4 months with different post-harvest treatments.**

Gross benefit compares the sale in February at 80,000CFA t⁻¹ to the sale in the beginning of June at 180,000CFA t⁻¹.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Post-harvest losses %</th>
<th>Ranking by farmers a</th>
<th>Mean gross benefit of storage CFA t⁻¹</th>
<th>% b</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaDip 150</td>
<td>24.9 a</td>
<td>1.7 a</td>
<td>56,300</td>
<td>153</td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>25.9 a</td>
<td>2.4 ab</td>
<td>53,400</td>
<td>146</td>
</tr>
<tr>
<td>GaSoil 25</td>
<td>29.7 b</td>
<td>2.9 ab</td>
<td>46,600</td>
<td>127</td>
</tr>
<tr>
<td>Despr</td>
<td>31.3 b</td>
<td>3.2bc</td>
<td>43,600</td>
<td>119</td>
</tr>
<tr>
<td>Control</td>
<td>35.2 c</td>
<td>4.2 c</td>
<td>36,700</td>
<td>100</td>
</tr>
</tbody>
</table>

*SEM 1.26 0.37
N 90 90

a. 1 = most preferred treatment
b. 100% = control
c. Indicated sources of variation were either not significant (ns.), indicating a tendency (†, p<10%), or significant at the 5% level (*), or 1% level (**). Means in columns followed by different letters are significantly different based on Least Square Means.

The prices of Krenglé had risen during the 4 months from 80,000CFA to 180,000CFA t⁻¹. A comparison of the value of the yam before and after conservation revealed that the price changes had overcompensated for the storage losses. Even tubers stored without a post-harvest treatment led to a gross benefit of storage of 36,700CFA t⁻¹. Using any of the proposed post-harvest treatments, this benefit was increased by 19 to 53%, in accordance with the severity of storage losses. Only one farmer lost 1,700CFA t⁻¹ with control tubers, corresponding to 2.5% of the tubers value in February. The best farmer nearly doubled his gross benefit by gaining 155,600CFA t⁻¹ in June vs. 80,000CFA t⁻¹ in February.

**Partial budgets.** The technique of partial budgets (Zagbai & Stessens 1995) was used to estimate the economic significance of the on-farm data. The advantage of this approach, as opposed to a global budget, is that it requires less data, includes only varying factors, and also detects minor differences. It is, however, based on the fact that farmers make decisions in order to maximise their net benefit, and thus, excludes other decisive factors.

---

a. 1€ corresponds to 656 CFA (fixed rate, 2001).
The net added benefit was calculated by subtracting the varying costs from the gross benefit (Formula 7 - 1). The amount of GA3 used by each treatment was multiplied by the price of GA3 ranging from 2,400CFA g⁻¹ to 6,000CFA g⁻¹ as estimated from the cost of the substance in Europe. Labour was valued at 100 to 200CFA h⁻¹ according to local practice. The interest on invested capital was calculated using the value of the yam in February (80,000CFA t⁻¹) plus the varying costs (GA3 and labour) at an interest rate of 20% per annum discounted to 4 months of storage.

**FORMULA 7 - 1 Calculation of the net added benefit, return of investment and break even price for yam storage.**

1. \( NAB : \) net added benefit, \( GB : \) gross benefit, \( VC : \) varying costs, \( P : \) price, \( L : \) losses, \( C : \) cost, \( W : \) labour, \( I : \) interest.
2. \( RI : \) return of investment.
3. \( BEP : \) break even price when \( NAB=0. \)

\[
NAB = GB - VC = [P_{June} \times (1 - L) - P_{January}] - [C_{GA3} + C_{W} + I] \tag{1}
\]

\[
RI = \frac{VC}{GB} = \frac{V_{June} - V_{January}}{C_{GA3} + C_{L} + I} \tag{2}
\]

\[
BEP_{June} = \frac{P_{January} + [C_{GA3} + C_{W} + I]}{1 - L} \tag{3}
\]

The sum of the cost of GA3, labour and the interest on invested capital represented the varying costs. The return of investment is an indicator that expresses the benefit generated per invested unit. It was calculated as the gross benefit divided by the varying cost. The break even price is a hypothetical price at which no benefit is generated, i.e. at which the varying costs are equal to the gross benefit, or when the return of investment becomes 100%. For this purpose the formula for the net added benefit was solved for the price in June. Setting the net added benefit as 0, the break even price resulted. The steps leading to the net added benefit and derived indicators are given in Table 7 - 4 and Table 7 - 5.
Results

In Table 7 - 6 the economically best and worst cases that were encountered during the trial are presented. The choice was done for each treatment separately. The best farmers originated from Dikodougou or Bouaké, recorded virtually no rot in their heaps and low levels of fresh-matter losses. Consequently, their net added benefit was very high (approximately 60,000CFA t\(^{-1}\)) and few differences existed between the treatments. Similarly, the worst farmers suffered very high losses which were always associated with levels of rot from 10 to 28%. The range of net added benefit at their level was between -11,000CFA t\(^{-1}\) to 13,000CFA t\(^{-1}\).

