Work Environment and Respiratory Health among Sisal Processors in Tanzania

Studies in six sisal factories

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Table of Contents

List of figures,tables and appendices

1. List of figures

2. List of tables

3. List of appendices

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List of publications

This thesis is based on the following papers, which will be referred to in the text by their respective roman numbers;

Paper I...

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Paper IV...

Kayumba AV, Van-Do. T, Florvaag E, Bråtveit M, Baste V, Mashalla Y, Eduard W, and Moen BE (2008). High prevalence of immunoglobulin E (IgE) sensitization among sisal (*Agave sisalana*) processors in Tanzania. *(Submitted manuscript)*

List of abbreviations

AM	Arithmetic mean
ATS-LD	American Thoracic Society and Lung Diseases
BMRC	British Medical Research Council
BMI	Body Mass Index
CAC	Cellulose acetate
CI	Confidence interval
CV	coefficient of variation
DSE	Dry sisal extract
EAACI	European Academy of Allergology and Clinical Immunology
EBC	Exhaled Breath Condensate
ELISA	Enzyme-linked immuno-sorbent assay
FSS	Fresh sisal sap
GF	Glass fibre
GM	Geometric mean
GSD	Geometric standard deviation
HDM	House dust mite (*Dermatophagoides pteronyssinus)*
IEC	Information Education and Communication
IgE	Immunoglobin E
ILO	International Labour Organisation
ME	Median
LOD	Limit of detection
NUFU	Norwegian Council of University Committee for Development Research and Education

OD	Optical density
OHS	Occupational health and safety
OR	Odds ratio
PC	Polycarbonate
PCR	Polymerise chain reaction
PEF	Peak expiratory flow
PPE	personal protective equipment
PVC	Polyvinyl chloride
RR	Relative Risk
SD	Standard deviation
SDS-PAGE	Sodium dodecyl sulphate-polyacrylamide gel electrophoresis
SE	Sisal Extract
SEM	Standard error of the mean
SPT	Skin prick test
SPSS	Statistical Package of Social Sciences
TGP	Timothy pollen (*Phleum pratense*)
TOHS	Tanzania occupational health services
UNIDO	United Nations Industrial Development Organization
USD	United State Dollar

Abstract

Background: Very little is known about work and health in the sisal industry. Previous studies on sisal are old and mainly focused on sisal fibre textiles and rope factories. Stationary dust concentration rather than personal exposures has been measured in a few studies but not bio-aerosols content of sisal dust. Globally, Tanzania occupies a third place in annual sisal export. Production methods in Tanzanian sisal factories are still labour intensive, implying that many workers are currently employed in the country's 82 sisal estates. Yet very little is known about work-related health risks among sisal workers in Tanzania.

Methods: Six sisal processing factories were selected for the study. Walkthrough surveys were conducted in the decortication and brushing departments and all 165 sisal processing workers (exposed) in these departments (including 93 decorticators, 72 brushing) and 32 randomly selected security guards (low exposed) were invited to participate in the study. Daily interviews on acute respiratory symptoms arising during or after work, and assessment of peak expiratory flow rates before and after work shifts were performed from Monday to Friday. All sisal workers and security guards were also interviewed for chronic respiratory symptoms. Thirty-eight randomly selected sisal workers were involved to collect personal dust samples using 30 cellulose acetate and 48 polycarbonate filters for gravimetric dust analysis and for bacteria and fungi spore counting, respectively. Furthermore, 138 out of 165 sisal processing workers and 78 conveniently sampled urban-based control participants were skin prick tested with dry and fresh sisal extracts. Serum samples from a subset of 43 skin pricked participants were tested for total and sisal specific IgE, Phadiatop^{TM}, and ELISA. A fresh sisal extract was examined by SDS PAGE (electrophoresis method) to look for sisal allergen proteins.

Results: Walkthrough surveys indicated generally poor working conditions in five of the six sisal factories, with workplaces characterized by wet floors, visible dust emissions, long stressful work shifts, monotonous tasks at awkward postures and

heavy manual lifting. Use of personal protective equipment and other general occupational health and safety services was almost absent. Old brushing and decortication machinery from as early as the 1890s was still in use.

The arithmetic mean exposure of all sisal processors was 1.18 mg thoracic dust/m^3, 43x10^6 bacteria /m3, and 2.35 x 10^6 fungal spores/m^3. The highest mean thoracic dust (2.06 mg/m^3), bacteria spores (230 x 10^6/m^3) as well as fungal spores (15.10 x 10^6/m^3) were measured when cleaning corona drums at the decortication. Personal exposure measurements showed significant differences in thoracic dust levels and bacteria exposures between work departments and workers tasks. Positive correlations were found between fungal and bacteria counts (r = 0.47; p = 0.01; n = 32), but no significant differences were detected among the study groups for fungal exposure. Mixed effect models including the brushing and decortication departments explained 64.7% of the thoracic dust exposure variance between workers. The models also showed that working in the brushing department was a significant exposure determinant (p = 0.04)

After the first day of work (Monday), and when compared to security guards, odds ratios for sisal processing workers were for sneezing 4.2 (95%CI; 1.6–11.1) and for dry cough 2.9 (95%CI; 1.3–5.4) after adjusting for age, smoking and past respiratory illnesses. Compared to decortication workers, brushing workers had significantly higher odds ratio for sneezing; 3.2 (95%CI; 1.6–6.2) and stuffy nose 3.1 (95%CI; 1.4–7.0). With the exception of shortness of breath and wheezing, brushing workers had significantly higher prevalence for all acute respiratory symptoms than decortication workers. During the five days of follow-up, brushing workers showed significantly higher severity scores and prevalences for most acute respiratory symptom than security guards and decorticators. Compared to security guards, workers in decortication had significantly higher prevalence of shortness of breath. A significantly decreasing trend across the week was found for the prevalence of shortness of breath among brushing workers (from 39% to 20%: *P* <0.01).

During the study week, brushing workers had consistently lower pre- and post-shift PEF values than decortication workers and security guards.

Brushing workers reported the highest prevalence of all chronic respiratory symptoms, and compared to security guards they had a significantly higher prevalence of chest tightness (48% versus 3%) and chronic sputum (30% versus 3%). Decortication workers and security guards differed significantly for chest tightness (30% versus 3%). Brushing and decortication workers differed significantly with regards to the prevalence of chronic sputum and chest tightness.

Sensitization to either fresh sisal sap or dry sisal extract was 74% in decortication and 71% in brushing, compared to 17% among urban-based control participants. The prevalence of elevated sisal-specific IgE was about 27% among the 43 tested individuals. Age- and smoking-adjusted relative risk for sensitization to sisal was higher for sisal workers than for control participants (RR 4.0; 95% CI; 2.4–6.7). Comparing sensitized and non-sensitized workers, prevalences of respiratory symptoms were not significantly different. All exposed workers and all but one control participant had elevated (>100kU/L) IgE levels. Analysis of the sisal extract showed two IgE binding protein bands at 45 kDa.

Discussion and conclusion: The combined effect of poor working conditions, use of old machinery and lack of protective clothing implies increased health risks due to possible exposures to sisal dust and bio-aerosols among sisal processing workers. Sisal processing workers had significantly higher severity scores and prevalence of respiratory symptoms, and were more sensitized to sisal than controls, indicating a possible association with exposure arising within the sisal fibre processing areas. Dust and bio-aerosol exposure levels appear to be higher for some tasks, emphasizing the need to consider differences in workers tasks when assessing workplace exposures and when planning control measures. Preventive action and more studies are recommended in this industry.

1. Introduction

In this introductory chapter, I will start by defining sisal. I will also briefly explain the introduction of sisal farming in Tanzania and describe how sisal leaves are processed to obtain sisal fibres. The chapter is concluded by a literature review of studies on health effects among sisal workers.

1.1 What is sisal ?

Sisal is natural plant fibre named after a seaport town (Sisal) in the state of Yucatan, Mexico. The term ‘sisal’, however, may refer to either the plant itself or the fibre produced from its leaves.

Kingdom:	Plantae
Division:	Magnoliophyta
Class:	Liliopsida
Order:	Asparagales
Family:	Agavaceae
Genus:	Agave
Species:	*A. sisalana*

Figure 1: A matured sisal plant and scientific classification of sisal [1].

A matured sisal plant (Figure 1) is a cactus consisting of a rosette of sword-shaped leaves, each about 1.5 to 2 meters long. There are many varieties of sisal plants but of commercially importance are *Agave sisalana* and *Agave fourcroydes*. Sisal plants can tolerate prolonged droughts and high temperatures, and they grow best in tropical and subtropical regions. Cultivation of sisal does not normally require use of pesticides, but herbicides have been used experimentally. Some fertilizers such as superphosphate, urea and lime may be required for soil nourishment and pH maintenance, especially where hybrid types are grown.

Sisal matures 3–5 years after planting and has a 7–10 year lifespan – or even longer in regions where growth is slower. For the entire lifespan, a typical sisal plant will produce 200–300 commercially usable leaves (hybrid varieties up to 400–450 leaves), each leaf containing an average of 1000 fibres, equivalent to 500–600 tonnes of fibre/hectar [2].

Plant fibres provide 65% of the global fibre production. Sisal fibres are the coarsest vegetable fibres and accounts for two-thirds of all ‘hard’ fibres. Traditionally, sisal has been the leading source of agricultural twine. Sisal long fibres (>90cm) are commonly used for ropes and binder twine, while shorter fibres (flume tow and tow fibre) are used for padding, mats, carpets, paper and building panels. Due to its strength, durability, elasticity/flexibility, affinity for certain dyes, and resistance to deterioration in salty water, sisal has found uses as a strengthening agent to replace asbestos and fibreglass in cement and other composite materials [3-8]. Recently sisal has increasingly been applied as an environmentally friendly material in pulp and paper industry [9] and as reinforcement material in the automobile industry [7]. However, only 4% of the sisal plant consists of fibrous materials. The remaining ~96% of the sisal leaf weight has traditionally been used as fertilizer and more recently for biogas production [10].

1.2 Tanzanian sisal industry; historical perspective

Sisal production in Tanzania is of both social and economic importance. By the end of the 19th century, sisal production spread from Florida to the Caribbean islands, to East Africa and later to Brazil. The East African sisal plants originate from the Yucatan peninsula in Mexico. With the help of plant dealers in Florida, the German agronomist Richard Hindorf managed to procure 1000 sisal seedlings. Arriving in

1893, only 62 seedlings survived the long journey to Tanganyika [11, 12]. The surviving sisal seedlings were planted at Kikogwe nursery near Pangani area and later at Mwera estate which today is among the leading sisal producing plantations in Tanzania.

From Pangani, sisal farming soon spread to other regions of the country where it became a favoured cash crop in less fertile areas. The increased demand for agricultural twine during the industrial revolution in Europe led to a historic labour migration, wherein young men were recruited from all parts of Tanzania and transferred by rail to the sisal estates [13]. The majority of sisal workers were thus recruited as labourers during their early teens, or they were born within the sisal estates. Today, they form a unique population in which most Tanzanian tribes are represented.

The labour intensive mode of production in the sisal plantations has ever since offered economical stability and social wellbeing for a large rural population. Sisal, once termed ‘*white gold*’, was the leading Tanzanian export product when it came to earning foreign currency in the 1960s. At that time Tanzania was the world’s leading sisal fibre exporter, exporting 200,000 tons of fibre annually. Changes in technology leading to the introduction of synthetic fibres reduced the sisal market by more than 60%, leading to a decline in sisal demand worldwide. During the 1990s nationalization strategies, all sisal estates were put under the Tanzania Sisal Board (TSB). However, the increased cost of production and lack of markets led to closure or abandonment of most sisal estates. There are currently about 82 sisal estates in the country [14] believed to create about 90,000 jobs for the surrounding agricultural communities. As part of ongoing economical restructuring and poverty reduction strategies, more estates are now being privatized, and sisal production is re-started in once dormant estates. Approximately 26,000 tonnes of sisal were exported in 2006 bringing about 105 million USD of revenue (TSB reports 2006). Globally, Brazil is the largest sisal producer followed by Kenya, Tanzania and Madagascar. Smaller quantities of sisal are also produced in China, South Africa, Mozambique, Haiti, Venezuela and Cuba.

1.3 Sisal processing methods in Tanzania

Sisal growing and fibre processing in Tanzania is still carried out in factories established during colonial times. A typical Tanzanian sisal estate comprises several thousands hectares of sisal fields, small camp villages where estate workers live, and a fibre processing factory. All sisal-processing factories basically have the same setup consisting of a central decorticating machine, drying yards, a brushing hall with several fibre-combing machines and a bale-pressing unit, a small workshop and an administrative office. Sisal fibre processing starts by the arrival of freshly cut sisal leaves at the central decorticator. In this machine, sisal leaves are crushed and scrapped to remove all green leaf sap which is washed away by water, leaving creamy white sisal fibres. Figures 2–5 show various stages of the decortication process.

Figure 2: Unloading of sisal leaves

Figure 3: Feeding sisal leaves onto the conveyor

Figure 4: Decortication of sisal leaves

Figure 5: Tying of wet sisal fibres

Wet decorticated fibres are dried in the sun (Figure 6) and sent to the brushing hall where the fibres are mechanically combed, sorted and packed into various grades (Figures 7–8). Partially brushed and non-brushed fibres are re-sorted and sent back for brushing (Figure 9).

Figure 6: Drying of sisal fibres

Figure 7 Brushing of sisal fibres

Figure 8: Sorting & grading of brushed fibres

Figure 9: Re-sorting of non brushed
fibres

Work organization in sisal factories and sisal fibre processing methods in Tanzania have remained unchanged over the decades. Labour-intensive and long, task-based work shifts are applied, and old machinery from as early as 1890s is still used. Some current developments in sisal processing involve pilot projects on the application of new technologies to produce high-quality sisal fibres for paper-making and innovative biogas-production methods from sisal wastes. These projects involve collaborative efforts between Tanzanian sisal producers and the United Nations Industrial Development Organisation (UNIDO) [5, 10].