### TABLE 7 - 4 Calculation of the varying costs for different post-harvest treatments.
The amounts of GA\(_3\) and labour from Table 7 - 2. All values are expressed as CFA t\(^{-1}\) of yam.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cost of work [CFA h(^{-1})]</th>
<th>Cost of GA(_3) [CFA g(^{-1})]</th>
<th>Interest on capital</th>
<th>Varying costs(^a) [CFA t(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cheap(^b)</td>
<td>exp.(^b)</td>
<td>cheap(^b)</td>
<td>exp.(^b)</td>
</tr>
<tr>
<td>GaDip 150</td>
<td>1,410</td>
<td>2,820</td>
<td>7,080</td>
<td>17,700</td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>790</td>
<td>1,580</td>
<td>3,888</td>
<td>9,720</td>
</tr>
<tr>
<td>GaSoil 25</td>
<td>710</td>
<td>1,420</td>
<td>1,608</td>
<td>4,020</td>
</tr>
<tr>
<td>Despr</td>
<td>1,000</td>
<td>2,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Price** | 100 | 200 | 2400 | 6400 | 20% p.a. |
|-----------|------|------|------|------|-----------|

\(^{a}\) Sum of cost of work, GA\(_3\) and interest.
\(^{b}\) Cheap and expensive (exp.) alternative, i.e. low and high cost of work and GA\(_3\), i.e. low and high prices for GA\(_3\) and work (see last row).

### TABLE 7 - 5 Calculation of the net added benefit, return of investment of storage, and break even price for different post-harvest treatments.
The gross benefit comes from Table 7 - 3, and the varying cost from Table 7 - 4. The actual price in the beginning of June was 180 000CFA t\(^{-1}\).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean gross benefit [CFA t(^{-1})]</th>
<th>Varying costs (^d)</th>
<th>Net added benefit(^a) [CFA t(^{-1})]</th>
<th>Return of investment of storage (^b) [%]</th>
<th>Break even price for yam in June(^c) [CFA t(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cheap(^d)</td>
<td>exp.(^d)</td>
<td>cheap(^d)</td>
<td>exp.(^d)</td>
<td>cheap(^d)</td>
</tr>
<tr>
<td>GaDip 150</td>
<td>56,300</td>
<td>14,389</td>
<td>27,221</td>
<td>41,911</td>
<td>29,079</td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>53,400</td>
<td>10,323</td>
<td>17,387</td>
<td>43,077</td>
<td>36,013</td>
</tr>
<tr>
<td>GaSoil 25</td>
<td>46,600</td>
<td>7,806</td>
<td>11,136</td>
<td>38,794</td>
<td>35,464</td>
</tr>
<tr>
<td>Despr</td>
<td>43,600</td>
<td>6,400</td>
<td>7,467</td>
<td>37,200</td>
<td>36,133</td>
</tr>
<tr>
<td>Control</td>
<td>36,700</td>
<td>5,333</td>
<td>5,333</td>
<td>31,367</td>
<td>31,367</td>
</tr>
</tbody>
</table>

\(^a\) Gross benefit minus varying costs.
\(^b\) Gross benefit divided by varying costs
\(^c\) Hypothetical price of Krenglé in June, at which the net added benefit would be exactly zero.
\(^d\) Cheap and expensive (exp.) alternative, i.e. low and high cost of work and GA\(_3\)
Feasibility of GA₃ Application in Farm Conditions

Characteristics of farmers. The three regions in which the on-farm trial was run comprised three ethnic groups in which growing, storing and selling yam were deeply embedded in the cultures. The data relevant to the strategy of the farmers with Krenglé is summarised in the Table 7 - 7. The farmers were asked which part of the total harvest of Krenglé they normally attributed to immediate sale, to mid- or long term storage and for seed yam. The time of harvest and whether and why a farmer wished to increase the production of this cultivar were also recorded. Characteristics of commercialisation are given in Table 7 - 8. Among the three most important species/genotypes *D. cayenensis-rotundata* was always cited first by the farmers, and the cultivar Krenglé was more important in Bouaké and Dikodougou than in Dabakala. It was also in those two regions that farmers stored yam for longer and sold it later. The major problems encountered in the commercialisation were the instability or unpredictability of the prices and unfair dealing through falsified scales and the monopoly of traders. All farmers also used yam as a "short-term bank account". If they had an urgent need for money, they would sell a few tubers of highly priced yam (generally Krenglé) on the local market.

TABLE 7 - 6 Storage economy of the best and the worst farmer.
Per treatment, the gross and net benefits, and varying costs of the farmers with the lowest (A) and highest (B) post-harvest losses are shown. Cheap alternative for the varying costs were used.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Post-harvest losses [%]</th>
<th>Gross benefit [CFA t⁻¹]</th>
<th>Varying costs [CFA t⁻¹]</th>
<th>Net added benefit [CFA t⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaDip 150</td>
<td>13.5</td>
<td>75,700</td>
<td>15,800</td>
<td>59,900</td>
</tr>
<tr>
<td>GaStarch 860</td>
<td>16.0</td>
<td>71,200</td>
<td>9,900</td>
<td>61,300</td>
</tr>
<tr>
<td>GaSoil 25</td>
<td>18.5</td>
<td>66,700</td>
<td>6,700</td>
<td>60,000</td>
</tr>
<tr>
<td>Despr</td>
<td>20.0</td>
<td>63,900</td>
<td>6,400</td>
<td>57,500</td>
</tr>
<tr>
<td>Control</td>
<td>19.8</td>
<td>64,400</td>
<td>5,300</td>
<td>59,000</td>
</tr>
</tbody>
</table>

TABLE 7 - 7 Characteristics of the strategy used by farmers with *D. cayenensis-rotundata* cv. Krenglé in three regions of the Ivory Coast.
The data is based on interviews (18 farmers)

<table>
<thead>
<tr>
<th>Region</th>
<th>Seed</th>
<th>Storage</th>
<th>Immediate Sale</th>
<th>Time of harvest</th>
<th>Wish to increase production</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bouaké</td>
<td>17 - 40%</td>
<td>17 - 23%</td>
<td>40 - 60%</td>
<td>Nov. - Dec.</td>
<td>Yes</td>
<td>High price</td>
</tr>
<tr>
<td>Dabakala</td>
<td>28 - 50%</td>
<td>0 - 27%</td>
<td>32 - 56%</td>
<td>Dec. - Jan.</td>
<td>No</td>
<td>Other genotypes are better</td>
</tr>
<tr>
<td>Dikodougou</td>
<td>30 - 65% a</td>
<td>15 - 30%</td>
<td>15 - 46%</td>
<td>Dec. - Feb.</td>
<td>Yes</td>
<td>High price</td>
</tr>
</tbody>
</table>

a. High percentage of seed storage was accompanied by the wish to increase the surface of Krenglé in the coming season.
Results

On-farm storage in Nigeria. The following data was obtained from experiment no. 9 (page 32). As shown in Figure 7 - 2, GA3 prolonged dormancy by two months irrespective of the level of PNC removal. The difference in sprouting between the GA3 treatments and control was significant. Post-harvest losses were significantly reduced by both GA3 treatments (26.6% for PNC wounded and 28.4% for PNC removed). Control tubers had lost 33.4% after 4 months of storage. However, only 20% of the variation could be attributed to the treatments, and 58% of the variation was due to the blocks (villages). This data should be taken with caution, as the scales were of poor precision (0.1 to 1kg). GA3-treated tubers had a lower percentage of rots (3.8 and 4.4%) compared to control tubers (9.0%).

The choice of variety was left to the farmer and 12 genotypes were used in the trial. As shown in Table 7 - 9, the response to GA3 was genotype dependent. Because most genotypes occurred only once, statistical analysis of this factor was not possible. Three groups of genotypes were formed, according to their response to GA3. 42% of the farmers stored their yam in yam barns (french: "claie"), 24% in heaps in the shade, 22% in thatched houses, and the rest in various other structures (ware house, living room, pits). Of the farmers that gave answers, 61% stored the yam for sale, 33% for own consumption and 7% for both purposes. Regarding the storage behaviour of yam in the experiment, 34% remarked the reduction of sprouting, 8% were concerned about rodents, 6% about rots and 44% of the farmers gave no answer. The farmers were of 9 different ethnic groups, of which 47% were Mada and 25% were Eggon. None of the parameters measured could be related to ethnic preference, which was also due to the small size of the sample and the numerous but singly occurring minorities (Gwandara, Haussa, Jukun, Kanuri, Mggon, Migili, Zagizzagi).

### TABLE 7 - 8 Importance and commercialisation of yam in three different regions of the Ivory Coast.

<table>
<thead>
<tr>
<th></th>
<th>1st genotype</th>
<th>2nd genotype</th>
<th>3rd genotype</th>
<th>Time of sale</th>
<th>Major constraints</th>
<th>Place of sale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bouaké</td>
<td>Krenglè</td>
<td>Bètè bètè/Florido/Kponan</td>
<td>Krenglè</td>
<td>progressive(^b)</td>
<td>Cost of transport, unstable prices, prices unknown</td>
<td>local markets</td>
</tr>
<tr>
<td>Dabakala</td>
<td>Kponan(^a)</td>
<td>Assawa</td>
<td>Krenglè</td>
<td>January(^c)</td>
<td>Prices unknown, monopoly of buyers, falsified scales</td>
<td>Field</td>
</tr>
<tr>
<td>Dikodougou</td>
<td>Krenglè</td>
<td>Bètè bètè/Florido/Kponan</td>
<td>January through July(^{cd})</td>
<td>falsified scales, unstable prices, rots</td>
<td>Field</td>
<td></td>
</tr>
</tbody>
</table>

\(\text{a. synonym for Wacrou}\)
\(\text{b. The farmer sells yam throughout the storage period.}\)
\(\text{c. September for Kponan and Assawa}\)
\(\text{d. generally at two periods, at harvest and a later time depending on the variety.}\)

D. *cayenensis-rotundata* late harvest genotype: Krenglè
D. *cayenensis-rotundata* early harvest genotypes: Kponan, Assawa
D. *alata* late harvest genotype: Bètè bètè, Florido

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96
FIGURE 7.2 Evolution of sprouting of GA$_3$-treated and untreated tubers of *D. cayenensis-rotundata* in Nigeria.