1.4 Literature review on sisal exposure and health effects

Sisal dust is classified as organic dust similar to hemp, flax and jute [15-17]. Industrial handling and processing of sisal may lead to emission of airborne particles and fibres from the sisal plant being processed, which may contain fungi, bacteria and/or components of gram negative bacteria (endotoxins). In addition, dust from such processes may also contain inorganic particles originating from the soil. Both immunological and non-immunological reactions have been assumed to be responsible for respiratory health effects of organic dust [15, 17-19]. Possibly workers handling sisal are also exposed to a wide range of similar health hazards. Scanty and mainly old literature exists on occupational exposure and health effects of sisal (Tables 1-3). Some researchers have measured dust exposure in sisal textile and sisal rope making industries [20-26] (Table 1). Work in the initial stages of fibre preparation in sisal textiles and sisal rope making industries has been associated with acute and chronic respiratory symptoms [20-23, 27] and changes in lung functions [20, 21, 23-25, 27] (Table 2). Furthermore, a few researchers have described immunological health effects of sisal [21, 23, 28] (Table 3)

Table 1: Summary of dust exposure studies in sisal industries

Author[(Ref)] ***(country)***	**Year**	**Industry/ work process**	**Tasks**	**Sample Number**	**Sampling method**	**Sampling tools**	**Exposure levels**
Stott H[23] *(Kenya)*	1958	Sisal rope factory	Batching and carding	21	Stationary	Thermal precipitator	Total particles count /ml 243 (0-5µ) *302 near 124 away from carding machines,* range (30–1,787 particles/ml)
Gilson *et al.*[24] *(Kenya)*	1962	Sisal factory	Bale opening, breakers, carding, spinning and weaving	(NA)	Stationary	Horizontal Elutriator with FP	Coarse (>2mm)- no course particles Medium (7µ -2mm) - 4.5mg/m^3 Fine (<7µ)-1.6 mg/m^3 Total 6.05 mg/m^3
Zuskin *et al.*[20] *(Croatia)*	1972	Sisal textile workers	Drawing, combing, and spinning	26	Stationary	Modified Hexhlet 2-stage sampler	Total dust 1.92 mg/m^3 (range;0.43–5.20) Respirable 0.71 mg/m^3 (range;0.32–0.94)
Baker *et al.*[25] *(South Africa)*	1979	Sisal rope makers	Sisal loading on the conveyor	4 ?	Stationary	Casella hexhlet with GF filters	Total dust -10 mg/m^3 (at sisal loading) <1 µg/m^3 (away from loading) Respirable dust -1 mg/m^3 at conveyor
Thomas *et al.*[22] *(Ireland)*	1988	Rope workers	1.Preparatory *Shakers, carding, hacking* 2.Finishing *Trawl twine, ropes making*	NA	stationary	Total dust	Total dust 1–1.6 mg/m^3 (preparatory areas) Total dust 0.8–0.9 mg/m^3 (finishing areas)
Muchiri [26] *(Kenya)*	1988	Brushing & tow	Brushing, sorting, grading, and baling	41 (27)[a]	Stationary	Vertical Elutriator PVC filter	Dust levels 4.4mg/m^3 (brush room) 10.8 mg/m^3 (tow sorting) 2.3–3.4 mg/m^3 (tow cleaning, and baling)
Zuskin *et al.*[21] *(Croatia)*	1994	Sisal textile workers *F/up of 1972*	Drawing, combing, and spinning	(NA)	Stationary	Modified Hexhlet 2-stage sampler	Total dust 1.89 mg/m^3 (range;0.44–5.20) Respirable 0.698 mg/m^3(range;0.32–0.92)

Key: FP: Filter Paper; GF: Glass Fibres: PVC: Polyvinyl Chloride; NA: Not Available; (27)[a] only 27 out of 41 eligible for analysis.

1:4:1 Dust exposure levels in sisal industries

Table 1 shows results from exposure studies in sisal factories. Total dust levels between 0.8 to 1.6 mg/m^3 were measured in a sisal rope factory in Ireland [22]. The authors considered these dust levels to be low and attributed the low level to improvements made in the industry. Low and unchanged dust levels of both total dust (1.9 mg/m^3) and respirable dust (0.7 mg/m^3) were reported in two studies conducted 19 years apart in a sisal textile factory in Croatia [20, 21]. The mean total dust level of 1.9 mg/m^3 was below the national (Croatian) permissible level of 5 mg/m^3 for total dust. In Africa, only a few studies between 1950s and the 1980s have described dust exposure levels in the sisal industry [23-26]. A study conducted in a Kenyan sisal textile factory in 1955 reported the concentrations of dust of size range “0-5µ” to be more than twice as high around sisal carding machines (i.e. 302 particles/ml) than elsewhere in the carding room (124 particles/ml) [23]. Investigations carried out in 1961 in the same factory, found that the concentration of particles of size range (7µ-2 mm) was 4.5 mg/m^3 while the concentration of particles of size range <7µ was 1.6 mg/m^3 [24]. In another sisal processing factory in Kenya average dust levels of between 2.3 mg/m^3 and 10.8 mg/m^3 were reported in various sections of the brushing departments [26]. In a sisal rope making factory in South Africa, stationary dust measurements at the sisal unloading conveyor showed a total dust level of 10 mg/m^3 (about 1 mg/m^3 was estimated to be respirable) [25]. The only previous sisal study in Tanzania [27] did not include dust exposure measurements.

The majority of the above-mentioned studies measured stationary dust using different sampling equipment and filter media. In addition, the type of industry and work processes involved differed. None of these studies attempted to report bio-aerosol components in the dust such as fungi, bacteria and/or endotoxins which have been estimated in other studies of similar organic dusts [29-34].

1:4:2: Respiratory symptoms among sisal workers

In 1955, the hospital attendance rate for chest complaints among workers in the carding room of a Kenyan sisal rope making factory was reported to be twice as high as that of workers from other sections in the same factory [23]. The same study also reported that dust emitted in sisal carding rooms had an irritating effect on the upper respiratory airways and on the eyes, especially to the "unacclimatized visitor". Thirty years ago, investigators in Tanzania [27] reported prevalences of 10% for chronic cough and 12% for chronic bronchitis among sisal brushing workers versus 3% and 1%, respectively, among sisal spinning workers (Table 2). In the same study [27], a high prevalence of byssinosis (48.2%) was reported among sisal brushing workers compared to 5.2% among spinning workers. A study among rope makers in Ireland reported a lower prevalence (2.8%) of byssinosis among workers handling hard fibres (including sisal) compared to (15%) among those handling soft fibres such as jute [22]. In a Croatian sisal textile factory, an initial study among 50 non-smoking female workers reported the prevalence of chronic cough and chronic bronchitis to be 17.6% and 9.8%, respectively [20]. In a 19-year follow-up study among the 20 remaining female sisal textile workers in the same factory the prevalence of respiratory symptoms had increased significantly; chronic cough from 15% to 65%, dyspnoea from 5% to 80%, and chest tightness from 25% to 90% , but none had byssinosis [21]. A summary of the above-mentioned studies is shown in Table 2.

1:4:3: Lung function changes among sisal workers

Acute cross-shift changes in ventilatory capacities have been reported among sisal workers in Croatia [20, 21] and Tanzania [27] (Table 2). Significant reductions of 6.4%, 3.9%, and 1.7% in the mean cross-shift PEF, FEV_1 and FVC, respectively were observed among female sisal workers compared to a cross-shift increase of 1.4%, 0.8% and 0.9%, respectively, among controls. Sisal workers with chronic respiratory symptoms had the highest decline in both PEF and FEV_1 [20]. In a follow-up study performed 19 years later, sisal workers who were still employed in the same textile industry showed significantly lower pre-shift FEV_1 and FVC than predicted (85.7% and 88%, respectively) [21]. An annual decline in FEV_1 0.036 litres/year and FVC 0.027 litres/year was estimated among these workers. In Tanzania, sisal brushing men with byssinosis were reported to have a 15% cross-shift decline in FEV_1[27], meanwhile a lung function study among sisal rope makers in South Africa did not show any evidence of acute lung function changes among sisal workers [25].

Chronic effects on lung function have also been studied among sisal workers. A study in Kenya showed that persons who had been working in the carding room for two or more years had significantly lower mean vital and maximum breathing capacities than those who had never worked in this section [23]. The investigators found no significant differences in mean vital capacity between carding room workers who had worked for more than 2 years as compared to those who had worked for less than 2 years [23]. Indirect Maximum Breathing Capacities (IMBC- estimated as $FEV_{0.75}$ x 40) of 10 men selected from the same factory when assessed during work inside the carding room did not significantly differ from values obtained when they worked outside the factory [24].

Mustafa *et al.* [27] found that only 2 brushing workers with byssinosis had severe impairment in FEV_1 and at least 6–16 % of the study population of 160 sisal workers showed slight to moderate impairment in FEV_1. A short duration of exposure was claimed to be the reason for lack of significant impairments [27]. In a small group of sisal rope makers, Baker *et al.* [25] found that workers with less than 4 years of sisal exposure had higher lung function than their sex, age, height and smoking status matched controls. However, only FVC was found to be significantly higher.

Table 2: Studies on respiratory health effects among workers in sisal industries

Author[Ref] ***(country)***	**Year**	**Industry/ work process**	**Exposed**	**Controls**	**Acute respiratory Symptoms**	**Chronic Respiratory symptoms**	**Acute Lung functions Changes**	**Chronic lung function effects**
Stott H[23] *(Kenya)*	1958	Sisal factory	37 (M)[a] 29(M)[c]	27(M)[b]	Eye irritations? Airway irritations??	53.8% chest complaints pneumonias, but no byssinosis	*↓ VC *↓ MBC exposed >2 yrs vs. controls	
Gilson *et al.*[24] *(Kenya)*	1962	Sisal factory	10 (M)	10 (M)	NA	-	Ns ↓ IMBC outside vs. inside	
Zuskin *et al.*[20] *(Croatia)*	1972	Textile workers	50 (F)		Dry cough (2 workers) Chest tightness (2 workers)	Persistent cough 17.6% Persistent sputum 13.7% Chronic bronchitis 9.8% Byssinosis (0%) **Nasal catarrhal 19.6%	*↓ FVC across shift (1.7%) *↓ FEV$_1$ across shift (3.9%) *↓ PEF across shift (6.4%) ↓ FEV$_1$ 194mls and ↓PEF 55l/min among symptomatic	No chronic effects
Mustafa *et al.*[27] *(Tanzania)*	1978	Sisal brushing & spinning	160 (M)		NA	Chronic cough 9.6% Chronic bronchitis 12% Byssinosis 48.2 %	*15% ↓ FEV$_1$ across shift 6% ↓ FVC across the shift byssinotic brushing workers	10% chronic deficit 6-16% ≤ moderate
Baker *et al.*[25] *(South Africa)*	1979	Sisal rope makers	66(M)	66 (M)	NA	NA	No acute changes	
Thomas *et al*[22] *(Ireland)*	1988	Rope workers	369 (F) 98 (M)	??	NA	Byssinosis 2.8% hard fibres (+sisal) 15% soft fibres(+jute)	NA	
Zuskin *et al.*[21] *(Croatia)*	1994	Textile workers *Follow-up of 1972*	20(F)	30 (F)	Cough 60%, Dyspnoea 35% Eye irritation 60% Nasal catarrhal 75% Sinusitis 25% Chest tightness 60% Dry/irritate throat 45%	Chronic cough 65% Chronic bronchitis 30% Dyspnoea 80% Occupational asthma 10% Byssinosis (0%) Chest tightness 90%	*↓ FVC across the shift *↓ FEV$_1$ across shift	*↓ FEV$_1$ 85.7% of predicted *↓ FVC 88% of predicted ↓ FVC -0.027 l/year ↓ FEV$_1$ -0.036 l/year

Key: MBC - Maximum Breathing Capacity; IMBC - Indirect Maximum Breathing Capacity (FEV$_{0.75}$ x 40); VC - Vital Capacity; PEF - Peak Expiratory Flow ; FVC - Forced Vital Capacity; FEV$_1$ - Forced Expiratory Volume in 1st Second; NA - Data Not Available; F - Females; M - Males [a] - >6 months in carding section, [b] - controls (never in carding), [c] - >2.5 in sisal in general * significant change ($p<0.05$, <0.01 or <0.001)

Table 3: Summary studies on Immunological health effects of sisal

Author[(Ref)] **(country)**	**Year**	**Industry/ work process**	**Sample size E- Exposed C- Controls**	**Test substances (extract used)**	**SPT results (mm/ %positive) (exposed)**	**SPT results (mm/ %positive (control)**	**Other tests**
Stott H[23] *(Kenya)*	1950	Sisal factory	69 E 36 C	Dry sisal extract from rafters.	10.94 mm	11.9 mm	NA
				Dust from another factory	10.27 mm	8.5 mm	NA
Zuskin et al.[21] *(Croatia)*	1994	Sisal textile workers Follow-up of 1972	20 E 35 C	Sisal Dust Extract (from work room)	10%	5.7%	↑ Total IgE[a] 10% exposed 2.9% controls
				House dust	40%	28.6%	
				Jute extract	0%	5.7%	
Nicholls et al .[28] *(Yugoslavia)*		Experimental study	NA	SE from combing SE from spinning	NA	NA	Histamine release from human lung tissue

Key: a - IgE >125 kU/L: E - exposed**;** **C** - controls; SE - sisal extracts: NA - not applicable and/or available

1:4:4: Immunological reactions of sisal

Table 3 summarizes the studies on immunological health effects of sisal. Skin reactions were reported among 105 male sisal factory workers in Kenya in 1955 [23]. Intra-cutaneous injections with sisal extracts from rafters in the sisal factory were found to cause mean indurations of 10–11mm among workers being employed for more than six months in the sisal carding room. These skin reactions were, however, found to be similar to indurations of 8–12 mm observed among workers with less than 6 months or no previous experience in the sisal carding room at all [23]. In another study, a group of 20 female sisal textile workers in Croatia were examined by skin prick tests using sisal dust collected in a common work-room [21]. In this study, only 2 (10%) workers were found to have a positive reaction to sisal. The above mentioned studies differ in that they applied different methods during sisal extract preparation and during skin testing (intra-cutaneous vs. sub-cutaneous). While the Kenyan study [23] was done among males sisal factory workers the Croatian study [21] was done on female textile workers handling sisal fibres as one among other raw materials.

In a small Croatian study elevated serum IgE levels were reported in only one female sisal textile worker [21]. Nicholls *et al.* [28], showed that sisal extract has histamine-releasing properties on human lung tissues. In this experimental study, sisal collected from the combing machines showed more histamine-releasing properties than sisal collected from the spinning section. Little research has been done on immunology among Africans [35] but previous sisal studies among African populations [23-27] have not reported on immunological parameters. Since histamine has been shown to cause broncho-constrictive effects [36, 37], sisal exposure might therefore contribute to type-1 immunological mechanisms leading to respiratory health effects.

2. Background for the study and rationale

Organic dust includes airborne particles of vegetable, animal or microbial origin. The dangers of inhaling organic dust among agricultural workers were noted by Ramazzini in the 700s [38]. Numerous studies have subsequently demonstrated an increased risk of respiratory morbidity among workers in agricultural industries [15, 17, 39-43]. Inhalation of vegetable dusts from cotton, flax, hemp, jute and sisal etc has been associated with asthma-like syndromes such as byssinosis rather than asthma [17, 40, 44]. Unlike asthma, such symptoms are often worsened on the first day of the working week following the worker's return from the weekend rest. Immunological effects, and other respiratory symptoms including changes in lung functions have also been associated with occupational exposures to organic dust [39, 45].