Approximately 600 tubers per treatment and 12 different cultivars, with a majority of the genotype Pepa, were used. The means and standard errors of untreated (●), GaSoil 25 treated tubers with PNC removed (■), and GaSoil 25 treated tubers with PNC only wounded (◆) are shown.

TABLE 7.9 Post-harvest losses and intensity of sprouting after 4 months of storage of 12 genotypes of *D. cayenensis-rotundata* from Nigeria as affected by different post-harvest treatments. Response to application of GA$_3$:

<table>
<thead>
<tr>
<th>Genotype</th>
<th>No. of farmers</th>
<th>Post-harvest losses [%]</th>
<th>Sprouting after 4 months of storage [%]</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Control GaSoil PNC removed GaSoil PNC wounded</td>
<td>Control GaSoil PNC removed GaSoil PNC wounded</td>
<td></td>
</tr>
<tr>
<td>Amola</td>
<td>13</td>
<td>33 28 28</td>
<td>97 41 27</td>
<td></td>
</tr>
<tr>
<td>Asakidab</td>
<td>1</td>
<td>40 33 25</td>
<td>90 40 30</td>
<td></td>
</tr>
<tr>
<td>Dananach</td>
<td>1</td>
<td>38 33 30</td>
<td>100 60 40</td>
<td></td>
</tr>
<tr>
<td>Gwari</td>
<td>2</td>
<td>54 36 39</td>
<td>90 40 20</td>
<td></td>
</tr>
<tr>
<td>Pepa</td>
<td>32</td>
<td>36 28 25</td>
<td>93 57 51</td>
<td></td>
</tr>
<tr>
<td>Agbomaga</td>
<td>4</td>
<td>17 22 25</td>
<td>88 43 43</td>
<td></td>
</tr>
<tr>
<td>Ashakata</td>
<td>1</td>
<td>20 17 21</td>
<td>80 60 40</td>
<td></td>
</tr>
<tr>
<td>Didio</td>
<td>1</td>
<td>29 31 28</td>
<td>80 60 60</td>
<td></td>
</tr>
<tr>
<td>Shapara</td>
<td>1</td>
<td>25 22 20</td>
<td>90 90 60</td>
<td></td>
</tr>
<tr>
<td>Aduru</td>
<td>1</td>
<td>50 67 75</td>
<td>60 80 90</td>
<td></td>
</tr>
<tr>
<td>Shigaku</td>
<td>1</td>
<td>11 21 15</td>
<td>60 40 40</td>
<td></td>
</tr>
<tr>
<td>Yerima</td>
<td>1</td>
<td>12 25 22</td>
<td>100 90 30</td>
<td></td>
</tr>
</tbody>
</table>
7 - 1 Discussion

Post-harvest losses at farm level. The prolongation of dormancy by GA$_3$ observed in the Ivory Coast (maximum 19d) is smaller than normally measured in on-station studies. Girardin et al. (1998) has measured 37d, Nnodu and Alozie (1992) reported a sprout suppression for one month. The on-farm effect of GA$_3$ here is, however, well within the range of the on-station data shown here (Table 6 on page 90). A lower prolongation of dormancy may be explained by the lateness of treatment. The tubers had already passed maturity, which is thought to be the ideal point of application (see page 47). Nevertheless, the decrease in weight loss was close to what other researchers have measured, i.e. in the range of 10 to 12% (Nnodu & Alozie 1992, Girardin et al. 1998) and results presented here earlier. It can be concluded that the efficacy of a GA$_3$ treatment is not significantly altered when transferred from on-station to farmer's field.

Quite a different situation was observed in Nigeria. The prolongation of dormancy for two months was accompanied by only a small decrease in weight loss. This must be partly attributed to imprecise weighing. If the precision of the scales was ±1kg, the comparison of two means can be erroneous by as much as 2kg. More than half of the farmers in Nigeria stored less than 20kg of yam per treatment. The error of weighing can, therefore, attain 10%, which is in the range of the expected reduction of weight loss. With such a high measurement error the expected differences between the post-harvest treatments cannot be detect. The measurement of sprouting more accurate and therefore more trustworthy. It appears that GA$_3$ is generally functional in the yam tested in Nigeria.