Today, respiratory diseases among agricultural workers are important public health problems [43] especially in developing countries where the majority of the work force is involved in agriculture while the advancements in agricultural technology are still lagging behind. In Tanzania, agriculture employs about 70% of Tanzania's active labour force, the majority of whom are located in rural areas [14]. Agricultural industry is the leading economic sector in Tanzania as it contributes to slightly more than 50% of the Gross Domestic Product (GDP) and about 75% of the foreign exchange earnings. Traditional export crops of Tanzania are coffee, cotton, tea, sisal and cashew nuts [14]. In recent times, sisal production in Tanzania has expanded through the involvement of small and medium scale farmers and private investors. New technologies involving new uses of sisal are also being introduced [3, 5, 9, 10]. The Tanzania Sisal Board plans to enlarge the total sisal plantation area with a production target set at 190,000 tons by 2016.

Rationale of the study

Globally as well as locally, very little is documented when it comes to health and work in the sisal industry. Despite the importance of sisal to the Tanzanian economy, little information exists on the current working conditions and on workers' health in the sisal factories. Historically [13], sisal industry in Tanzania is labour intensive, requiring a large labour force on the plantations and in sisal processing factories. As such, a considerably large number of workers are employed in the sisal processing factories and may be exposed to a variety of bio-aerosols that may have detrimental health effects. Only one previous study has been published among workers in sisal factories in Tanzania [27]. This study was undertaken three decades ago and involved ventilatory function and respiratory symptoms among brushing and spinning workers. Immunological tests and exposure measurements were not performed. Previous sisal studies have been carried out mostly among workers handling processed sisal fibre to make textiles and in sisal rope making industries. Decortication workers who are involved in sisal leaf processing to make fibres have not been studied.

Information on current working conditions, dust exposures and on work-related respiratory health effects among sisal workers in Tanzania is therefore needed. Data gathered by the present study add to our knowledge on health and work in sisal industry and provide evidence-based information to those involved in planning and implementation of suitable preventive services for this industry. The present study also opens avenues for more research to be done among workers in sisal industries.

3. Study aim and objectives

3:1: Main aim

This study aimed at increasing the existing body of knowledge on occupational health effects of organic dust by exploring and describing the status of working conditions, dust exposures and respiratory and immunological health effects among sisal processors in Tanzania.

Study hypothesis: This study was performed based on the hypothesis that in Tanzania, sisal fibre processing is carried out under substandard working conditions, and that sisal processors are exposed to higher levels of sisal dust and bio-aerosols that are associated with high prevalence of respiratory symptoms, changes in lung function and type 1 sensitization to sisal than other workers with lower or no exposure to sisal.

3:2: Specific objectives

Specifically, the study aimed to achieve the following;

1) To assess working conditions, dust exposure levels, use of preventive measures and the status of occupational health and safety in sisal processing factories. **(Paper I)**

2) To investigate the frequency and severity of acute and chronic respiratory symptoms among sisal processors in Tanzania. **(Paper II& III)**

3) To describe acute effects on lung function (peak expiratory flows) among sisal processors in Tanzania. **(Paper III)**

4) To determine the prevalence of type 1 (IgE) immunological sensitization among sisal processors in Tanzania. **(Paper IV)**

4. Materials and Methods

In this chapter, general study methodological aspects are presented first, followed by specific data collection methods as applied in this particular study.

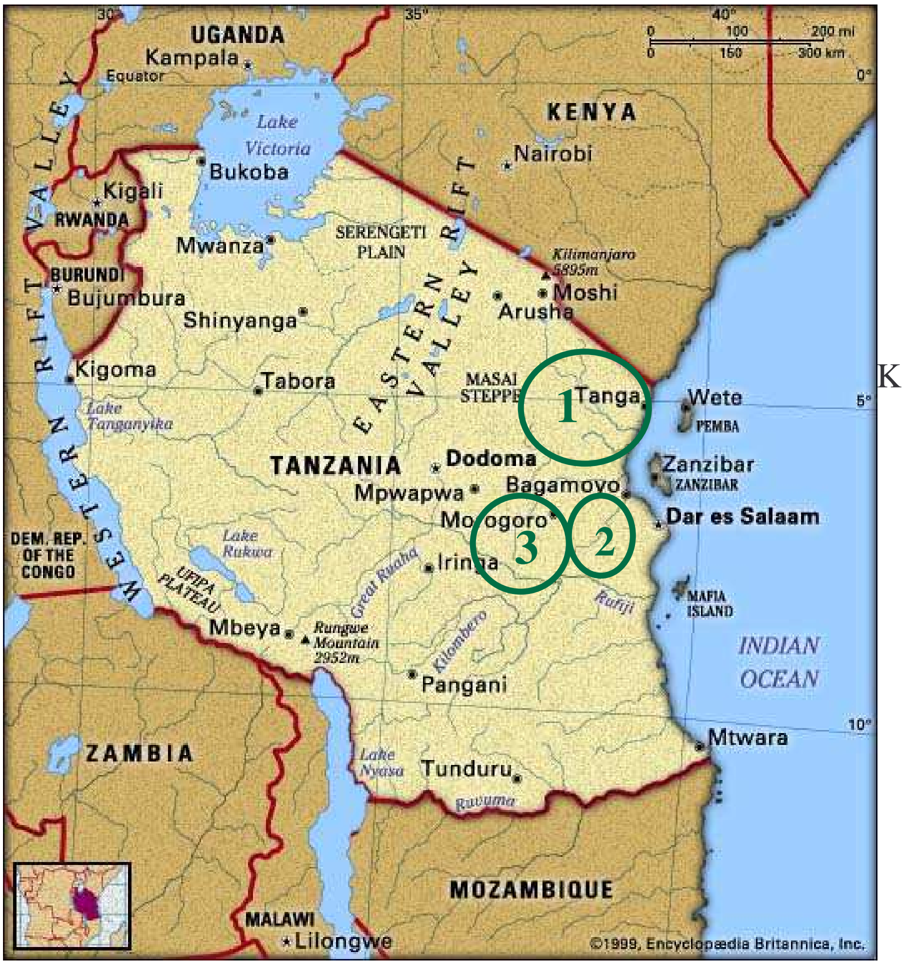
4.1 Methods (general aspects)

Study area and study population

Six sisal estates were selected from a list of 28 sisal estates actively processing sisal fibres (Tanzania Sisal Board Annual Report, 2004). The six estates were selected from the three main sisal producing regions (Figure 10), based on the presence of planned daily production during the study period and accessibility from the main roads. A prior visit to the sisal factories indicated that old brushing and decortication machinery from as early as the 1890s was still in use. The decortication and brushing departments covered most of sisal fibre processing steps and employed an average of 30 workers per factory. Workers in these departments were more likely to be exposed to higher levels of sisal dust than workers from other departments and therefore were the focus of this study. Various tasks carried out by decortication and brushing workers are shown in Figures 2-9.

Study design and sample size

For practical reasons and based on the University of Bergen’s guidelines for conducting field work, two cross-sectional studies, one year apart, were carried out between June and September 2005 (period 1), and between July and September 2006 (period 2). During period 1 a walkthrough survey was carried out in the decortication and brushing departments, followed by a one-week follow-up questionnaire interview on acute work-related respiratory symptoms, lung function measurements pre- and post-shift peak expiratory flow rates and personal dust exposure measurements. During period 2, the same factories were visited for skin prick tests and immunological tests among sisal processing workers. A framework of the study design is shown in Figure 11.



Key:

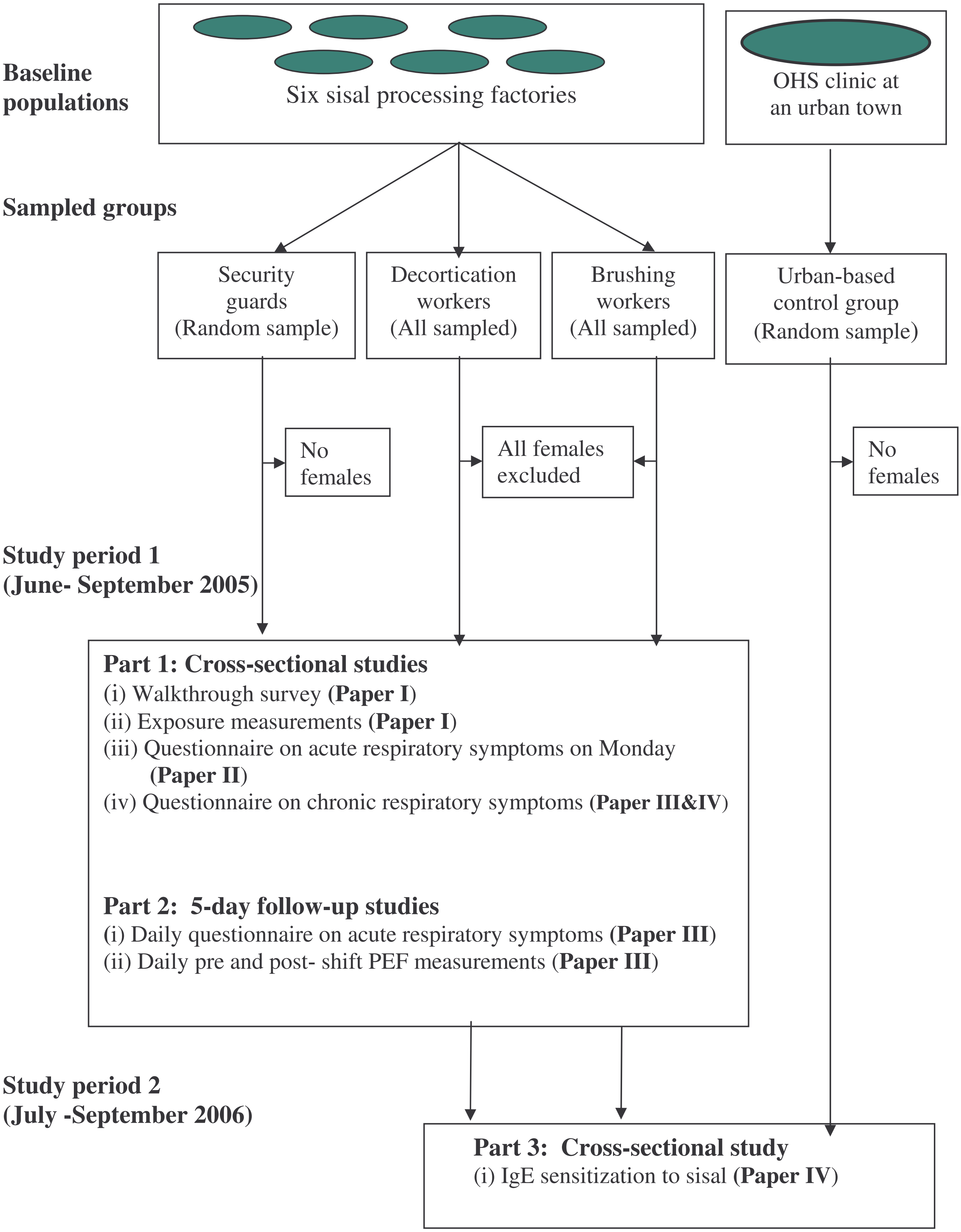
1. Tanga region (four estates)
2. Coastal region (one estate near Bagamoyo)
3. Morogoro region (one estate)

Figure 10: Map of Tanzania showing study regions

Exposed groups

By the end of 2005, the six selected estates were estimated to employ about 1,700 workers in various departments; sisal planting, weeding, cutting, decortications, drying, brushing, bale pressing and security. A large part of the workforce in the processing factories consisted of men. Most of the female employees were found in the weeding section, very few (2–3 women per estate) in the administration and (0–5 women per estate) in the sisal processing departments.

Figure 11: Summary of final study profile



Setting our statistical power at 85% and P value of 0.05, we used a power sample online tool and applied data on the prevalence of chronic cough among coffee workers in Uganda [46] to estimate a tentative sample size of 180 participants. Since each factory employed an average of 30 workers all available men in the brushing and decortication departments were therefore invited, to take part in the study as a dust-exposed group. In total 165 sisal processors consisting of 93 decorticators and 72 brushing workers were enrolled from the six factories during period 1. In addition, all encountered females in decortication (n = 4) and brushing (n = 23) were enrolled. During data analysis, however, all women were excluded due to their small number and lack of a comparison group of females among the security guards. Two men, one with a hearing impairment from decortication and one brushing worker who was hospitalized for malaria treatment were excluded from the final analysis due to incomplete data.

During period 2, 139 out of the 165 men enrolled during period I from the decortication and brushing departments were present for skin prick tests. They included 78 out of the 93 decorticators and 61 out of the 72 brushing workers. One decortication worker on short-acting antihistamines was not examined. A total of 27 previously enrolled men were not found during period 2. The reasons for their absence were death (n = 5), shifted or promoted to other jobs (n = 9), sickness absence during period 2 (n = 4), sacked or left the estates on their own will (n = 7) and on leave (n = 2). For immunological tests only four nearby factories were visited and 37 of 56 expected decorticators and 21 of 37 expected brushing workers did not turn up for blood sampling.