In this country, post-harvest losses for untreated tubers after 4 months of storage varied from 11 to 54% depending on the genotype. This is lower than the 58% found by N’Kpenu (1997) in Togo but well within the genotypic range observed in other trials (page 49). The presented values correspond also better to Serpantie's on-farm measurement of post-harvest losses: he estimated, for a mixture of varieties, physiological losses of 10 to 20%, and rots of 0 to 15% (Serpantie 1983). The most common genotypes in the trial (Pepa and Amola) showed a strong prolongation of dormancy and an appreciable reduction of post-harvest losses even under the limitations of weighing explained above. The genetic variability in relation to GA$_3$ application was strong, which is in accordance with other experiments carried out. It is clear from these experiments, that the GA$_3$ treatment must be fine-tuned for each genotype with regard to dosage and time of application. Certain genotypes may not be suitable for this treatment. The high potential of GA$_3$ for reducing post-harvest losses must, however, be stressed: in the genotypes Gwari and Asakidab, post-harvest losses were reduced by 15 to 20%.

As expected, the level of PNC removal does not alter the response to GA$_3$ (see also page 46). This, as pointed out before, is an important asset because the PNC is considered an integral part of the yam tuber in Nigeria. Its removal is ill-viewed by consumers (G.C. Orkwor, pers. comm. b, own interviews in Zaki Biam, Nigeria). In Ghana it was found that 91% of the marketed yam tubers had their PNC...
removed (Bancroft et al. 1998). In the Ivory Coast the presence of the PNC also seems to be of no importance (own observations). In these countries the PNC may be completely removed for simplicity's sake if a GA₃ application is envisaged.

All GA₃ treatments require the measurement of volume to attain the correct concentration of GA₃. The wet soil treatment implies that approximately 25kg of the product must be prepared per ton of yam. A vessel to dissolve the GA₃ and to mix the soil, and some litres of water are necessary. Two farmers in the Ivory Coast had been quite avaricious and had employed very little of GaSoil per tuber (resulting in a use of GA₃ of 0.35g t⁻¹). Their data suggests that in spite of the considerably lower use of GA₃ in wet soil the losses were still reduced by 10% vs. untreated tubers. The potential to lower the use of GA₃ with the soil technique is still underexploited. GaDip requires relatively more water and several vessels to soak the tubers, if an efficient speed is wanted. Furthermore, some measurement of time is mandatory for GaDip. Gelatinised starch demands the cooking of approximately 300g of starch with 1.1l of water per ton of yam. The GA₃ is dissolved in a small container (300ml per pill). A cooking pot and a fire are needed and the recipe must be known to the farmer. Clearly, the GaStarch is the most difficult method to explain. Ideally, GA₃ should come in a more convenient form for the GaStarch application, i.e. pre-mixed with starch in a sachet to be cooked shortly in a defined volume, for example a multiple of the volume of the sachet.

It seems clear from my experience that neither GA₃ application poses severe difficulties for the farmer. However, neither are really as easy to perform as desprouting.

**Economic evaluation of GA₃ application in the Ivory Coast.** A more watertight economic appraisal of improved storage techniques for yam was attempted in the thesis of Dao (2003). The estimation of the price of GA₃ is based on prices in Europe because the chemical is not yet sold in West Africa. The cost of labour is also assessed with difficulty in rural Africa, as the work force is mostly made up of family members or non-family cooperative groups. The cost of labour reflects more the availability of work force, which may be limiting at times. The cost of labour used here is based on experience, i.e. about 500 to 2,000CFA d⁻¹. Likewise, the interest on immobilised capital is a compromise to a Western economic concept, which, for people who have difficult access to credit facilities, has little meaning. Last but not least, the price of yam used in the calculations was based on the on-farm trial. Although it corresponds to other sources (Touré et al. 2002), fluctuations on the yam market are high, and low market transparency make it difficult to uphold the assumption.

With these restrictions in mind, the economic evaluation presented in Table 7 - 5 seems to attest some of the improved GA₃ applications an economic feasibility. Even with expensive labour and GA₃, all treatments have a positive net added benefit, i.e. storage with any technique seems principally rewarding. Also, all treatments have a return of investment greater than 100%.

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If the farmer wishes to maximise his return-on-investment rate, none of the improved post-harvest treatments is better than traditional storage, with which his investment will be compensated almost seven times. Desprouting and the best GA$_3$ treatment offer only five to six times compensation. This, because the lower post-harvest losses must be "bought" with work and GA$_3$, a process that seems to follow the law of diminishing returns. Even in the best case, i.e. cheap labour and GA$_3$, the highest return-on-investment remains with the untreated group. The examples of the worst and best case (Table 7 - 6) illustrate that very good, or lucky, farmers have less benefit from the improved storage techniques compared to traditional storage. With the prices assumed here, 60,000CFA t$^{-1}$ net added benefit is the upper limit of benefit. Average farmers benefit most from the improved methods, while the worst may lose up to 10,000CFA t$^{-1}$ with prolonged storage. Farmers must choose carefully the cultivars and storage structures as well as supervise the stock and, if necessary, apply curative measures to ensure a beneficial yam storage.

Resource-poor farmers will tend to attribute their resources to investments that offer a higher return-of-investment (Bachmann 1985). Yam storage offers rates of 200 to 700%. The yam farmer will, thus, only invest in storage, if he has no more rewarding opportunities.