Control groups

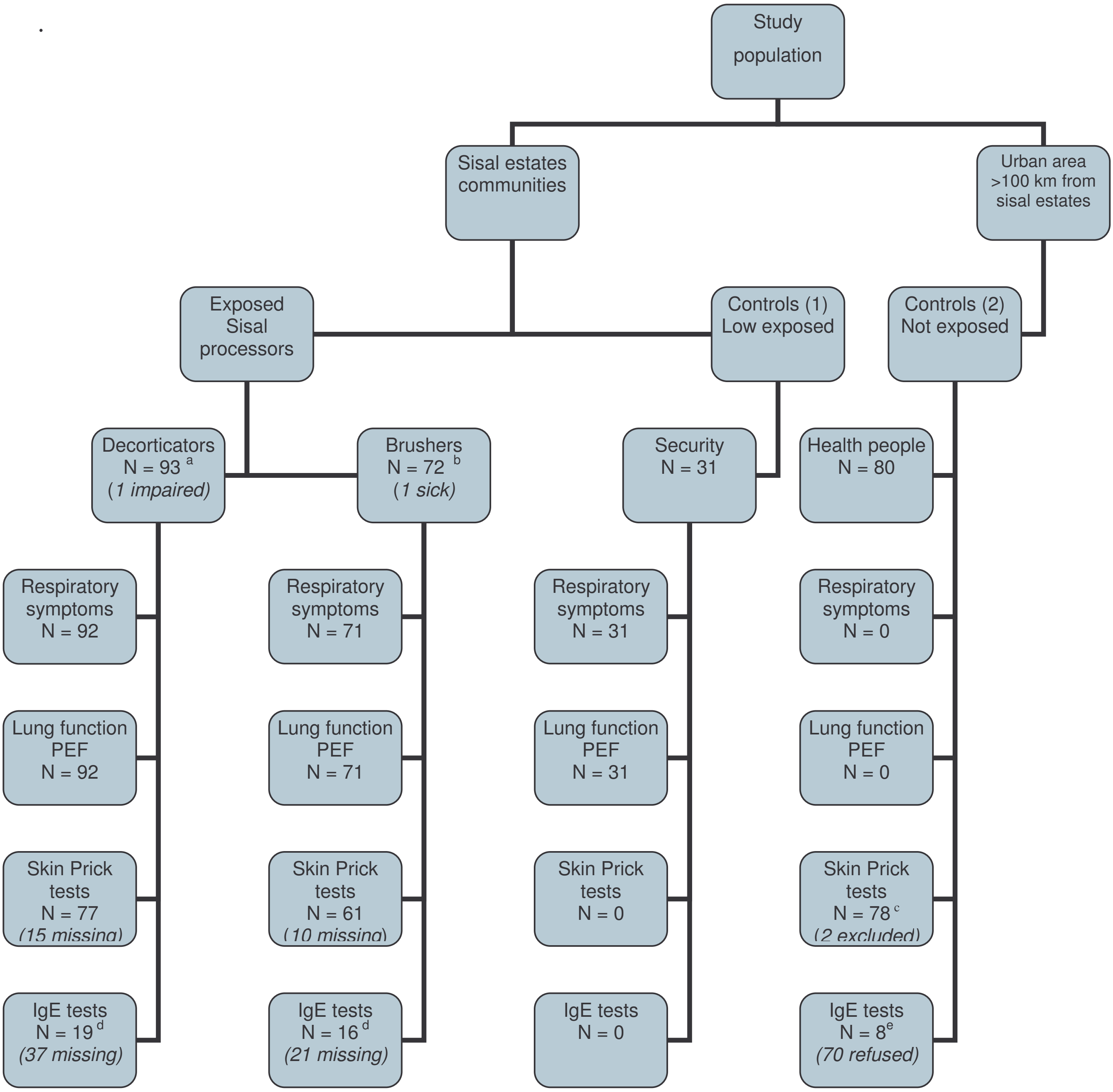
Two different control groups were enrolled for this study. During period 1 a control group comprising of 31 security guards (4–6 security guards/factory) were randomly selected from lists of estates guards working in the administration and residential areas located outside the sisal-processing factories. Like the exposed group, security guards came from within and around the sisal estates, but they did not handle sisal and were therefore presumed to have low exposure to sisal.

Based on observations during the factory visits in period 1, it was assumed that the security guards might not constitute a good control group for the immunological study (i.e. skin prick tests and blood for immunochemistry) due to their proximity to sisal plants within the plantations. During period 2, therefore, 80 African men who had never worked in sisal estates were invited as controls. They consisted of all available and willing healthy men at an occupational health clinic situated about 120 kilometres from the nearest sisal processing factory. This urban-based control group consisted of guards, cleaners, car drivers, mechanics, salesmen and office clerks. Two who were on short-acting antihistamines were not pricked and only 8 of the skin-pricked urban-based controls agreed to give blood for immunochemistry. The number and distribution of study participants is shown in Figure 12.

Ethical considerations

In conformity with international guidelines this study received ethical clearance from both the Western Norway Regional Committee of Medical Research Ethics **(Appendix V)** and the Tanzanian National Institute for Medical Research **(Appendix VI).** Each invited participant was informed about the purpose and methods of the study and of his/her right to voluntary participation and/or withdrawal from the study at any stage of participation. All except one security guard provided their written consent **(Appendix VII).** Individual workers were informed of their study results and those who needed medical consultation were advised on the appropriate treatment and/or preventive measures. All studies and publications summarized in this thesis were performed in accordance with the ethical standard as expressed by the declaration of Helsinki [47].

Figure 12: Number and distribution of study participants



Key: N = 0: none in the group was tested; PEF = Peak Expiratory Flow

[a] One decortication worker excluded during analysis due to hearing impairment

[b] One brushing worker excluded due to acute malaria during study time

[c] Two controls excluded due to use of short-acting antihistamines during skin examinations

[d] Only sisal processors present at site were bled, others did not turn up for blood tests

[e] Only 8 out of 78 controls accepted to be bled for IgE tests

4.2 Specific study methods

Table 4: Summary of specific methods and tools used for data collection

	Methods	Paper	Tool/guideline/test
1	Walkthrough surveys	I	ILO checklist
2	Personal exposure assessment to sisal dust	I	Cellulose acetate for Gravimetric samples Polycarbonate filters for bacteria and fungi microscopy
2	Face to face interviews	II, III. & IV	Modified Optimal Symptom Score questionnaire on respiratory symptoms Modified BMRC questionnaire on respiratory symptoms Standardized questionnaire on respiratory symptoms from American Thoracic Society and Division of Lung Diseases
3	Lung functions (Peak expiratory rates)	III	Mini-Wright flow meter
4	SPT tests using fresh sisal sap and a dry sisal extract	IV	EAACI guidelines
5	Biochemical analysis of sera and sisal extract	IV	ELISA, Phadiatop^{TM} and SDS-PAGE

4.2.1 Walkthrough surveys (Paper I)

Walkthrough surveys were conducted by the author during period 1(June- September 2005). The decortication and brushing departments of the six selected sisal estates were visited during the morning work shifts to observe production processes, work organization, tools and equipment used so as to identify possible hazards and workplace practices that may cause ill health or injury to workers.

A checklist developed by International Labour Organization (ILO) [48] was used to score thirty-two relevant work environment items. Items observed to be missing (i.e.

items not observed or reported not to be provided) or inadequately provided (i.e. worn-out, damaged or inappropriate tools and equipments are used, services not accessible to all eligible workers) were assigned *'inadequate score'* (score = 0) whereas items observed to be adequately provided (i.e. appropriate tools in good condition are regularly used by all eligible workers, all required services provided) were scored *'adequate'* (score = 1). Additional information on production schedules and other basic occupational health and safety (OHS) services provided in each factory were obtained by interviews with department leaders.

During data analysis the checklist items were grouped into three categories, A: Ergonomics and work organization (8 items), B: Physical environment (11 items), and C: OHS services (13 items). In each category, the numbers of departments showing adequate score for the respective item were summarized for the six brushing and six decortication departments. A list of 32 items and their original scores is attached **(Appendix VIII).**

4.2.2 Exposure Assessment (Paper I)

Sampling methods

Personal thoracic dust measurements were performed during period 1 (June-September 2005). Based on the walkthrough survey observations, sisal processing workers in the decortication departments were expected to have the highest exposure, brushing workers to have medium exposure and security guards to have the lowest exposure to sisal dust. According to the recommendation by Loomis DP *et al.* [49] it was planned to have a weighted ratio of 5:3:1 number of samples in the expected high, medium, and low exposed groups, respectively. Workers were randomly selected for sampling from the personnel lists in the respective departments. For each selected worker 1-3 exposure samples were collected during morning work shifts.

Cellulose Acetate (*CAC*) filters (Millipore AAWP03700) and Polycarbonate (PC) filters (Poretics®, Osmonics, Livermore, CA, USA), were used for gravimetric dust, and for bacteria and fungal spores sampling, respectively. Both filter types had a pore size 0.8µm. In each of the six sisal factories, 30 *CAC* and 8 PC filters were sampled with modified Casella cyclones [50] placed within the workers breathing zone (Figure 13). A flow rate of 0.8 L/min was maintained by personal Sidekick sampling pumps (SKC Ltd, London, UK) (Figure 14). During sampling, the flow rate was regularly checked and any visible sisal fibres and fly were removed from the cyclone inlet. After sampling the exposed filters were stored at room temperature inside an airtight container half filled with dry silica gel. The mean sampling time was 442 minutes (range; 180–539 minutes) for gravimetric samples and 422 (range; 180–715 minutes) for microbial samples, respectively.

After 24 hours, filters were packed into plastic bags and transported to Norway for analysis. Due to a limited number of available cyclone cassettes, most of the filters had to be transferred from temporary storage cassettes to sampling cyclones and back into storage cassettes after sampling.

Figure 13: Personal exposure assessment

Figure 14. Sampling tools

Analytical methods for dust samples

Gravimetric analysis of thoracic dust samples was performed with a microbalance (Mettler Toledo AT261, Delta range, Mettler Instruments, Zurich, Switzerland). Limit of detection (LOD) of the gravimetric analysis was 0.1 mg/m^3 for 8 hours of sampling at a flow rate of 0.8 Litres/minute. The quality of the analyses was assured by laboratory participation in an inter-calibration scheme run by the Norwegian Institute of Occupational Health (NIOH), Oslo, Norway.

In our study, we only report dust exposure results for 30 CAC samples that were sampled from the first visited factory and 48 PC samples from all six factories (Table 5). These were samples from filters that were pre-weighed and directly mounted into cyclone cassettes at a Norwegian laboratory. The remaining 150 samples whose filters were transferred in the field to and from the storage cassettes are not included, because of weight loss presumably due to traumas on filters.

Table 5: Summary distribution of exposure samples

	Presumed exposure levels	**Thoracic dust (1 factory)**		**Bacteria & Fungi (6 factories)**	
Number of samples		N	(n)	N	(n)
Available filters		30		48	
Decortication	High	15	(1)	16	(5)
Brushing	Medium	8	-	14	(2)
Security guards	Low	3	(1)	12	(3)
Field blanks		4		6	
Totals		24	(2)	32	(10)

Key: N = total number sampled; (n) number of samples excluded in final analysis

Microbial samples on PC filters were re-suspended in filtered Tween 80 solution (0.05% weight/volume) for 3 minutes in an ultrasonic bath (Sonorex RK510H, Bandelin Electric, Berlin, Germany). An adequate aliquot was filtered through a black-stained polycarbonate filter with pore size 0.4µm for microscopic analysis of microorganisms. Spores from fungi and bacteria were then counted by fluorescence microscopy [51]. The minimum countable number was 650 bacteria or mould spores. Ten fungal spore samples below detection level were assigned half the value of lowest countable number of spores [52]. None of the gravimetric samples or bacteria samples were below limit of detection. Two CAC and 10 PC filters were excluded due to technical problems (i.e pump failure, misplacement or ambiguity on labelling). Ten filters (4 CAC and 6 PC filters) were analysed as field blanks (Table 5).

4.2.3 Interviews on Acute Respiratory Symptoms (Paper II & III)

During data collection in period 1, all study participants were interviewed face to face on acute respiratory symptoms. The interviews were conducted daily from Monday to Friday, immediately after the respective morning work shifts. 196 interviews were conducted on Monday, 165 on Tuesday, 170 on Wednesday, 143 on Thursday, and 181 on Friday. In total, 127 (65%) workers completed the interviews on all 5 consecutive days. For workers who did not complete all 5 daily interviews, the main reasons for absence of the whole department were either too few sisal leaves or fibres to process or a public holiday. A few workers (n <5) either had to attend a meeting elsewhere or were absent because of sickness.

The daily acute symptoms were recorded by using a modified Optimal Symptom Score questionnaire on acute respiratory symptoms [53] **(Appendix IX).** Participants were asked to rate their symptom experiences from the time they began work to immediately after a particular work shift, according to how they perceived the severity of the symptoms on a 5-point scale; 0 (never), 1 (mild), 2 (moderate), 3 (severe), and 4 (very severe). The symptoms asked for were dry cough, productive cough, shortness of breath, wheezing, stuffy nose, running nose and sneezing.

During analysis the scores for each respiratory symptom were dichotomized into ‘yes’ for mild, moderate, severe, and very severe responses and ‘no’ for the never response. In addition, overall severity scores for the sum of all seven individual symptoms (range 0–28) were computed by adding up each symptom’s severity scores (range 0–4) (*formula i*).

$$Overall\ severity\ \ score_{\ (day1-5)} = \left\{ \begin{array}{c} dry\ \ cough\ \ score +\ \ productive\ cough\ score \\ +\ shortness\ of\ \ breath\ score + wheezing\ \ score \\ +\ stuffynose\ score + sneezing\ score + \\ runninnose\ score \end{array} \right\}_{(day1-5)} \quad \cdots\cdots (i)$$

4.2.4 Interviews on Chronic Respiratory Symptoms (Paper III)

Questionnaire interviews on chronic respiratory symptoms were carried out during data collection period 1. During each work shift, 5–10 workers were interviewed one by one for chronic respiratory symptoms (Figure 15). With the exception of questions on chronic cough and chronic sputum, which were derived from a standardized respiratory symptoms questionnaire of the American Thoracic Society-Division of Lung Diseases (ATS-DLD-78-A)[54], symptoms of chronic bronchitis, dyspnoea, wheezes and chest tightness were derived from the standardized British Medical Research Council Questionnaire [55]. Workers’ standing height and weight were recorded. Workers in the decortication and brushing departments were also asked whether they used any respiratory dust masks. In total, 196 sisal workers were interviewed on chronic respiratory symptoms **(Appendix X).**

For all study participants’ from period 1 and 2, general demographic information such as age in years, education level and area of residence (inside or outside estate camps) were recorded. Workers were asked about their smoking habits (never, ex- and current smoker). Duration of employment in other dusty industries and past respiratory health problems (bronchitis, pneumonia, asthma or tuberculosis) were also recorded. Responses for all chronic respiratory symptoms were categorized as (1 = 'yes') or (0 = 'No') depending on responses to a corresponding set of questions. The questionnaires were administered in a local language (Kiswahili) following a forward and back translation procedure and a pretesting of the translated questionnaire at one of the estates. The urban-based control participants from period 2 were not interviewed for acute or chronic respiratory symptoms.

Figure 15: Interviews

Figure 16: PEF assessment

4.2.5 Peak Expiratory Flow (PEF) Measurements (Paper III)

During period 1, PEF was measured daily from Monday to Friday among all workers interviewed for acute symptoms. PEF was recorded using a portable handheld Mini-Wright Standard Peak Flow Meter (Clement Clarke International, Essex, UK). PEF measurements were performed both in the morning before the shift (between 3:30 and 10:30 AM) and after the work shift (between 2 and 7 PM).

Based on the American Thoracic Society guidelines [56] and European Respiratory Society recommendation [57] for acceptability and reproducibility, each worker was trained on the relevant manoeuvre with the following instruction: "Take a deep breath (inhale) rapidly and completely, place the flow meter in the mouth between the teeth and close the lips around the mouthpiece, then immediately exhale with maximal force without coughing or spitting out the mouthpiece". For each test, each participant was encouraged to perform at least 3 acceptable measurements. All PEF measurements were performed while participants were standing (Figure 16), and the maximum recorded value in litres/minute was used in the analysis. The percentage change in PEF across the shift *(formula ii)* was computed and compared between the groups.

$$\%\ \text{change in PEF} = \frac{(\text{post shift PEF}) - (\text{pre shift PEF})}{\text{Pre shift PEF}} * 100 \cdots\cdots\cdots\cdots\cdots (ii)$$

4.2.6 Skin Prick Tests (Paper IV)

Skin prick tests (SPT) were performed during study period 2. All SPTs were performed according to the recommendations given by the European Academy of Allergology and Clinical Immunology [58]. Single droplets of test solutions each of Fresh Sisal Sap (FSS), Dry Sisal Extract (DSE) and commercially available extract solutions of common environmental allergens of Timothy Grass Pollen (TGP), *Phleum pratense,* House Dust Mite (HDM), *Dermatophagoides pteronyssinus*, histamine (positive control) and diluent (negative control) all from ALK-Abelló, Hørsholm, Denmark, were applied on prior marked points on the volar aspect of the distal arm (Figure 17). The droplets were then pricked in duplicates about 3 mm apart, by using standardised 1 mm point lancets (AB Nordic Medifield, Sweden). Excess solution at the test area was carefully wiped off using sterile cotton swabs to avoid cross contamination. After 15 minutes, skin reactions (wheals) were observed and their outline marked by a fine line stylo-pen (Figure 18). The wheal markings were then transferred onto a registration sheet by applying cello-tape.

During analysis mean diameters of skin wheal reactions were analysed as a continuous variable. Wheal diameters below 0.5 mm limit of detection were assigned the value 0.5/√2 (i.e. 0.35 mm) in accordance with Hornung and Reed [52]. SPT was considered positive if the mean diameters of the duplicate wheals given by equation (*formulae iii*) were 3 millimetres or greater than that of the negative controls. Differences in mean wheal diameters and prevalence of positive SPT were compared between the groups.

$$Mean\ SPT_{(WD)} = \frac{D1(longest) + d1(perpendicular) + D2(longest) + d2(perpendicular)}{4} \cdots (iii)$$

Where; *WD* is wheal diameter; *D1* and d1 are the longest horizontal and corresponding perpendicular diameters of the first wheal and *D2* and *d2* the corresponding diameters of the duplicate wheal, respectively.

Figure 17: Skin prick testing

Figure 18: Skin prick reaction wheals

4.2.7 Immunochemistry tests (Paper IV)

During study period 2, blood samples for immunochemical analysis were collected from 35 exposed sisal workers and 8 control participants. Three sisal factories which are located within a 4 hours drive from Dar es Salaam were visited on the same day.

Blood samples were collected from all workers available at the time of the visit. The samples were immediately stored in a cold container and sent to Tanzania Occupational Health Services (TOHS) Clinic Laboratory in Dar es Salaam, where serum was extracted and stored in ice packed container. For the 8 control participants who were willing to give blood samples, their samples were collected at TOHS clinic immediately after their SPTs results. All serum samples were transported to the Laboratory of Clinical Biochemistry, Haukeland University Hospital, Bergen, in Norway for analysis.

Total IgE and Phadiatop Tests

Serum IgE measurements were performed using the Immuno CAP-FEIA system (Phadia, Uppsala, Sweden), assaying total IgE and Phadiatop^{TM}. Phadiatop^{TM} is allergen-specific IgE for main inhalation allergens including house dust mites (*Dermatophagoides pteronyssinus and D. farinae*), cat epithelium and dander, horse dander, dog dander, mould spores (*Cladosporium herbarum*), pollen from timothy (*Pleum pratense*), birch (*Betula pendula*), mugwort (*Artemisia vulgaris*) and olive *(Parietaria judaica*). Total serum IgE ≥ 100 kU/l [59] was considered as elevated and for Phadiatop^{TM} results were interpreted positive if ≥ 0.35 kU/l [60].

Analysis for sisal specific IgE

In addition to the blood samples a fresh cut sisal leaf was transported to the Laboratory of Clinical Biochemistry, Haukeland University Hospital, Bergen, in Norway. A piece of the sisal leaf was homogenized and suspended in NH_4HCO_3 and incubated. After overnight incubation the mixture was dialyzed for 48 hours, lyophilized and stored at minus 20 ^{o}C. A direct Enzyme-linked immuno-sorbent assay (ELISA) was then performed to determine IgE reactivity to sisal by using the sisal extract *(SE)*. Serial concentrations from 0.0, 0.1 to 4.0 µg (micrograms) of sisal extract were tested as coating allergen by use of serum pool of 7 sisal allergic subjects. Sisal extract cut off point of 0.5 μg was found to be the optimal concentration for coating of plates. The absorbance was read at 405 nm after 10 minutes in an ELISA reader and considered to be positive if >0.1 OD (Optical Density). Sisal sensitization was therefore defined as positive SPTs to fresh sisal sap and/or to dry sisal extract and/or positive ELISA for sisal specific IgE.

Protein separation and immunoblotting

Sisal protein separation and immunoblotting was performed using Sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS-PAGE) [61]. Immunoblotting was performed by transferring the proteins onto nitrocellulose membranes (0.45 μm, Schleicher and Schüell, Dassel, Germany) and then incubating overnight with serum from sisal allergic patients for IgE binding. The colours were developed using SIGMA *FAST*™ BCIP/NBT tablets (Sigma).

4.3 Statistical methods

Participants groups were compared using several statistical methods as summarised in Table 6. Using descriptive statistics, differences were shown among sisal processing workers and/or the presumably low exposed security guards **(Paper 1, II and III),** and/or the urban-based control participants **(Paper IV).** Personal exposure data **(Paper I)** were log-normally distributed, hence log-transformed values were used during statistical testing. Mean exposure levels were compared between work departments and work tasks by using analysis of variance (ANOVA). To establish determinants of dust exposure, linear mixed effect models were developed for thoracic dust using “workers” ID as a random factor and departments as fixed factors. Where applicable, logistic and linear regression models were developed to adjust for the effects of age, height, duration of employment, smoking habits and past respiratory illnesses. **(Paper II- IV).**

The 5-day data on acute respiratory symptoms and PEF were also tested for trends across the work-week by applying mixed effect models taking into account repeated measurements **(Paper III).**

With the exception of the log-binomial regression models developed using STATA version 9.2 (**Paper IV**), other statistical analyses were performed by using SPSS version 13 for Windows (SPSS Inc., Chicago, IL, USA). Statistical significance level was set to 0.05.

Table 6: Summary of the statistical methods applied in paper I–IV

Paper	Group variables	Test Methods
I	Mean thoracic dust, Mean bacteria & fungal spore counts	ANOVA & Tukey HSD post hoc adjustments
	Correlation between bacteria and fungal counts collected on polycarbonate filters	Pearson correlation
	Within-worker and between-worker variance estimates	Linear mixed effect models
II	Mean ages and mean duration of current employment	Student's *t*-test
	Prevalence for demographics (i.e. education, smoking etc) Prevalence of past respiratory illnesses Prevalence of acute respiratory symptoms	Pearson chi-square or Fisher's exact tests
	Odds ratios for acute respiratory symptoms *(adjusted for age, current smoking, area of residence & past respiratory illnesses)*	Logistic regression models
III	Demographics, mean age, BMI, duration of employment	Student's *t*-test
	Mean severity scores for acute respiratory symptoms Mean pre- and post-shift PEF Mean %-change in PEF across shifts	ANOVA and Tukey HSD post hoc adjustments
	Mean pre-shift and mean post-shift PEF.	Paired *t*-test
	Prevalence of smoking Prevalence of acute and chronic respiratory symptoms	Pearson chi-square tests or Fisher's exact tests
	Odds ratios for chronic respiratory symptoms *(adjusted for age, ever smoking, past respiratory illnesses and BMI).*	Logistic regression models
	Differences in acute symptom severity scores, *(adjusted for age, BMI, past respiratory illnesses and current smoking).*	Linear multiple regression
	Trends for acute symptom severity scores, *(taking into account repeated measurements during the work week)*	Linear mixed effect models
IV	Demographics (prevalence of education, and smoking etc) Prevalence of past respiratory illnesses, Prevalence of lower and upper respiratory symptoms, Prevalences of positive SPTs and Phadiatop^{TM}, Prevalences of elevated total and sisal specific IgEs	Pearson chi-square tests or Fisher's exact tests
	Demographics (mean age, duration current employment) Mean SPTs wheal and Phadiatop^{TM} reactions Mean total and sisal-specific IgE levels	Independent t-test
	Correlation between SPT reaction wheals, total IgE etc	Pearson's correlations.
	Relative risks for sisal sensitization & upper and lower respiratory symptoms *(adjusting for age, past respiratory illnesses and smoking)*	Log-binomial regression models (STATA)

5. Study Results

5.1 General characteristics of the study groups

The study included all available 165 sisal processing workers, 31 sisal estate security guards and 80 urban-based controls. All participants except urban based participants were interviewed for respiratory symptoms, and their lung function examined **(Paper II & III).** 138 (84%) of the sisal processors and 78 (97.5%) of the urban-based control participants but not sisal estate security guards were skin prick tested **(Paper IV)**. Immunological tests were performed for a subset of 43 participants who agreed to be tested **(Paper IV).** Thoracic dust (n = 24), bacteria and fungi (n = 32) samples were analysed **(Paper I).**

Table 7 shows the characteristics of the study participants. Brushing workers and security guards were found to be older than decorticators. The urban-based control participants were the youngest. Brushing workers had worked for significantly more years in their current employment than decortication workers. Decortication and brushing workers were shorter and had lower Body Mass Index than did security guards. There were no statistical significant differences in education status between the groups from the sisal processing factories. Sisal processing workers and security guards smoked more and they had a lower level of education than the urban-based control participants (Table 7).

Current smoking was significantly higher among brushing workers and decorticators than among security guards. More than 30% of the sisal processing workers had a history of past respiratory illnesses of pneumonia or bronchitis compared to 19% among the security guards.

Table 7: Distribution characteristics of the various study groups

	Decortication	**Brushing**	**Security guards**	**Urban-based Controls**
Number of participants	92	71	31	78
Demographics				
Age (years) AM: (range)	43 (19–94)	51(17–85)	51 (21–75)	35 (19–65)
Height (cm) AM (SD)	165 (6.6)	164 (6.7)	168 (6.0)	NA
BMI (kg/m^2) AM (SD)	20.3 (2.0)	19.7 (1.9)	21.9 (3.3)	NA
Years in current employment AM (range)	7(<1-64)	13(<1-66)	8(<1-24)	NA
Formal education (years)				
None; n (%)	24 (26)	20 (28)	4 (13)	4 (5)
<7 years: n (%)	68 (74)	51 (72)	27 (88)	29 (37)
>7 years: n (%)	-	-	-	45 (58)
Residence				
Inside estates n (%)	74 (80)	58 (82)	20 (64)	NA
Smoking habits				
Never smokers n (%)	24 (26)	12 (17)	7 (23)	55 (70)
Ex -smokers n (%)	19 (21)	14 (20)	14 (45)	3 (4)
Current smokers: n (%)	49 (53)	45 (63)	10 (32)	20 (26)
Past respiratory illness				
n (%)‡	52 (56.5)	35(49,3)	7 (22.6)	NA

Key: AM - arithmetic mean, BMI - Body mass index

NA - data not available, SD - standard deviation

‡ - Past respiratory illness (i.e. history of bronchitis, pneumonia, asthma and/or TB)

5.2 Main findings (Paper I)

Working Conditions and Exposure to dust and bio-aerosol in Sisal Processing Factories in Tanzania **(Appendix I)**

The overall findings from walkthrough surveys indicated generally poor working conditions in 5 of the 6 sisal factories.

The workplaces were characterized by wet floor, visible dust emissions, long stressful work shifts, monotonous tasks at awkward postures and heavy manual lifting. Use of personal protective equipments and/or clothing and other general occupational health and safety services were almost absent.

The arithmetic mean exposure of all sisal processors was 1.18 mg thoracic dust/m^3, $43x10^6$ bacteria /m3, and 2.35 x 10^6 fungal spores/m^3. The highest mean thoracic dust (2.06 mg/m^3), bacteria spores (230 x 10^6/m^3) as well as fungal spores (15.10 x 10^6/m^3) were measured when cleaning corona drums at the decortication.

Analysis of variances revealed significant differences between the three departments for mean exposure to thoracic dust ($p<0.05$) and bacteria counts ($p<0.01$) but not for fungi. Further testing showed that mean thoracic dust levels ($p = 0.036$) and mean bacteria counts ($p = 0.005$) were significantly higher among brushing than among security workers (Tukey HSD test of multiple comparisons). Thoracic dust and bacteria exposures, respectively, were not significantly different between brushing and decortication or between decortication and security workers.

For both thoracic dust and bacteria counts, work tasks in the sisal processing departments were associated with higher exposure levels than for security workers, although the differences were significant ($p = 0.02$) for bacteria only. Tasks related to resorting and cleaning of outlet/vents in the brushing departments were associated with significantly higher bacteria levels than among security workers (Tukey HSD test of multiple comparisons, $p = 0.003$). No differences were found for bacteria or fungi exposure between the sampled sisal factories. Positive correlations were found between fungal and bacteria counts (r = 0.47; p = 0.01;n = 32).

Mixed effect models including the brushing and decortication departments explained 64.7% of the thoracic dust exposure variance between workers. The models also showed that working in the brushing department was a significant exposure determinant (p = 0.04).

5.3 Main findings (Paper II)

Acute respiratory symptoms among sisal workers in Tanzania **(Appendix II)**

Sisal processing workers in brushing and decortication departments had significantly higher prevalence of dry cough (p<0.01), wheezing (p<0.05) and sneezing (p<0.01) compared to security guards. The prevalence of Monday symptoms was highest among brushing workers for dry cough (73%), sneezing (66%), productive cough (65%), running nose (63%), shortness of breath (37%) and stuffy nose (34%) compared to decortication workers (50%, 39%, 43%, 40%, 33% and 16%, respectively) or security guards (32%, 19%, 35%, 32%, 0% and 10%, respectively). With the exception of shortness of breath and wheezing symptoms, brushing workers had significantly higher prevalences for acute respiratory symptoms than decortication workers did**.**

Sisal processing workers had higher odds ratios for sneezing 4.2 (95%CI 1.6–11.1) and dry cough 2.9 (95%CI 1.3–5.4) when compared to security guards and after adjusting for age, smoking and past respiratory illnesses. Workers in the brushing department had significantly higher odds ratio compared to decortication workers for sneezing; 3.2 (95%CI; 1.6–6.2) and stuffy nose 3.1 (95%CI; 1.4–7.0).