A different approach to assess the economic viability can be given by comparison with other attempts to improve storage of yam. Cold storage was priced at 35 to 40CFA kg$^{-1}$ and ionisation at 2 to 4CFA kg$^{-1}$ in 1984 (Demeaux & Vivier 1984). At today's prices, the cost of cold storage and ionisation would be 160 to 180CFA kg$^{-1}$ and 9 to 18CFA kg$^{-1}$, respectively. A post-harvest treatment with thiabendazole can be evaluated at approximately 25CFA kg$^{-1}$ (100g active substance t$^{-1}$ of yam (Ricci et al. 1978)). These figures offer a fair comparison to GA$_3$-treatments and desprouting, costing 6 to 24CFA kg$^{-1}$. Of course, neither cold storage nor ionisation are feasible under farm conditions, nor are their impact on post-harvest losses comparable to a GA$_3$ treatment. Improved storage structures increased the benefit by 4,000 to 6,000CFA t$^{-1}$ compared to a sale at harvest according to Fiagan (1991). The net added benefits calculated here are much higher than these figures.

If we compare yam production with yam storage economically, a similarly positive conclusion can be drawn. According to Ndegwe (1990), staking resulted in a maximum 35% benefit for yam. Improved fallow and subsequent staking with *Gliricidia sepium* led to an estimated benefit of 90,000 to 120,000CFA ha$^{-1}$ (Kouamé 1999), i.e. approximately 10,000CFA t$^{-1}$. If a farmer sets aside 30% of his production for later sale as shown in Table 7 - 7, he can expect a benefit of 90,000 to 120,000CFA ha$^{-1}$ (assuming a yield of 10t ha$^{-1}$). These figures show that the benefits of yam storage are in the range of other improved yam technologies.

c. For this rough estimation, only inflation is taken into account: 100% devaluation of the CFA in 1992, plus 5% inflation rate per year before and after 1992.
The cultivation of yam demands 300 to 500 man days ha\(^{-1}\) (Onwueme 1982b, Oyolu 1982). Assuming a yield of 10 t ha\(^{-1}\) and 30% of the yam being stored, improved storage will add 2.5 to 5 man days ha\(^{-1}\). In view of the benefit, this time is very well compensated financially. Improved storage increases the value of the work invested into yam cultivation.

Different strategies for farmers who wish to maximise their benefit can be formulated. If financial investment is limiting, GA\(_3\) with wet soil or manual desprouting are techniques with low input and moderate return. There is a low risk that both treatments have a lower benefit than no treatment. Maximising tonnage and benefit is only possible with a high financial investment by employing the dipping method or gelatinised starch. Particularly, dipping poses a risk of no benefit compared to untreated tubers, although investment will be fully reimbursed. Gelatinised starch has the highest potential benefit, but it demands higher investment than wet soil. Expensive or unavailable labour call for wet soil, gelatinised starch, or no special post-harvest treatment.

**Economics of storage in Nigeria.** In large parts of Nigeria, yam is not sold by weight but by piece and grade (G.C. Orkwor, pers. comm., own experience in Zaki Biam). Although researchers generally circumvented this fact by using derived per kg prices, in the case of improved storage as proposed here, this is not easily done. In contrast to cultivation techniques, or methods prevailing rots, a GA\(_3\) treatment has no impact on the number of saleable tubers. There is an inherent risk in Nigeria that GA\(_3\) treatment of yam tubers will not result in increased revenue from their sale. A board of Nigerian and other West African researchers and extension agents have, however, suggested that this may not be the case. It is likely that such tubers, due to their smoother skin, and "heavier feeling", pass into a higher grade and such fetch a higher price. This statement could only be properly verified with an on-farm trial that sells the tubers in a kind of blind test where neither seller nor buyer knows if the tubers concerned were treated with GA\(_3\) or not.

**Risk assessment.** In the present economic model the risk lies only on two sides: the farmer and the market. This is suggested by Formula 7 - 1, where the major varying factors seem to be the price of yam in June and the extent of post-harvest losses. Prices in January of yam, of GA\(_3\), labour and interest are determined largely by exogenous factors, or else react to long term changes and may be disregarded here. The level of post-harvest losses is in the hands of the farmers. If they generally practise good yam storage, their risk of exorbitant losses is minimal (see also Table 7 - 6). The choice of well storable genotypes, the protection of the storage structure from theft, stray animals, and rodents, and the application of post-harvest measures to combat rots and sprouting are all part of such good yam storage practice. The price is determined by the market. Market studies confirm relatively high price stability for yam (Touré et al.).

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2002), however, long-term analysis of price trends have still not been accomplished (Dao, pers. comm.). If the population growth continues and thus overall expenditure of the concerned societies increases, yam demand will outweigh yam availability. Consequently, the positive expenditure-elasticity for yam demand as shown by Nweke et al. (1992, 1994) would lead to stable high prices. The formation of cooperatives and market information services should greatly enhance market transparency and diminish the market-wise risk of yam storage.

**Contribution of farmers to improved storage.** For the farmers in Bouaké (central Ivory Coast) and in Dikodougou (Northern Ivory Coast), Krenglè is the most important yam genotype and it is often an important factor for the household revenue. This is also reflected by their wish to increase the area dedicated to Krenglè (Table 7 - 7 on page 95). Farmers in the North-East of the Ivory Coast, Dabakala, rely more on double harvest varieties and Krenglè has only recently been introduced as a cash yam. While the Baoulé and Senoufo ethnic groups (in Bouaké and Dikodougou) have cultivated Krenglè for a long time and also consume it, farmers in Dabakala (Djoula, allochtonous) grow it solely for sale. This is reflected in the low percentage of the harvest they store for later sale and their urge to sell Krenglè immediately (Table 7 - 7 on page 95). They seem to have little cultural knowledge about storage of this genotype, and about price dynamics, and have no habit of storing for their own consumption. This was also observed in the storage structures employed by each group of farmers (Table 7 - 1 on page 89). The heap method used in Dabakala led to generally higher losses and higher level of rot compared to the more specialised structures (thatched huts and yam barns) used by the other ethnic groups. Consequently, the farmers in Dabakala had lower gross benefits (27,000CFA t⁻¹ on average) vs. the two other regions (49,000CFA t⁻¹ on average). Of course, this difference could also have been due to a slight genotypic difference within Krenglè. If the impact of the farmer on storage was true, this fact should be taken into account if a dissemination of the methods are planned. Good storage practice is vital if improved storage techniques are to be economically yielding. Serpantie (1983) reported that Krenglè was desprouted in the population he had observed, because pounding quality dropped once dormancy was broken. This was never the case in the present study. There is possibly a cultural erosion of (storage) practice which must be counteracted by dissemination of new (storage) methods.

Farmers in Dabakala, less acquainted with Krenglè, had also a more fatalistic approach to the commercialisation. They had no clear idea of how to solve the problems caused by the commercialisation of yam. The instability of the price, or more the ignorance of the price of yam at a certain period, was countered with "we don't manage the system", or "we discuss the price with the buyer". The farmers in Dikodougou and Bouaké had a positive vision of how to tackle this problem. Either the problem did arise, or they recommended to solve it through farmer cooperatives, a better credit system, or even by
not selling the yam if the price was not to their expectation. These facts underline that only good farmers should, and will, engage in risky enterprises, such as a late sale of yam.

**Perception of improved storage by farmers.** The farmers unanimously agreed that GA\textsubscript{3} delayed sprouting, and many stated that the skin remains smooth in GA\textsubscript{3}-treated tubers. Desprouting was seen like untreated tubers, sprouting and losing weight quickly. This was finally reflected in the preference of the treatments by the farmers (Table 7 - 3 on page 92). The control tubers were viewed as the worst, while GA\textsubscript{3}-treated tubers pleased the farmers most. They were asked to include the difficulty experienced during the setup and the storage period into their judgement. Nevertheless, such a global value has the risk of being biased by the presence of the researcher (who generally wishes "his" treatments to be superior). Until proven otherwise, it is a fair assumption that these storage techniques have a high potential of adoption. This is also in agreement with Dao *et al.* (2002), who stated that yam farmers in the North of the Ivory Coast are most sensitive to the degree of post-harvest loss reduction. According to Guessan Bi (1997) who studied a different region, farmers tended to minimise risk of loss during storage and sold when in need of cash.

The farmers were ready to pay between 250 and 15,000CFA for 1 pill of GA\textsubscript{3}. They had, however, no real understanding of what quantity of yam 1 pill can treat. GA\textsubscript{3} should be available in the local agricultural store, or at least in the nearby provincial town. The sale of GA\textsubscript{3} through rural cooperatives, or the National Extension Service, was proposed. In the Northern Ivory Coast it was observed that farmers diverted agricultural inputs with multiple uses (i.e. fertilisers, herbicides) from the cotton fields to the yam crop. The inputs were pre-financed and subsidised by the cotton buyer. This shows clearly the economic and innovative interest the farmers have in yam growing compared to the cash-crop cotton.

A major problem regarding investment by resource poor farmers is the unavailability of funds, or rather the competition of many elements for funds which are rarely available. The example of cotton also clearly shows the advantage of a cooperative or of contract production regarding the availability of inputs for these resource-poor farmers.

The farmers greatly appreciated the revenue in June, when the new fields were prepared and investments were necessary. Most farmers deplored, however, the lacking information on the current yam price. How should a farmer decide whether to apply an expensive post-harvest treatment if he lacks the information to calculate the prospective benefit?

**7 - 2 Conclusion and recommendations**

Within the limitations of the present economic model and on-farm trials, farmers who have no options offering more than 200% return on investment, should engage in prolonged yam storage. Storage without any precautions other than careful choice of
Conclusion and recommendations

genotype and avoidance of non-physiological storage hazards is economically rewarding. The improved methods proposed here have a proven impact on fresh storage of yam under rural conditions, a high potential to increase yam supply, and to increase the producer's revenue. There is an array of methods to apply GA$_3$, which should suit many farmers' situations. Given the importance of yam for revenue in certain regions, the use of GA$_3$ helps reducing the risk of storage and empowers the farmers to wait longer for the ideal selling time. Storage of yam is thus not only profitable but distributes the farmer's income over a longer period.