5.4 Main findings (Paper III)

Prevalence of respiratory symptoms among sisal processors in Tanzania
(Appendix III)

During the five days of follow-up, brushing workers had significantly higher severity scores for acute symptoms (*P* <0.01) and significantly higher prevalence of almost all acute respiratory symptoms than security guards. For most days of the week, workers in decortication had significantly higher prevalence of shortness of breath than security guards. Decorticators also reported higher prevalences for most other symptoms when compared to security guards, although not at a significant level. Among sisal processors brushing workers had higher prevalence for most acute symptoms compared to decorticators, but significant differences were for the nasal symptoms only.

A significantly decreasing trend across the week was found for the prevalence of shortness of breath among brushing workers (from 39% to 20%: *P* <0.01). Brushing workers also exhibited significantly increasing trends for running nose (*P* <0.01) and sneezing (*P* <0.01). There were no significant trends for acute respiratory symptoms among decortication workers, whereas security guards showed decreasing trends across the week (*P* <0.05) for productive cough and running nose. These differences were present also after adjusting for confounding factors.

During the study week, PEF increased across the shifts in all groups of workers. Significantly lower mean pre-shift PEF and post-shift PEF were recorded for brushing workers compared to security guards during the five days of the follow-up. The percentage change in PEF across the shifts did not differ significantly between the study groups. PEF results were adjusted for age, current smoking, body mass index and past respiratory illnesses.

Brushing workers reported the highest prevalence of all chronic respiratory symptoms. When compared to the security guards, brushing workers had a significantly higher prevalence of chest tightness (48% versus 3%) and chronic sputum (30% versus 3%). Between security guards and decortication workers the difference was only significant for chest tightness (30% versus 3%). Brushing and decortication workers differed significantly in the prevalence of chronic sputum and chest tightness. Similar results were found after controlling for potential confounders

5.5 Main findings (Paper IV)

High prevalence of immunoglobulin E (IgE) sensitization among sisal (Agave sisalana) processors in Tanzania **(Appendix IV)**

The mean wheal diameters of skin prick tests and the prevalence of positive SPT for both dry sisal and fresh sisal extracts were significantly higher among sisal processing workers than among urban-based control participants. Sensitization to either fresh sisal sap or dry sisal extract was 74% in decortication and 71% in brushing and the prevalence of elevated sisal specific IgE was about 27% among the 43 tested individuals. Age and smoking-adjusted relative risk for sensitization to sisal was 4 times higher for sisal workers than for the control participants (RR 4.0; 95% CI; 2.4–6.7). Analysis of the sisal extract showed two IgE binding protein bands located at about 45 kDa.

High and similar prevalences of acute rhinitis (71%), acute lower respiratory symptoms (74%) and chronic respiratory symptoms (52%) were found for the sensitized sisal workers as compared to 68%, 77% and 45%, respectively, among the non-sensitized. Relative risks for these symptoms were not significantly different between sensitized and non-sensitized workers. All exposed workers and all but one control participant were atopic based on elevated (>100kU/L) IgE levels.

6. Discussions

6.1 Discussion on general methods

6.1.1: The study design

In occupational epidemiology cross-sectional studies are considered to be useful in providing information on the prevalence of health outcomes by offering a description of ‘who has health effects and where’ in the workplace [62]. Since very little is documented about work and health in the sisal industry, this study design was useful for obtaining information on the distribution of health effects (prevalence), on working conditions and exposure characteristics in the surveyed sisal factories. Furthermore, based on the allocated time for doctoral studies at the University of Bergen and resources made available for this study, a cross-sectional study method was the most feasible option.

Like in other cross-sectional studies, information on exposures and health outcomes was collected at the same time. Therefore, concise causal exposure-effect associations (i.e. the degree to which the rate symptoms and/or sensitization among sisal exposed is higher than the corresponding rate among security guards and/or urban-based controls) can not be drawn [62, 63]. However, in all articles, **(Paper I–IV**) we applied robust statistical methods and adjusted for confounders and found significant differences in prevalence odds ratios, relative risks and means between exposed and control groups indicating significant relationship between exposure and outcome variables. Furthermore, a short (one week) follow-up investigation of acute respiratory symptoms and PEF measurements **(Paper III)** showed similar supporting results.

Healthy worker effect

A cross-sectional study design in occupational epidemiology will always imply a risk of a “healthy worker selection effect” due to selection of healthy workers during employment and a “health worker survivor effect” since healthy individuals will always stay at work while those diseased will leave their jobs [64-66]. These phenomena indicate a systematic difference between workers included and those excluded from the study. Sisal workers, who experience severe respiratory symptoms and/or severe allergic sensitization in the processing departments, may have left the factories or joined other departments with less exposure. Inevitably the effects of exposure may have been underestimated. We could not obtain data from workers who had left the factories, and although we studied all available workers, a healthy worker effect ought not to be ruled out. However, the confounding effect of any healthy worker effect in our respiratory symptoms and exposure studies in particular, is presumably non-significant since the comparison groups (security workers) were selected from within the same working population [64]. Furthermore, due to high unemployment rates in rural areas and strict regulations laid down by sisal factory owners which require all estate inhabitants to work, the magnitude of any healthy worker effect may not be significant in this population.

6.1.2: Sample size estimation and assignment of exposure groups

An important aspect of epidemiological studies is the need to have a representative sample with enough power to detect the actual magnitude of the problem being investigated [67]. To be able to estimate a proper sample size, information from previous studies on the particular area of research, availability of resources and desired accuracy must be considered [68]. The only previously published study of sisal workers in Tanzania did not include a control group [27]. Data from a study on a similar organic dust among coffee workers in Uganda [46] was therefore, used when estimating our sample size. A sample of 180 was required to achieve a statistical power of 85% at P value of 0.05. We therefore studied all available workers in the sisal processing areas from six factories to achieve the desired sample size.

In order to obtain a good control group, both the exposed group and the control group should come from the same general population and differ only on the exposure factor under study, in this case exposure to sisal. The selection of a suitable control group within the sisal estate was not easy, since all sisal estate inhabitants are required to work for the respective sisal factory. This may imply that the whole population in the sisal estate could be exposed to sisal in some ways. Our control group consisted of a random selection of security guards who live in the same estate communities but work outside the sisal processing factories. These guards were assumed to have low exposure to sisal and hence considered to be a more appropriate control group for respiratory symptoms studies. Four security guards who had worked in the processing factories in the past were ultimately included in the study, since some 25 years had elapsed since they worked in sisal processing areas, and their inclusion could have only marginal effect on our final results.

On the other hand, if we regard sisal to be allergenic, the whole population living within or near to the sisal estate might be expected to be sensitized to sisal. When conducting our IgE sensitization study (**Paper IV**), we therefore recruited a convenient random sample of men from an occupational health clinic situated in a city more than 120 kilometres from the nearest sisal estate. These control participants from an urban area were more educated and probably had a higher socioeconomic status than sisal workers. Such differences were assumed to be outweighed by the advantage that these urban-based control participants had no previous contact with sisal and could thus be considered more suitable for studying differences in sisal sensitization than any other group selected from within the sisal estate population.

6.1.3: Statistical methods

Pearson chi square tests, ANOVA and t-independent tests were frequently used in this study. These simple tests are considered to be appropriate in comparing proportions of categorical and means of continuous variables [63, 69]. Where several comparisons were carried out Tukey HSD test for multiple comparisons was used to compare the sub groups [70] within ANOVA.

Logistic regression models used in **Paper II & III** permitted adjustments to be made for the effects of common confounders. A similar advantage can be applied to our use of multiple linear regressions for the continuous variables **(Paper III).** To take into account the repeated measurements of dust exposure measurements and peak expiratory flow, linear mixed effect modelling was used in **Paper II and IV**. This allowed for the estimation of between- and within-workers variability [71, 72].

Relative risk (RR) or risk ratios are more appropriate estimates than odds ratios, especially when dealing with highly prevalent outcomes [63, 69]. Due to a high prevalence of respiratory symptoms among study participants log-binomial regression models were developed to estimate the relative risks while controlling for common confounders (**Paper III).**

6.2 Discussion on specific methods

6.2.1: Walkthrough surveys

Walkthrough surveys, by use of detailed checklists to observe and document workplace hazards, permit easy on-the-spot recording of deficiencies [73], and have been shown to be useful in obtaining workplace information [29, 74]. The application of this tool within agricultural industries and particularly in Tanzania is not well documented. During walkthroughs many varieties of checklists, including purpose-made checklists, are commonly used. The standard ILO-designed checklist used in this study has a broad range of items **(Appendix VIII),** that are relevant to any industry. Although we could not find published studies using the ILO checklist, the checklist is a simple, cheap and user-friendly tool that can be useful in settings with limited resources [75]. This method proved to be useful in gathering information on sisal processing methods and working conditions in the factories, which otherwise would have been difficult to record.

6.2.2: Exposure measurement

Correct assessment of occupational exposure to organic aerosols depends on the nature of the dust being studied [76] and therefore use of appropriate sampling and analytical methods for determination of dust constituents of interest [77-79]. We distributed samples based on presumed exposure levels among groups assuming that the exposure variability increased with exposure levels. We used two types of filter media, to allow for both gravimetric and microbial analysis of dust samples (**Paper 1**). However, during walkthrough surveys we observed that liquid or wet aerosols were released at the decortication due to wetting and rinsing processes. The CAC filters might therefore not have been the most appropriate filter material for this department because of their high absorption of water. We did not measure viable microorganisms because their quantitative assessment is subject to substantial errors [80] but also because non-culturable microorganisms may also cause health effects.

Estimation of exposure to bio-aerosols also depends on available resources. This study strived to use cost-effective analytical methods, therefore Fluorescence Microscopy (FM) [51] was used for fungi and bacteria spores counting, although this method tends to underestimate fungal spore counts, and have large recognition errors for bacterial spores when compared to Scanning Electron Microscopy (SEM). However, structural differences were probably visualized better by FM method [81] .

Proper field handling, transport and storage of sampling filters helps to ensure accurate estimation of exposure levels [76]. In this study sampled CAC filters from five factories were not included in the final analysis due to technical problems. Although all the samples were handled as gently as possible, weighing of filters that had been transferred from temporary storage cassettes to sampling cyclones and back into storage cassettes after sampling, revealed weight losses presumably due to traumas on filters during transfers between storage and sampling cassettes. Furthermore, dust samples in the current study were transported by road from factories located in three different regions of Tanzania and by plane as hand luggage to Norway for final analysis. Losses due to physical damages or other traumas to the filters, or systematic variations in relative air humidity during weighing of the filters, are however not uncommon, since other studies have reported up to 28 % mean weight losses [82] and up to 50% rejection of samples [83] due to similar problems.. Similar rejection of a large number of samples (44%) was also reported in a sisal dust exposure study in Kenya [26].

We conducted personal sampling as opposed to area sampling because it is the preferable option for assessing occupational exposure [76, 79, 84] among groups of workers and often a mandatory method for compliance testing (CEN 689) [85]. We chose to measure thoracic dust fraction [84] because this dust fraction has been suggested to be a relevant [43, 86, 87] when relating respiratory effects in the tracheobrochial regions of the lung [76] to occupational exposures.

Although comparison with recommended values were limited by lack of occupational limit values for occupational thoracic dust, bacteria and fungi [88], we found that on average exposure to thoracic dust, fungi, and bacteria was 3, 5, and 100 times higher, respectively, in the sisal processing departments than among security guards. This finding indicates relative differences in exposures between the groups and may explain some of the outcome variables such as high prevalence of respiratory symptoms among brushing workers **(Paper II &III).**

6.2.3: Questionnaires and interviews

Questionnaires are preferred in large prevalence studies of respiratory symptoms [63]. Although they lack concrete objective measurements the major strength of questionnaire surveys is their low cost and rapid data acquisition, facilitating detailed studies of large populations. Since use of sophisticated clinical examinations was not feasible due to the location of the sisal estates, allocated time frame and budgetory limits, questionnaires were considered to be an appropriate choice for this study. Since the majority of the sisal workers could not read and write the questionnaires were used as an interview guide. This method may have introduced an interviewer's bias [89, 90], but our use of reliable and validated questionnaire tools [91, 92] based on standardized BMRC and ATS-LD questionnaires and the involvement of one interviewer in all factories is assumed to have minimized the bias.

6.2.4: Peak expiratory flow

Due to the rural location of the factories, daily assessment of pre- and post-shift PEF (**Paper III**) by use of a portable peak flow meter was chosen due to its simplicity and affordability. The standard Mini-Wright flow meter that was used in our study (Figure 16) can be considered to be reliable and widely validated [93]. In addition we followed the standard guidelines [56] for measurement reproducibility and validity. In studies involving occupational exposures serial PEF measurement (monitoring) including days away from work are often recommended [94, 95]. Some researchers have also shown that measuring PEF at serial short–time intervals rather than before and after shift can reveal sudden declines in PEF that may arise shortly after starting work [95]. We could not conduct serial PEF measurements or carryout measurements during off-work days. Any changes occurring shortly after the shift or when workers stay away from their workplaces could hence, not be studied.

PEF values tend to vary with sex, age, height, smoking status and many other factors [96]. In the present study only PEF data from male participants were analyzed, and all PEF results were adjusted for age/(duration of employment), smoking habits and height or BMI during statistical testing. It may be appropriate to compare lung function parameters to predicted values from a suitable reference population [56], we however compared individual worker PEF readings since predicted PEF values from a representative Tanzanian agricultural population was not easily found.

6.2.5: Skin prick methods

Skin prick tests are cheap, simple and easy to perform. Compared to intradermal testing this method is less invasive and is without any adverse reaction [58]. Skin prick tests furthermore have a high degree of reproducibility. The skin prick tests in our study were conducted in duplicates and by following routines outlined by the EAACI guidelines for reproducibility [58] **(Paper IV).** An acceptable arithmetic mean diameter of 5.42 mm with coefficient of variation (CV) of 17% was estimated from the differences between 50 randomly selected histamine wheal duplicates. Based on scientific guidelines, a 3-mm diameter cut-off point is enough to indicate the presence of specific IgE, but larger ≥ 4-mm wheal sizes may reliably predict a positive RAST and/or a positive provocation test. Tests with fresh sisal sap produced twice as many (36%) 4 mm-wheal diameters than dry sisal extract (16%) did. Furthermore, other objective measures such as total and specific IgE quantification, which has less inter-observer variance, showed good agreement with skin prick results.