Unfortunately, none of the yam producing countries has yet legally approved the use of GA$_3$ as an agricultural chemical. This should be straightforward as GA$_3$ has no toxic or environmental hazards. Its use is allowed in all developed countries. Private enterprises should be encouraged to carry out the necessary procedures to make GA$_3$ available to farmers. A vertical market integration of yam production and storage should be studied closely because one main barrier for agricultural inputs in tropical Africa is the availability of financial resources. The Ivory Coast produces 2.8 million metric tons of yam per year (FAO 2002). According to experts in yam markets, roughly 5% of this volume may be Krenglè that is sold in June, i.e. about 140 000 metric tons (M. Touré, J.Stessens, pers.comm.). If the whole quantity was treated with GA$_3$, the market size of GA$_3$ would range from 0.35 to 2.5 million €, assuming the prices of GA$_3$ and application rates given above. There is no reliable data on quantities sold in Nigeria, but if similar ratios applied, the market volume would easily be multiplied by ten (Nigeria produces 25 million t of yam per year (FAO 2002)).

Furthermore, there is a need to train agricultural extension officers in these new technologies. Most farmers are aware of the influence of sprouting on storage losses and so it can be expected that adoption of this new technology will be high. Certain problems outlined by Dao et al. (2002) like the time needed to apply GA$_3$ and the cost of the method were successfully reduced in this study. This also should increase the rate of adoption.

The pitfalls of the promotion and adoption of technology in yam have been outlined by Bakang (1998). Nine years after the introduction of the minisett technolgy (Igwilo & Okoli 1988, Kalu 1989), it had "remained in a demonstration stage with only a few trials by curious innovators". The program failed due to lack of adaptive trials, inadequate training, a mis-direction of the efforts undertaken (wrong target clientele), top-down approach, short duration of the programme and lack of funding. Another result of the study was that non-traditional regions had higher adoption rates because of, among other reasons, a lower cultural attachment to the yam.

It is evident that an improved method of storage cannot be solely transmitted to the farming society. For this, the expected benefit is too small to justify a specially designed campaign. Improved storage must be assembled with other techniques. As part of a yam improvement scheme, including superior genotypes, soil management techniques, and possibly better market access, improved storage has high potential. Even further afield, a catalogue of measures, or possibilities, should be compiled, listing clearly the
possibilities a farmer can take, if he wishes so. For, where there is no need, no improvement can be made. The need is always formulated by the one having most profit: the farmer.

To carry the development of a new technology as far as to the end user is, in the relatively unknown setting of yam and rural Africa, a tricky endeavour. The amount of speculation and uncertainty which has also appeared here, pushes such approaches to the border of what many would refer to as "science". To observe the repercussions of such a technology was, however, highly rewarding and allows me to propose the elaboration of a more complex and more complete understanding of the yam production system as met here. The levers that act, the resilience encountered, the functionality of the different elements and their interaction should be visualised and to a certain extent quantified. The impact of any intervention could then be predicted with more certainty, and new axes of research and development defined with more confidence. Therefore, the close collaboration with researchers from other disciplines focusing on other aspects of the same system, with rural experts such as farmers and extension agents and with development workers is encouraged here.
References


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References


Curriculum Vitae

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Born in Aarau (Switzerland) of Elsbeth and Christian Tschannen-Röthlisberger.

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with thanks to the Botany Library of the Natural History Museum, London
Storage of fresh tubers allows a year round availability of *Dioscorea spp.* but losses due to sprouting are high. GA$_3$ prolongs tuber dormancy and reduces post-harvest losses accordingly. Its application is so far, however, not feasible under farm conditions.

Two new methods of application were developed and tested. GA$_3$ in soil or in gelatinised starch was applied to tuber heads and reduced storage losses as efficiently as the established dipping procedure. It was also shown that for both investigated species, *D. cayenensis-rotundata* and *D. alata*, the ideal time of application was immediately after harvesting.

Under on-farm conditions, both new methods were superior to the dipping procedure in terms of GA$_3$ usage and time needed for application. Post-harvest losses were reduced by about 10%. All improved treatments, including manual desprouting, were economically beneficial and acceptable to the farmers. GA$_3$ application for prolonged storage of yam is recommended because it increases the availability to consumers and the revenue of the producers.

For planting, tubers are cut into pieces, called setts. It was shown that setts with sprouts at planting emerge more rapidly and have significantly higher yields. Also, setts cut from apical tuber parts have higher yields than other setts. A GA$_3$ treatment led to more sprouts on the middle and basal parts, and yield and emergence were therefore more homogenous when GA$_3$ treated seed tubers were planted.

Cover pictures: Freshly harvested tuber of *D. cayenensis-rotundata* with roots.

Chemical structure of Gibberellic Acid A3 (GA$_3$)