Use of uniform test solution and maintaining uniformity in SPT methodology is essential for consistent findings in skin prick results [58]. Thus, the same skin prick test protocol, carried out by one investigator, was applied in all factories. Fresh sisal leaves from individual sisal estates were used make extract for skin prick tests to ensure that sisal workers in each factory were tested with sisal to which they had been exposed.

6.2.6: Immunological tests

Sisal extract antigen made in this study may be considered not to be highly purified or enriched; such that by using standard or conventional ELISA method we may have underestimated the prevalence of subjects with elevated IgE to sisal. However, the underestimation may not be significant since we used the same method both for the exposed and control groups, showing high prevalence of elevated IgE levels in both groups. The method is also widely used, validated and affordable

6.3 Validity aspects

Internal validity

Several factors may have affected the validity of our study findings. Some of the factors pertaining to our study are elaborated below.

Participation rate: In this study, all interviews and examinations were carried out at the respective workplaces (Figure 15) in order to avoid disturbances to the normal production routines. This factor contributed to the high response rate among the various study groups. The two weeks stay per factory increased the confidence of the principal investigator and allowed her to cultivate a good relationship with the invited workers. The inclusion of two processing departments in all six sisal processing factories and an internal control group consisting of security guards has probably provided representative data within the industry. However, our small number of immunological blood samples and thoracic dust samples from control groups in particular may increase the risk of drawing false conclusions, as some outcomes may have failed to reach statistical significance due to small number of variables.

Selection biases: Whereas all sisal processing workers were invited into the study, the random selection of controls from a special group of security workers (I.e.only security guards not working near or within the sisal processing factory were selected) may have introduced some element of selection bias. The same applies to immunological studies whereby the controls were selected from members of the general population (i.e health Tanzanian men from an urban area).

Observer's biases: In this study, most sisal workers could not read and write, which made face-to-face administered interviews necessary. The involvement of only one investigator has avoided multiple observers' biases. However the subjective assessment by one investigator could not be eliminated entirely [63].

Recall bias: Differential recalling of exposure factors, unpleasant events or symptoms among the exposed as compared to the non-exposed may lead to biasness [63]. To avoid recall biases we asked for acute respiratory symptoms arising during or immediately after the work shift since they did not require much effort to remember **(Paper II, III)**. In addition we used the 5-scale severity ranking of the acute respiratory symptoms and included a short follow-up of daily interviews to ensure better precision and greater reliability since this method is less affected by chance and/or bias. For chronic respiratory symptoms, we asked for several individual outcomes responses to arrive at the chronic respiratory symptoms of interest. These methodological approaches should have minimized any chances for recall bias.

Misclassification: The exposure status among study participants in this study was either determined by their respective work departments **(Paper I & II, III***)* or their sisal sensitization status **(Paper IV).** By grouping workers into exposure departments we may have introduced a certain degree of misclassification [64]. This is evidenced by the difference in exposures between the various tasks within the individual departments (**Paper I**). Nevertheless; we observed significant results even with departmental groups.

The role of confounding factors: Because of the non-random distribution of risk factors in any population, certain characteristics among the study population may result in misleading effect estimates [63, 64]. Such differences may be avoided by matching the exposed subjects to controls based on common risk factors such as age, height and smoking habits. Due to the small number of eligible control candidates we could not match our study participants accordingly.

Age is commonly associated with increased years of exposure, implying higher cumulative exposure. In the present study age was found to correlate positively with the duration of employment ($r = 0.52$; $P < 0.01$). In this respect, aged workers may therefore report increased prevalences of health effects, e.g. brushing workers in the current study were older, had worked for more years with sisal and they reported more respiratory symptoms than decortication workers. The effect of ageing alone, could not, however, explain the observed significant differences for both acute and chronic health effects between brushing workers and security guards with whom they had similar age distribution. Given that the significant differences between study groups persisted after adjusting for age, our observations are therefore likely to be linked to sisal exposure characteristics.

Smoking has been implicated in the aetiology of most chronic respiratory illnesses [97-99], and also has an influence on lung functioning [100]. Furthermore, current smoking has been reported to be positively correlated with IgE levels [101], but is also found to be inversely related to skin prick positivity [102]. With the exception of our urban-based control group, all study groups from the sisal factories had significantly higher prevalence of smoking than the general population in Tanzania [103]. To eliminate the effect of smoking all outcome variables were therefore adjusted for smoking status during statistical testing.

Differences in gender and body physique may also lead to differences in dose-responses relationships [96, 104]. Body mass index was controlled for during analysis, but we could not study gender differences since the number of female workers per factory was small. The few encountered female sisal processors were excluded.

Environmental pollution, past illnesses and/or parasitic infections may potentiate both respiratory and immunological effects [102, 105]. Tanzania has a typical tropical environment where helminthic infestations, malaria and pulmonary tuberculosis may co-exist. We did not collect data on some of these parameters but where necessary area of residence **(Paper1)** and past respiratory illnesses (**Paper I- IV)** were adjusted for during analysis.

Socio-economic factors have an influence on both exposure and outcome. Our second control group was people living in Dar es Salaam city. The difference in geographical location makes them less likely to be exposed to sisal than workers in the sisal estates. They were thus assumed to be an appropriate control group for studying differences in sensitization to sisal despite their presumed higher socioeconomic status.

External validity (Generalisability)

As a result of a historic labour migration [13], workers in the sisal estates represent all Tanzanian ethnic groups. The inclusion of six sisal processing factories located in the three main sisal producing regions in Tanzania ensures a greater external validity of our study findings. This study had both internal (security guards) and external (urban participants) control groups, allowing us to study differences in health effects between the exposed (decortication and brushing), the lower exposed security guards and non-sisal-exposed participants from an urban area (in case of sisal sensitization).

Our findings of high prevalence of symptoms among brushing workers are in agreement with previously reports among brushing workers in six sisal factories in

Tanzania [27].This shows representativeness of our data among sisal processing workers in Tanzania, however since we did not collect data on respiratory symptoms from the urban based control group one should be cautious of generalizing extensively..

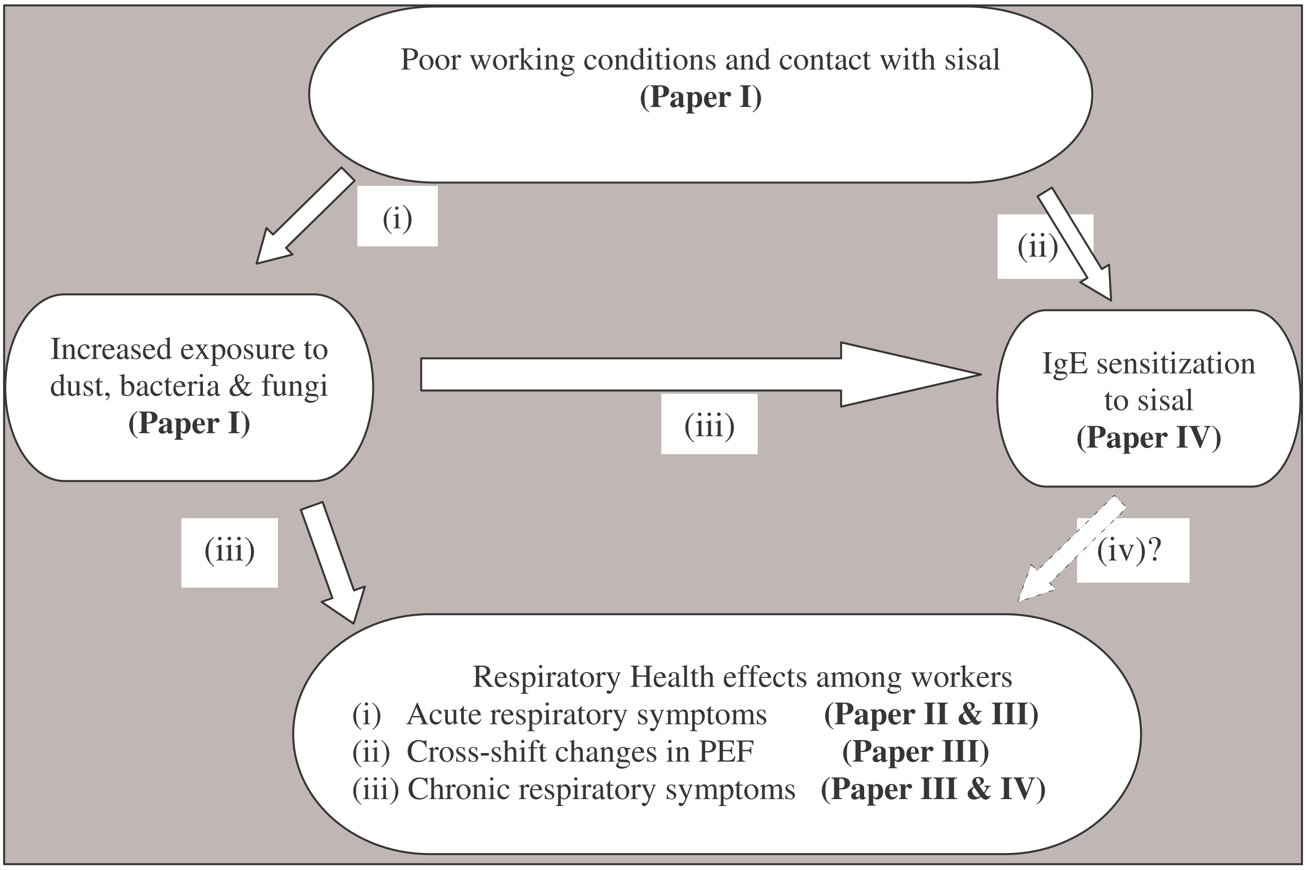
Our thoracic dust exposure assessment is based on data from only one sisal processing factory, and in addition dust measurements have never been performed in Tanzanian sisal factory to provide some baseline comparison. The thoracic dust, bacteria and fungi results among sisal workers may still need to be validated. Nevertheless, the estimated average exposures in the present study may be representative for Tanzanian sisal factories since no significant differences in bacteria or fungi levels were found between the surveyed factories.

Only a few sisal immunological studies have been done among sisal workers (Table 3) and our immunochemistry tests involved a moderate small number of participants who agreed to be blood tested. In addition to possible differences in the type of sisal species between countries, there are also methodological variations between our study and previous immunological studies in sisal. Still we have used standard and more update methods and showed findings that can be generalised as regards a high prevalence to atopy in our study population which is in agreement with other studies among African population [59, 106]

We believe that the present results are representative of other sisal processing factories in Tanzania and within East Africa, where similar production methods are employed. However, it is worth mentioning; that exposure among sisal workers in other parts of the world, such as Mexico and Brazil, may be different due to differences in sisal species, differences in the sisal processing methods and also due to a possibility of improvements in technology and working conditions in other parts of the world.

6.4 Discussion on main findings

Figure 19: Interrelationship of variables in the study



Key

(i) Poor working conditions imply dust emission, and work without PPE (gloves, masks, aprons etc.) indicates easy exposure to dust and bio-aerosols.

(ii) Prolonged inhalation or dermal contact with sisal, sap, aerosols etc. as a result of poor working conditions and non-use of protective clothing may lead to IgE sensitization to sisal.

(iii) Dust- and bio-aerosol-exposed sisal workers may be prone to becoming IgE sensitized to sisal and/or developing respiratory symptoms.

(iv) IgE sensitized workers may ***be expected to*** develop health effects such as respiratory symptoms compared to non-sensitized (– *not significant in this study)*.

6.4.1 Physical working conditions

In the current study, walkthrough survey findings showed poor physical conditions characterised by wet and contaminated working areas in the decortication departments and dust/aerosol emissions from old machinery **(Paper I).** Similar findings have been reported in a study in agro-processing industries in Ghana [107] where 55.4% of the tasks were reported to be performed in dusty and smoky environments. In addition workers in the present study were observed not to use any protective clothing/equipment. Lack of use of personal protective devices and protective arrangements on machines were found to be associated with a doubled risk of occupational lost-day injuries in smaller enterprises in Norway [108]. The presence of poor working conditions and the lack of proper ventilation in absence of workers protection indicate an increased risk of respiratory effects by inhalation of harmful substances. In this study we also identified potentials for health risks arising from other factors such as poor ergonomics, vibrations, high noise leves and possible accidents dues to poor work organization, poor lifting techniques and highly demanding work shifts (**Paper I).** Similar workplace hazards have been associated with accidents and/or illnesses in other agricultural industries [107-110], but since these were not the main focus of our study, no in-depth discussion is given.

6.4.2 Exposure to sisal dust

It was observed during walkthrough surveys that when sisal is processed, liquid or wet aerosols were released at the decortications due to fibre washing and rinsing, whereas in the brushing department dry sisal fibres were mechanically combed leading to emission of dry dust particles. **Paper I** describes the arithmetic mean exposure of all sisal processors to be 1.18 mg thoracic dust/m^3, 43 x 10^6 bacteria /m^3, and 2.35 x 10^6 fungal spores/m^3. On average this exposure to thoracic dust, fungi, and bacteria was 3, 5, and 100 times higher, respectively, in the sisal processing departments than among security guards. Significant differences were found between the three departments for thoracic dust and bacteria counts but not for fungi. Further analyses showed that working in the brushing department was a significant exposure determinant and that work in the processing departments explained 65% of the thoracic dust exposure variance between workers **(Paper I)**

Depending on the dust content and composition, respiratory symptoms may be reported even at low levels of organic dust [111]. Previous studies in sisal have not attempted to estimate bio-aerosols content in the sisal dust. In **Paper I** we report mean counts for bacteria (43 x $10^6/m^3$) and fungal spores (2.35 x $10^6/m^3$) among sisal processing workers. Wet contaminated floors in the decortication may have contributed to the higher exposures to bacteria 62 x $10^6/m^3$ and fungi 4.2 x $10^6/m^3$ in this department, compared to 25 x $10^6/m^3$ and 0.49 x $10^6/m^3$ counts, respectively, in the brushing department. The overall mean fungal spore counts in the present study are more than 20 times higher than the 10^5 spores /m^3 level proposed to be the lowest observed health effect level for non toxic/non pathogenic fungal spores [81]. The finding of high prevalence of respiratory symptoms among sisal processors compared to the lower exposed security workers in these factories **(Paper 1 & III)** might be therefore associated with their exposure to bio-aerosols.

Dust exposure levels in the present study could be considered to be relatively similar to 0.8 to 1.6 mg/m^3levels of total dust measured in a sisal rope factory in Ireland [22], and to 1.6 and 1.9 mg/m^3, respectively total dust measured in a Croatian sisal textile factory [20, 21], but lower than the total dust levels of 6.05 mg/m^3 and 10 mg/m^3 which were measured in sisal factories in Kenya [24] and South Africa [25], respectively.

The differences in dust exposure levels between sisal studies may be explained by different sampling methods, sampling fractions or sampling media. Apart from day-to-day and seasonal variations in production, workers' tasks, type of operation and/or processes and the stages in the production process have all been shown to determine dust exposures among agricultural workers [29, 31, 112]. Similar differences have been shown in the present study, whereby some specific tasks were associated with higher dust exposure than others **(Paper I)**. For example decortication workers, especially those involved with cleaning sap and waste from corona drums, were exposed to the highest thoracic dust (2.06 mg/m^3), bacteria (230 x 10^6/m^3) and fungal spore levels (15.10 x 10^6/m^3) compared to all other tasks. This can be explained by their working in close proximity to the exposure source (Figure 4). None of the drum-cleaning workers were observed to use respiratory protection/masks **(Paper I)**.

6.4.3 Exposure to sisal allergens

In our study, allergic sensitization was measured by *in vivo* skin prick tests and validated by *in vitro* specific IgE in a subset of participants. A positive allergen skin prick result indicates the individual's ability to mount an IgE mediated response towards an applied allergen [58]. Within 5 minutes of a prick with the allergen, mast cells within the skin have been shown to be activated and degranulated, releasing inflammatory mediators such as histamine. Experimental studies have shown that sisal extract has an ability to release histamine in human lung tissues [28]. Therefore, in addition to possible non specific irritation in the airways, exposure to sisal dust can be associated with allergic inflammatory responses.

In **Paper IV**, about four and half times as many exposed sisal workers were sensitized to sisal as compared to non-exposed individuals. Our mean diameter for skin prick wheals tested with DSE was 2.4 mm (range 0.3–6.8 mm). This response is less than the 10–13 mm indurations reported among workers in a Kenyan sisal factory in 1958 [23]. The observed differences could be explained by different skin testing methods (i.e intra-cutaneous vs. our subcutaneous method).

The prevalence of sensitization to sisal is 2–3 times higher than the previously reported 20% prevalence among female sisal textile workers in Croatia [21]. In the present study higher prevalence of sensitization among all sisal processors was found for fresh sisal sap (59%) than for dry sisal extract (39%). This may suggest that fresh sisal leaves contain more of the allergenic and/or irritating substance(s) which progressively become(s) reduced during processing of sisal fibres. This is in agreement with findings in the Croatian study [21] where sisal extract made from presumably dry and processed sisal did not show similar high prevalence of sensitization. However, our high prevalence of sensitization among sisal workers is similar to findings of immunological studies among workers handling other vegetable fibres [45].

IgE sensitization is characterized by an elevation of total and/or specific serum IgE to the offending substance. A high prevalence of elevated serum IgE levels was found for the whole study group regardless the exposure status, and 27% of the tested sera from exposed sisal workers had elevated sisal specific IgE (**Paper IV**). Parasitic infections in our African study population may contribute to increased levels of serum IgE. Previous studies have shown elevated serum IgE levels in patients with allergic rhinitis and asthma [113-115]. Our data, however, did not show any significant relationship between respiratory symptoms and sensitization among sisal processors. A possible 'healthy worker effect' may explain the lack of significant differences between sensitized and non-sensitized. We did not obtain information on workers who had left the processing department, the majority of whom may have left due to severe symptoms following sensitization to sisal.

Sisal sensitization may on another hand be an intermediate exposure factor (Figure 18) co-existing with other factors. Although we could not differentiate between sensitization by inhalation and/or by skin contact, both mechanisms may be relevant for our study group since neither respiratory nor skin protective clothing were used **(Paper I*).*** Thus the protein bands detected from a sisal extract represent a possible sisal allergen **(Paper IV).**

6.4.4 Health effects; Acute and Chronic respiratory symptoms

This study showed that sisal workers in the processing departments have significantly higher prevalences of acute and chronic respiratory symptoms than security guards who do no handle sisal in their daily work. Such differences persisted after adjusting for age, smoking, past respiratory diseases (**Paper II, III & IV**). Higher thoracic dust, concentrations and bacteria and fungal spore counts were measured among the sisal processing workers than among security guards **(Paper 1).** The higher prevalence of acute respiratory symptoms among sisal processors therefore indicates a relationship between dust exposure and the experienced symptoms (Figure 19). These findings are similar to those reported in Kenya, where twice as many workers from the carding section of a sisal factory complained about respiratory problems as compared to workers from other sections of the same factory [23]. High levels of medium particles (4.5 mg/m^3) and fine particles (1.6 mg/m^3) were later reported in the carding rooms of the same Kenyan factory [24].

The high prevalence of respiratory symptoms among workers in the processing departments might be a result of direct irritation and/or inflammatory effect of inhaled sisal fibres and/or contaminating bio-aerosols on both large and peripheral airways and on the nasal passages. Brushing workers had correspondingly high prevalence of nasal symptoms compared to other study groups (**Paper II, III & IV**). This may be explained by the dry processes in the brushing departments as opposed to the wet processes in decortication. The dry processes, poor ventilation and lack of use of protective masks **(Paper 1)** probably contribute to increased inhalations risks among brushing workers (Figure 19). These findings support the previous report of higher respiratory symptoms in a previous study among brushing workers in Tanzania [27]. The declining prevalence of shortness of breath among brushing workers from 39% to 20% over the working week (**Paper III**), could be interpreted to indicate similar features to byssinosis and may be an adaption response to repeated sisal dust exposure across the work week.

Endotoxins have been documented among workers handling other organic dusts [29, 33, 116-119]. We did not estimate endotoxins, but the presence of bacteria spores in the estimated sisal dust is supportive of possible endotoxins exposure among sisal processors..

Due to the design of our study we know little about other factors such as prevalence of diseases like TB and HIV among the study population. These diseases would primarily affect the respiratory systems and can be associated with similar symptoms. Other factors such as indoor pollution in the homes from cooking fuels may lead to smoke inhalation contributing to similar health effects, this may not apply strongly to our study population which included men. Since both the exposed and control groups for respiratory symptoms studies came from the same population, and presumably have an equal share of these factors, the differences between sisal processors and security guards could to a large extent be due to the processors being exposed to sisal dust during their daily work.

6.4.5 Health effects; Acute changes in lung functions

We observed that PEF values differed significantly between brushing workers and security guards but not between decortication workers and security guards. Brushing workers had consistently lower PEF values than did decorticators whilst security guards who are not exposed to sisal had the highest PEF values throughout the week **(Paper III).** Based on the observed lack of effective ventilation, and none use of personal protective clothing’s despite obvious contaminations in the processing departments **(Paper I),** the finding of lower levels of PEF among sisal processors than among security guards may in part be explained by exposures in the sisal processing workplaces (Figure 19).

Past analyses for acute lung function changes among sisal workers have not yielded consistent findings. Whereas both Zuskin *et al.* [20, 21] and Mustafa *et al.* [27] observed a significant decline in PEF across the shift, Baker *et al.* [25] could not establish any cross-shift changes in lung functions. Similarly, cross-shift changes in

PEF in the present study are difficult to interpret. Our data show non-significant cross-shift increments in PEF among all study groups regardless of their exposure status. The normal circadian rhythms [120, 121], and the physically demanding nature of the tasks in the sisal processing departments [122], may be a possible explanation.

6.4.6 Dose-response relationships and other factors

The design of the present study places restrictions on the type of conclusions that can be drawn from the study results. However, some aspects of our study findings indicate dose-response relationships.

Increased odds ratios for respiratory symptoms among sisal processors were in accordance with their exposure levels/departments. In **Paper II**, adjusted odds ratios for most acute respiratory symptoms showed a dose response gradient, being highest among brushing workers followed by decorticators and least among security guards. Similarly, in **Paper III** adjusted odds ratios for chest tightness were almost 21:16: 1, respectively, among brushing workers, decorticators, and security guards who had the lowest exposure, respectively. Another dose-response relationships aspect was for the symptoms severity scores among study groups (**Paper III).** For all acute respiratory symptoms, and for the entire follow-up week, brushing workers reported higher severe scores followed by decortication workers while security guards had the lowest score. Similar differences were seen for sensitization to sisal **(Paper IV**). We observed a four times higher relative risk for sisal sensitization among sisal processors compared to non-exposed urban-based participants.

The observed differences between brushing and decortication workers both of whom are involved with sisal processing maybe indicate differences in actual exposure levels (**Paper I).** Alternatively the differences in work tasks and work processes (i.e. mostly wet in the decortication and largely dry in the brushing departments) may suggests exposure to dust of different texture and content leading therefore to different mechanisms of the inhaled dust in the airways.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions from the study

To our knowledge, this may be the first study to document health effects among sisal decortication workers and the first also to report on exposure to bio-aerosols and a week-long follow-up of acute symptoms among sisal workers. Several conclusions can be drawn based on our specific objectives.

Specific objective 1

To assess working conditions, use of preventive measures and the status of occupational health and safety, and workplace sisal dust exposure levels in participating sisal processing factories. **(Paper I -Appendix 1)**

- Sisal processing is performed in poor work environment using old machinery and ancient methods of production. Provision of OHS services including the use of protective clothing among workers was infrequent and even absent in some factories.

- Work in sisal processing departments was found to be a significant determinant for dust exposure. The combined exposure to bio-aerosols may represent health risks among sisal processing workers

Specific objectives 2

To investigate the frequency and severity of work-related acute and chronic respiratory symptoms among sisal processors in Tanzania. **(Paper II & III - Appendices II & III)**

- Decortication and brushing workers had significantly higher prevalence of chronic respiratory symptoms and acute respiratory symptoms and also showed consistently higher symptoms severity scores across the work week than observed among the presumably low exposed security guards.

- Workers in the brushing department had the highest adjusted odds ratios for both acute and chronic respiratory symptoms compared to decorticators or security guards.
- The finding of high prevalence of respiratory symptoms among sisal processors compared to the lower exposed security workers might be associated with their exposure to bio-aerosols and fibre in the processing areas.

Specific objective 3:

To describe acute effects on lung function (peak expiratory flows) among sisal processors in Tanzania. **(Paper III - Appendix III)**

- Lower pre-shift PEF values were recorded among brushing workers than among decorticators or security guards.

- We did not find any cross-shift reduction in PEF among the study groups.

Specific objective 4:

To determine the prevalence of type 1 (IgE) immunological sensitization and atopy among sisal processors in Tanzania. **(Paper IV - Appendix IV)**

- In this study a four times increased risk of IgE sensitization was associated with work in sisal processing as compared to not working with sisal at all.

- A high prevalence of elevated serum IgE levels was found among all participating groups in this study.

7.2 Recommendations for improvement

7:2:1 Preventive measures to reduce dust emission during sisal processing should be established or improved. Simple measures such as proper regular cleaning routines and repair of leakages from the machines may be a good start.

7:2:2: Since long term dust control measures such as installation of modern machines and ventilation systems require heavy capital investment and may take time, use of protective clothing among workers should be instituted and re-enforced in all departments, i.e. heavy duty gloves and dust masks should be given to all sisal processors, while boots and aprons are necessary in preventing contact with irritating sap in the wet-processes in the decortication departments.

7:2:3: Work organization within sisal processing departments will benefit from application of low-cost measures such as job rotations and simple in-house improvements on work routines and more attention to work tasks associated with the highest exposure levels.

7:2:4: Campaigns to raise health awareness among sisal workers about the various risks and how they can contribute to improve their working environment and/or behaviours should be carried out.

7:3:5: Currently, the work-shifts in most sisal processing factories are task determined and often exceed the normal 8 hour shifts on which exposure limit levels are based. We therefore recommend regular workplace inspections as well as health examinations and dust monitoring according to Tanzanian rules and regulations in order to evaluate and continually improve working conditions in the factories.

8. Policy implications of study results

Good health among industrial workers is a prerequisite for increased productivity and poverty reduction. Except for one old study, very little is known about work, work environment and health status of workers in the sisal industry in Tanzania. This study has not only produced baseline information on the prevailing working conditions in the sisal processing industry in Tanzania but is also an update on workplace exposure characteristics, respiratory disorders and immunological health effects among sisal workers.

The results of this study are probably the first to vividly describe the working conditions and report on microbial exposure in the sisal processing industry. The deficiencies in working environment, high prevalence of acute and chronic respiratory symptoms and immunological responses that have been documented in this study are challenges to the global development of sisal industry and to poverty reduction efforts. The results of this study are therefore vital in providing proper feedback to the management of the sisal factories and other stakeholders including e.g. the Sisal Association of Tanzania, sisal buyers, factory inspectorates and workers themselves. These findings can be used in raising the awareness of hazards and health risks in sisal factory workplaces and to stimulate future research on sisal industry.

At present Tanzania does not have occupational hygiene standards/exposure limits for organic dust, and there is low coverage of occupational health service in agricultural companies. Our findings call for improved guidance on industrial surveillances and policy formulation on national exposure standards.

It is envisaged that application of the results from this study will lead to improved work environments and improved wellbeing of exposed sisal employees, not only in Tanzania but also in other sisal producing countries.

9. Further research options

9:1 Exposure studies

Since only one sisal factory was involved in the dust sampling, more representative sampling from other factories is essential. In addition, further exposure studies ought to be performed to validate our bio-aerosol exposure levels, as well as to assess viable microorganisms and other dust components like endotoxins and other dust fractions (inhalable and respirable). Use of better analytical methods such as use of scanning electron microscopy in the counting of bacteria and fungal spores may be beneficial in avoiding possible underestimation.

9:2: Studies on chronic changes in lung functions

In this study, only before- and after-shift assessments were performed. An assessment of chronic changes in lung functions is another area worth exploring. The only previous study in Tanzania had postulated a short exposure to sisal dust (5 years) as a reason for not seeing any chronic effects among sisal workers [27]. On average, our sisal processors have longer duration of exposure to sisal. Future studies among these workers should investigate possible chronic lung functions effects of sisal.

9:3: Cohort and intervention studies of sisal workers

IgE sensitization may be a result of inhalation and/or dermal contact to allergenic substances [44]. However, in this study we could not determine whether the very high prevalence of sisal sensitization is a result of airway (inhalation) or dermal exposure to sisal although both mechanisms may co-exist in our study population. A well-planned longitudinal study should be carried out to ascertain the involved sensitization mechanism. Intervention studies may also be planned to evaluate effectiveness of preventive measures.

9:5: The role of modern research techniques

A higher prevalence of nasal symptoms was shown by our data. Application of nasal larvage, Exhaled Breath Condensate (EBC) and use of biomarkers to study inflammatory cells and/or mechanisms involved in the airways will be beneficial. Other research methods including provocation tests could also be carried out with sisal dust extract and/or its elements. Further analysis building on the identified protein bands from the sisal extract by use of advanced technology (e.g. Polymerase Chain Reaction) may further identify and characterize the sisal allergen(s).

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